
ANDES Manual

Release 1.9.1

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ANDES MANUAL

1	Getting started	3
1.1	Package Overview	3
1.2	Installation	4
1.2.1	New to Python	4
1.2.2	Extra support package	5
1.2.3	Develop Install	5
1.2.4	Updating ANDES	7
1.2.5	Uninstall Multiple Copies	7
1.2.6	Troubleshooting	7
1.3	Tutorial	8
1.3.1	Command line	8
1.3.2	Scripting	20
1.3.3	Cheatsheet	28
1.3.4	Documentation	28
1.4	Config	29
1.4.1	Format	29
1.4.2	Adjusting on the fly	30
1.4.3	Config reference	31
1.5	Input formats	34
1.5.1	ANDES xlsx	34
1.5.2	PSS/E RAW and DYR	38
1.5.3	MATPOWER	42
1.5.4	ANDES JSON	42
1.5.5	Disturbances	44
1.6	Test Cases	45
1.6.1	Summary	45
1.6.2	Example data	46
1.6.3	MATPOWER cases	46
1.6.4	How to contribute	47
1.7	Performance	47
1.7.1	Numba compilation	47
1.7.2	MATPOWER cases	48
1.8	Verification	50
1.8.1	IEEE 14-Bus Verification	50
1.8.2	CURRENT NPCC Verification	60

1.8.3	CURRENT WECC Verification	89
1.9	Miscellaneous	131
1.9.1	Per Unit System	131
1.9.2	Notes	132
1.9.3	Profiling Import	133
1.9.4	What won't work	133
1.10	Frequently Asked Questions	133
1.10.1	Program Startup	133
1.10.2	General	133
1.10.3	Modeling	133
1.11	License	134
1.11.1	GNU Public License v3	134
1.12	Quick install	134
2	Examples	135
2.1	Simulate and Plot	135
2.1.1	Import and Setting the Verbosity Level	135
2.1.2	Run Time-Domain Simulation	136
2.1.3	Export and Plot Results	137
2.1.4	Cleanup	148
2.2	Working with Data	149
2.2.1	Load System from an ANDES XLSX File	149
2.2.2	Load System from PSS/E RAW and DYR Files	151
2.2.3	Variables	156
2.2.4	Altering Fault duration	159
2.2.5	Cleanup	161
2.3	Inspecting Models	161
2.3.1	Inspect Model Equations	161
2.3.2	Check model documentation	162
2.4	Eigenvalue Analysis	169
2.4.1	Run Eigenvalue Analysis	169
2.4.2	Plotting in S-Domain	170
2.4.3	Report	170
2.4.4	Parameter Sweep and Root Loci Plot	189
2.4.5	Cleanup	190
2.5	Using CLI from Notebook	190
2.5.1	The ! magic in iPython	190
2.5.2	Set up on Windows	190
2.5.3	Running Shell Commands	190
2.5.4	Run a simulation	191
2.5.5	Check the output <code>lst</code> file	194
2.5.6	Plot and save to file	198
2.5.7	Display image	199
2.5.8	Using <code>xargs</code> for index lookup	199
2.5.9	Cleanup	200
2.6	Batch Processing - Generate Cases	200
2.6.1	Create Cases in Batch	200
2.6.2	Parallel Simulation	201

2.7	Batch Processing - in Memory	205
2.7.1	Batch Power Flow Calculation	206
2.7.2	Batch Time-Domain Simulation	207
2.8	Changing Setpoints	217
2.8.1	Step 1: Case Setup	218
2.8.2	Step 2: Set the First Stop Time	219
2.8.3	Step 3: Run Simulation	219
2.8.4	Step 4. Apply the auxiliary power setpoints to <code>TGOV1.paux0.v</code>	219
2.8.5	Step 5: Set Another New Setpoints and New Ending Time.	224
2.9	Load Frequency Control	226
2.9.1	Tripping a Generator in the IEEE 14-Bus System	227
2.9.2	Adjusting Load to Compensate for the Generation Loss	230
2.10	Profile in Notebook	234
2.10.1	Profiling with Python CProfiler	234
2.10.2	Profiling with <code>line_profiler</code>	237
2.10.3	Cleanup	246
2.11	MATPOWER Interface	246
2.11.1	Create an Octave/MATLAB instance	246
2.11.2	Convert to MATPOWER	246
2.11.3	Convert from MATPOWER	248
2.11.4	Add dynamic data	249
2.12	pandapower Interface	250
2.12.1	Load case	251
2.12.2	Convert to pandapower net	252
2.12.3	Compare Power Flow Results	253
2.12.4	Generator dispatch based on OPF from pandapower	256
2.13	pypowsybl Interface	259
2.13.1	Imports	259
2.13.2	Conversion	259
2.13.3	Diagrams	259
3	Development	261
3.1	System	261
3.1.1	Overview	261
3.1.2	DAE Storage	264
3.1.3	Model and DAE Values	265
3.1.4	Calling Model Methods	266
3.1.5	Configuration	267
3.2	Group	268
3.2.1	<code>andes.models.group.GroupBase</code>	268
3.3	Models	273
3.3.1	<code>andes.core.model.ModelData</code>	274
3.3.2	<code>andes.core.model.Model</code>	277
3.3.3	<code>andes.core.model.ModelCache</code>	290
3.3.4	<code>andes.core.model.ModelCall</code>	291
3.3.5	Cache	292
3.3.6	Define Voltage Ratings	293
3.3.7	Commonly Used Attributes in Models	295

3.3.8	Attributes in <i>Model.cache</i>	296
3.3.9	Abstract Jacobian Storage	298
3.3.10	Concrete Jacobian Storage	298
3.4	Atomic Types	299
3.4.1	Value Provider	300
3.4.2	Equation Provider	300
3.5	Parameters	301
3.5.1	Background	301
3.6	Variables	324
3.6.1	andes.core.var.BaseVar	325
3.6.2	andes.core.var.ExtVar	327
3.6.3	andes.core.var.State	330
3.6.4	andes.core.var.Algeb	332
3.6.5	andes.core.var.ExtState	335
3.6.6	andes.core.var.ExtAlgeb	338
3.6.7	andes.core.var.AliasState	340
3.6.8	andes.core.var.AliasAlgeb	343
3.6.9	Variable, Equation and Address	346
3.6.10	Value and Equation Strings	346
3.6.11	Values Between DAE and Models	346
3.6.12	Flags for Value Overwriting	347
3.6.13	A <i>v_setter</i> Example	347
3.7	Services	347
3.7.1	andes.core.service.BaseService	348
3.7.2	andes.core.service.OperationService	349
3.7.3	Internal Constants	352
3.7.4	External Constants	354
3.7.5	Shape Manipulators	355
3.7.6	Value Manipulation	359
3.7.7	Idx and References	359
3.7.8	Events	362
3.7.9	Flags	363
3.7.10	Data Select	364
3.7.11	Miscellaneous	365
3.8	Discrete	367
3.8.1	Background	367
3.8.2	Limiters	371
3.8.3	Comparers	373
3.8.4	Deadband	375
3.8.5	Others	377
3.9	Blocks	379
3.9.1	Background	379
3.9.2	Transfer Functions	382
3.9.3	Saturation	400
3.9.4	Naming Convention	401
3.10	Examples	401
3.10.1	TGOV1	401
3.10.2	IEEEEST	404

4	Release notes	409
4.1	v1.9 Notes	409
4.1.1	v1.3.1 (2024-02-04)	409
4.1.2	v1.9.0 (2024-02-01)	409
4.2	v1.8 Notes	409
4.2.1	v1.8.10 (2023-08-10)	409
4.2.2	v1.8.9 (2023-06-22)	410
4.2.3	v1.8.8 (2023-04-24)	410
4.2.4	v1.8.7 (2023-03-10)	410
4.2.5	v1.8.6 (2023-02-13)	410
4.2.6	v1.8.5 (2022-12-22)	410
4.2.7	v1.8.4 (2022-11-23)	410
4.2.8	v1.8.3 (2022-11-15)	411
4.2.9	v1.8.2 (2022-10-30)	411
4.2.10	v1.8.1 (2022-09-24)	411
4.2.11	v1.8.0 (2022-08-30)	411
4.3	v1.7 Notes	411
4.3.1	v1.7.8 (2022-08-24)	411
4.3.2	v1.7.7 (2022-08-02)	412
4.3.3	v1.7.6 (2022-07-11)	412
4.3.4	v1.7.5 (2022-07-05)	412
4.3.5	v1.7.4 (2022-07-01)	412
4.3.6	v1.7.3 (2022-06-25)	413
4.3.7	v1.7.2 (2022-06-07)	413
4.3.8	v1.7.1 (2022-05-31)	413
4.3.9	v1.7.0 (2022-05-22)	413
4.4	v1.6 Notes	414
4.4.1	v1.6.6 (2022-04-30)	414
4.4.2	v1.6.5 (2022-04-19)	414
4.4.3	v1.6.4 (2022-04-17)	415
4.4.4	v1.6.3 (2022-04-06)	415
4.4.5	v1.6.2 (2022-03-27)	416
4.4.6	v1.6.1 (2022-03-13)	416
4.4.7	v1.6.0 (2022-03-11)	416
4.5	v1.5 Notes	416
4.5.1	v1.5.12 (2022-03-05)	416
4.5.2	v1.5.11 (2022-02-23)	417
4.5.3	v1.5.10 (2022-02-01)	417
4.5.4	v1.5.9 (2022-01-31)	417
4.5.5	v1.5.8 (2021-12-21)	417
4.5.6	v1.5.7 (2021-12-11)	417
4.5.7	v1.5.6 (2021-11-25)	418
4.5.8	v1.5.5 (2021-11-13)	418
4.5.9	v1.5.4 (2021-11-02)	418
4.5.10	v1.5.3 (2021-10-31)	419
4.5.11	v1.5.2 (2021-10-27)	419
4.5.12	v1.5.1 (2021-10-23)	419
4.5.13	v1.5.0 (2021-10-13)	419

4.6	v1.4 Notes	420
4.6.1	v1.4.4 (2021-10-05)	420
4.6.2	v1.4.3 (2021-09-25)	420
4.6.3	v1.4.2 (2021-09-12)	420
4.6.4	v1.4.1 (2021-09-12)	420
4.6.5	v1.4.0 (2021-09-08)	421
4.7	v1.3 Notes	421
4.7.1	v1.3.12 (2021-08-22)	421
4.7.2	v1.3.11 (2021-07-27)	421
4.7.3	v1.3.10 (2021-06-08)	421
4.7.4	v1.3.9 (2021-06-02)	422
4.7.5	v1.3.8 (2021-06-02)	422
4.7.6	v1.3.7 (2021-05-03)	422
4.7.7	v1.3.6 (2021-04-23)	422
4.7.8	v1.3.5 (2021-03-20)	422
4.7.9	v1.3.4 (2021-03-13)	422
4.7.10	v1.3.2 (2021-03-08)	422
4.7.11	v1.3.1 (2021-03-07)	423
4.7.12	v1.3.0 (2021-02-20)	423
4.8	v1.2 Notes	423
4.8.1	v1.2.9 (2021-01-16)	423
4.8.2	v1.2.7 (2020-12-08)	423
4.8.3	v1.2.6 (2020-12-01)	424
4.8.4	v1.2.5 (2020-11-19)	424
4.8.5	v1.2.4 (2020-11-13)	424
4.8.6	v1.2.3 (2020-11-02)	424
4.8.7	v1.2.2 (2020-11-01)	424
4.8.8	v1.2.1 (2020-10-11)	425
4.8.9	v1.2.0 (2020-10-10)	425
4.9	v1.1 Notes	425
4.9.1	v1.1.5 (2020-10-08)	425
4.9.2	v1.1.4 (2020-09-22)	426
4.9.3	v1.1.3 (2020-09-05)	426
4.9.4	v1.1.2 (2020-09-03)	426
4.9.5	v1.1.1 (2020-09-02)	426
4.9.6	v1.1.0 (2020-09-01)	426
4.10	v1.0 Notes	427
4.10.1	v1.0.8 (2020-07-29)	427
4.10.2	v1.0.7 (2020-07-18)	427
4.10.3	v1.0.6 (2020-07-08)	428
4.10.4	v1.0.5 (2020-07-02)	428
4.10.5	v1.0.4 (2020-06-26)	428
4.10.6	v1.0.3 (2020-06-02)	428
4.10.7	v1.0.2 (2020-06-01)	428
4.10.8	v1.0.1 (2020-05-27)	428
4.10.9	v1.0.0 (2020-05-25)	429
4.11	Pre-v1.0.0	429
4.11.1	v0.9.4 (2020-05-20)	429

4.11.2	v0.9.3 (2020-05-05)	429
4.11.3	v0.9.1 (2020-05-02)	430
4.11.4	v0.8.8 (2020-04-28)	430
4.11.5	v0.8.7 (2020-04-28)	431
4.11.6	v0.8.6 (2020-04-21)	431
4.11.7	v0.8.5 (2020-04-17)	431
4.11.8	v0.8.4 (2020-04-07)	432
4.11.9	v0.8.3 (2020-03-25)	432
4.11.10	v0.8.0 (2020-02-12)	432
4.11.11	v0.6.9 (2020-02-12)	432

5	Model reference	433
5.1	ACLine	434
5.1.1	Line	434
5.2	ACShort	437
5.2.1	Jumper	437
5.3	ACTopology	439
5.3.1	Bus	439
5.4	Calculation	440
5.4.1	ACE	440
5.4.2	ACEc	442
5.4.3	COI	444
5.5	Collection	445
5.5.1	Area	446
5.6	DCLink	446
5.6.1	Ground	446
5.6.2	R	447
5.6.3	L	449
5.6.4	C	450
5.6.5	RCp	452
5.6.6	RCs	453
5.6.7	RLs	455
5.6.8	RLCs	456
5.6.9	RLCp	458
5.7	DCTopology	459
5.7.1	Node	459
5.8	DG	461
5.8.1	PVD1	461
5.8.2	ESD1	469
5.8.3	EV1	476
5.8.4	EV2	483
5.9	DGProtection	490
5.9.1	DGPRCT1	490
5.9.2	DGPRCTExt	496
5.10	DataSeries	502
5.10.1	TimeSeries	502
5.11	DynLoad	504
5.11.1	ZIP	504

5.11.2	FLoad	506
5.12	Exciter	507
5.12.1	EXDC2	507
5.12.2	IEEEEX1	512
5.12.3	ESDC1A	517
5.12.4	ESDC2A	523
5.12.5	EXST1	528
5.12.6	ESST3A	531
5.12.7	SEXS	538
5.12.8	IEEET1	540
5.12.9	EXAC1	545
5.12.10	EXAC2	551
5.12.11	EXAC4	558
5.12.12	ESST4B	561
5.12.13	AC8B	568
5.12.14	IEEET3	574
5.12.15	ESAC1A	579
5.12.16	ESST1A	585
5.12.17	ESAC5A	592
5.13	Experimental	598
5.14	FreqMeasurement	598
5.14.1	BusFreq	598
5.14.2	BusROCOF	600
5.15	Information	602
5.15.1	Summary	603
5.16	Interface	603
5.16.1	Fortescue	603
5.17	Motor	607
5.17.1	Motor3	607
5.17.2	Motor5	610
5.18	OutputSelect	614
5.18.1	Output	614
5.19	PLL	614
5.19.1	PLL1	615
5.19.2	PLL2	617
5.20	PSS	618
5.20.1	IEEEEST	619
5.20.2	ST2CUT	625
5.21	PhasorMeasurement	630
5.21.1	PMU	630
5.22	RenAerodynamics	631
5.22.1	WTARA1	631
5.22.2	WTARV1	633
5.23	RenExciter	634
5.23.1	REECA1	634
5.23.2	REECA1E	642
5.23.3	REECA1G	650
5.24	RenGen	658

5.24.1	REGCA1	659
5.24.2	REGCP1	664
5.24.3	REGCV1	671
5.24.4	REGCV2	676
5.24.5	REGF1	681
5.24.6	REGF2	686
5.24.7	REGF3	692
5.25	RenGovernor	699
5.25.1	WTDTA1	699
5.25.2	WTDS	702
5.26	RenPitch	705
5.26.1	WTPTA1	705
5.27	RenPlant	708
5.27.1	REPCA1	708
5.28	RenTorque	714
5.28.1	WTTQA1	714
5.29	StaticACDC	719
5.29.1	VSCShunt	719
5.30	StaticGen	722
5.30.1	PV	723
5.30.2	Slack	725
5.31	StaticLoad	728
5.31.1	PQ	728
5.32	StaticShunt	731
5.32.1	Shunt	731
5.32.2	ShuntTD	732
5.32.3	ShuntSw	733
5.33	SynGen	736
5.33.1	GENCLS	736
5.33.2	GENROU	741
5.33.3	PLBVFU1	746
5.34	TimedEvent	749
5.34.1	Toggle	749
5.34.2	Fault	750
5.34.3	Alter	752
5.35	TurbineGov	754
5.35.1	TG2	754
5.35.2	TGOV1	757
5.35.3	TGOV1DB	760
5.35.4	TGOV1N	763
5.35.5	TGOV1NDB	766
5.35.6	IEEEG1	770
5.35.7	IEESGO	774
5.35.8	GAST	778
5.35.9	HYGOV	781
5.35.10	HYGOVDB	785
5.35.11	HYGOV4	789
5.36	Undefined	793

5.37	VoltComp	793
5.37.1	IEEEVC	794
6	API reference	797
6.1	System	797
6.1.1	andes.system	797
6.1.2	andes.variables	814
6.2	Routines	829
6.2.1	andes.routines	829
6.3	Plot	850
6.3.1	andes.plot	850
6.4	I/O	861
6.4.1	andes.io	862
6.5	Interoperability	873
6.5.1	andes.interop	873
6.6	Others	882
6.6.1	andes.cli	882
6.6.2	andes.main	883
6.6.3	andes.utils.paths	890
6.6.4	andes.utils.snapshot	894
6.6.5	andes.utils.widgets	895
	Bibliography	897
	Python Module Index	899
	Index	901

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LTB ANDES is an open-source Python library for power system modeling, computation, analysis, and control, serving as the core simulation engine for the CURENT Large scale Testbed (LTB). It supports power flow calculation, transient stability simulation, and small-signal stability analysis for transmission systems. ANDES implements a symbolic-numeric framework for rapid prototyping of differential-algebraic equation-based models. In this framework, a comprehensive *library of models* is developed, including the full second-generation renewable models. Models in ANDES have been *verified* with commercial software.

Getting started

New to ANDES? Check out the Getting Started guides. They contain tutorials to the ANDES command-line interface, scripting usages, as well as guides to configure ANDES and work with case files.

[To the getting started guides](#)

Examples

The examples provide in-depth usage of ANDES in a Python scripting environment. Advanced usage and power system studies are shown with explanation.

[To the examples](#)

Model development guide

Looking to implement new models, algorithms, and functionalities in ANDES? The development guide provides in-depth information on the design philosophy, data structure, and implementation of the hybrid symbolic-numeric framework.

[To the development guide](#)

API reference

The API reference contains a detailed description of the ANDES package. The reference describes how the methods work and which parameters can be used. It assumes that you have an understanding of the key concepts.

[To the API reference](#)

Using ANDES for Research?

Please cite our paper [[Cui2021](#)] if ANDES is used in your research for publication.

GETTING STARTED

1.1 Package Overview

ANDES is an open-source Python package for power system modeling, computation, analysis, and control. It establishes a unique **hybrid symbolic-numeric framework** for modeling differential algebraic equations (DAEs) for numerical analysis. The main features of ANDES include

- a unique hybrid symbolic-numeric approach to modeling and simulation that enables descriptive DAE modeling and automatic numerical code generation
- a rich library of transfer functions and discontinuous components (including limiters, dead-bands, and saturation) available for prototyping models, which can be readily instantiated as multiple devices for system analysis
- industry-grade second-generation renewable models (solar PV, type 3 and type 4 wind), distributed PV, and energy storage model
- comes with the Newton method for power flow calculation, the implicit trapezoidal method for time-domain simulation, and full eigenvalue calculation
- rigorously verified models with commercial software. ANDES obtains identical time-domain simulation results for IEEE 14-bus and NPCC system with GENROU and multiple controller models. See the verification link for details.
- developed with performance in mind. While written in Python, ANDES comes with a performance package and can finish a 20-second transient simulation of a 2000-bus system in a few seconds on a typical desktop computer
- out-of-the-box PSS/E raw and dyr file support for available models. Once a model is developed, inputs from a dyr file can be readily supported
- always up-to-date equation documentation of implemented models

ANDES is currently under active development. To get involved,

- Follow the tutorial at <https://andes.readthedocs.io>
- Checkout the Notebook examples in the [examples folder](#)
- Try ANDES in Jupyter Notebook [with Binder](#)
- Download the PDF manual at [download](#)

- Report issues in the [GitHub issues page](#)
- Learn version control with the [command-line git](#) or [GitHub Desktop](#)
- If you are looking to develop models, read the [Modeling Cookbook](#)

This work was supported in part by the Engineering Research Center Program of the National Science Foundation and the Department of Energy under NSF Award Number EEC-1041877 and the [CURENT](#) Industry Partnership Program. ANDES is made open source as part of the CURENT Large Scale Testbed project.

ANDES is developed and actively maintained by [Hantao Cui](#). See the GitHub repository for a full list of contributors.

1.2 Installation

1.2.1 New to Python

Setting Up Mambaforge

If you are new to Python and want to get started quickly, you can use Mambaforge, which is a conda-like package manager configured with conda-forge.

Step 1:

Downloaded the latest Mambaforge for your platform from <https://github.com/conda-forge/miniforge#mambaforge>. Most users will use `x86_64 (amd64)` for Intel and AMD processors. Mac users with Apple Silicon should use `arm64 (Apple Silicon)` for best performance.

Next, complete the Mambaforge installation on your system.

Note: Mambaforge is a drop-in replacement for conda. If you have an existing conda installation, you can replace all the following `mamba` commands with `conda` and achieve the same outcome.

If you are using Anaconda or Miniconda on Windows, you should open `Anaconda Prompt` instead of `Miniforge Prompt`.

Step 2:

Open Terminal (on Linux or macOS) or *Miniforge Prompt* (on Windows, **not cmd!!**). Make sure you are in a conda environment - you should see `(base)` prepended to the command-line prompt, such as `(base) C:\Users\username>`.

Create an environment for ANDES (recommended)

```
mamba create --name andes python=3.8
```

Activate the new environment with

```
mamba activate andes
```

Note: You will need to activate the `andes` environment every time in a new Miniforge Prompt or shell.

If you have completed these steps without error, you now have a working Python environment. See the commands at the top for *Getting started*.

1.2.2 Extra support package

Some ANDES features require extra support packages that are not installed by default. For example, to build the documentation, one will need to install development packages. Other packages will be required for interoperability.

The extra support packages are specified in groups. The following group names are supported, with descriptions given below:

- `dev`: packages to support development such as testing and documentation
- `interop`: packages to support interoperability of ANDES and other power systems tools.

Note: Extra support packages are not supported by conda/mamba installation. One needs to install ANDES with `pip`.

To install packages in the `dev` when installing ANDES, do:

```
pip install andes[dev]
```

To install all extra packages, do:

```
pip install andes[all]
```

One can also inspect the `requirements-extra.txt` to identify the packages for manual installation.

1.2.3 Develop Install

The development mode installation is for users who want to modify the code and, for example, develop new models or routines. The benefit of development mode installation is that changes to source code will be reflected immediately without re-installation.

Step 1: Get ANDES source code

As a developer, you are strongly encouraged to clone the source code using `git` from either your fork or the original repository. Clone the repository with

```
git clone https://github.com/cuihantao/andes
```

Note: Replace the URL with yours to use your fork. With `git`, you can later easily update the source code and perform version control.

Alternatively, you can download the ANDES source code from <https://github.com/cuihantao/andes> and extract all files to the path of your choice. Although works, this method is discouraged because tracking changes and pushing back code edits will require significant manual efforts.

Step 2: Install dependencies

In the Mambaforge environment, use `cd` to change directory to the ANDES root folder. The folder should contain the `setup.py` file.

Install dependencies with

```
mamba install --file requirements.txt
mamba install --file requirements-extra.txt
```

Alternatively, you can install them with `pip`:

```
pip install -r requirements.txt
pip install -r requirements-extra.txt
```

Step 3: Install ANDES in the development mode using

```
python3 -m pip install -e .
```

Note the dot at the end. `Pip` will take care of the rest.

Note: The ANDES version number shown in `pip list` will stuck at the version that was intalled, unless ANDES is develop-installed again. It will not update automatically with `git pull`.

To check the latest version number, check the preamble by running the `andes` command or chek the output of `python -c "import andes; print(andes.__version__)"`

Note: ANDES updates may infrequently introduce new package requirements. If you see an `ImportError` after updating ANDES, you can manually install the missing dependencies or redo [Step 2](#).

Note: To install extra support packages, one can append `[NAME_OF_EXTRA]` to `pip install -e ..`. For example, `pip install -e .[interop]` will install packages to support interoperability when installing ANDES in the development, editable mode.

1.2.4 Updating ANDES

Warning: If ANDES has been installed in the development mode using source code, you will need to use `git` or the manual approach to update the source code. In this case, Do not proceed with the following steps, as they will install a separate site-package installation on top of the development one.

Regular ANDES updates will be pushed to both `conda-forge` and Python package index. It is recommended to use the latest version for bug fixes and new features. We also recommended you to check the [Release notes](#) before updating to stay informed of changes that might break your downstream code.

Depending you how you installed ANDES, you will use one of the following ways to upgrade.

If you installed it from mamba or conda, run

```
conda install -c conda-forge --yes andes
```

If you install it from PyPI (namely, through `pip`), run

```
python3 -m pip install --yes andes
```

1.2.5 Uninstall Multiple Copies

A common mistake new users make is to have multiple copies of ANDES installed in the same environment. This can happen when one previously installed ANDES in the development mode but later ran `conda install` or `python3 -m pip install` to install the latest version. As a result, only the most recently installed version will be accessible.

In this case, we recommend that you uninstall all version and reinstall only one copy using your preferred mode. Uninstalling all copies can be done by calling `conda remove andes` and `python3 -m pip uninstall andes`. The prompted path will indicate the copy to be removed. One may need to run the two commands for a couple of time until the package managers indicate that the `andes` package can no longer be found.

1.2.6 Troubleshooting

If you get an error message on Windows, reading

```
ImportError: DLL load failed: The specified module could not be found.
```

It is a path issue of your Python. In fact, Python on Windows is so broken that many people are resorting to WSL2 just for Python. Fixes can be convoluted, but the easiest one is to install ANDES in a Conda/Mambaforge environment.

1.3 Tutorial

ANDES can be used as a command-line tool or a library. The command-line interface (CLI) comes in handy to run studies. As a library, it can be used interactively in the IPython shell or the Jupyter Notebook. This chapter describes the most common usages.

Please see the CLI [cheatsheet](#) if you are looking for quick help.

1.3.1 Command line

Basics

ANDES is invoked from the command line using the command `andes`. Running `andes` without any input is equal to `andes -h` or `andes --help`. It prints out a preamble with version and environment information, followed by `and` and `help` commands

```

      _ _ _ _ _ _ _ _ _ _ | Version 1.6.0
    / _ \ _ _ _ _ _ | | _ _ _ _ | Python 3.9.10 on Linux, 03/12/2022 10:30:44 AM
  / _ \ \ | ' \ / _ \ / _ \ _ _ < |
 / _ \ \ _ \ | | \ _ \, _ \ _ _ / _ \ | This program comes with ABSOLUTELY NO WARRANTY.

usage: andes [-h] [-v {1,10,20,30,40}]
           {run,plot,doc,misc,prepare,prep,selftest,st,demo} ...

positional arguments:
{run,plot,doc,misc,prepare,prep,selftest,st,demo}
    [run] run simulation routine; [plot] plot
    results; [doc] quick documentation; [misc] misc.
    functions; [prepare] prepare the numerical code;
    [selftest] run self test;

optional arguments:
-h, --help            show this help message and exit
-v {1,10,20,30,40}, --verbose {1,10,20,30,40}
                      Verbosity level in 10-DEBUG, 20-INFO, 30-WARNING,
                      or 40-ERROR.
```

Note: If the `andes` command is not found, it could be due to

- (1) missed steps in your installation process
 - (2) errors during installation
 - (3) forgot to activated the environment with ANDES
-

`andes` accepts an optional arugment to control verbosity level. It is done through `-v LEVEL` or `--verbose LEVEL`, where `level` is a number. Logging level by default is 20 (INFO) and can be chosen from:

- 1 (DEBUG with code location info)

- 10 (DEBUG)
- 20 (INFO)
- 30 (WARNING)
- 40 (ERROR)
- 50 (CRITICAL)

To show debugging outputs, use `andes -v 10`, followed by top-level commands. To only show warnings and errors, use `andes -v 30`.

The top-level commands are `{run, plot, doc, misc, prepare, selftest}`. Each command contains a group of subcommands, which can be looked up with `-h`. For example, use `andes run -h` to look up the subcommands for `andes run`. Frequently used commands are explained below.

Note: Some subcommands have shorthand names:

- `andes st` is equivalent to `andes selftest`
 - `andes prep` is equivalent to `andes prepare`
-

andes selftest

After the installation, please run `andes selftest` from the command line to test ANDES functionality. It might take a minute to run the full self-test suite. An example output looks like

```
test_docs (test_1st_system.TestCodegen) ... ok
...
... (outputs are truncated)
...
test_pflow_mpc (test_pflow_matpower.TestMATPOWER) ... ok
-----
Ran 60 tests in 10.109s

OK
```

There may be more test than what is shown above. Make sure that all tests have passed.

ANDES receives frequent updates. After each update, please run `andes st` to confirm the functionality. The command also makes sure the generated code is up to date. See [andes prepare](#) for more details on automatic code generation.

Note: There is a quick mode to test ANDES by skipping code generation. This should only be used when you are certain that there is no modification to models between the last code generation and now.

The quick mode is invoked by `andes st -q`.

andes prepare

The symbolically defined models in ANDES need to be generated into numerical code for simulation. The code generation process is *automatic* the first time you use ANDES to run any case study. It takes 10 seconds to one minute to generate the code depending on your platform. When done, no code generation is needed in your future use until you modify the models.

It is also possible to generate the code manually with `andes prepare` or `andes prep`. In addition, `andes selftest` automatically calls the code generation.

Note: Generated code files are stored in Python code in `$HOME/.andes/pycode`. While being human-readable, they are not human-friendly and should only be consulted during low-level debugging.

The default code generation mode is known as the "quick mode". It skips the generation of *L^AT_EX*-formatted equations, which are only useful in documentation and the interactive mode.

Option `-i` or `--incremental` can be used to speed up code generation during model development. `andes prepare -i` only generates code for models that are detected with changes since the last code generation.

Warning: To developers:

`andes prepare -i` needs to be called following model changes, such as equation modification and adding variables. Otherwise, due to mismatches in model and code, simulation results will not reflect the new changes, at best, or even lead to unexpected errors

ANDES supports precompiling the generated Python code using Numba. See [Numba compilation](#). Numba needs to be installed separately. Check the version of installed numba and other dependencies with `andes misc --version`.

andes run

`andes run` is the entry point for power system analysis routines. The full list of options can be printed with `andes run -h`. `andes run` takes one positional argument, `filename`, along with other optional keyword arguments. `filename` is the path to cases, either relative or absolute.

- **Relative path:** `andes run kundur_full.xlsx`, e.g., uses a relative path. It works only if `kundur_full.xlsx` exists in the *working directory* of the command line.
- **Absolute path:** `andes run /Users/hcui7/kundur_full.xlsx` (on macOS) or `andes run C:/Users/hcui7/kundur_full.xlsx` (on Windows) use absolute paths to the case files. They do not depend on the command-line current directory.

Note: When working with the command line, use `cd` to change directory to the folder containing your test case. Spaces in folder and file names need to be escaped properly, so it's generally advised to *avoid spaces in file and folder names*.

To find out your current working directory, look for the line below the ANDES preamble that reads like

```
Working directory: "/home/hacui/repos/andes/andes/cases/kundur"
```

Input path

ANDES allows one to specify the path to look for the case file instead of the working directory. This is done by using the `-p` or `--input-path` option. For example, if `kundur_full.xlsx` is in folder `/home/hacui/cases`, one can do

```
andes run kundur_full.xlsx -p /home/hacui/cases
```

The argument passed to `-p` or `--input-path` can also be a relative path. If you need further help understanding paths, please consult other online articles.

Multiprocessing

ANDES takes multiple files inputs or wildcard. Multiprocessing will be triggered if more than one valid input files are passed to `filename`.

- **Multiple files:** to run the power flow for `kundur_full.xlsx` and `kundur_motor.xlsx` simultaneously, one can do

```
andes run kundur_full.xlsx kundur_motor.xlsx
```

The output will look like

```
Working directory: "/home/hacui/repos/andes/andes/cases/kundur"
-> Processing 2 jobs on 12 CPUs.
Process 0 for "kundur_full.xlsx" started.
Process 1 for "kundur_motor.xlsx" started.
Log saved to "/tmp/andes/andes-uopdutii/andes.log".
-> Multiprocessing finished in 2.4680 seconds.
```

- **Wildcard:** to run power flow for files with a prefix of `kundur_` and a suffix (file extension) of `.xlsx`, run

```
andes run kundur_*.xlsx
```

Case files with such name pattern, including `kundur_full.xlsx` and `kundur_motor.xlsx`, among others, will be processed.

Option `--ncpu NCPU` can be used to specify the maximum number of parallel processes. By default, all cores will be used. A small number can be specified to increase operating system responsiveness.

Routine

Option `-r` or `-routine` is used for specifying the analysis routine, followed by the routine name. Available routine names include

- `pflow` for power flow calculation
- `tds` for time domain simulation
- `eig` for eigenvalue analysis

If `-r` is not given, the power flow calculation routine will be called. There are routine specific options that can be passed to `andes run` and are discussed next.

Each routine has a list of configuration options (called "config") to control their behaviors. Config needs to be distinguished from command-line options as not all config options are available in the command-line. Refer to [Config](#) for details.

Power flow

Note: Examples in the following will utilize the `kundur_full.xlsx` test case. If you have cloned the ANDES repository, it can be found in `andes/cases/kundur` in the source code folder. You can also download it from [here](#).

To run power flow, change to the directory containing `kundur_full.xlsx`, and execute the following in the command line:

```
andes run kundur_full.xlsx
```

Alternatively, the full path to the case file is also recognizable, such as

```
andes run /home/user/andes/cases/kundur/kundur_full.xlsx
```

The power flow report will be saved to the current directory where ANDES is invoked. The report contains four sections:

- 1) system statistics,
- 2) ac bus and dc node data
- 3) ac line data, and
- 4) results of other algebraic variables and state variables.

By default, the power flow routine is configured to use full Newton Raphson method, and reactive power limits are not checked. To change these config, edit the config file by referring to `andes doc PFlow` and `andes doc PV`.

Following power flow, ANDES does not initialize dynamic models to save time. When developing dynamic models, one can enable the initialization by setting in the config file


```
[PFlow]
init_tds = 1
```

Time-domain simulation

To run the time domain simulation (TDS) for `kundur_full.xlsx`, run

```
andes run kundur_full.xlsx -r tds
```

The output looks like:

```
Parsing input file "kundur_full.xlsx"...
Input file parsed in 0.1533 seconds.
System internal structure set up in 0.0174 seconds.
-> System connectivity check results:
No islanded bus detected.
System is interconnected.
Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
Sparse solver: KLU
Solution method: NR method
Numba compilation initiated with caching.
Power flow initialized in 0.1428 seconds.
0: |F(x)| = 14.9282832
1: |F(x)| = 3.608627841
2: |F(x)| = 0.1701107882
3: |F(x)| = 0.002038626956
4: |F(x)| = 3.745103977e-07
Converged in 5 iterations in 0.0014 seconds.
Report saved to "kundur_full_out.txt" in 0.0004 seconds.

-> Time Domain Simulation Summary:
Sparse Solver: KLU
Simulation time: 0.0-20.0 s.
Fixed step size: h=33.33 ms. Shrink if not converged.
Numba compilation initiated with caching.
Initialization for dynamics completed in 0.0626 seconds.
Initialization was successful.
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
100%|#####| 100/100 [00:00<00:00, 241.53%/
->s]
Simulation completed in 0.4141 seconds.
Outputs to "kundur_full_out.lst" and "kundur_full_out.npz".
Outputs written in 0.0171 seconds.
-> Single process finished in 0.8890 seconds.
```

The output contains the key information for the simulation, such as solver name and step size. It prints out the disturbance information, the trip of Line Line_8 at time $t=2.0$ sec.

There are a few places needing to be noted:

1. Make sure the power flow calculation is successful. Otherwise, there is no good starting point for dynamic simulation.
2. Make sure no suspect initialization error is found. Otherwise, the system will not be at steady state even before disturbances.

TDS writes two output files: a variable list file `kundur_full_out.lst`, and a compressed NumPy data file `kundur_full_out.npz`:

- List file: it is a plain-text file with three columns: variable indices, variable name in plain text, and variable name in the \LaTeX format. The variable indices are needed to plot the needed variable.
- Data file: it is a zipped NumPy binary file. Although not directly editable, it can be used for plotting or can be converted to a CSV file. See the subsection on [andes plot](#).

There are TDS-specific options that can be passed to `andes run`:

- `--tf TF`: the final time of the simulation. `TF` should be a number in seconds. By default, it is set to 20.0.
- `--addfile ADDFILE`: specify an additional data file. This is currently used to supply PSS/E `dyr` file in addition to a raw file.
- `--flat`: turn on "flat run" mode to ignore all disturbances. The simulation will be performed up to the end time.
- `--no-pbar`: turn off progress bar.
- `--from-csv FROM_CSV`: use data from a CSV file to perform mock simulation. The CSV file should be in the format of `andes plot --to-csv`.

Disable output

Output to files can be disabled with `--no-output` or `-n`. It is useful when computation is needed but results can be discarded. It is also useful when results are processed in memory, combined with the `--shell` option discussed next.

IPython shell

The ANDES CLI will exit to the system shell when finished running. It is sometimes useful to script in Python to quickly process the simulation results in memory, such as plotting. ANDES can exit to the IPython shell with `--shell` or `-s`. For example:

```
andes run kundur_full.xlsx -r tds -s -n
```

Note the `-n` is optional to disable file output. The terminal output will look like

```
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
100%|#####| 100/100 [00:00<00:00, 246.07%/
↪s]
Simulation completed in 0.4064 seconds.
```

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```

Outputs to "kundur_full_out.lst" and "kundur_full_out.npz".
Outputs written in 0.0171 seconds.
-> Single process finished in 0.8796 seconds.
IPython: Access System object in variable `system`.
Python 3.9.10 | packaged by conda-forge | (main, Feb 1 2022, 21:24:11)
Type 'copyright', 'credits' or 'license' for more information
IPython 8.1.1 -- An enhanced Interactive Python. Type '?' for help.

In [1]:

```

A prompt will appear following `In [1]:` to indicate an IPython shell. If the test case file is parsed without error, the system object will be stored in variable `system`, i.e.

```

In [1]: system
Out[1]: <andes.system.System at 0x7fc1cd992790>

```

Python commands can be executed thereafter. To exit, type `exit` and press enter.

Format converter

ANDES uses the Excel format to store power system data in the ANDES semantics. In addition, multiple input formats are recognized and can be converted to the ANDES `xlsx` format. Converting data into the ANDES has pros and cons:

- Pros: - The data can be readily edited with an Excel-like tool - Data for models unique to ANDES can be readily added to the `xlsx` file
- Cons: - Conversion from ANDES `xlsx` back to the original format is not supported

Note: It is recommended to stay with the original data format to maximize compatibility when no ANDES-specific models are used.

Format conversion is done through `--convert FORMAT` or `-c FORMAT`, where `FORMAT` is the output format. For now, the following formats are supported:

- `xlsx`: an Excel spread sheet format with ANDES-specific data. It is not compatible with `xlsx` with data from other tools such as [Pandapower](#).
- `json`: a JSON plain-text file with ANDES-specific data. Likewise, it is unlikely to be compatible with JSON from other power system tools. JSON is much faster to parse than `xlsx` but not as friendly to edit.

To convert `kundur_full.xlsx`, for example, to the `json` format, run

```
andes run kundur_full.xlsx --convert json
```

The output messages will look like

```
Parsing input file "kundur_full.xlsx"...  
Input file parsed in 0.1576 seconds.  
System internal structure set up in 0.0175 seconds.  
JSON file written to "kundur_full.json"  
Format conversion completed in 0.0053 seconds.  
-> Single process finished in 0.2582 seconds.
```

Note that `--convert` will only create sheets for existing models.

The converter works with any input formats that are currently supported. These include:

- `.m`: MATPOWER case file
- `.raw` and `.dyr`: PSS/E raw and dyr files
- `.xlsx`: Excel spreadsheet file with ANDES data
- `.json`: JSON plain-text file with ANDES data

PSS/E inputs

To work with PSS/E input files (`.raw` and `.dyr`), one need to provide the raw file through `casefile` and pass the dyr file through `--addfile`. For example, in `andes/cases/kundur`, one can run the power flow using

```
andes run kundur.raw
```

and run a no-disturbance time-domain simulation using

```
andes run kundur.raw --addfile kundur_full.dyr -r tds
```

Note: If one wants to modify the parameters of models that are supported by both PSS/E and ANDES, one can directly edit those dynamic parameters in the `.raw` and `.dyr` files to maintain interoperability with other tools.

To create add a disturbance, there are two options. The recommended option is to convert the PSS/E data into an ANDES `xlsx` file, edit it and run (see the previous subsection). The alternative approach is documented in [Creating disturbances](#).

Profiling

Profiling is useful for analyzing the computation time and code efficiency. Option `--profile` enables the profiling of ANDES execution. The profiling output will be written in two files in the current folder, one ending with `_prof.txt` and the other one with `_prof.prof`.

The text file can be opened with a text editor, and the `.prof` file can be visualized with `snakeviz`, which can be installed with `pip install snakeviz`.

If the output is disabled, profiling results will be printed to `stdio`.

andes plot

`andes plot` is the command-line tool for plotting. It currently supports time-domain simulation data. Three positional arguments are required, and a dozen of optional arguments are supported.

positional arguments:

Argument	Description
filename	simulation output file name, which should end with <i>out</i> . File extension can be omitted.
x	the X-axis variable index, typically 0 for Time
y	Y-axis variable indices. Space-separated indices or a colon-separated range is accepted

For the list of optional arguments, see the output of `andes plot -h`.

To plot the generator speed variable `omega` of `GENROU_1` `omega GENROU 1` versus time, one way is to supply the variable indices found in the `.lst` output file. The index of the variable `omega GENROU 1` is found to be 5, and Time is found to be 0, so the plot command should be

```
andes plot kundur_full_out.lst 0 5
```

where `kundur_full_out.lst` is list file name, 0 is the index of Time for the x-axis, and 5 is the index of `omega GENROU 1`. Note that for the file name, either `kundur_full_out.lst` or `kundur_full_out.npz` works as the program will automatically extract the file name.

The y-axis variable indices can also be specified as a Python range. For example, `andes plot kundur_full_out.npz 0 2:21:6` will plot the variables with indices 2, 8, 14 and 20.

It can become tedious to look up the indices of variables in the `.lst` file. `andes plot` supports `--xargs` or `-a` for searching for variable indices and passing them as arguments to `andes plot`. See Examples - "Using CLI from Notebook".

LaTeX rendering

`andes plot` will attempt to render with LaTeX if `dvipng` program is in the search path. Figures rendered by LaTeX has publication-quality aesthetics for symbols but takes considerably longer time. In case LaTeX is available but fails (frequently happens on Windows), the option `-d` can be used to disable LaTeX rendering.

andes doc

`andes doc` is a handy tool to look up model, routine and config documentation. Model documentation include the descriptions of parameters, variables, and configs. A pretty-print version is available online in [Model reference](#).

The basic usage of `andes doc` is to provide a model name or a routine name as the positional argument. For a model, it will print out model parameters, variables, and equations to the stdio. For a routine, it will print out fields in the Config file.

Note: For full model documentation, visit [Model reference](#).

For example, to check the parameters for model `Toggle`, run

```
$ andes doc Toggle
Model <Toggle> in Group <TimedEvent>

    Time-based connectivity status toggle.

Parameters

Name | Description | Default | Unit | Type |
--Properties
-----+-----+-----+-----+-----+
--
u | connection status | 1 | bool | NumParam |
name | device name | | | DataParam |
model | Model or Group of the device | | | DataParam |
--mandatory
| to control | | | |
dev | idx of the device to control | | | IdxParam |
--mandatory
t | switch time for connection | -1 | | TimerParam |
--mandatory
| status | | | |
```

To list all supported models, run

```
$ andes doc -l
Supported Groups and Models

Group | Models
-----+-----
ACLine | Line
ACTopology | Bus
Collection | Area
DCLink | Ground, R, L, C, RCp, RCs, RLs, RLCs, RLCp
DCTopology | Node
Exciter | EXDC2
Experimental | PI2
FreqMeasurement | BusFreq, BusROCOF
```

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StaticACDC	VSCShunt
StaticGen	PV, Slack
StaticLoad	PQ
StaticShunt	Shunt
SynGen	GENCLS, GENROU
TimedEvent	Toggle, Fault
TurbineGov	TG2, TGOV1

To view the Config fields for a routine, run

```
$ andes doc TDS
Config Fields in [TDS]
```

Option	Value	Info	Acceptable
values			
--			
sparselib	klu	linear sparse solver name	('klu', 'umfpack')
tol	0.000	convergence tolerance	float
t0	0	simulation starting time	>=0
tf	20	simulation ending time	>t0
fixt	0	use fixed step size (1) or variable	(0, 1)
		(0)	
shrinkt	1	shrink step size for fixed method if	(0, 1)
		not converged	
tstep	0.010	the initial step step size	float
max_iter	15	maximum number of iterations	>=10

andes misc

`andes misc` contains miscellaneous functions, such as configuration and output cleaning.

Configuration

ANDES uses a configuration file to set runtime configs for the system routines, and models. `andes misc --save-config` saves all configs to a file. By default, it saves to `$HOME/.andes/andes.conf` file, where `$HOME` is the path to your home directory.

With `andes misc --edit-config`, you can edit ANDES configuration handy. The command will automatically save the configuration to the default location if not exist. The shorter version `--edit` can be used instead as Python matches it with `--edit-config`.

You can pass an editor name to `--edit`, such as `--edit vim`. If the editor name is not provided, it will use the following defaults: - Microsoft Windows: `notepad`. - GNU/Linux: the `$EDITOR` environment variable, or `vim` if not exist.

For macOS users, the default is `vim`. If not familiar with `vim`, you can use `nano` with `--edit nano` or `TextEdit` with `--edit "open -a TextEdit"`.

Cleanup

```
andes misc -C, --clean
```

Option to remove any generated files. Removes files with any of the following suffix: `_out.txt` (power flow report), `_out.npy` (time domain data), `_out.lst` (time domain variable list), and `_eig.txt` (eigenvalue report).

Version

Check the version of ANDES and the core packages it uses, use

```
andes misc --version
```

Please include the output in your bug report.

1.3.2 Scripting

This section is a tutorial for using ANDES in an interactive/scripting environment. All scripting shells are supported, including Python shell, IPython, Jupyter Notebook, and Jupyter Lab. The examples below use Jupyter Notebook.

Jupyter Notebook

Jupyter Notebook is a convenient tool to run Python code and present results. Jupyter Notebook can be installed with

```
conda install jupyter notebook
```

After the installation, change the directory to the folder where you wish to store notebooks, then start the notebook with

```
jupyter notebook
```

A browser window should open automatically with the notebook browser loaded. To create a new notebook, use the "New" button near the upper-right corner.

Note: In the following, code blocks starting with `>>>` are Python code and should be executed inside Python, IPython, or Jupyter Notebook. Python code should not be entered into Anaconda Prompt or Linux shell.

Import

Like other Python libraries, ANDES needs to be imported into an interactive scripting Python environment.

```
>>> import andes
>>> andes.config_logger()
```

Verbosity

If you are debugging ANDES, you can enable debug messages with

```
>>> andes.config_logger(stream_level=10)
```

or simply

```
>>> andes.config_logger(10)
```

The `stream_level` uses the same verbosity levels as for the command line. If not explicitly enabled, the default level 20 (INFO) will apply.

To set a new logging level for the current session, call `config_logger` with the desired new levels.

Making a System

Before running studies, an `andes.system.System` object needs to be created to hold the system data. The System object can be created by passing the path to the case file to the entry-point function.

There are multiple ways to create the System object. Among them, `andes.main.run` is the most convenient way. For example, to run the file `kundur_full.xlsx` in the same directory as the notebook, use

```
>>> ss = andes.run('kundur_full.xlsx')
```

This function will parse the input file, run the power flow, and return the system as an object. Outputs will look like

```
Parsing input file </Users/user/notebooks/kundur/kundur_full.xlsx>
Input file kundur_full.xlsx parsed in 0.4172 second.
-> Power flow calculation with Newton Raphson method:
0: |F(x)| = 14.9283
1: |F(x)| = 3.60859
2: |F(x)| = 0.170093
3: |F(x)| = 0.00203827
4: |F(x)| = 3.76414e-07
Converged in 5 iterations in 0.0222 second.
Report saved to </Users/user/notebooks/kundur_full_out.txt> in 0.0015 second.
-> Single process finished in 0.4677 second.
```

In this example, `ss` is an instance of `andes.System`. It contains member attributes for models, routines, and numerical DAE.

The naming convention for the `System` attributes is as follows

- Model attributes share the same name as class names. For example, `ss.Bus` is the `Bus` instance, and `ss.GENROU` is the `GENROU` instance.
- Routine attributes share the same name as class names. For example, `ss.PFlow` and `ss.TDS` are the routine instances.
- The numerical DAE instance is in lower case `ss.dae`.

To work with PSS/E inputs, refer to [Examples](#) - "Working with Data".

Note: `andes.main.run` can accept multiple input files for multiprocessing. They can be passed as a list of strings to the first positional argument.

Passing options

`andes.run()` can accept options that are available to the command-line `andes run`. Options need to be passed as keyword arguments to `andes.run()` in addition to the positional argument for the test case. For example, setting `no_output` to `True` will disable all file outputs. When scripting, one can do

```
>>> ss = andes.run('kundur_full.xlsx', no_output=True)
```

which is equivalent to the following shell command:

```
andes run kundur_full.xlsx --no-output
```

Please note that the dash between `no` and `output` needs to be replaced with an underscore for scripting. This is the convention in Python's argument parser.

Another example is to specify a folder for output files. By default, outputs will be saved to the folder where Python is run (or where the notebook is run). In case you need to organize outputs, a path prefix can be passed to `andes.run()` through `output_path`:

```
>>> ss = andes.run('kundur_full.xlsx', output_path='outputs/')
```

which will put outputs into folder `outputs` relative to the current path. You can also supply an absolute path to `output_path`.

The next example is to specify the simulation time for a time-domain simulation. There are multiple ways to implement it (see [Examples](#)), and one way is to pass the end time (in sec) through argument `tf` and set the routine to `tds`:

```
>>> ss = andes.run('kundur_full.xlsx', routine='tds', tf=5)
```

which will set the simulation time to 5 seconds.

Note: While `andes run` accepts single-letter alias for the option, such as `andes run -n` for `andes run --no-output`, `andes.run()` can only work with the full option name (with hyphen replaced by

underscore)

Load Only

In many workflows, one will simulate many scenarios with largely identical system data. A base case can be loaded and modified to create scenarios in memory. See Example "Working with Data" for details

Inspecting Parameter

DataFrame

Parameters for the loaded system can be readily inspected in Jupyter Notebook using Pandas.

Parameters for a model instance can be retrieved in a DataFrame using the `as_df()` method on the model instance. For example, to view the parameters of `Bus`, use

```
>>> ss.Bus.as_df()
```

A table will be printed with the columns being parameters and the rows being Bus devices/instances. For a system that has been setup, parameters have been converted to per unit values in the system base specified by `ss.config.mva`. The per-unit values in the system base will be used in computation as all computation in ANDES uses system-base per-unit data.

To view the original input values, use the `as_df(vin=True)` method. For example, to view the system-base per unit value of `GENROU`, use

```
>>> ss.GENROU.as_df(vin=True)
```

Parameter in the table is the same as that in the input file without any conversion. Some input data, by convention, are given as per unit in the device base; see [Per Unit System](#) for details.

Note that `andes.core.modeldata.ModelData.as_df()` returns a *view*. Modifying the returned dataframe *will not* affect the original data used for simulation. To modify the data, see Example "Working with Data".

Running Studies

Three routines are currently supported: PFlow, TDS and EIG. Each routine provides a `run()` method to execute. The System instance contains member attributes having the same names. For example, to run the time-domain simulation for `ss`, use

```
>>> ss.TDS.run()
```

To change configuration for routines, one can set the attribute before calling run. For example, to change the end time to 5 sec, one can do

```
>>> ss.TDS.config.tf = 5
>>> ss.TDS.run()
```

Note that not all config changes are respected. Some config values are used while creating the routine instance. For config changes that does not necessarily have to be done on-the-fly, it is recommended to edit the config file.

Checking Exit Code

`andes.System` contains field `exit_code` for checking if error occurred in run time. A normal completion without error should always have `exit_code == 0`. One should read output messages carefully and check the exit code, which is particularly useful for batch simulations.

Error may occur in any phase - data parsing, power flow, or simulation. To diagnose, split the simulation steps and check the outputs from each one.

Plotting TDS Results

TDS comes with a plotting utility for scripting usage. After running the simulation, a `plotter` attributed will be created for TDS. To use the plotter, provide the attribute instance of the variable to plot. For example, to plot all the generator speed, use

```
>>> ss.TDS.plotter.plot(ss.GENROU.omega)
```

Note: If you see the error

AttributeError: 'NoneType' object has no attribute 'plot'

You will need to manually load plotter with

```
>>> ss.TDS.load_plotter()
```

Optional indices is accepted to choose the specific elements to plot. It can be passed as a tuple through the `a` argument

```
>>> ss.TDS.plotter.plot(ss.GENROU.omega, a=(0, ))
```

In the above example, the speed of the "zero-th" generator will be plotted.

Scaling

A lambda function can be passed to argument `ycalc` to scale the values. This is useful to convert a per-unit variable to nominal. For example, to plot generator speed in Hertz, use

```
>>> ss.TDS.plotter.plot(ss.GENROU.omega, a=(0, ),
                        ycalc=lambda x: 60*x,
                        )
```

Formatting

A few formatting arguments are supported:

- `grid = True` to turn on grid display
- `greyscale = True` to switch to greyscale
- `ylabel` takes a string for the y-axis label

Extracting Data

One can extract data from ANDES for custom plotting. Variable names can be extracted from the following fields of `ss.dae`:

Un-formatted names (non-LaTeX):

- `x_name`: state variable names
- `y_name`: algebraic variable names
- `xy_name`: state variable names followed by algebraic ones

LaTeX-formatted names:

- `x_tex_name`: state variable names
- `y_tex_name`: algebraic variable names
- `xy_tex_name`: state variable names followed by algebraic ones

These lists only contain the variable names used in the current analysis routine. If you only ran power flow, `ss.dae.y_name` will only contain the power flow algebraic variables, and `ss.dae.x_name` will likely be empty. After initializing time-domain simulation, these lists will be extended to include all variables used by TDS.

In case you want to extract the discontinuous flags from TDS, you can set `store_z` to 1 in the config file under section `[TDS]`. When enabled, discontinuous flag names will be populated at

- `ss.dae.z_name`: discontinuous flag names
- `ss.dae.z_tex_name`: LaTeX-formatted discontinuous flag names

If not enabled, both lists will be empty.

Power flow solutions

The full power flow solutions are stored at `ss.dae.xy` after running power flow (and before initializing dynamic models). You can extract values from `ss.dae.xy`, which corresponds to the names in `ss.dae.xy_name` or `ss.dae.xy_tex_name`.

If you want to extract variables from a particular model, for example, bus voltages, you can directly access the `v` field of that variable

```
>>> import numpy as np
>>> voltages = np.array(ss.Bus.v.v)
```

which stores a **copy** of the bus voltage values. Note that the first `v` is the voltage variable of `Bus`, and the second `v` stands for *value*. It is important to make a copy by using `np.array()` to avoid accidental changes to the solutions.

If you want to extract bus voltage phase angles, do

```
>>> angle = np.array(ss.Bus.a.v)
```

where `a` is the field name for voltage angle.

To find out names of variables in a model, use command `andes doc` or refer to [Model reference](#).

Time-domain data

Time-domain simulation data will be ready when simulation completes. It is stored in `ss.dae.ts`, which has the following fields:

- `txyz`: a two-dimensional array. The first column is time stamps, and the following are variables. Each row contains all variables for that time step.
- `t`: all time stamps.
- `x`: all state variables (one column per variable).
- `y`: all algebraic variables (one column per variable).
- `z`: all discontinuous flags (if enabled, one column per flag).

If you want the output in pandas DataFrame, call

```
ss.dae.ts.unpack(df=True)
```

Dataframes are stored in the following fields of `ss.dae.ts`:

- `df`: dataframe for states and algebraic variables
- `df_z`: dataframe for discontinuous flags (if enabled)

For both dataframes, time is the index column, and each column correspond to one variable.

Note: Looking to extract data for a single variable? See [Examples](#) - "Working with Data".

Pretty Print of Equations

Each ANDES models offers pretty print of $\text{L}^{\text{A}}\text{T}_{\text{E}}\text{X}$ -formatted equations in the jupyter notebook environment.

To use this feature, symbolic equations need to be generated in the current session using

```
import andes ss = andes.System() ss.prepare()
```

Or, more concisely, one can do

```
import andes ss = andes.prepare()
```

This process may take a few minutes to complete. To save time, you can selectively generate it only for interested models. For example, to generate for the classical generator model GENCLS, do

```
import andes ss = andes.System() ss.GENROU.prepare()
```

Once done, equations can be viewed by accessing `ss.<ModelName>.syms.<PrintName>`, where `<ModelName>` is the model name, and `<PrintName>` is the equation or Jacobian name.

Note: Pretty print only works for the particular `System` instance whose `prepare()` method is called. In the above example, pretty print only works for `ss` after calling `prepare()`.

Supported equation names include the following:

- `xy`: variables in the order of *State*, *ExtState*, *Algeb* and *ExtAlgeb*
- `f`: the **right-hand side of** differential equations $\mathbf{M}\dot{\mathbf{x}} = \mathbf{f}$
- `g`: implicit algebraic equations $0 = \mathbf{g}$
- `df`: derivatives of `f` over all variables `xy`
- `dg`: derivatives of `g` over all variables `xy`
- `s`: the value equations for *ConstService*

For example, to print the algebraic equations of model GENCLS, one can use `ss.GENCLS.syms.g`.

Finding Help

docstring

To find out how a Python class, method, or function should be used, use the built-in `help()` function. This will print out the docstring of the class/method/function. For example, to check how the `get` method of `GENROU` should be called, do

```
help(ss.GENROU.get)
```

In Jupyter notebook, this can be simplified into `?ss.GENROU.get` or `ss.GENROU.get?`.

Please report issues if you find missing docstring.

Model docs

Model docs can be shown by printing the return of `doc()`. For example, to check the docs of `GENCLS`, do

```
print(ss.GENCLS.doc())
```

It is the same as calling `andes doc GENCLS` from the command line. Likewise, a pretty-print version is available online in [Model reference](#).

1.3.3 Cheatsheet

A cheatsheet is available for quick lookup of supported commands.

View the PDF version at

<https://www.cheatography.com/cuihantao/cheat-sheets/andes-for-power-system-simulation/pdf/>

1.3.4 Documentation

The documentation you are viewing can be made locally in a variety of formats. To make HTML documentation, change directory to `docs`, and do

```
make html
```

After a few minutes, HTML documentation will be saved to `docs/build/html` with the index page being `index.html`. You can use Python to serve it locally. In the folder `docs/build/html`, run

```
python -m http.server
```

A list of supported formats is as follows. Note that some format require additional compiler or library

html	to make standalone HTML files
dirhtml	to make HTML files named index.html in directories
singlehtml	to make a single large HTML file
pickle	to make pickle files
json	to make JSON files
htmlhelp	to make HTML files and an HTML help project
qthelp	to make HTML files and a qthelp project
devhelp	to make HTML files and a Devhelp project
epub	to make an epub
latex	to make LaTeX files, you can set PAPER=a4 or PAPER=letter
latexpdf	to make LaTeX and PDF files (default pdflatex)
latexpdfja	to make LaTeX files and run them through platex/dvipdfmx
text	to make text files
man	to make manual pages
texinfo	to make Texinfo files
info	to make Texinfo files and run them through makeinfo
gettext	to make PO message catalogs
changes	to make an overview of all changed/added/deprecated items
xml	to make Docutils-native XML files
pseudoxml	to make pseudoxml-XML files for display purposes
linkcheck	to check all external links for integrity
doctest	to run all doctests embedded in the documentation (if enabled)
coverage	to run coverage check of the documentation (if enabled)

1.4 Config

ANDES uses a config file to store the various options for routines and models. As discussed in *andes misc*, the config file is at `$HOME/.andes/andes.rc`. The reference for the config fields can be found in *Config reference*.

1.4.1 Format

The ANDES config file uses the format provided by Python module `configparser`. The syntax is like the following:

```
[System]
freq = 60
mva = 100
...

[PFlow]
sparselib = klu
linsolve = 0
tol = 1e-6
...

[TGOV1]
allow_adjust = 1
```

(continues on next page)

(continued from previous page)

```
adjust_lower = 0
adjust_upper = 1
```

In the above, `System`, `PFlow` and `TGOV1` are two sections. `freq = 60`, for example, is a pair of option and value in the `[System]` section. Note the space before and after the equal sign.

The meaning of the fields in each section can be found in [Config reference](#), which contains the default values and acceptable values for each option. The values for config fields can be a string or a number. Fields with acceptable values being (0, 1) can only accept 0 or 1 to indicate true or false. Non-binary values for such options will cause unexpected errors in the program.

Limits in models

All models have three config options:

- `allow_adjust`: allow limits of limiters in this model to be adjusted if the inputs, at steady state, is out of the limits. `allow_adjust = 0` is the global off-switch for this model.
- `adjust_lower`: allow reducing the lower limit to the input value, if the input at steady-state is below the lower limit. This is disabled by default.
- `adjust_upper`: allow increasing the upper limit to the steady-state input. This is enabled by default.

Note that setting `allow_adjust = 0` is equal to setting `adjust_lower = 0` and `adjust_upper = 0`, but the former saves some time for function calls.

The limit adjustment feature is to alleviate issues caused by the model parameters. Commercial tools have a more sophisticated mechanism for autocorrection, and the limit adjustment is part of it. However, if you see an limit adjustment warning or even initialization error, it is important not to rely on autocorrection but fix the data by yourself. Autocorrected data can yield some results but issues can remain hidden.

1.4.2 Adjusting on the fly

CLI

One can adjust config on the fly *in command line* without modifying or even storing the config file. This is useful when the config change is one-time or ANDES CLI is stored in a read-only container. The config update is done by `andes run --config-option SECTION.OPTION=VALUE`, where `SECTION` is the section name, `OPTION` is the option name, and `VALUE` is the new value. *No space is allowed* around `.` and `=`.

For example, to solve `kundur_full.json` with reactive power limit enforced, one can do:

```
andes run kundur_full.json -O PV.pv2pq=1
```

where `-O` is the shorthand command for `--config-option`, and the enabled `pv2pq` will allow PV to be converted to PQ once reactive power limit is hit.

Multiple config updates can be passed simultaneously, separated by *space*. For example, to enable reactive power limit and switch the power flow solver to UMFPACK, do:

```
andes run kundur_full.json -O PV.pv2pq=1 PFlow.sparselib=umfpack
```

Scripting

To adjust config on the fly when scripting, there are two cases:

- Update the config when creating a new System object
- Update the config for an existing System object

To update the config when creating a new System object, one can pass a list of strings to `config_option` for `andes.main.run`:

```
>>> ss = andes.run("kundur_full.json", config_option=["PV.pv2pq=1"])
```

which directly calls the backend API for the CLI. To update multiple configs, one can do

```
>>> ss = andes.run("kundur_full.json",
                  config_option=["PV.pv2pq=1", "PFlow.sparselib=umfpack"])
```

When the System object gets created, the config values will be distributed to member attributes of the System object. Therefore, the config for a System object `ss` is stored in `ss.config`, and the config for the power flow routine is stored in `ss.PFlow.config`.

To update the config for an existing system, one can directly access the `config` attribute and set the new value. To set a new simulation end time, one can overwrite the `ss.TDS.config.tf` field, such as:

```
# load system and run power flow
>>> ss = andes.run("kundur_full.json")
>>> ss.TDS.config.tf = 5.0
>>> ss.TDS.run()
```

Warning: Not all config options can be updated on the fly. Those config that are used for constructing the system object can only be updated when creating a new System object.

1.4.3 Config reference

System

Option	Value	Info	Accepted values
freq	60	base frequency [Hz]	float
mva	100	system base MVA	float
ipadd	1	use spmatrix.ipadd if available	(0, 1)
seed	None	seed (or None) for random number generator	int or None
diag_eps	0.000	small value for Jacobian diagonals	
warn_limits	1	warn variables initialized at limits	(0, 1)
warn_abnormal	1	warn initialization out of normal values	(0, 1)
dime_enabled	0		
dime_name	andes		
dime_address	ipc:///tmp/dime		
numba	0	use numba for JIT compilation	(0, 1)
numba_parallel	0	enable parallel for numba.jit	(0, 1)
numba_nopython	1	nopython mode for numba	(0, 1)
yapf_pycode	0	format generated code with yapf	(0, 1)
save_stats	0	store statistics of function calls	(0, 1)
np_divide	warn	treatment for division by zero	{'raise', 'ignore', 'warn', 'call', 'print', 'log'}
np_invalid	warn	treatment for invalid floating-point ops.	{'raise', 'ignore', 'warn', 'call', 'print', 'log'}

PFlow

Option	Value	Info	Accepted values
sparselib	klu	linear sparse solver name	('klu', 'umfpack', 'spsolve', 'cupy')
linsolve	0	solve symbolic factorization each step (enable when KLU segfaults)	(0, 1)
tol	0.000	convergence tolerance	float
max_iter	25	max. number of iterations	>=10
method	NR	calculation method	('NR', 'dishonest', 'NK')
check_conn	1	check connectivity before power flow	(0, 1)
n_factorize	4	first N iterations to factorize Jacobian in dishonest method	>0
report	1	write output report	(0, 1)
degree	0	use degree in report	(0, 1)
init_tds	0	initialize TDS after PFlow	(0, 1)

TDS

Option	Value	Info	Accepted values
sparselib	klu	linear sparse solver name	('klu', 'umfpack', 'spsolve', 'cupy')
linsolve	0	solve symbolic factorization each step (enable when KLU segfaults)	(0, 1)
method	trapezoid	DAE solution method	('trapezoid', 'backeuler')
tol	0.000	convergence tolerance	float
t0	0	simulation starting time	≥ 0
tf	20	simulation ending time	$> t_0$
fixt	1	use fixed step size (1) or variable (0)	(0, 1)
shrinkt	1	shrink step size for fixed method if not converged	(0, 1)
honest	0	honest Newton method that updates Jac at each step	(0, 1)
tstep	0.033	integration step size	float
max_iter	15	maximum number of iterations	≥ 10
refresh_event	0	refresh events at each step	(0, 1)
test_init	1	test if initialization passes	(0, 1)
check_conn	1	re-check connectivity after event	(0, 1)
criteria	1	use criteria to stop simulation if unstable	(0, 1)
ddelta_limit	180	delta diff. limit to be considered unstable, in degree	
g_scale	1	scale algebraic residuals with time step size	positive
reset_tiny	1	reset tiny residuals to zero to avoid chattering	(0, 1)
qrt	0	quasi-real-time stepping	(0, 1)
kqrt	1	quasi-real-time scaling factor; kqrt > 1 means slowing down	positive
store_z	0	store limiter status in TDS output	(0, 1)
store_f	0	store RHS of diff. equations	(0, 1)
store_h	0	store RHS of external diff. equations	(0, 1)
store_i	0	store RHS of external algeb. equations	(0, 1)
limit_store	0	limit in-memory timeseries storage	(0, 1)
max_store	900	maximum steps of data stored in memory before offloading	positive integer
save_every	1	save one step to memory every N simulation steps	integer
save_mode	auto	automatically or manually save output data when done	('auto', 'manual')
no_tqdm	0	disable tqdm progressbar and outputs	(0, 1)
chatter_iter	4	minimum iterations to detect chattering	$\text{int} \geq 4$

EIG

Option	Value	Info	Accepted values
sparselib	klu	linear sparse solver name	('klu', 'umfpack', 'spsolve', 'cupy')
lin-solve	0	solve symbolic factorization each step (enable when KLU segfaults)	(0, 1)
plot	0	show plot after computation	(0, 1)
tol	0.000	numerical tolerance to treat eigenvalues as zeros	

1.5 Input formats

ANDES currently supports the following input formats:

- `.xlsx`: Excel spreadsheet file with ANDES data
- `.raw` and `.dyr`: PSS/E RAW and DYR formats
- `.m`: MATPOWER format
- `.json`: JSON plain-text format with ANDES data

1.5.1 ANDES xlsx

The ANDES xlsx format allows one to use Excel for convenient viewing and editing. If you do not use Excel, there are alternatives such as the free and open-source [LibreOffice](#).

Format definition

The ANDES xlsx format contains multiple workbooks (also known as "sheets") shown as tabs at the bottom. The name of a workbook is a *model* name, and each workbook contains the parameters of all *devices* that are *instances* of the model.

In each sheet, the first row contains the names of parameters of the model. Starting from the second row, each row corresponds to a *device instance* with the parameters in the corresponding columns. An example of the Bus sheet is shown in the following screenshot.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	uid	idx	u	name	Vn	vmax	vmin	v0	a0	xcoord	ycoord	area	zone	owner			
2	0	1	1	1	20	1.1	0.9	1	0.570255	0	0	1	1	1			
3	1	2	1	2	20	1.1	0.9	0.99761	0.368746	0	0	1	1	1			
4	2	3	1	12	20	1.1	0.9	0.96263	0.185317	0	0	2	1	1			
5	3	4	1	11	20	1.1	0.9	0.81691	0.462359	0	0	2	1	1			
6	4	5	1	101	230	1.1	0.9	0.97928	0.480203	0	0	1	1	1			
7	5	6	1	102	230	1.1	0.9	0.95796	0.283887	0	0	1	1	1			
8	6	7	1	3	230	1.1	0.9	0.9362	0.126901	0	0	1	1	1			
9	7	8	1	13	230	1.1	0.9	0.87904	-0.08059	0	0	2	1	1			
10	8	9	1	112	230	1.1	0.9	0.89054	0.093618	0	0	2	1	1			
11	9	10	1	111	230	1.1	0.9	0.82958	0.336601	0	0	2	1	1			

Common parameters

A few columns are used across all models. That includes `uid`, `idx`, `name` and `u`:

- `uid` is an unique index that is generated and used *internally*. This column can be left empty when the sheet is being created manually. Exporting systems to `xlsx` with `--convert` (see [Format converter](#)) will have the `uid` overwritten.
- `idx` is the *unique index to identify a device* of the model. An unique `idx` should be provided explicitly for each instance for best consistency. Accepted types for `idx` include numbers and strings without spaces.

Warning: ANDES will check the uniqueness of `idx` and assign new ones when duplication is detected. Duplicate `idx` indicates data inconsistency and will likely cause simulations to fail.

- `u` is the connectivity status of the instance. Accepted values are 0 for disconnected (turned off) and 1 for connected (turned on). Disconnected devices will still have the variables assigned in ANDES but will not interact with the simulation. Unexpected behaviors may occur if numerical values other than 0 and 1 are assigned, as `u` is often used as a multiplier in equations.
- `name` is the name for the device instance. It is used for display purposes and can be left empty.

Connecting devices

Most importantly, `idx` is the *unique* index for referencing a device, so that it can be properly connected by supported devices. In a system, a PQ (constant PQ load) device needs to connect to a Bus device to inject power. That is, the PQ device needs to indicate the Bus device to which it is connected. Such connection is done in the PQ sheet by setting the `bus` parameter to the `idx` of the connected bus.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	uid	idx	u	name	bus	Vn	p0	q0	vmax	vmin	owner						
2	0	PQ_0	1		7	230	11.59	-0.735	1.1	0.9	1						
3	1	PQ_1	1		8	230	15.75	-0.899	1.1	0.9	1						
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
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The screenshot above is from the case file `andes/cases/kundur/kundur_fault.xlsx`. In this PQ workbook, there are two PQ instances (also known as "devices") called `PQ_0` and `PQ_1` (referred to by `idx`). They are connected to buses 7 and 8, respectively. The `bus` parameter of PQ is known as an indexing parameter (`andes.core.param.IdxParam`) through which the connections are specified. To get the connection actually work, on the `Bus` sheet, two rows must exist for two bus devices, respectively, with `idx` being 7 and 8.

To find out the `IdxParams` of a device for connecting to other devices, refer to [Model reference](#). For example, to find out how a device of the exciter model `EXDC2` should be connected to a synchronous generator, in the **Parameters** section, check the *Properties* column for *mandatory* parameters. Almost all `IdxParams` are mandatory, meaning that they must be specified to build a consistent test case. It can be seen that for `EXDC2`, `syn` is mandatory. From the description, one can tell that this is the "Synchronous generator `idx`", which should be the `idx` of an existing synchronous generator, i.e., `GENROU` or `GENCLS`.

Typically, models of the same group use the same `IdxParams` to connect to other models. Each link on the left sidebar of [Model reference](#) is a group, such as the `Exciter` group. With this convention, all exciters have a `syn` parameter for connecting to synchronous generators.

Creating cases

It is often easier to modify from existing cases than creating from scratch. We recommend that you get familiar with the cases available with ANDES, see [Test Cases](#).

Adding devices

Adding devices to an existing workbook is straightforward. Navigate to the sheet corresponding to the model and add a new line below the existing lines.

Almost all models have so-called mandatory parameters. They are essential to describe a complete and consistent test case. For example, the PQ model has the `bus` parameter as mandatory to indicate the connected bus. To look up mandatory parameters, see [Model reference](#) or use `andes doc MODEL_NAME`. Check for "mandatory" in the last column called "Properties". This column also contains other data consistency requirements discussed in the following.

Non-mandatory parameters are optional, meaning that if not provided, ANDES will use the default parameters. The default values can also be found in [Model reference](#). This does not mean that such parameters should always be left blank. For example, the `p0` (active power load) of PQ is optional, but likely one wants to set it to a non-zero value.

There are consistency requirements for parameters, such as `non_zero`, `non_negative` or `non_positive`. If unmet, the default values will be used. See the class reference in `andes.core.param.NumParam`.

Autofill data

When you finished adding devices but left some optional parameters empty, you can use ANDES to autofill them. This is useful when you want to populate a large number of devices with the same parameters that can be modified later.

The autofill is done through the data converter, namely, `--convert` or `-c`. ANDES will read in the Excel file, fill the optional parameters with default values, fix the inconsistent values, and then export the data back to Excel.

Warning: Please backup the spreadsheet if it contains customized edits. Inconsistent data will be replaced during the conversion. Formatting in the spreadsheet will be lost. Unrecognized sheets will also be discarded.

To autofill `kundur_full.xlsx`, do

```
andes run kundur_full.xlsx -c
```

You will be prompted to confirm the overwrite.

Since this autofill feature utilizes the converter, the autofilled data can be exported to other formats, such as `.json`. To do so, use `-c json`.

Adding workbooks

If one wants to add workbooks for models that does not exist in an `xlsx` file, one can use `--add-book` `ADD_BOOK` (or `-b ADD_BOOK`), where `ADD_BOOK` can be a single model name or comma-separated model names (*without space*). For example,

```
andes run kundur_full.xlsx -b Fault
```

will add an empty `Fault` sheet to `kundur_full.xlsx`.

Warning: With `--add-book`, the `xlsx` file will be overwritten with the same parameter corrections as in the autofill. Please make backups as needed.

Format conversion and workbook addition can be performed together. To convert a PSS/E raw file and a `dyr` file into an `xlsx` file and add a workbook for `Fault`, do

```
andes run kundur.raw -addfile kundur_full.dyr -c -b Fault
```

The output will have the same name as the raw file.

Data Consistency

Input data needs to have consistent types for `idx`. Both string and numerical types are allowed for `idx`, but the original type and the referencing type must be the same. Suppose we have a bus and a connected PQ. The Bus device may use 1 or '1' as its `idx`, as long as the PQ device uses the same value for its `bus` parameter.

The ANDES xlsx reader will try to convert data into numerical types when possible. This is especially relevant when the input `idx` is string literal of numbers, the exported file will have them converted to numbers. The conversion does not affect the consistency of data.

Parameter Check

The following parameter checks are applied after converting input values to array:

- Any NaN values will raise a `ValueError`
- Any `inf` will be replaced with 10^8 , and `-inf` will be replaced with -10^8 .

1.5.2 PSS/E RAW and DYR

The Siemens PSS/E data format is a widely used for power system simulation. PSS/E uses a variety of plain-text files to store data for different actions. The RAW format (with file extension `.raw`) is used to store the steady-state data for power flow analysis, and the DYR format (with extension `.dyr`) is used to store the parameters of dynamic devices for transient simulation.

RAW Compatibility

ANDES supports PSS/E RAW in versions 32 and 33. Newer versions of `raw` files can store PSS/E settings along with the system data, but such feature is not yet supported in ANDES. Also, manually edited `raw` files can confuse the parser in ANDES. Following manual edits, it is strongly recommended to load the data into PSS/E and save the case as a v33 RAW file.

ANDES supports most power flow models in PSS/E. It needs to be recognized that the power flow models in PSS/E is a larger set compared with those in ANDES. For example, switched shunts in PSS/E are converted to fixed ones, not all three-winding transformer flags are supported, and HVDC devices are not yet converted. This is not an exhaustive list, but all of them are advanced models.

We welcome contributions but please also reach out to us if you need to arrange the development of such models.

DYR Compatibility

Fortunately, the DYR format does not have different versions yet. ANDES support reading parameters from DYR files for models that have been implemented in ANDES. Owing to the descriptive modeling framework, we implement the identical model so that parameters can be without conversion. If a dyr file contains models that are not recognized by ANDES, an error will be thrown. One needs to manually remove those unsupported models to load.

Like RAW files, manually edited DYR files can often be understood by PSS/E but may confuse the ANDES parser. We also recommend to load and re-save the file using PSS/E.

Loading files

In the command line, PSS/E files can be loaded with

```
andes run kundur.raw --addfile kundur.dyr
```

where `--addfile` or `-a` is used to specify the optional DYR file. For now, DYR files can only be added to a RAW file. We will allow different formats to be mixed in the future.

Likewise, one can convert PSS/E files to ANDES `xlsx`:

```
andes run kundur.raw --addfile kundur.dyr -c
```

This will convert all models in the RAW and DYR files. If only the RAW file is provided, only power flow models will be converted. One cannot easily append those in a DYR file to an existing `xlsx` file yet.

To load PSS/E files into a scripting environment, see Example - "Working with Data".

Creating disturbances

Instead of converting `raw` and `dyr` to `xlsx` before adding disturbances, one can edit the `.dyr` file with a plain-text editor (such as Notepad) and append lines customized for ANDES models. This is for advanced users after referring to `andes/io/psse-dyr.yaml`, at the end of which one can find the format of `Toggle`:

```
# == Custom Models ==
Toggle:
  inputs:
    - model
    - dev
    - t
```

To define two Toggles in the `.dyr` file, one can append lines to the end of the file using, for example,

```
Line   'Toggle'   Line_2   1 /
Line   'Toggle'   Line_2   1.1 /
```

which is separated by spaces and ended with a slash. The second parameter is fixed to the model name quoted by a pair of single quotation marks, and the others correspond to the fields defined in the above `inputs`. Each entry is properly terminated with a forward slash.

Mapping dyr to ANDES models

ANDES supporting parsing PSS/E dynamic files in the format of `.dyr`. Support new dynamic models can be added by editing the input and output conversion definition file in `andes/io/psse-dyr.yaml`, which is in the standard YAML format. To add support for a new dynamic model, it is recommended to start with an existing model of similar functionality.

Consider a GENCLS entry in a dyr file. The entry looks like

```
1 'GENCLS' 1 13.0000 0.000000 /
```

where the fields are in the order of bus index, model name, generator index on the bus, inertia (H) and damping coefficient (D).

The input-output conversion definition for GENCLS is as follows

```
GENCLS:
  destination: GENCLS
  inputs:
    - BUS
    - ID
    - H
    - D
  find:
    gen:
      StaticGen:
        bus: BUS
        subidx: ID
  get:
    u:
      StaticGen:
        src: u
        idx: gen
    Sn:
      StaticGen:
        src: Sn
        idx: gen
    Vn:
      Bus:
        src: Vn
        idx: BUS
    ra:
      StaticGen:
        src: ra
        idx: gen
    xs:
      StaticGen:
```

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```

src: xs
idx: gen
outputs:
  u: u
  bus: BUS
  gen: gen
  Sn: Sn
  Vn: Vn
  D: D
  M: "GENCLS.H; lambda x: 2 * x"
  ra: ra
  xd1: xs

```

It begins with a base-level definition of the model name to be parsed from the dyr file, namely, GENCLS. Five directives can be defined for each model: `destination`, `inputs`, `outputs`, `find` and `get`. Note that `find` and `get` are optional, but the other three are mandatory.

- `destination` is ANDES model to which the original PSS/E model will be converted. In this case, the ANDES model have the same name GENCLS.
- `inputs` is a list of the parameter names for the PSS/E data. Arbitrary names can be used, but it is recommended to use the same notation following the PSS/E manual.
- `outputs` is a dictionary where the keys are the ANDES model parameter and the values are the input parameter or lambda functions that processes the inputs (see notes below).
- `find` is a dictionary with the keys being the temporary parameter name to store the `idx` of external devices and the values being the criteria to locate the devices. In the example above, GENCLS will try to find the `idx` of `StaticGen` with `bus == BUS` and the `subidx == ID`, where `BUS` and `ID` are from the dyr file.
- `get` is a dictionary with each key being a temporary parameter name for storing an external parameter and each value being the criteria to find the external parameter. In the example above, a temporary parameter `u` is the `u` parameter of `StaticGen` whose `idx == gen`. Note that `gen` is the `idx` of `StaticGen` retrieved in the above `find` section.

For the `inputs` section, one will need to skip the model name because for any model, the second field is always the model name. That is why for GENCLS below, we only list four input parameters.

```
1 'GENCLS' 1      13.0000  0.000000  /
```

For the `outputs` section, the order can be arbitrary, but it is recommended to follow the input order as much as possible for maintainability. In particular, the right-hand-side of the outputs can be either an input parameter name or an anonymous expression that processes the input parameters. For the example of GENCLS, since ANDES internally uses the parameter of $M = 2H$, the input `H` needs to be multiplied by 2. It is done by the following

```
M: "GENCLS.H; lambda x: 2 * x"
```

where the left-hand-side is the output parameter name (destination ANDES model parameter name), and the right-hand-side is arguments and the lambda function separated by semi-colon, all in a pair of double quotation

marks. Multiple arguments are accepted and should be separated by comma. Arguments can come from the same model or another model. In the case of the same model, the model name can be neglected, namely, by writing `M: "H; lambda x: 2 * x"`.

1.5.3 MATPOWER

ANDES supports MATPOWER data in version 2 in part for power flow calculation. The following fields are supported:

- `mpc.busMVA`
- `mpc.bus`
- `mpc.gen`
- `mpc.branch`
- `mpc.area`
- `mpc.bus_name`

Other fields are not supported, most notably, `mpc.gencost`.

Power flow calculation results for MATPOWER cases are typically identical to that from MATPOWER using default settings. These settings include no reactive power limits and following all generator connectivity status. Discrepancies in the power flow solution between ANDES and MATPOWER are typically due to configuration issues or different interpretation of the data, rather than in the power flow models.

1.5.4 ANDES JSON

Overview

JSON is a portable format for storing data. It has been used in several other power system tools, including [PowerModels](#), [Pandapower](#), [NREL-SIIP](#), and [GridCal](#). It must be noted that JSON files from these tools are not interoperable because JSON only defines the data structure, not the meaning of data.

Compared with the *xlsx* file which is a zipped package, the ANDES JSON file is much faster to parse. We recommend that you use JSON in the following scenarios:

- Your test case is stable and require no manual editing, or
- You will read/write a large number of cases

To convert `kundur_full.xlsx` to the ANDES JSON format, do

```
andes run kundur_full.xlsx -c json
```

The output file will be named `kundur_full.json`.

Data storage

The ANDES JSON format uses one large dictionary for all devices in the system. The keys of the dictionary are the model names, and the values are lists of dictionaries. In each dictionary, the keys are the parameter names and the values are the parameter values.

The following shows the structure of a JSON file:

```
{
  "Toggle": [
    {
      "idx": 1,
      "u": 1.0,
      "name": "Toggle_1",
      "model": "Line",
      "dev": "Line_8",
      "t": 2.0
    } //      <- Toggle_1 ends
  ], //      <- Toggle model ends
  "Bus": [
    {
      "idx": 1,
      "u": 1.0,
      "name": 1,
      "Vn": 20.0,
      "vmax": 1.1,
      "vmin": 0.9,
      ... //      <- other parameters are omitted
    },
    {
      "idx": 2,
      "u": 1.0,
      "name": 2,
      "Vn": 20.0,
      "vmax": 1.1,
      "vmin": 0.9,
      ... //      <- other parameters are omitted
    },
    ... //      <- other buses
  ], //      <- Bus model ends
  ... //      <- other models
} //      <- whole system ends
```

There are thirdparty tools for editing JSON files, but we still recommend to convert files to `xlsx` for editing. The conversion can be readily done with

```
andes run kundur_full.json -c xlsx
```

1.5.5 Disturbances

Disturbance Devices

Predefined disturbances at specified time can be created by adding the corresponding devices. Three types of predefined disturbances are supported:

1. Three-phase-to-ground fault on buses. See *Fault* for details.
2. Connectivity status toggling. Disconnecting, connecting, or reconnecting any device, including lines, generators and motors can be implemented by *Toggle*.
3. Alteration of values. See *Alter* for details.

To use these devices, the time of disturbance needs to be known ahead of the simulation. The simulation program by default checks the network connectivity status after any disturbance.

Perturbation File

One can implement any custom disturbance using a perturbation file as discussed in [Milano2010]. The perturbation file is a Python script with a function named `pert`. The example for the perturbation file can be found in `andes/cases/ieee14/pert.py`.

```
andes.cases.ieee14.pert.pert(t, system)
```

Perturbation function called at each step.

The function needs to be named `pert` and takes two positional arguments: `t` for the simulation time, and `system` for the system object. Arbitrary logic and calculations can be applied in this function to `system`.

If the perturbation event involves switching, such as disconnecting a line, one will need to set the `system.TDS.custom_event` flag to `True` to trigger a system connectivity checking, and Jacobian rebuilding and refactorization. To implement, add the following line to the scope where the event is triggered:

```
system.TDS.custom_event = True
```

In other scopes of the code where events are not triggered, do not add the above line as it may cause significant slow-down.

The perturbation file can be supplied to the CLI using the `--pert` argument or supplied to `andes.main.run()` using the `pert` keyword.

Parameters

t

[float] Simulation time.

system

[andes.system.System] System object supplied by the simulator.

1.6 Test Cases

ANDES ships with with test cases in the `andes/cases` folder. The cases can be found in the [online repository](#).

1.6.1 Summary

Below is a summary of the folders and the corresponding test cases. Some folders contain a README file with notes. When viewing the case folder on GitHub, one can conveniently read the README file below the file listing.

- `smib`: single machine infinite bus (SMIB) system [[Sauer](#)].
- `5bus`: a small PJM 5-bus test case for power flow study [[PJM5](#)].
- `GBnetwork`: a 2,000-bus system for the Great Britain network [[GB](#)]. Dynamic data is randomly generated.
- `EI`: the CURENT Eastern Interconnection network [[EI](#)].
- `ieee14` and `ieee39`: the IEEE 14-bus and 39-bus test cases [[IEEE](#)].
- `kundur`: a modified Kundur's two area system from [[RLGC](#)]. The modified system is different in the number of buses and lines from the textbook.
- `matpower`: a subset of test cases from [[MATPOWER](#)].
- `nordic44`: Nordpool 44-bus test case [[Nordic](#)]. Not all dynamic models are supported.
- `npcc`: the 140-bus Northeast Power Coordinating Council (NPCC) test case originated from Power System Toolbox [[PST](#)].
- `wecc`: the 179-bus Western Electric Coordinating Council (WECC) test case [[WECC](#)].
- `wsc`: the 9-bus WSCC (succeeded by WECC) power flow data converted from [[PSAT](#)].

Note: Different systems exhibit different dynamics, thus the appropriate systems should be used to study power system stability. For example:

- The Kundur's two-area system has under-damped modes and two coherent groups of generators. It is suitable for oscillation study and transient stability studies.
 - The WECC system is known for the inter-area oscillation.
 - The IEEE 14-bus system and the 140-bus NPCC system are frequently used for frequency control studies. So is the Eastern Interconnection system.
-

Currently, the Kundur's 2-area system, IEEE 14-bus system, NPCC 140-bus system, and the WECC 179-bus system has been verified against DSATools TSAT.

1.6.2 Example data

When developing models, we manually create cases with example data to verify the models. The Kundur's system and the IEEE 14-bus system are used as the bases for adding specific models. One can find many cases in the folder `andes/cases/kundur`. The case file names typically indicate the specific model added to the file. These example cases with specific models are useful when one needs to find example parameters for the model. For example:

- `kundur_ieeeeg1` indicates the use of `IEEEG1` model in a Kundur's system
- `ieee14_solar.xlsx` contains the solar PV models (`REGCA1`, `REECA1`, and `REPCA1`)
- `ieee14_plbvf1.xlsx` is the case for `PLBVFU1` (playback of voltage and frequency). The case provides an example of specifying `plbvf.xlsx`
- `ieee14_timeseries.xlsx` is an example for specifying timeseries for load data, which is provided in `pqts.xlsx`

1.6.3 MATPOWER cases

MATPOWER cases have been tested in ANDES for power flow calculation. All following cases are calculated with the provided initial values using the full Newton-Raphson iterative approach.

Benchmark

See *MATPOWER cases* for the benchmark of MATPOWER cases.

Synthetic systems

The 70K and the USA synthetic systems have difficulties to converge using the provided initial values. One can solve the case in MATPOWER and save it as a new case for ANDES. For example, the SyntheticUSA case can be converted in MATLAB with

```
mpc = runpf(case_SyntheticUSA)
savecase('USA.m', mpc)
```

And then solve it with ANDES from command line:

```
andes run USA.m
```

The output should look like

```
-> Power flow calculation
Sparse solver: KLU
Solution method: NR method
Power flow initialized.
0: |F(x)| = 140.5782767
1: |F(x)| = 29.61673314
```

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```

2: |F(x)| = 4.161452394
3: |F(x)| = 0.2337870537
4: |F(x)| = 0.001149488448
5: |F(x)| = 3.646516689e-08
Converged in 6 iterations in 1.6082 seconds.

```

1.6.4 How to contribute

We welcome the contribution of test cases! You can make a pull request to contribute new test cases. Please follow the structure in the `cases` folder and provide an example Jupyter notebook (see `examples/demonstration`) to showcase the results of your system.

1.7 Performance

We discuss methods to improve the computational performance in ANDES using Numba. Performance benchmarks are also presented.

1.7.1 Numba compilation

In nearly all numerical simulation software, time is mostly spent on *constructing* the numerical system and *solving* it. The construction of the DAE in ANDES involves the evaluation of functions from models that implement the residuals and Jacobians.

Numba is a just-in-time compiler in Python that can turn numerical functions into compiled machine code. In ANDES, it can speed up simulations by as much as 30%. The speedup is most effective in medium-sized systems with multiple models. Such systems involve heavy function calls but rather moderate load for linear equation solvers. It is less significant in large-scale systems where solving equations is the major time consumer.

Note: Numba is supported since ANDES 1.5.0. One needs to manually install it with `python -m pip install numba` from the Anaconda Prompt.

Enabling Numba JIT

Numba needs to be enabled *manually*. In the ANDES config file: in section `[System]`, set `numba = 1`, so that it looks like

```

[System]
...
numba = 1
...

```

where the . . . are other options that are omitted here.

Just-in-time compilation will compile the code upon the *first execution* based on the input types. This is the default mode of Numba. When compilation is triggered, ANDES may appear frozen due to the compilation lag. To reuse the compiled code and save compilation time for future runs, the compiled binary code will be automatically cached. The default cache folder is in `$HOME/.andes/pydata/__pycache__` with file extensions `nbc` and `nbi`.

Numba compilation needs to be distinguished from the ANDES code generation by *andes prepare*. The ANDES code generation is to generate Python code from symbolically defined models and is relatively fast. The Numba compilation further compiles the generated Python code to machine code. Whenever the ANDES code generation produces new Python code, the cached Numba binary code will be invalidated.

When not to compile

when developing models, we recommend disabling numba to avoid spending time on compilation.

Ahead-of-time compilation

Just-in-time compilation can feel laggy. When ANDES is not being developed, one can compile the generated Python code ahead of time to avoid just-in-time delays. We call it "precompilation".

Precompilation is invoked by

```
andes prep -c
```

It may take a minute for the first time. Owing to caching, future compilations will be incremental and much faster.

1.7.2 MATPOWER cases

The hardware platform is an AMD Ryzen 9 5950X with 64GB of 3200 MHz DDR4 RAM. The operating system is WSL2 Ubuntu 20.04 on Windows 10. Software packages are:

- ANDES 1.5.3
- KVXOPT 1.2.7.1
- NumPy 1.20.3
- numba 0.54.1
- OpenBLAS 0.3.18.

Numba is enabled, and all generated code are precompiled. Network connectivity checking is turned off (`[PFlow] check_conn=0`). Time to read numba cache (~0.3s) is not included.

The table below shows the power flow time in ANDES. All the cases are original in MATPOWER 7.0, and cases not listed below will not solve with ANDES 1.5.3. The computation time may vary depending on hardware, operating system, and software.

File Name	Converged?	# of Iterations	ANDES Time [s]
case1354pegase.m	1	4	0.034
case13659pegase.m	1	5	0.276
case14.m	1	2	0.009
case145.m	1	3	0.014
case15nbr.m	1	17	0.024
case17me.m	1	3	0.010
case18.m	1	3	0.011
case1888rte.m	1	2	0.025
case18nbr.m	1	18	0.026
case1951rte.m	1	3	0.031
case2383wp.m	1	6	0.059
case24_ieee_rts.m	1	4	0.012
case2736sp.m	1	4	0.053
case2737sop.m	1	5	0.060
case2746wop.m	1	4	0.053
case2746wp.m	1	4	0.054
case2848rte.m	1	3	0.043
case2868rte.m	1	4	0.056
case2869pegase.m	1	6	0.084
case30.m	1	3	0.010
case300.m	1	5	0.019
case30Q.m	1	3	0.009
case30pwl.m	1	3	0.010
case39.m	1	1	0.008
case4_dist.m	1	3	0.010
case4gs.m	1	3	0.011
case5.m	1	3	0.011
case57.m	1	3	0.010
case60nordic.m	1	1	0.008
case6468rte.m	1	6	0.144
case6470rte.m	1	4	0.111
case6495rte.m	1	5	0.130
case6515rte.m	1	4	0.116
case6ww.m	1	3	0.010
case8387pegase.m	1	3	0.143
case89pegase.m	1	5	0.015
case9.m	1	3	0.011
case9241pegase.m	1	6	0.243
case9Q.m	1	3	0.011
case9target.m	1	4	0.010
case_ACTIVSg10k.m	1	4	0.157
case_ACTIVSg200.m	1	2	0.010
case_ACTIVSg2000.m	1	3	0.042
case_ACTIVSg25k.m	1	7	0.549

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Table 2 – continued from previous page

File Name	Converged?	# of Iterations	ANDES Time [s]
case_ACTIVSg500.m	1	3	0.015
case_ACTIVSg70k.m	1	5	1.398
case_RTS_GMLC.m	1	3	0.013
case_SyntheticUSA.m	1	5	1.727
case_ieee30.m	1	2	0.008

1.8 Verification

This section presents the verification of the models and algorithms implemented in ANDES by comparing the time-domain simulation results with commercial tools.

ANDES produces identical results for the IEEE 14-bus and the NPCC systems with several models. For the CURENT WECC system, ANDES, TSAT, and PSS/E produce slightly different results. In fact, results from different tools can hardly match for large systems with a variety of dynamic models.

1.8.1 IEEE 14-Bus Verification

Prepared by [Hantao Cui](#). Last revised 23 May 2020.

Background

Two line trip scenarios are used to verify ANDES simulation results with DSATools TSAT.

Dynamic data is created to utilize the available models, including GENROU, TGOV1, IEEEG1, EXST2, EXDC2, ESST3A, IEEEEST and ST2CUT. Test case data can be found at the end of the notebook.

Simulation Parameters

Integretion method: Trapezidal Rule (ANDES and TSAT).

Time step size: 1/120 sec. (Note: step size between 1/30 to 1/120 has little impact on the ANDES results. One can use `tstep=1/30` to obtain almost the same results.)

Load conversion: static loads are converted to 100% constant impedances for both P and Q.

TSAT automatic parameter correction is disabled.

Initialization

Power flow solutions are identical across all the two software.

GENROU initialization (E_{FD} , E_{TERM} , P , Q , δ , I_d and I_q) is identical to that from PSS/E for all cases (with and without generator saturation). Note that I_d and I_q are in machine base in PSS/E but in system base in ANDES.

GENROU initialization (including all the internal variables $E'd$, $E'q$, ψ_{kd} , ψ_{kq} , ψ''_d , and ψ''_q) is identical to that from **OpenIPSL**.

No controller limit violation occurs during initialization.

Conclusion

IEEE 14-bus system simulation results from ANDES are identical to that from TSAT.

```
import andes
import numpy as np
from andes.utils.tsat import tsat_to_df, plot_comparison, run_cmp

andes.config_logger(stream_level=30)
```

```
# load scenario 1 data
omega_lt2 = tsat_to_df('omega_lt2s.xls')
v_lt2 = tsat_to_df('v_lt2s.xls')

# load scenario 2 data
omega_gt = tsat_to_df('omega_gt.xls')
v_gt = tsat_to_df('v_gt.xls')
```

Scenario 1

Line 1-2 trips at 1 sec. and reconnects after 2.0 sec. The reconnection delay is set to 2 seconds to trigger a large disturbance to the system to verify nonlinear models.

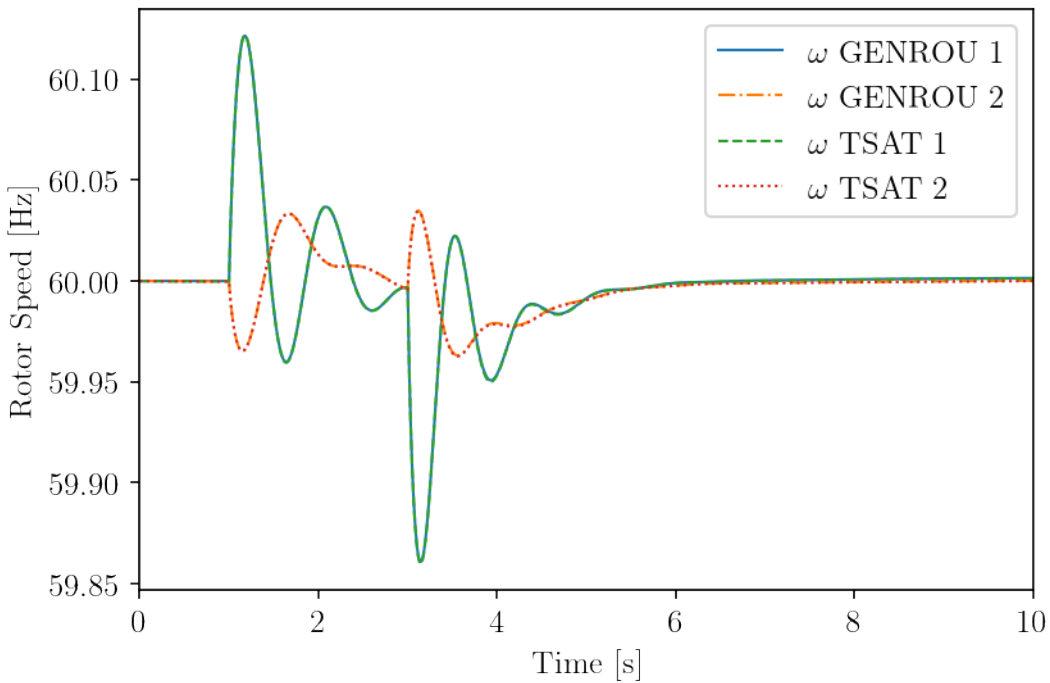
Simulation Setup

```
ss = run_cmp('ieee14.raw', dyr='ieee14.dyr', fault_line='Line_1',
            t1=1.0, t2=3.0, tstep=1/120)
```

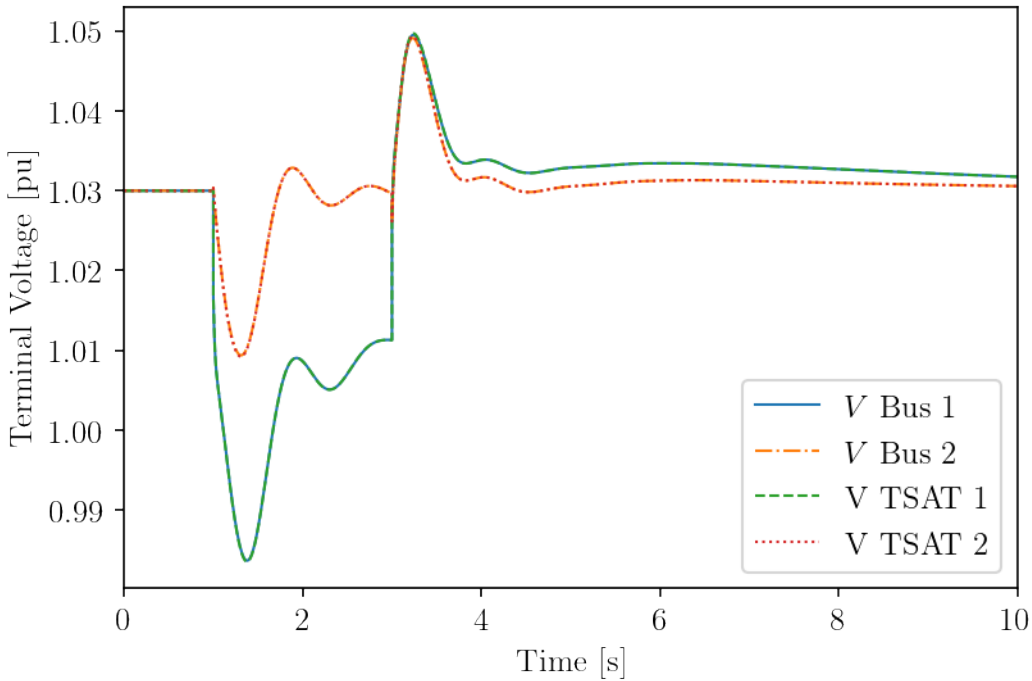
```
<Toggle Toggle_1>: Line.Line_1 status changed to 0.0 at t=1.0 sec.
<Toggle Toggle_2>: Line.Line_1 status changed to 1.0 at t=3.0 sec.
100%|████████████████████████████████████████| 100/100 [00:16<00:00, 6.15%/s]
```

Scenario 1 Plots

```
fig, ax = plot_comparison(ss, ss.GENROU.omega,
                        omega_lt2, a=[0, 1],
                        ylabel="Rotor Speed [Hz]",
                        tsat_header=[r'$\omega$ TSAT 1', r'$\omega$ TSAT 2'],
                        scale=60, left=0, right=10)
```



```
fig, ax = plot_comparison(ss, ss.GENROU.v,
                        v_lt2, a=[0, 1],
                        ylabel="Terminal Voltage [pu]",
                        tsat_header=['V TSAT 1', 'V TSAT 2'],
                        left=0, right=10)
```

Scenario 2

Line 7-8 trips at 1 sec. and reconnects after 0.1 sec. The line is an equivalent branch of the three-winding transformer. Tripping 7-8 will isolate Bus 8.

Simulation Setup

```
ss2 = run_cmp('ieee14.raw', dyr='ieee14.dyr', fault_line='Line_20',
             t1=1.0, t2=1.1, tstep=1/120)
```

```
<Toggle Toggle_1>: Line.Line_20 status changed to 0.0 at t=1.0 sec.
<Toggle Toggle_2>: Line.Line_20 status changed to 1.0 at t=1.1 sec.
100%|████████████████████████████████████████████████████████████████████████████████| 100/100 [00:12<00:00, 8.10%/s]
```

```
# line data
ss2.Line.cache.df.iloc[19]
```

```
idx      Line_20
u         1
name      Line_20
bus1       8
bus2       7
Sn        100
fn         60
Vn1        69
```

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```

Vn2          138
r             0
x          0.17615
b             0
g             0
b1            0
g1            0
b2            0
g2            0
trans         1
tap          0.99677
phi           0
owner         None
xcoord        None
ycoord        None
Name: 19, dtype: object

```

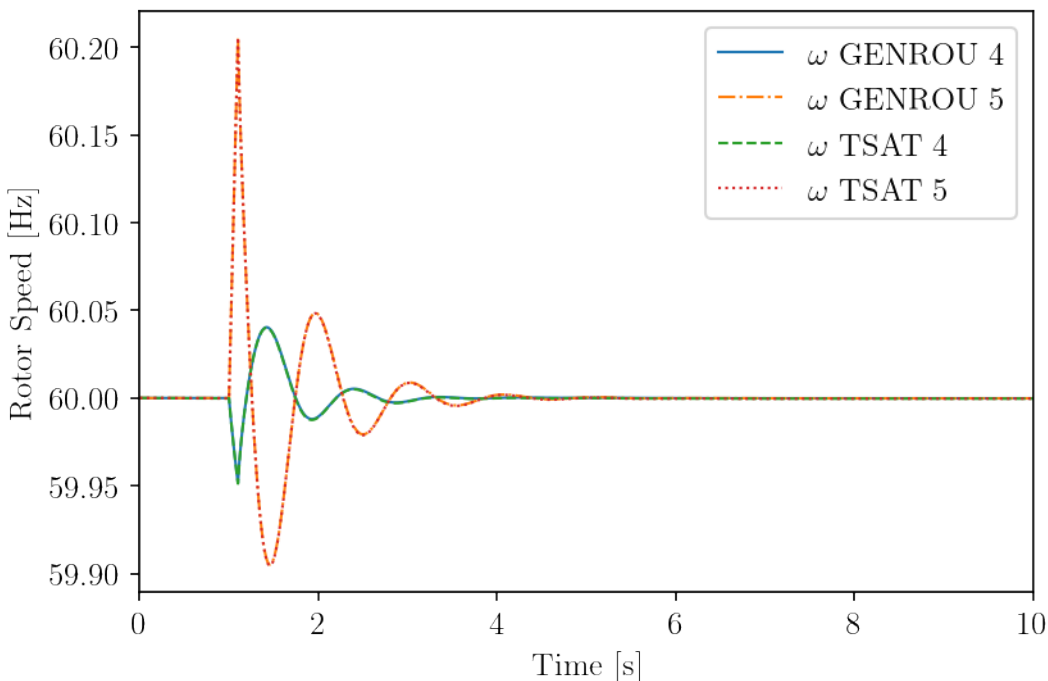
Scenario 2 Plots

```

tsat_omega_headers = [ss.TDS.plt._fname[i + 1] for i in ss.GENROU.omega.a]
tsat_omega_headers = [i.replace('GENROU', 'TSAT') for i in tsat_omega_headers]

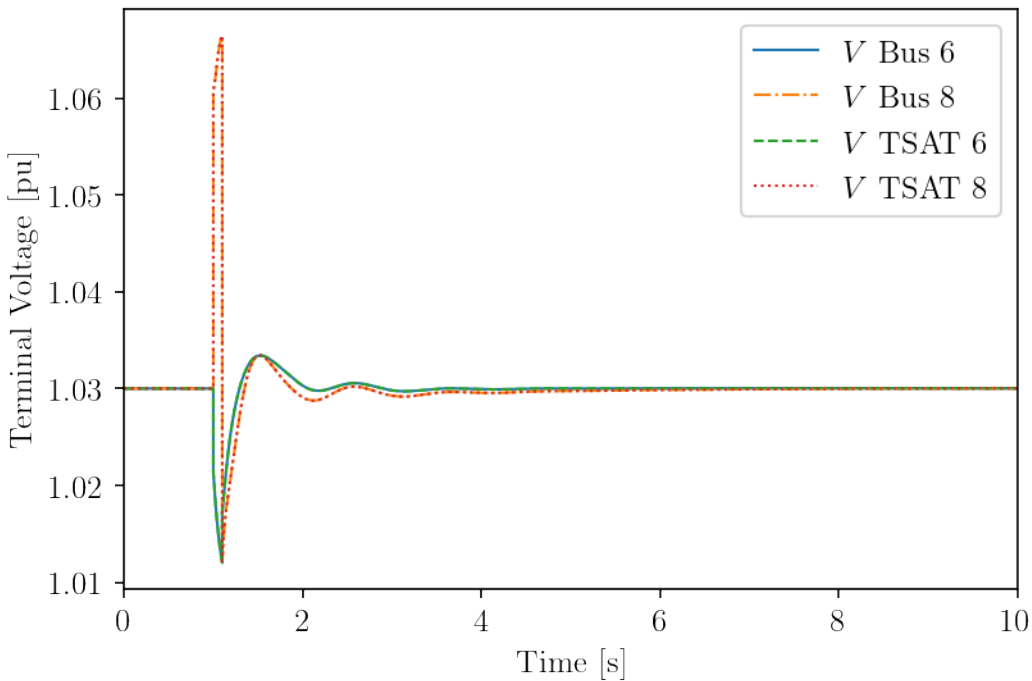
fig2, ax2 = plot_comparison(ss2, ss2.GENROU.omega,
                           omega_gt, a=[3, 4],
                           ylabel="Rotor Speed [Hz]",
                           tsat_header=tsat_omega_headers,
                           scale=60, left=0, right=10)

```



```
tsat_v_headers = [ss.TDS.plt._fname[i + 1 + ss.dae.n] for i in ss.GENROU.v.a]
tsat_v_headers = [i.replace('Bus', 'TSAT') for i in tsat_v_headers]

fig2, ax2 = plot_comparison(ss2, ss2.GENROU.v,
                           v_gt, a=[3, 4],
                           ylabel="Terminal Voltage [pu]",
                           tsat_header=tsat_v_headers,
                           left=0, right=10)
```



Appendix

IEEE 14-Bus System Data

Power Flow Data (PSS/E RAW format)

```
# !cat results won't save to PDF

data = !cat ieee14.raw
print('\n'.join(data))
```

```
0, 100.00, 32, 0, 1, 60.00 / PSS(R)E 32 RAW created by rawd32 SUN,
MAY 17 2020 20:38
IEEE 14 BUS TEST CASE
DISTRIBUTED WITH ANDES (HTTPS://GITHUB.COM/CURRENT/ANDES)
1, 'BUS1', 69.0000, 3, 1, 1, 1, 1.03000, 0.0000
```

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```

2, 'BUS2      ', 69.0000, 2, 1, 1, 1, 1.01970, -1.6032
3, 'BUS3      ', 69.0000, 2, 1, 1, 1, 1.00042, -3.4433
4, 'BUS4      ', 69.0000, 1, 1, 1, 1, 0.99858, -4.2812
5, 'BUS5      ', 69.0000, 1, 1, 1, 1, 1.00443, -3.6850
6, 'BUS6      ', 138.0000, 2, 2, 2, 2, 0.99871, -6.3024
7, 'BUS7      ', 138.0000, 1, 2, 2, 2, 1.00682, -4.8292
8, 'BUS8      ', 69.0000, 2, 2, 2, 2, 1.01895, -1.3945
9, 'BUS9      ', 138.0000, 1, 2, 2, 2, 1.00193, -7.3053
10, 'BUS10     ', 138.0000, 1, 2, 2, 2, 0.99351, -7.4600
11, 'BUS11     ', 138.0000, 1, 2, 2, 2, 0.99245, -7.0444
12, 'BUS12     ', 138.0000, 1, 2, 2, 2, 0.98639, -7.3874
13, 'BUS13     ', 138.0000, 1, 2, 2, 2, 0.98403, -7.6654
14, 'BUS14     ', 138.0000, 1, 2, 2, 2, 0.99063, -9.5636
0 /End of Bus data, Begin Load data
2, '1 '1, 1, 1, 21.700, 12.700, 0.000, 0.000, 0.
↪000, 0.000, 1, 1
3, '1 '1, 1, 1, 50.000, 25.000, 0.000, 0.000, 0.
↪000, 0.000, 1, 1
4, '1 '1, 1, 1, 47.800, 10.000, 0.000, 0.000, 0.
↪000, 0.000, 1, 1
5, '1 '1, 1, 1, 7.600, 1.600, 0.000, 0.000, 0.
↪000, 0.000, 1, 1
6, '1 '1, 2, 2, 15.000, 7.500, 0.000, 0.000, 0.
↪000, 0.000, 2, 1
9, '1 '1, 2, 2, 29.500, 16.600, 0.000, 0.000, 0.
↪000, 0.000, 2, 1
10, '1 '1, 2, 2, 9.000, 5.800, 0.000, 0.000, 0.
↪000, 0.000, 2, 1
11, '1 '1, 2, 2, 3.500, 1.800, 0.000, 0.000, 0.
↪000, 0.000, 2, 1
12, '1 '1, 2, 2, 6.100, 1.600, 0.000, 0.000, 0.
↪000, 0.000, 2, 1
13, '1 '1, 2, 2, 13.500, 5.800, 0.000, 0.000, 0.
↪000, 0.000, 2, 1
14, '1 '1, 2, 2, 20.000, 7.000, 0.000, 0.000, 0.
↪000, 0.000, 2, 1
0 /End of Load data, Begin Fixed shunt data
0 /End of Fixed shunt data, Begin Generator data
1, '1 ', 81.442, 1.962, 100.000, -50.000, 1.03000, 0, 100.
↪000, 0.00000E+0, 2.30000E-1, 0.00000E+0, 0.00000E+0, 1.00000, 1, 100.0, ↪
↪200.000, 50.000, 1, 1.0000
2, '1 ', 40.000, 15.000, 15.000, -40.000, 1.03000, 0, 100.
↪000, 0.00000E+0, 1.30000E-1, 0.00000E+0, 0.00000E+0, 1.00000, 1, 100.0, ↪
↪50.000, 10.000, 1, 1.0000
3, '1 ', 40.000, 15.000, 15.000, -10.000, 1.01000, 0, 100.
↪000, 0.00000E+0, 1.30000E-1, 0.00000E+0, 0.00000E+0, 1.00000, 1, 100.0, ↪
↪50.000, 10.000, 1, 1.0000
6, '1 ', 30.000, 10.000, 10.000, -6.000, 1.03000, 0, 100.
↪000, 0.00000E+0, 1.20000E-1, 0.00000E+0, 0.00000E+0, 1.00000, 1, 100.0, ↪
↪50.000, 10.000, 1, 1.0000
8, '1 ', 35.000, 10.000, 10.000, -6.000, 1.03000, 0, 100.
↪000, 0.00000E+0, 1.20000E-1, 0.00000E+0, 0.00000E+0, 1.00000, 1, 100.0, ↪

```

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```

↪50.000,    10.000,    1,1.0000
0 /End of Generator data, Begin Branch data
    1,        2,'1 ', 1.93800E-2, 5.91700E-2,    0.05280, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
    1,        5,'1 ', 5.40300E-2, 2.23040E-1,    0.04920, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
    2,        3,'1 ', 4.69900E-2, 1.97970E-1,    0.04380, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
    2,        4,'1 ', 5.81100E-2, 1.76320E-1,    0.03400, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
    2,        5,'1 ', 5.69500E-2, 1.73880E-1,    0.03460, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
    3,        4,'1 ', 6.70100E-2, 1.71030E-1,    0.01280, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
    4,        5,'1 ', 1.33500E-2, 4.21100E-2,    0.00000, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
    6,       11,'1 ', 9.49800E-2, 1.98900E-1,    0.00000, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
    6,       12,'1 ', 1.22910E-1, 2.55810E-1,    0.00000, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
    6,       13,'1 ', 6.61500E-2, 1.30270E-1,    0.00000, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
    7,        9,'1 ',-0.00000E+0, 1.10010E-1,    0.00000, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
    9,       10,'1 ', 3.18100E-2, 8.45000E-2,    0.00000, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
    9,       14,'1 ', 1.27110E-1, 2.70380E-1,    0.00000, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
   10,       11,'1 ', 8.20500E-2, 1.92070E-1,    0.00000, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
   12,       13,'1 ', 2.20920E-1, 1.99880E-1,    0.00000, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
   13,       14,'1 ', 1.70930E-1, 3.48020E-1,    0.00000, 100.00, 100.00,
↪0.00,    0.00000,    0.00000, 0.00000, 0.00000,1,1,    0.00,    1,1.0000
0 /End of Branch data, Begin Transformer data
    4,        7,    0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↪    ',1,    1,1.0000
    0.00000E+0, 2.09120E-1, 100.00
0.99677,    0.000,    0.000,    20.00,    20.00,    0.00,-1,    0, 1.10000,
↪0.90000, 1.10000, 0.90000, 32, 0, 0.00000, 0.00000, 0.000
1.00000,    0.000
    4,        9,    0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↪    ',1,    1,1.0000
    0.00000E+0, 5.56180E-1, 100.00
0.99677,    0.000,    0.000,    20.00,    20.00,    0.00,-1,    0, 1.10000,
↪0.90000, 1.10000, 0.90000, 32, 0, 0.00000, 0.00000, 0.000
1.00000,    0.000
    6,        5,    0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,1,'
↪    ',1,    1,1.0000
    0.00000E+0, 2.52020E-1, 100.00
0.99677,    0.000,    0.000,    50.00,    50.00,    0.00,-1,    0, 1.10000,
↪0.90000, 1.10000, 0.90000, 32, 0, 0.00000, 0.00000, 0.000

```

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```

1.00000, 0.000
      8,      7,      0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 1, '
→      ', 1,      1, 1.0000
0.00000E+0, 1.76150E-1, 100.00
0.99677, 0.000, 0.000, 50.00, 50.00, 0.00, -1, 0, 1.10000,
→ 0.90000, 1.10000, 0.90000, 32, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
0 /End of Transformer data, Begin Area interchange data
  1,      2,      0.000, 999.990, 'AREA1      '
  2,      0,      0.000, 10.000, 'AREA2      '
0 /End of Area interchange data, Begin Two-terminal dc line data
0 /End of Two-terminal dc line data, Begin VSC dc line data
0 /End of VSC dc line data, Begin Impedance correction table data
0 /End of Impedance correction table data, Begin Multi-terminal dc line data
0 /End of Multi-terminal dc line data, Begin Multi-section line data
0 /End of Multi-section line data, Begin Zone data
  1, 'ZONE1      '
  2, 'ZONE2      '
0 /End of Zone data, Begin Inter-area transfer data
0 /End of Inter-area transfer data, Begin Owner data
  1, 'OWNER1      '
  2, 'OWNER2      '
0 /End of Owner data, Begin FACTS device data
0 /End of FACTS device data, Begin Switched shunt data
  9, 1, 0, 1, 1.02500, 0.96000,      0, 100.0, '      ', 19.00, 3, 5.
→ 00, 1, 4.00
 14, 1, 0, 1, 1.02500, 0.96000,      0, 100.0, '      ', 15.00, 3, 5.00
0 /End of Switched shunt data, Begin GNE device data
0 /End of GNE device data
Q

```

Dynamic Data (PSS/E DYR format)

```

data = !cat ieee14.dyr
print ('\n'.join(data))

```

1	'GENROU'	1	6.5000	0.60000E-01	0.20000	0.50000E-01	
			4.0000	0.0000	1.8000	1.7500	0.60000
			0.80000	0.23000	0.15000	0.90000E-01	0.38000 /
1	'ST2CUT'	1	1	0	0	0	
			0.0000	0.0000	0.0000	0.0000	30.000
			30.000	0.23000	0.25000E-01	0.23000	0.25000E-01
			0.0000	0.0000	0.60000E-01	-0.60000E-01	0.0000
			0.0000	/			
1	'ESST3A'	1	0.20000E-01	0.20000	-0.20000	8.0000	
			1.0000	5.0000	20.000	0.0000	99.000
			-99.000	1.0000	3.6700	0.43500	5.4800
			0.10000E-01	0.98000E-02	3.8600	3.3300	0.40000
			99.000	0.0000	/		

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1	'TGOV1'	1	0.50000E-01	0.50000E-01	1.0500	0.30000
	1.0000		2.1000	0.0000	/	
2	'GENROU'	1	6.5000	0.60000E-01	0.20000	0.50000E-01
	6.5000		0.0000	1.8000	1.7500	0.60000
	0.80000		0.28000	0.15000	0.90000E-01	0.38000 /
2	'ST2CUT'	1	1	0	0	0
	10.000		0.0000	0.0000	0.0000	3.0000
	3.0000		0.15000	0.50000E-01	0.15000	0.50000E-01
	0.15000		0.50000E-01	0.50000E-01	-0.50000E-01	0.0000
	0.0000		/			
2	'EXST1'	1	0.20000E-01	99.000	-99.000	0.0000
	0.20000E-01		50.000	0.20000E-01	9999.0	-9999.0
	0.0000		0.10000E-01	1.0000	/	
2	'IEEEG1'	1	0	0	20.000	0.10000
	0.0000		0.20000	1.0000	-1.0000	0.95000
	0.0000		0.10000	0.0000	0.0000	0.0000
	0.0000		0.0000	0.0000	0.30000	0.0000
	8.7200		0.70000	0.0000	/	
3	'GENROU'	1	6.5000	0.60000E-01	0.20000	0.50000E-01
	5.0000		0.0000	1.8000	1.7500	0.60000
	0.80000		0.34000	0.15000	0.90000E-01	0.38000 /
3	'IEEEST'	1	3	0	0.0000	0.0000
	0.0000		0.0000	0.0000	0.0000	0.0000
	0.0000		0.0000	0.75000	1.0000	4.2000
	-2.0000		0.10000	-0.10000	0.0000	0.0000 /
3	'ESST3A'	1	0.20000E-01	0.20000	-0.20000	8.0000
	1.0000		5.0000	20.000	0.0000	99.000
	-99.000		1.0000	3.6700	0.43500	5.4800
	0.10000E-01		0.98000E-02	3.8600	3.3300	0.40000
	99.000		0.0000	/		
3	'IEEEG1'	1	0	0	20.000	0.10000
	0.0000		0.20000	1.0000	-1.0000	0.95000
	0.0000		0.10000	0.0000	0.0000	0.0000
	0.0000		0.0000	0.0000	0.30000	0.0000
	8.7200		0.70000	0.0000	/	
6	'GENROU'	1	6.5000	0.60000E-01	0.20000	0.50000E-01
	5.0000		0.0000	1.8000	1.7500	0.60000
	0.80000		0.28000	0.15000	0.90000E-01	0.38000 /
6	'ESST3A'	1	0.20000E-01	0.20000	-0.20000	8.0000
	1.0000		5.0000	20.000	0.0000	99.000
	-99.000		1.0000	3.6700	0.43500	5.4800
	0.10000E-01		0.98000E-02	3.8600	3.3300	0.40000
	99.000		0.0000	/		
6	'TGOV1'	1	0.50000E-01	0.50000E-01	1.0500	0.30000
	1.0000		2.1000	0.0000	/	
8	'GENROU'	1	6.5000	0.60000E-01	0.20000	0.50000E-01
	5.0000		0.0000	1.8000	1.7500	0.60000
	0.80000		0.34000	0.15000	0.90000E-01	0.38000 /
8	'ESST3A'	1	0.20000E-01	0.20000	-0.20000	8.0000
	1.0000		5.0000	20.000	0.0000	99.000
	-99.000		1.0000	3.6700	0.43500	5.4800
	0.10000E-01		0.98000E-02	3.8600	3.3300	0.40000

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99.000	0.0000	/			
8 'TGOV1' 1	0.50000E-01	0.50000E-01	1.0500	0.30000	
1.0000	2.1000	0.0000	/		

1.8.2 CURENT NPCC Verification

Prepared by [Hantao Cui](#). Last revised 23 May 2020.

Background

The **CURENT** NPCC test system contains 140 buses, 233 branches, and 48 generators. Dynamic data uses models GENROU, GENCLS, TGOV1 and IEEEEX1.

One line trip scenario is used to verify ANDES simulation results with DSATools TSAT.

Simulation Parameters

Integretion method: Trapezidal Rule (ANDES and TSAT).

Time step size: 1/120 sec. (Note: step size between 1/30 to 1/120 has little impact on the ANDES results. One can use `tstep=1/30` to obtain almost the same results.)

Load conversion: static loads are converted to 100% constant impedances for both P and Q.

TSAT automatic parameter correction is disabled.

Initialization

Power flow solutions are identical across all the two software.

GENROU initialization (E_{FD} , E_{TERM} , P , Q , δ , I_d and I_q) is identical to that from **PSS/E** for all cases (with and without generator saturation). Note that I_d and I_q are in machine base in PSS/E but in system base in ANDES.

GENROU initialization (including all the internal variables $E'd$, $E'q$, ψ_{kd} , ψ_{kq} , ψ''_d , and ψ''_q) is identical to that from **OpenIPSL**.

No controller limit violation occurs during initialization.

Conclusion

NPCC simulation results from ANDES are identical to that from TSAT.

```
import andes
import numpy as np
from andes.utils.tsat import tsat_to_df, plot_comparison, run_cmp

andes.config_logger(stream_level=30)
```

```
omega_lt2s = tsat_to_df('omega_lt2s.xls')
v_lt2s = tsat_to_df('v_lt2s.xls')
```

Scenario 1

Line 1-2 trips at 1 sec. and reconnects after 2.0 sec. The reconnection delay is set to 2 seconds to trigger a large disturbance to the system to verify nonlinear models.

Simulation Setup

```
ss = run_cmp('npcc.raw', dyr='npcc.dyr', fault_line='Line_1',
            t1=1.0, t2=3.0, tstep=1/120)
```

```
<Toggle Toggle_1>: Line.Line_1 status changed to 0.0 at t=1.0 sec.
<Toggle Toggle_2>: Line.Line_1 status changed to 1.0 at t=3.0 sec.
100%|████████████████████████████████████████| 100/100 [00:10<00:00, 9.87%/s]
```

```
# line information
ss.Line.cache.df_in.iloc[0]
```

```
idx      Line_1
u         1
name      Line_1
bus1       1
bus2       2
Sn        100
fn         60
Vn1       345
Vn2       345
r         0.0004
x         0.0043
b         0.07
g          0
b1         0
g1          0
b2         0
g2          0
```

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```

trans          0
tap            1
phi            0
owner          None
xcoord         None
ycoord         None
Name: 0, dtype: object

```

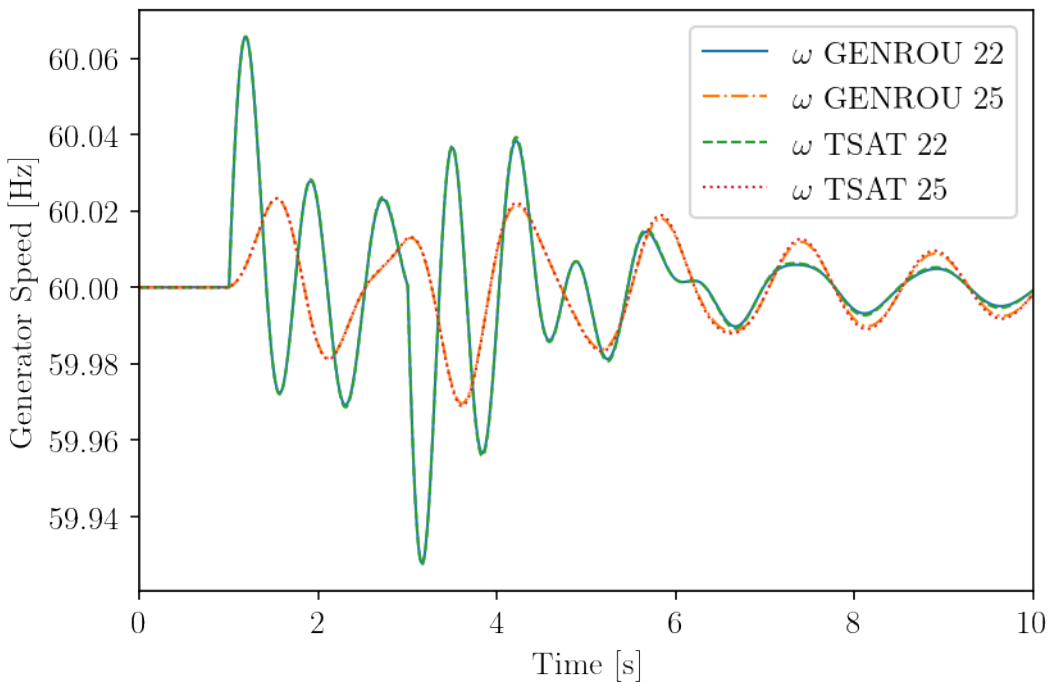
Scenario 1 Plots

```

tsat_omega_headers = [ss.TDS.plt._fname[i + 1] for i in ss.GENROU.omega.a]
tsat_omega_headers = [i.replace('GENROU', 'TSAT') for i in tsat_omega_headers]

fig, ax = plot_comparison(ss, ss.GENROU.omega, omega_lt2s,
                          a=[0, 3], ylabel="Generator Speed [Hz]",
                          tsat_header=tsat_omega_headers,
                          scale=60, right=10)

```

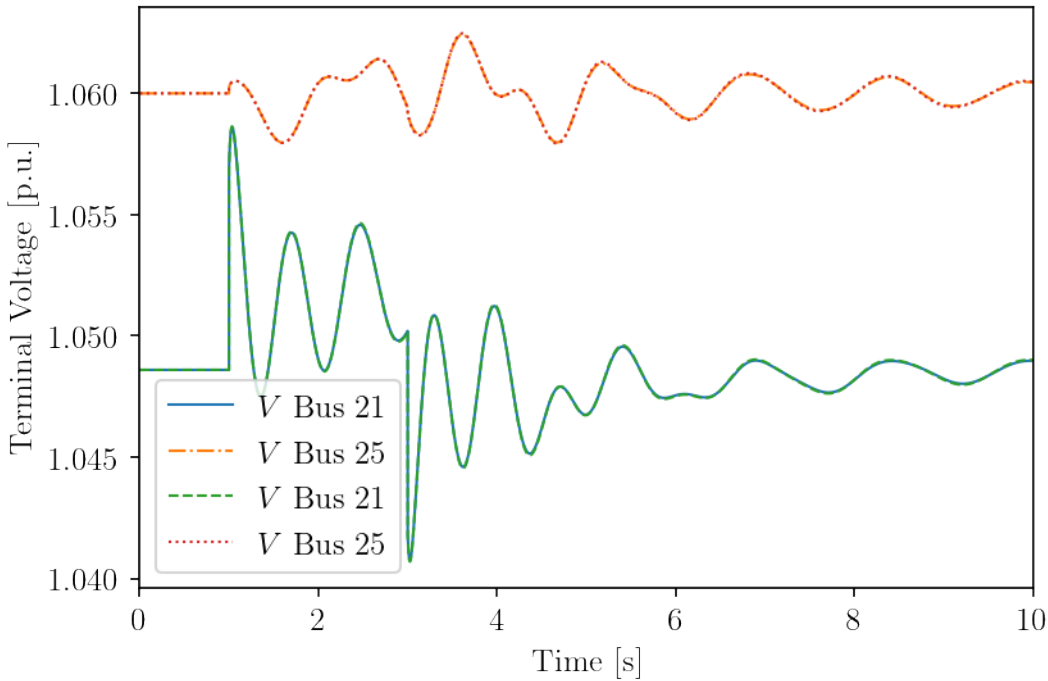


```

tsat_v_headers = [ss.TDS.plt._fname[i + 1 + ss.dae.n] for i in ss.GENROU.v.a]
tsat_v_headers = [i.replace('GENROU', 'TSAT') for i in tsat_v_headers]

fig, ax = plot_comparison(ss, ss.GENROU.v,
                          v_lt2s, a=[0, 5],
                          ylabel="Terminal Voltage [p.u.]",
                          tsat_header=tsat_v_headers, right=10)

```



Appendix

CURRENT NPCC 140-Bus System Data

Power Flow Data (PSS/E RAW format)

```
data = !cat npcc.raw
print('\n'.join(data))
```

```
0, 100.00, 32, 0, 1, 60.00 / PSS(R)E 32 RAW created by rawd32 MON, JUN 22 2015 8:32
CURRENT NPCC 48-MACHINE TESTBED, CONVERTED FROM PST BY BIN WANG
REVISED BY YIN LEI, 11/18/2013
1, 'MILLSTONE PT', 345.0000, 1, 1, 1, 1, 1.01517, 4.8434
2, 'MONTVILLE ', 345.0000, 1, 1, 1, 1, 1.01090, 4.0566
3, 'MONTVILLE ', 115.0000, 1, 1, 1, 1, 0.99170, 4.0069
4, 'MONTVILLE ', 345.0000, 1, 1, 1, 1, 1.01125, 4.1005
5, 'CARD ST ', 345.0000, 1, 1, 1, 1, 1.00618, 2.3527
6, 'SHERMAN RD ', 345.0000, 1, 1, 1, 1, 1.00594, 1.8603
7, 'MEDWAY ', 345.0000, 1, 1, 1, 1, 1.02071, 3.2654
8, 'MILLBURY ', 115.0000, 1, 1, 1, 1, 1.02151, 1.9975
9, 'CARPENTER HL', 115.0000, 1, 1, 1, 1, 1.01811, 1.0727
10, 'BRAYTON PT ', 115.0000, 1, 1, 1, 1, 1.03060, 8.0176
11, 'BRAYTON PT ', 115.0000, 1, 1, 1, 1, 1.01169, 6.7075
12, 'BRIDGEWATER ', 115.0000, 1, 1, 1, 1, 1.02371, 5.9431
13, 'PILGRIM ', 345.0000, 1, 1, 1, 1, 1.04565, 10.6737
```

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14, 'CANAL	'	345.0000,1,	1,	1,	1,1.03950,	10.3866
15, 'WALPOLA	'	345.0000,1,	1,	1,	1,1.02697,	3.4395
16, 'VERMONT YNK	'	345.0000,1,	1,	1,	1,1.04108,	4.4713
17, 'SCOBIE	'	345.0000,1,	1,	1,	1,1.04016,	3.2759
18, 'SANDY POND	'	115.0000,1,	1,	1,	1,1.02570,	1.5065
19, 'POWNA	'	345.0000,1,	1,	1,	1,1.04132,	6.4689
20, 'MAINE YANKEE'		345.0000,1,	1,	1,	1,1.04211,	9.1477
21, 'MILLSTONE PT'		24.0000,2,	1,	1,	1,1.04860,	11.8582
22, 'BRAYTON PT	'	18.0000,2,	1,	1,	1,1.05930,	12.6562
23, 'BRAYTON PT	'	20.0000,2,	1,	1,	1,1.01570,	11.7526
24, 'PILGRIM	'	22.8000,2,	1,	1,	1,1.07625,	15.7768
25, 'CANAL	'	20.0000,2,	1,	1,	1,1.06000,	18.3042
26, 'MAINE YANKEE'		20.0000,2,	1,	1,	1,1.04550,	15.7134
27, 'VERMONT YNK	'	22.0000,2,	1,	1,	1,1.04550,	11.0690
28, 'NORTHFIELD	'	13.8000,1,	1,	1,	1,1.02751,	3.2234
29, 'NORTHFIELD	'	345.0000,1,	1,	1,	1,1.02751,	3.2234
30, 'LUDLOW	'	345.0000,1,	1,	1,	1,1.01622,	0.7209
31, 'MANCHESTER	'	345.0000,1,	1,	1,	1,0.99761,	0.3966
32, 'SCOVILL ROCK'		345.0000,1,	1,	1,	1,1.00329,	1.8450
33, 'HADDAM NECK	'	345.0000,1,	1,	1,	1,1.00627,	2.5437
34, 'BLACK POND	'	345.0000,1,	1,	1,	1,0.99603,	0.4986
35, 'SOUTHINGTON	'	345.0000,1,	1,	1,	1,0.99524,	0.0743
36, 'CONN YANKEE	'	345.0000,2,	1,	1,	1,1.04860,	9.9630
37, 'NEW SEATHED	'	345.0000,1,	2,	1,	1,1.04419,	4.6062
38, 'GILBOA	'	345.0000,1,	2,	1,	1,1.04210,	6.9752
39, 'LEEDS	'	345.0000,1,	2,	1,	1,1.04100,	3.2739
40, 'NEW SEATHED	'	230.0000,1,	2,	1,	1,1.03072,	0.5762
41, 'ROTTERDAM	'	115.0000,1,	2,	1,	1,1.02634,	-3.3709
42, 'ALBANY	'	115.0000,2,	2,	1,	1,1.04000,	-2.5665
43, 'EDIC	'	345.0000,1,	2,	1,	1,1.04908,	8.3430
44, 'PORTER	'	230.0000,1,	2,	1,	1,1.04792,	6.5696
45, 'PORTER	'	115.0000,1,	2,	1,	1,1.04349,	3.9472
46, 'COLTON	'	115.0000,1,	2,	1,	1,1.04781,	6.1850
47, 'MOSES W	'	230.0000,2,	2,	1,	1,1.03000,	11.6793
48, 'MOSES E	'	230.0000,2,	2,	1,	1,1.05000,	15.0127
49, 'PLATTSBURGH	'	115.0000,1,	2,	1,	1,0.96523,	-1.1162
50, 'CLAY	'	345.0000,2,	2,	1,	1,1.05000,	13.2144
51, 'CLAY	'	115.0000,2,	2,	1,	1,1.04000,	8.5283
52, 'ROCHESTER	'	345.0000,1,	2,	1,	1,1.04193,	19.4130
53, 'ROCHESTER	'	115.0000,2,	2,	1,	1,1.03000,	18.0053
54, 'NIAGARA W	'	230.0000,2,	2,	1,	1,1.04080,	26.9321
55, 'NIAGARA E	'	230.0000,2,	2,	1,	1,1.04000,	26.2095
56, 'HUNTLEY	'	230.0000,2,	2,	1,	1,1.03000,	26.8995
57, 'HUNTLEY	'	115.0000,2,	2,	1,	1,1.03000,	25.7233
58, 'GARDENVILLE	'	230.0000,1,	2,	1,	1,1.01010,	24.5883
59, 'GARDENVILLE	'	115.0000,1,	2,	1,	1,0.99669,	22.1857
60, 'DUNKIRK	'	230.0000,2,	2,	1,	1,1.04000,	30.2181
61, 'DUNKIRK	'	115.0000,2,	2,	1,	1,1.04000,	26.7270
62, 'STOLLE RD	'	230.0000,1,	2,	1,	1,1.01628,	23.9633
63, 'MEYER	'	230.0000,1,	2,	1,	1,1.00548,	17.6467
64, 'MEYER	'	115.0000,1,	2,	1,	1,1.00715,	14.5476
65, 'GESONIDGE	'	115.0000,2,	2,	1,	1,1.04000,	15.7558

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66, 'WATERCURE	'	345.0000,1,	2,	1,	1,1.01975,	20.8736
67, 'WRHL	'	230.0000,1,	2,	1,	1,1.00265,	16.6813
68, 'HILLSIDE	'	115.0000,2,	2,	1,	1,0.99000,	12.7432
69, 'BINGHAMTON	'	345.0000,1,	2,	1,	1,1.01948,	14.3356
70, 'BINGHAMTON	'	230.0000,1,	2,	1,	1,0.99894,	13.5662
71, 'BINGHAMTON	'	115.0000,2,	2,	1,	1,1.00000,	11.1142
72, 'LAPEER	'	115.0000,2,	2,	1,	1,1.05000,	10.1183
73, 'PLEASANT VLY	'	345.0000,1,	3,	1,	1,1.03292,	1.6376
74, 'MILLWOOD	'	345.0000,1,	3,	1,	1,1.02708,	0.2979
75, 'RAMAPO	'	138.0000,1,	3,	1,	1,1.04944,	1.2631
76, 'RAMAPO	'	345.0000,1,	3,	1,	1,1.04639,	0.7974
77, 'BUCHANAN	'	345.0000,1,	3,	1,	1,1.03539,	0.5458
78, 'CE UG	'	345.0000,3,	3,	1,	1,1.02000,	0.0000
79, 'RAV A-3	'	22.0000,2,	3,	1,	1,1.05000,	8.1715
80, 'NORTHPORT	'	138.0000,2,	3,	1,	1,1.02320,	0.6309
81, 'GOETHALS	'	345.0000,1,	3,	1,	1,1.02198,	-3.2846
82, 'AK-3	'	22.0000,2,	3,	1,	1,1.05000,	7.5680
83, 'KEITH	'	220.0000,1,	4,	1,	1,0.95576,	22.9842
84, 'KEITH JCT	'	118.1000,1,	4,	1,	1,0.96323,	23.4874
85, 'LAMBTON	'	220.0000,1,	4,	1,	1,0.99128,	36.4486
86, 'LAMBTON	'	24.0000,2,	4,	1,	1,1.00000,	41.7274
87, 'LAMBTON	'	220.0000,1,	4,	1,	1,1.01813,	33.6520
88, 'SCOTT	'	220.0000,1,	4,	1,	1,0.97335,	32.8563
89, 'SCOTT	'	220.0000,1,	4,	1,	1,0.95584,	30.2514
90, 'VIDA	'	220.0000,1,	4,	1,	1,0.95411,	30.1020
91, 'RICHVIEW	'	220.0000,2,	4,	1,	1,1.04000,	11.2134
92, 'HANMER	'	500.0000,2,	4,	1,	1,1.04000,	18.6819
93, 'ESSA	'	220.0000,1,	4,	1,	1,0.96211,	7.5454
94, 'ORANGEVILLE	'	220.0000,1,	4,	1,	1,0.95948,	7.7792
95, 'DES JOAC	'	220.0000,1,	4,	1,	1,0.97264,	14.6338
96, 'HOLDEN	'	13.8000,1,	4,	1,	1,1.02323,	15.2006
97, 'MARTINDELE	'	220.0000,2,	4,	1,	1,1.04000,	14.0482
98, 'STLA	'	220.0000,2,	4,	1,	1,1.04000,	31.9721
99, 'PVR	'	220.0000,1,	4,	1,	1,1.03842,	31.3229
100, 'PHAS	'	220.0000,1,	4,	1,	1,1.03248,	26.3181
101, 'SAB 2	'	220.0000,2,	4,	1,	1,1.05000,	24.3484
102, 'BP 76	'	220.0000,1,	4,	1,	1,1.04550,	25.5246
103, 'PA 27	'	220.0000,1,	4,	1,	1,1.04629,	25.3162
104, 'BEACH	'	220.0000,1,	4,	1,	1,0.99699,	13.1740
105, 'BUCHANAN	'	220.0000,1,	4,	1,	1,0.97457,	24.1225
106, 'NEALE	'	220.0000,1,	4,	1,	1,0.99289,	14.5859
107, 'NEALE	'	220.0000,1,	4,	1,	1,1.00616,	15.9332
108, 'S CT	'	220.0000,1,	4,	1,	1,1.00033,	13.9155
109, 'SLT	'	220.0000,1,	4,	1,	1,1.00029,	13.8910
110, 'BURLINGTON	'	220.0000,1,	4,	1,	1,1.00281,	12.4399
111, 'DETWIERER	'	220.0000,1,	4,	1,	1,0.96194,	10.0383
112, 'CHATHAM	'	220.0000,1,	4,	1,	1,0.97541,	29.6056
113, 'LAUZON	'	118.1000,1,	4,	1,	1,0.95230,	22.4473
114, 'MARYSVILLE	'	220.0000,1,	5,	1,	1,0.95972,	30.6392
115, 'ST CLAIR	'	500.0000,2,	5,	1,	1,1.02000,	33.4478
116, 'WATERMAN	'	220.0000,1,	5,	1,	1,0.99338,	26.8500
117, 'PONTIAC	'	230.0000,1,	5,	1,	1,1.00506,	30.8651

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118,	'WAYNE	,	115.0000,1,	5,	1,	1,0.99857,	31.7891	
119,	'THETFORD	,	220.0000,2,	5,	1,	1,1.00000,	30.2408	
120,	'ARGENTA	,	220.0000,2,	5,	1,	1,1.02000,	26.6696	
121,	'SC415	,	220.0000,2,	5,	1,	1,1.04000,	32.8926	
122,	'WATERMAN	,	220.0000,2,	5,	1,	1,1.05000,	32.3212	
123,	'MONROE	,	230.0000,2,	5,	1,	1,1.01000,	37.6123	
124,	'BRANCHBURG	,	230.0000,1,	6,	1,	1,1.04471,	2.3841	
125,	'LINDON	,	230.0000,1,	6,	1,	1,1.02196,	-3.4160	
126,	'HUDSON	,	230.0000,1,	6,	1,	1,1.02261,	-5.3945	
127,	'ALBURTIS	,	500.0000,1,	6,	1,	1,1.04853,	6.5520	
128,	'WHITPAIN	,	500.0000,1,	6,	1,	1,1.03926,	2.7377	
129,	'KEENEY	,	500.0000,1,	6,	1,	1,1.02303,	8.9401	
130,	'PEACH BOTTOM	,	500.0000,2,	6,	1,	1,1.02000,	12.1966	
131,	'CONASTONE	,	500.0000,1,	6,	1,	1,1.02604,	13.4125	
132,	'JUNIATA	,	500.0000,1,	6,	1,	1,1.03978,	19.5565	
133,	'CONEMAUGH	,	500.0000,2,	6,	1,	1,1.02000,	34.3480	
134,	'HOMER CITY	,	230.0000,2,	6,	1,	1,1.03000,	25.5764	
135,	'KEYSTONE	,	500.0000,2,	6,	1,	1,1.02000,	35.0063	
136,	'ERIE W	,	345.0000,1,	6,	1,	1,1.00058,	19.7176	
137,	'ERIE S	,	230.0000,2,	6,	1,	1,1.04000,	20.3245	
138,	'E TOMANO	,	230.0000,1,	6,	1,	1,0.97073,	13.5527	
139,	'KYGER	,	345.0000,2,	6,	1,	1,1.01000,	29.3780	
140,	'TE	,	230.0000,1,	6,	1,	1,1.04132,	30.2102	
0 /End of Bus data, Begin Load data								
3,	'1	,	1, 1, 1,	9.000,	88.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
6,	'1	,	1, 1, 1,	320.000,	153.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
7,	'1	,	1, 1, 1,	329.000,	32.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
9,	'1	,	1, 1, 1,	158.000,	30.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
11,	'1	,	1, 1, 1,	680.000,	103.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
12,	'1	,	1, 1, 1,	274.000,	115.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
14,	'1	,	1, 1, 1,	248.000,	85.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
15,	'1	,	1, 1, 1,	309.000,	-92.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
16,	'1	,	1, 1, 1,	224.000,	47.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
17,	'1	,	1, 1, 1,	139.000,	17.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
18,	'1	,	1, 1, 1,	281.000,	76.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
19,	'1	,	1, 1, 1,	206.000,	28.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
20,	'1	,	1, 1, 1,	284.000,	27.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					
30,	'1	,	1, 1, 1,	322.000,	2.000,	0.000,	0.000,	0.
↪000,			0.000, 1,1					

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31, '1	',1,	1,	1,	500.000,	184.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
34, '1	',1,	1,	1,	234.000,	84.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
35, '1	',1,	1,	1,	522.000,	177.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
36, '1	',1,	1,	1,	9.000,	5.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
41, '1	',1,	2,	1,	700.000,	125.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
42, '1	',1,	2,	1,	177.000,	17.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
45, '1	',1,	2,	1,	256.000,	17.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
46, '1	',1,	2,	1,	177.000,	25.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
46, '2	',1,	2,	1,	-154.000,	-67.500,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
47, '1	',1,	2,	1,	528.000,	100.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
49, '1	',1,	2,	1,	208.000,	17.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
51, '1	',1,	2,	1,	731.000,	75.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
53, '1	',1,	2,	1,	923.000,	250.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
54, '1	',1,	2,	1,	20.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
55, '1	',1,	2,	1,	939.000,	132.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
56, '1	',1,	2,	1,	172.000,	44.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
57, '1	',1,	2,	1,	240.000,	-6.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
58, '1	',1,	2,	1,	84.000,	38.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
59, '1	',1,	2,	1,	705.000,	198.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
61, '1	',1,	2,	1,	237.000,	8.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
64, '1	',1,	2,	1,	143.000,	25.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
65, '1	',1,	2,	1,	91.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
68, '1	',1,	2,	1,	211.000,	41.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
71, '1	',1,	2,	1,	371.000,	53.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
74, '1	',1,	3,	1,	102.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						
78, '1	',1,	3,	1,	2000.000,	600.000,	0.000,	0.000,	0.
↪000,	0.000,	1,1						

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80, '1	' , 1,	3,	1,	700.000,	25.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
83, '1	' , 1,	4,	1,	80.000,	16.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
85, '1	' , 1,	4,	1,	18.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
86, '1	' , 1,	4,	1,	50.000,	25.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
88, '1	' , 1,	4,	1,	110.000,	55.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
89, '1	' , 1,	4,	1,	100.000,	70.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
90, '1	' , 1,	4,	1,	115.000,	45.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
91, '1	' , 1,	4,	1,	1650.000,	500.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
92, '1	' , 1,	4,	1,	10.000,	320.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
93, '1	' , 1,	4,	1,	125.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
94, '1	' , 1,	4,	1,	95.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
95, '1	' , 1,	4,	1,	25.000,	100.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
95, '2	' , 1,	4,	1,	-125.000,	-13.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
96, '1	' , 1,	4,	1,	20.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
96, '2	' , 1,	4,	1,	-60.000,	-25.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
97, '1	' , 1,	4,	1,	910.000,	50.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
101, '1	' , 1,	4,	1,	350.000,	130.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
104, '1	' , 1,	4,	1,	200.000,	90.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
105, '1	' , 1,	4,	1,	325.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
106, '1	' , 1,	4,	1,	0.000,	-12.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
107, '1	' , 1,	4,	1,	0.000,	-19.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
108, '1	' , 1,	4,	1,	0.000,	-13.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
109, '1	' , 1,	4,	1,	0.000,	-13.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
110, '1	' , 1,	4,	1,	718.000,	125.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
111, '1	' , 1,	4,	1,	399.000,	45.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
113, '1	' , 1,	4,	1,	206.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						

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114, '1	', 1,	5,	1,	0.000,	90.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
115, '1	', 1,	5,	1,	100.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
116, '1	', 1,	5,	1,	200.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
117, '1	', 1,	5,	1,	400.000,	97.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
118, '1	', 1,	5,	1,	280.000,	86.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
119, '1	', 1,	5,	1,	750.000,	200.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
120, '1	', 1,	5,	1,	946.000,	-40.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
123, '1	', 1,	5,	1,	63.000,	10.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
124, '1	', 1,	6,	1,	370.000,	71.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
124, '2	', 1,	6,	1,	0.000,	-22.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
125, '1	', 1,	6,	1,	320.000,	5.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
126, '1	', 1,	6,	1,	450.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
127, '1	', 1,	6,	1,	200.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
127, '2	', 1,	6,	1,	0.000,	-150.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
128, '1	', 1,	6,	1,	970.000,	60.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
128, '2	', 1,	6,	1,	0.000,	-162.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
129, '1	', 1,	6,	1,	610.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
129, '2	', 1,	6,	1,	0.000,	-50.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
130, '1	', 1,	6,	1,	180.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
131, '1	', 1,	6,	1,	1160.000,	468.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
131, '2	', 1,	6,	1,	0.000,	-900.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
132, '1	', 1,	6,	1,	210.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
132, '2	', 1,	6,	1,	0.000,	-337.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
135, '1	', 1,	6,	1,	170.000,	0.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
136, '1	', 1,	6,	1,	270.000,	223.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						
138, '1	', 1,	6,	1,	110.000,	64.000,	0.000,	0.000,	0.
↪000,	0.000,	1, 1						

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0 /End of Load data, Begin Fixed shunt data
0 /End of Fixed shunt data, Begin Generator data
  21,'1 ',    650.000,    215.117,    999.000,   -999.000,1.04860,    0,    750.
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↪9999.000, -9999.000,    1,1.0000
  22,'1 ',    632.000,    208.118,    999.000,   -999.000,1.05930,    0,    700.
↪000, 0.00000E+0, 2.06500E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0,  ⚡
↪9999.000, -9999.000,    1,1.0000
  23,'1 ',    276.650,     10.788,    999.000,   -999.000,1.01570,    0,    300.
↪000, 0.00000E+0, 9.99000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0,  ⚡
↪9999.000, -9999.000,    1,1.0000
  23,'2 ',    226.350,      8.827,   9999.000,  -9999.000,1.01570,    0,    300.
↪000, 0.00000E+0, 2.23500E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0,  ⚡
↪9999.000, -9999.000,    1,1.0000
  24,'1 ',    700.000,    261.533,    999.000,   -999.000,1.07625,    0,    800.
↪000, 0.00000E+0, 2.32000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0,  ⚡
↪9999.000, -9999.000,    1,1.0000
  25,'1 ',    560.000,    108.222,    999.000,   -999.000,1.06000,    0,    650.
↪000, 0.00000E+0, 2.09300E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0,  ⚡
↪9999.000, -9999.000,    1,1.0000
  26,'1 ',    800.000,    27.488,    999.000,   -999.000,1.04550,    0,    900.
↪000, 0.00000E+0, 2.81700E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0,  ⚡
↪9999.000, -9999.000,    1,1.0000
  27,'1 ',    540.000,    37.044,    999.000,   -999.000,1.04550,    0,    600.
↪000, 0.00000E+0, 1.80000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0,  ⚡
↪9999.000, -9999.000,    1,1.0000
  36,'1 ',    554.000,    217.901,    999.000,   -999.000,1.04860,    0,    650.
↪000, 0.00000E+0, 2.99000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0,  ⚡
↪9999.000, -9999.000,    1,1.0000
  42,'1 ',    370.000,    134.949,    999.000,   -999.000,1.04000,    0,    400.
↪000, 0.00000E+0, 1.78000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0,  ⚡
↪9999.000, -9999.000,    1,1.0000
  47,'1 ',    400.000,     -3.268,    999.000,   -999.000,1.03000,    0,    450.
↪000, 0.00000E+0, 3.51900E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0,  ⚡
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  48,'1 ',    400.000,    107.452,    999.000,   -999.000,1.05000,    0,    500.
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  50,'1 ',    600.000,    41.180,    999.000,   -999.000,1.05000,    0,    700.
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  51,'1 ',    141.000,     20.685,    999.000,   -999.000,1.04000,    0,    150.
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  53,'1 ',    833.000,    173.977,    999.000,   -999.000,1.03000,    0,    100.
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  54,'1 ',    557.500,     -0.649,    999.000,   -999.000,1.04080,    0,    650.
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↪9999.000, -9999.000,    1,1.0000
  54,'2 ',    557.500,     -0.649,   9999.000,  -9999.000,1.04080,    0,    650.
↪000, 0.00000E+0, 3.25000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0,  ⚡

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→9999.000, -9999.000, 1,1.0000
55,'1 ', 1095.000, 148.655, 999.000, -999.000,1.04000, 0, 1200.
→000, 0.00000E+0, 3.62400E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
→9999.000, -9999.000, 1,1.0000
56,'1 ', 410.000, 87.207, 999.000, -999.000,1.03000, 0, 500.
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57,'1 ', 298.000, 3.534, 999.000, -999.000,1.03000, 0, 350.
→000, 0.00000E+0, 1.62400E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
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60,'1 ', 410.000, 54.828, 999.000, -999.000,1.04000, 0, 450.
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→9999.000, -9999.000, 1,1.0000
61,'1 ', 194.000, 13.180, 999.000, -999.000,1.04000, 0, 200.
→000, 0.00000E+0, 1.89400E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
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65,'1 ', 91.000, 51.625, 999.000, -999.000,1.04000, 0, 100.
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68,'1 ', 66.000, -0.140, 999.000, -999.000,0.99000, 0, 100.
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71,'1 ', 134.000, -373.660, 999.000, -999.000,1.00000, 0, 100.
→000, 0.00000E+0, 2.00000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
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72,'1 ', 150.000, 379.422, 999.000, -999.000,1.05000, 0, 100.
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78,'1 ', 466.019, 74.010, 999.000, -999.000,1.02000, 0, 100.
→000, 0.00000E+0, 2.00000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
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79,'1 ', 1000.000, 257.345, 999.000, -999.000,1.05000, 0, 1150.
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80,'1 ', 720.000, -0.078, 999.000, -999.000,1.02320, 0, 800.
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82,'1 ', 460.000, 125.095, 999.000, -999.000,1.05000, 0, 500.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
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86,'1 ', 1650.000, 251.799, 999.000, -999.000,1.00000, 0, 1900.
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91,'1 ', 930.000, 1082.086, 999.000, -999.000,1.04000, 0, 100.
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92,'1 ', 450.000, 324.468, 999.000, -999.000,1.04000, 0, 100.
→000, 0.00000E+0, 2.00000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
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97,'1 ', 600.000, 96.902, 999.000, -999.000,1.04000, 0, 100.
→000, 0.00000E+0, 2.00000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
→9999.000, -9999.000, 1,1.0000

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98,'1 ', 585.000, 33.013, 999.000, -999.000,1.04000, 0, 650.
↪000, 0.00000E+0, 9.75000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
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101,'1 ', 1200.000, 506.878, 999.000, -999.000,1.05000, 0, 1350.
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115,'1 ', 550.000, 269.536, 999.000, -999.000,1.02000, 0, 100.
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↪9999.000, -9999.000, 1,1.0000
119,'1 ', 550.000, 145.624, 999.000, -999.000,1.00000, 0, 100.
↪000, 0.00000E+0, 2.00000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
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120,'1 ', 700.000, 57.157, 999.000, -999.000,1.02000, 0, 100.
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↪9999.000, -9999.000, 1,1.0000
121,'1 ', 145.000, 157.850, 999.000, -999.000,1.04000, 0, 100.
↪000, 0.00000E+0, 2.00000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
↪9999.000, -9999.000, 1,1.0000
122,'1 ', 155.000, 127.774, 999.000, -999.000,1.05000, 0, 100.
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↪9999.000, -9999.000, 1,1.0000
123,'1 ', 655.000, 58.623, 999.000, -999.000,1.01000, 0, 100.
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130,'1 ', 490.000, -467.860, 999.000, -999.000,1.02000, 0, 100.
↪000, 0.00000E+0, 2.00000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
↪9999.000, -9999.000, 1,1.0000
133,'1 ', 1700.000, -141.013, 999.000, -999.000,1.02000, 0, 100.
↪000, 0.00000E+0, 2.00000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
↪9999.000, -9999.000, 1,1.0000
134,'1 ', 880.000, 43.093, 999.000, -999.000,1.03000, 0, 100.
↪000, 0.00000E+0, 2.00000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
↪9999.000, -9999.000, 1,1.0000
135,'1 ', 2330.000, -100.279, 999.000, -999.000,1.02000, 0, 100.
↪000, 0.00000E+0, 2.00000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
↪9999.000, -9999.000, 1,1.0000
137,'1 ', 70.000, 174.600, 999.000, -999.000,1.04000, 0, 100.
↪000, 0.00000E+0, 2.00000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
↪9999.000, -9999.000, 1,1.0000
139,'1 ', 115.000, 18.439, 999.000, -999.000,1.01000, 0, 100.
↪000, 0.00000E+0, 2.00000E-2, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, _
↪9999.000, -9999.000, 1,1.0000
0 /End of Generator data, Begin Branch data
1, 2,'1 ', 4.00000E-4, 4.30000E-3, 0.07000, 0.00, 0.00, _
↪0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
1, 4,'1 ', 4.00000E-4, 4.30000E-3, 0.07000, 0.00, 0.00, _
↪0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
2, 33,'1 ', 7.00000E-4, 8.20000E-3, 0.14000, 0.00, 0.00, _
↪0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
4, 5,'1 ', 9.00000E-4, 1.01000E-2, 0.17000, 0.00, 0.00, _
↪0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
5, 6,'1 ', 1.80000E-3, 2.17000E-2, 0.37000, 0.00, 0.00, _

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→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
5,	31,'1	,	8.00000E-4,	1.29000E-2,	0.14000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
6,	7,'1	,	9.00000E-4,	9.40000E-3,	0.17000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
7,	8,'1	,	7.00000E-4,	8.90000E-3,	0.13000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
7,	10,'1	,	1.60000E-3,	1.95000E-2,	0.30000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
7,	12,'1	,	8.00000E-4,	1.35000E-2,	0.25000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
7,	15,'1	,	3.00000E-4,	5.90000E-3,	0.07000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
8,	9,'1	,	7.00000E-4,	8.20000E-3,	0.13000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
8,	18,'1	,	1.30000E-3,	1.73000E-2,	0.32000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
9,	30,'1	,	1.10000E-3,	1.33000E-2,	0.21000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
12,	13,'1	,	8.00000E-4,	1.40000E-2,	0.26000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
13,	14,'1	,	6.00000E-4,	9.60000E-3,	0.18000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
14,	15,'1	,	2.20000E-3,	3.50000E-2,	0.36000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
16,	17,'1	,	3.20000E-3,	3.23000E-2,	0.53000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
16,	29,'1	,	7.00000E-3,	8.60000E-3,	0.15000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
17,	18,'1	,	1.40000E-3,	1.47000E-2,	0.24000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
17,	19,'1	,	4.30000E-3,	4.74000E-2,	0.78000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
17,	20,'1	,	5.70000E-3,	6.25000E-2,	1.03000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
19,	20,'1	,	1.40000E-3,	1.51000E-2,	0.25000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
29,	30,'1	,	1.30000E-3,	1.51000E-2,	0.26000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
29,	37,'1	,	3.50000E-3,	4.11000E-2,	0.70000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
30,	31,'1	,	1.30000E-3,	2.13000E-2,	0.22000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
31,	32,'1	,	8.00000E-4,	1.28000E-2,	0.13000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
32,	33,'1	,	2.00000E-4,	2.60000E-3,	0.04000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
32,	35,'1	,	8.00000E-4,	1.12000E-2,	0.15000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
33,	34,'1	,	6.00000E-4,	9.20000E-3,	0.11000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
34,	35,'1	,	4.00000E-4,	4.60000E-3,	0.08000,	0.00,	0.00,	└

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→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
35,	73,'1	',	2.30000E-3,	3.63000E-2,	0.38000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
37,	38,'1	',	1.60000E-3,	1.63000E-2,	0.25000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
37,	39,'1	',	8.00000E-4,	7.40000E-3,	0.48000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
37,	40,'1	',	9.00000E-4,	3.15000E-2,	0.06000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
37,	43,'1	',	1.30000E-3,	1.88000E-2,	1.31000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
38,	69,'1	',	4.30000E-3,	4.85000E-2,	0.79000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
39,	73,'1	',	1.90000E-3,	1.83000E-2,	0.29000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
39,	73,'2	',	1.90000E-3,	1.83000E-2,	0.29000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
40,	44,'1	',	8.00000E-3,	5.30000E-2,	0.40000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
41,	42,'1	',	1.80000E-3,	8.90000E-3,	0.07000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
41,	45,'1	',	7.76000E-2,	2.24100E-1,	0.13000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
43,	44,'1	',	0.00000E+0,	1.10000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
43,	50,'1	',	2.50000E-3,	2.68000E-2,	0.40000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
43,	50,'2	',	2.50000E-3,	2.68000E-2,	0.40000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
44,	45,'1	',	0.00000E+0,	2.05000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
44,	48,'1	',	1.50000E-2,	1.05000E-1,	0.79000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
45,	46,'1	',	1.23500E-1,	3.54800E-1,	0.16000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
45,	51,'1	',	6.05000E-2,	1.89600E-1,	0.08000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
45,	71,'1	',	1.75100E-1,	5.57500E-1,	0.12000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
46,	47,'1	',	6.32000E-2,	1.21000E-1,	0.05000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
46,	49,'1	',	1.64000E-1,	5.78000E-1,	0.06000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
47,	48,'1	',	0.00000E+0,	3.30000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
50,	51,'1	',	0.00000E+0,	2.07000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
50,	52,'1	',	2.00000E-3,	2.20000E-2,	1.28000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
51,	53,'1	',	8.44000E-2,	2.16100E-1,	0.22000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
51,	72,'1	',	5.10000E-3,	2.32000E-2,	0.30000,	0.00,	0.00,	└

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→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
52,	53,'1	,	1.40000E-3,	3.88000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
53,	55,'1	,	3.00000E-2,	1.07000E-1,	0.30000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
53,	65,'1	,	3.50000E-2,	8.00000E-2,	0.05000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
54,	56,'1	,	1.00000E-2,	8.00000E-3,	0.07000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
54,	62,'1	,	8.00000E-3,	6.90000E-2,	0.13000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
54,	102,'1	,	1.60000E-3,	2.48000E-2,	0.06000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
54,	103,'1	,	1.60000E-3,	2.48000E-2,	0.06000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
55,	57,'1	,	7.40000E-3,	4.00000E-2,	0.02000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
55,	59,'1	,	1.60000E-2,	8.17000E-2,	0.04000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
56,	58,'1	,	2.00000E-3,	1.50000E-2,	0.11000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
57,	59,'1	,	1.40000E-2,	6.80000E-2,	0.03000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
58,	60,'1	,	3.50000E-3,	3.44000E-2,	0.27000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
58,	62,'1	,	2.00000E-3,	1.80000E-2,	0.03000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
59,	61,'1	,	6.80000E-2,	1.43000E-1,	0.06000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
60,	140,'1	,	3.90000E-3,	3.63000E-2,	0.07000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
62,	63,'1	,	1.29000E-2,	8.03000E-2,	0.15000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
63,	64,'1	,	0.00000E+0,	4.60000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
63,	67,'1	,	1.20000E-2,	9.30000E-2,	0.18000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
64,	65,'1	,	3.50000E-2,	8.00000E-2,	0.05000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
64,	68,'1	,	9.88000E-2,	2.31000E-1,	0.13000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
66,	67,'1	,	0.00000E+0,	2.31000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
66,	69,'1	,	1.80000E-3,	2.74000E-2,	0.27000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
66,	134,'1	,	7.60000E-4,	1.14100E-2,	1.16000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
67,	68,'1	,	0.00000E+0,	4.90000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
67,	70,'1	,	7.00000E-3,	6.19000E-2,	0.12000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
67,	138,'1	,	6.30000E-3,	4.91000E-2,	0.09000,	0.00,	0.00,	└

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→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
68,	71,'1	',	1.20300E-1,	2.04800E-1,	0.07000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
69,	71,'1	',	0.00000E+0,	3.75000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
70,	71,'1	',	0.00000E+0,	4.90000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
71,	72,'1	',	5.30000E-3,	1.35000E-2,	0.10000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
73,	74,'1	',	2.20000E-3,	1.96000E-2,	0.34000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
73,	74,'2	',	2.20000E-3,	1.96000E-2,	0.34000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
74,	77,'1	',	3.00000E-4,	4.30000E-3,	0.08000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
74,	78,'1	',	5.00000E-4,	4.50000E-3,	0.32000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
74,	78,'2	',	5.00000E-4,	4.50000E-3,	0.32000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
75,	124,'1	',	7.00000E-4,	1.75000E-2,	1.39000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
76,	77,'1	',	3.00000E-3,	6.80000E-3,	1.37000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
78,	79,'1	',	3.00000E-4,	1.53000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
78,	80,'1	',	1.35000E-2,	5.82000E-2,	0.50000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
78,	81,'1	',	5.00000E-4,	2.76000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
78,	82,'1	',	5.00000E-4,	3.08000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
81,	125,'1	',	1.00000E-4,	1.10000E-3,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
83,	112,'1	',	1.85000E-2,	1.53700E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
83,	113,'1	',	3.70000E-3,	2.02000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
84,	116,'1	',	1.50000E-3,	1.04500E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
85,	88,'1	',	1.60000E-3,	2.02000E-2,	0.03000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
85,	88,'2	',	1.60000E-3,	2.02000E-2,	0.03000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
85,	105,'1	',	1.00000E-2,	1.09000E-1,	0.18000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
85,	105,'2	',	1.00000E-2,	1.09000E-1,	0.18000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
85,	112,'1	',	6.90000E-3,	5.95000E-2,	0.10000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
85,	112,'2	',	6.90000E-3,	5.95000E-2,	0.10000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
87,	115,'1	',	1.00000E-4,	1.80000E-3,	0.02000,	0.00,	0.00,	└

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→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
88,	89,'1	',	5.00000E-4,	2.05000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
88,	105,'1	',	1.12000E-2,	9.93000E-2,	0.17000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
88,	105,'2	',	1.12000E-2,	9.93000E-2,	0.17000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
89,	90,'1	',	1.30000E-3,	4.90000E-3,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
89,	105,'1	',	8.94000E-2,	3.36300E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
89,	113,'1	',	1.45600E-1,	4.11500E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
90,	114,'1	',	2.40000E-3,	1.50000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
91,	92,'1	',	5.80000E-3,	9.28000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
91,	93,'1	',	4.21000E-2,	2.93200E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
91,	95,'1	',	2.61000E-2,	1.84400E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
91,	98,'1	',	1.20000E-2,	8.54000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
91,	110,'1	',	1.70000E-3,	1.17000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
92,	97,'1	',	8.00000E-4,	3.03000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
93,	94,'1	',	4.20000E-3,	2.83000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
93,	95,'1	',	1.87000E-2,	1.28400E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
94,	111,'1	',	4.90000E-3,	3.36000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
95,	96,'1	',	1.36000E-2,	9.55000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
96,	97,'1	',	1.60000E-2,	7.67000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
98,	99,'1	',	3.00000E-4,	9.20000E-3,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
99,	100,'1	',	1.00000E-3,	7.02000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
101,	104,'1	',	7.70000E-3,	7.73000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
101,	105,'1	',	1.88000E-2,	1.49300E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
101,	107,'1	',	7.60000E-3,	7.51000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
101,	108,'1	',	7.80000E-3,	7.72000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
101,	109,'1	',	7.80000E-3,	7.83000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
101,	110,'1	',	4.82000E-2,	2.63600E-1,	0.00000,	0.00,	0.00,	└

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→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
104,	106,'1	',	1.80000E-3,	1.80000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
104,	110,'1	',	6.00000E-4,	6.20000E-3,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
105,	106,'1	',	1.65000E-2,	1.15600E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
105,	107,'1	',	1.15000E-2,	1.10300E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
105,	111,'1	',	1.31000E-2,	8.09000E-2,	0.13000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
105,	112,'1	',	8.00000E-3,	4.97000E-2,	0.30000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
105,	113,'1	',	3.82400E-1,	9.47900E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
107,	110,'1	',	2.10000E-3,	1.86000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
108,	110,'1	',	2.60000E-3,	1.94000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
108,	111,'1	',	5.90000E-3,	5.77000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
109,	110,'1	',	2.60000E-3,	1.94000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
109,	111,'1	',	5.90000E-3,	5.77000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
112,	113,'1	',	1.01000E-2,	8.73000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
114,	117,'1	',	6.63000E-2,	3.69600E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
114,	119,'1	',	8.76000E-2,	2.54000E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
114,	121,'1	',	6.30000E-3,	8.02000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
115,	116,'1	',	7.33000E-2,	9.79900E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
115,	117,'1	',	1.00000E-3,	1.14000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
115,	118,'1	',	1.65700E-1,	1.55100E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
115,	119,'1	',	3.30000E-3,	3.92000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
115,	121,'1	',	2.20000E-2,	2.98400E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
115,	135,'1	',	0.00000E+0,	6.30900E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
115,	139,'1	',	0.00000E+0,	1.24300E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
116,	117,'1	',	4.74000E-2,	2.63100E-1,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
116,	118,'1	',	1.17000E-2,	7.44000E-2,	0.00000,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
116,	120,'1	',	2.30700E-1,	7.04100E-1,	0.00000,	0.00,	0.00,	└

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→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
116, 121,'1 ', 9.51000E-2, 4.57600E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
116, 122,'1 ', 3.30000E-3, 1.28700E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
117, 118,'1 ', 2.00000E-3, 1.99000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
117, 119,'1 ', 1.70000E-3, 1.89000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
117, 120,'1 ', 6.70000E-3, 7.97000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
117, 121,'1 ', 1.50000E-2, 8.69000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
117, 122,'1 ', 3.83000E-2, 8.86000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
118, 120,'1 ', 5.00000E-3, 6.29000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
118, 121,'1 ', 1.39100E-1, 4.79800E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
118, 122,'1 ', 9.50000E-2, 5.07100E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
118, 123,'1 ', 1.40000E-3, 1.74000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
119, 120,'1 ', 1.06500E-1, 3.49800E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
119, 121,'1 ', 1.63600E-1, 5.80400E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
121, 122,'1 ', 1.25000E-1, 4.69900E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
122, 135,'1 ', 5.73000E-2, 7.58100E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
122, 139,'1 ', 0.00000E+0, 1.53200E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
124, 125,'1 ', 2.50000E-3, 7.30000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
124, 126,'1 ', 0.00000E+0, 8.39000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
124, 127,'1 ', 4.00000E-4, 1.05000E-2, 0.72000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
124, 128,'1 ', 5.00000E-4, 1.17000E-2, 0.84000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
125, 126,'1 ', 0.00000E+0, 4.11000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
125, 128,'1 ', 4.90000E-3, 2.63400E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
126, 127,'1 ', 0.00000E+0, 2.53200E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
126, 128,'1 ', 0.00000E+0, 2.74100E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
126, 138,'1 ', 0.00000E+0, 6.80500E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
127, 128,'1 ', 0.00000E+0, 1.33900E-1, 0.00000, 0.00, 0.00,

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→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
127, 132,'1 ', 9.00000E-4, 2.21000E-2, 1.62000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
128, 129,'1 ', 0.00000E+0, 1.38100E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
128, 130,'1 ', 7.00000E-4, 1.75000E-2, 1.26000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
129, 130,'1 ', 4.00000E-4, 8.50000E-3, 0.60000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
130, 131,'1 ', 2.00000E-4, 3.80000E-3, 0.54000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
130, 132,'1 ', 7.00000E-4, 1.73000E-2, 1.25000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
131, 133,'1 ', 2.00000E-3, 3.90000E-2, 2.77000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
131, 135,'1 ', 5.70000E-3, 6.99000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
131, 139,'1 ', 5.90000E-3, 1.05200E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
132, 133,'1 ', 1.20000E-3, 2.93000E-2, 2.09000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
132, 134,'1 ', 2.35000E-3, 4.38800E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
132, 135,'1 ', 1.20000E-3, 2.88000E-2, 2.06000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
132, 138,'1 ', 3.31000E-2, 4.22400E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
133, 135,'1 ', 3.00000E-4, 6.30000E-3, 0.45000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
134, 135,'1 ', 4.60000E-3, 6.25000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
134, 136,'1 ', 4.60000E-3, 7.82000E-2, 0.79000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
135, 139,'1 ', 1.77000E-2, 6.61000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
136, 139,'1 ', 0.00000E+0, 2.05400E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
137, 138,'1 ', 2.55300E-1, 7.18000E-1, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
0 /End of Branch data, Begin Transformer data
1, 21, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,
→1,1.0000
0.00000E+0, 2.00000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000,
→0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
3, 2, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,
→1,1.0000
1.60000E-3, 4.35000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000,
→0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000

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      3,      4,      0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
1.60000E-3, 4.35000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
      10,     11,      0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
7.00000E-4, 1.38000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
      10,     22,      0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
7.00000E-4, 1.42000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
      11,     23,      0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
9.00000E-4, 1.80000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
      13,     24,      0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
0.00000E+0, 1.43000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
      14,     25,      0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
5.00000E-4, 2.72000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
      16,     27,      0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
6.00000E-4, 2.32000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
      20,     26,      0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
8.00000E-4, 1.56000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
      28,     29,      0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
0.00000E+0, 1.81000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _

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↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    33,    36,    0, '1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
0.00000E+0, 2.50000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000,  _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    40,    41,    0, '1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
0.00000E+0, 1.61000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000,  _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    49,    48,    0, '1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
1.56000E-2, 1.53600E-1, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000,  _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    48,   100,    0, '1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
1.00000E-3, 1.59500E-1, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000,  _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    54,    52,    0, '1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
2.00000E-3, 2.33000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000,  _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    54,    55,    0, '1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
0.00000E+0, 1.30000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000,  _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    56,    57,    0, '1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
0.00000E+0, 1.42000E-1, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000,  _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    58,    59,    0, '1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000
0.00000E+0, 9.30000E-3, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000,  _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    60,    61,    0, '1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'TWO-WINDINGS',1,  _
↪1,1.0000

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0.00000E+0, 6.40000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
75, 76, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, 'TWO-WINDINGS', 1, _
↪1, 1.0000
1.00000E-4, 7.40000E-3, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
84, 83, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, 'TWO-WINDINGS', 1, _
↪1, 1.0000
5.20000E-3, 1.74000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
85, 86, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, 'TWO-WINDINGS', 1, _
↪1, 1.0000
0.00000E+0, 5.70000E-3, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
87, 85, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, 'TWO-WINDINGS', 1, _
↪1, 1.0000
2.00000E-4, 2.46000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
101, 102, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, 'TWO-WINDINGS', 1, _
↪1, 1.0000
7.00000E-4, 2.11000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
101, 103, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, 'TWO-WINDINGS', 1, _
↪1, 1.0000
6.00000E-4, 1.51000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
137, 136, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, 'TWO-WINDINGS', 1, _
↪1, 1.0000
8.00000E-4, 2.39000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.10000, _
↪0.90000, 1.10000, 0.90000, 33, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
0 /End of Transformer data, Begin Area interchange data
1, 0, 0.000, 10.000, 'NEPOOL'
2, 0, 0.000, 10.000, 'NYISO'
3, 0, 0.000, 10.000, 'NYISO2'
4, 0, 0.000, 10.000, 'IESO'
5, 0, 0.000, 10.000, 'MISO'

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6,      0,      0.000,      10.000, 'PJM      '
0 /End of Area interchange data, Begin Two-terminal dc line data
0 /End of Two-terminal dc line data, Begin VSC dc line data
0 /End of VSC dc line data, Begin Impedance correction table data
0 /End of Impedance correction table data, Begin Multi-terminal dc line data
0 /End of Multi-terminal dc line data, Begin Multi-section line data
0 /End of Multi-section line data, Begin Zone data
0 /End of Zone data, Begin Inter-area transfer data
0 /End of Inter-area transfer data, Begin Owner data
0 /End of Owner data, Begin FACTS device data
0 /End of FACTS device data, Begin Switched shunt data
0 /End of Switched shunt data, Begin GNE device data
0 /End of GNE device data
Q

```

Dynamic Data (PSS/E DYN format)

```

data = !cat npcc.dyn
print('\n'.join(data))

```

21	'GENROU'	1	5.7000	0.30000E-01	0.35000	0.50000E-01
			4.6400	0.0000	1.9050	0.36000
			0.36000	0.23270	0.20270	0.0000 /
22	'GENROU'	1	5.6900	0.30000E-01	0.35000	0.50000E-01
			4.0857	0.0000	1.8340	0.30520
			0.30520	0.220955	0.200955	0.0000 /
23	'GENROU'	1	5.6000	0.30000E-01	0.35000	0.50000E-01
			2.4467	0.0000	1.7400	0.24450
			0.24450	0.100799	0.090799	0.0000 /
23	'GENROU'	2	5.2000	0.30000E-01	0.35000	0.50000E-01
			6.2000	0.0000	2.1150	0.54600
			0.54600	0.225511	0.205511	0.0000 /
24	'GENROU'	1	7.3000	0.30000E-01	0.35000	0.50000E-01
			4.3500	0.0000	2.0320	0.38400
			0.38400	0.23780	0.20780	0.0000 /
25	'GENROU'	1	5.7000	0.30000E-01	0.35000	0.50000E-01
			4.0615	0.0000	1.9175	0.31200
			0.31200	0.20930	0.19930	0.0000 /
26	'GENROU'	1	4.7900	0.30000E-01	0.35000	0.50000E-01
			3.8000	0.0000	1.8900	0.52200
			0.52200	0.28874	0.20874	0.0000 /
27	'GENROU'	1	6.7000	0.30000E-01	0.35000	0.50000E-01
			4.0500	0.0000	1.7400	0.33000
			0.33000	0.18450	0.10450	0.0000 /
36	'GENROU'	1	5.7000	0.30000E-01	0.35000	0.50000E-01
			4.6615	0.0000	1.9175	0.52650
			0.52650	0.319930	0.30993	0.0000 /
42	'GENROU'	1	5.0000	0.30000E-01	0.35000	0.50000E-01
			4.7150	0.0000	1.2648	0.23800

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	0.23800	0.17800	0.10800	0.0000	0.0000	/
47	'GENROU' 1	5.0000	0.30000E-01	0.35000	0.50000E-01	
	3.3711	0.0000	1.3410	0.76950	0.49500	
	0.49500	0.35190	0.30190	0.0000	0.0000	/
48	'GENROU' 1	5.0000	0.30000E-01	0.35000	0.50000E-01	
	3.0340	0.0000	1.4900	0.85500	0.55000	
	0.55000	0.39100	0.30100	0.0000	0.0000	/
50	'GENROU' 1	6.7000	0.30000E-01	0.35000	0.50000E-01	
	4.9200	0.0000	1.3750	1.3050	0.39000	
	0.39000	0.29500	0.20500	0.0000	0.0000	/
51	'GENROU' 1	5.5000	0.30000E-01	0.35000	0.50000E-01	
	14.307	0.0000	0.46545	0.44115	0.93750E-01	
	0.93750E-01	0.61950E-01	0.60950E-01	0.0000	0.0000	/
53	'GENCLS' 1	37.000	37.000	/		
54	'GENROU' 1	7.0000	0.30000E-01	0.35000	0.50000E-01	
	7.8831	0.0000	0.85930	0.58500	0.36790	
	0.36790	0.32500	0.30500	0.0000	0.0000	/
54	'GENROU' 2	7.0000	0.30000E-01	0.35000	0.50000E-01	
	7.8831	0.0000	0.85930	0.58500	0.36790	
	0.36790	0.32500	0.30500	0.0000	0.0000	/
55	'GENROU' 1	7.0000	0.30000E-01	0.35000	0.50000E-01	
	4.9817	0.0000	1.2192	0.77160	0.43680	
	0.43680	0.36240	0.30240	0.0000	0.0000	/
56	'GENROU' 1	5.5000	0.30000E-01	0.35000	0.50000E-01	
	4.3880	0.0000	1.9235	1.8485	0.35750	
	0.35750	0.25750	0.20750	0.0000	0.0000	/
57	'GENROU' 1	5.6000	0.30000E-01	0.35000	0.50000E-01	
	5.0600	0.0000	1.1805	1.1294	0.24465	
	0.24465	0.16240	0.10240	0.0000	0.0000	/
60	'GENROU' 1	5.5000	0.30000E-01	0.35000	0.50000E-01	
	4.8311	0.0000	1.7334	1.6673	0.32490	
	0.32490	0.23535	0.20535	0.0000	0.0000	/
61	'GENROU' 1	5.0000	0.30000E-01	0.35000	0.50000E-01	
	4.1600	0.0000	1.2768	1.2228	0.24960	
	0.24960	0.18940	0.10940	0.0000	0.0000	/
65	'GENCLS' 1	10.710	10.710	/		
68	'GENCLS' 1	3.7700	3.7700	/		
71	'GENCLS' 1	8.5000	8.5000	/		
72	'GENCLS' 1	11.770	11.770	/		
78	'GENCLS' 1	1000.0	1000.0	/		
79	'GENROU' 1	8.0000	0.30000E-01	0.35000	0.50000E-01	
	4.1739	0.0000	2.0010	1.9550	0.36800	
	0.36800	0.32200	0.30200	0.0000	0.0000	/
80	'GENROU' 1	4.0000	0.30000E-01	0.35000	0.50000E-01	
	2.9750	0.0000	1.7040	1.5440	0.37600	
	0.37600	0.20000	0.19000	0.0000	0.0000	/
82	'GENROU' 1	5.9000	0.30000E-01	0.35000	0.50000E-01	
	3.9200	0.0000	1.5450	1.5100	0.31000	
	0.31000	0.25000	0.20000	0.0000	0.0000	/
86	'GENROU' 1	6.0000	0.30000E-01	0.35000	0.50000E-01	
	4.1579	0.0000	1.9000	1.5060	0.38000	
	0.38000	0.2109	0.20090	0.0000	0.0000	/

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98	'GENROU'	1	4.6000	0.30000E-01	0.35000	0.50000E-01
	11.077		0.0000	0.4550	0.32500	0.143
	0.143		0.0975	0.0775	0.0000	0.0000 /
101	'GENROU'	1	5.5000	0.30000E-01	0.35000	0.50000E-01
	4.0740		0.0000	1.0125	0.648	0.351
	0.35100		0.2295	0.2095	0.0000	0.0000 /
91	'GENCLS'	1	98.700	98.700	/	
92	'GENCLS'	1	27.000	27.000	/	
97	'GENCLS'	1	36.000	36.000	/	
115	'GENCLS'	1	46.000	46.000	/	
119	'GENCLS'	1	30.000	30.000	/	
120	'GENCLS'	1	1000.0	1000.0	/	
121	'GENCLS'	1	66.000	66.000	/	
122	'GENCLS'	1	190.00	190.00	/	
123	'GENCLS'	1	33.000	33.000	/	
130	'GENCLS'	1	24.000	24.000	/	
133	'GENCLS'	1	1000.0	1000.0	/	
134	'GENCLS'	1	44.000	44.000	/	
135	'GENCLS'	1	115.00	115.00	/	
137	'GENCLS'	1	3.5000	3.5000	/	
139	'GENCLS'	1	1000.0	1000.0	/	
21	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
22	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
23	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
23	'TGOV1'	2	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
24	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
25	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
26	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
27	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
36	'TGOV1'	1	0.50000E-01	10.0000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
42	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
47	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
48	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
50	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
51	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
54	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	

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54	'TGOV1'	2	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
55	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
56	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
57	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
60	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
61	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
79	'TGOV1'	1	0.50000E-01	10.0000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
80	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
82	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
86	'TGOV1'	1	0.50000E-01	10.0000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
98	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
101	'TGOV1'	1	0.30000E-01	0.50000	1.0000	0.30000
	6.0000		6.0000	0.0000	/	
119	'TGOV1'	1	0.50000E-01	10.0000	100.0000	0.30000
	6.0000		6.0000	0.0000	/	
133	'TGOV1'	1	0.50000E-01	10.0000	100.0000	0.30000
	6.0000		6.0000	0.0000	/	
21	'IEEEX1'	1	0.0000	50.000	0.60000E-01	0.0000
	0.0000		1.0000	-1.0000	-0.20000E-01	0.50000
	0.80000E-01		1.0000	0.0000	2.0000	0.16000E-02
	3.0000		1.7300	/		
22	'IEEEX1'	1	0.0000	400.00	0.20000E-01	0.0000
	0.0000		7.3000	-7.3000	1.0000	0.79000
	0.30000E-01		1.0000	0.0000	2.0000	0.16000E-02
	3.0000		1.4500	/		
23	'IEEEX1'	1	0.0000	50.000	0.60000E-01	0.0000
	0.0000		1.0000	-1.0000	-0.50000E-01	0.50000
	0.80000E-01		1.0000	0.0000	2.0000	0.16000E-02
	3.0000		1.7300	/		
23	'IEEEX1'	2	0.0000	50.000	0.60000E-01	0.0000
	0.0000		1.0000	-1.0000	-0.50000E-01	0.50000
	0.80000E-01		1.0000	0.0000	2.0000	0.16000E-02
	3.0000		1.7300	/		
24	'IEEEX1'	1	0.0000	50.000	0.20000E-01	0.0000
	0.0000		1.0000	-1.0000	-0.40000E-01	0.47000
	0.60000E-01		1.2500	0.0000	2.0000	0.16000E-02
	3.0000		1.7300	/		
25	'IEEEX1'	1	0.0000	400.00	0.20000E-01	0.0000
	0.0000		6.5000	-6.5000	1.0000	0.73000
	0.30000E-01		1.0000	0.0000	2.0000	0.39000E-02

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	3.0000	1.5550	/		
26	'IEEEX1' 1	0.0000	200.00	0.20000E-01	0.0000
	0.0000	4.2600	-4.2600	1.0000	1.4000
	0.30000E-01	1.0000	0.0000	2.0000	0.16000E-02
	3.0000	1.4650	/		
27	'IEEEX1' 1	0.0000	50.000	0.20000E-01	0.0000
	0.0000	1.0000	-1.0000	-0.50000E-01	0.53000
	0.33200E-01	1.2600	0.0000	2.0000	0.16000E-02
	3.0000	1.4650	/		
36	'IEEEX1' 1	0.0000	62.000	0.50000E-01	0.0000
	0.0000	1.0000	-1.0000	-0.50000E-01	0.40500
	0.11400	0.50000	0.0000	2.0000	0.16000E-02
	3.0000	1.7300	/		
42	'IEEEX1' 1	0.0000	25.000	0.20000	0.0000
	0.0000	1.0000	-1.0000	-0.62000E-01	0.50000
	0.65710	0.35000	0.0000	2.0000	0.16000E-02
	3.0000	2.0250	/		
47	'IEEEX1' 1	0.0000	16.500	0.20000	0.0000
	0.0000	1.0000	-1.0000	-0.37000E-01	0.27000
	0.60000E-01	1.0000	0.0000	2.0000	0.58000E-02
	3.0000	1.1500	/		
48	'IEEEX1' 1	0.0000	16.500	0.20000	0.0000
	0.0000	1.0000	-1.0000	-0.37000E-01	0.27000
	0.60000E-01	1.0000	0.0000	2.0000	0.58000E-02
	3.0000	1.1500	/		
50	'IEEEX1' 1	0.0000	50.000	0.60000E-01	0.0000
	0.0000	1.0000	-1.0000	-0.46000E-01	0.50000
	0.80000E-01	1.0000	0.0000	2.0000	0.16000E-02
	3.0000	1.5250	/		
51	'IEEEX1' 1	0.0000	23.100	0.20000	0.0000
	0.0000	1.0000	-1.0000	-0.44000E-01	0.50000
	0.71430E-01	0.35000	0.0000	2.0000	0.16000E-02
	3.0000	1.4500	/		
54	'IEEEX1' 1	0.0000	50.000	0.50000E-01	0.0000
	0.0000	5.0000	-5.0000	1.0000	0.40000
	0.80000E-01	1.0000	0.0000	2.0000	0.16000E-02
	3.0000	1.4500	/		
54	'IEEEX1' 2	0.0000	50.000	0.50000E-01	0.0000
	0.0000	5.0000	-5.0000	1.0000	0.40000
	0.80000E-01	1.0000	0.0000	2.0000	0.16000E-02
	3.0000	1.4500	/		
55	'IEEEX1' 1	0.0000	23.100	0.20000	0.0000
	0.0000	1.0000	-1.0000	-0.50000E-01	0.50000
	0.71430E-01	0.35000	0.0000	2.0000	0.16000E-02
	3.0000	1.4500	/		
56	'IEEEX1' 1	0.0000	25.000	0.20000	0.0000
	0.0000	1.0000	-1.0000	-0.50000E-01	0.50000
	0.65710E-01	0.35000	0.0000	2.0000	0.16000E-02
	3.0000	1.6670	/		
57	'IEEEX1' 1	0.0000	25.000	0.20000	0.0000
	0.0000	1.0000	-1.0000	-0.50000E-01	0.50000
	0.65710E-01	0.35000	0.0000	2.0000	0.16000E-02

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	3.0000	2.0600	/		
60	'IEEEEX1' 1	0.0000	25.000	0.20000	0.0000
	0.0000	1.0000	-1.0000	-0.50000E-01	0.50000
	0.65710	0.35000	0.0000	2.0000	0.16000E-02
	3.0000	1.6670	/		
61	'IEEEEX1' 1	0.0000	25.000	0.20000	0.0000
	0.0000	1.0000	-1.0000	-0.62000E-01	0.50000
	0.65710	0.35000	0.0000	2.0000	0.16000E-02
	3.0000	2.0250	/		
79	'IEEEEX1' 1	0.0000	50.000	0.60000E-01	0.0000
	0.0000	1.0000	-1.0000	-0.40000E-01	0.50000
	0.80000E-01	1.0000	0.0000	2.0000	0.16000E-02
	3.0000	1.4500	/		
80	'IEEEEX1' 1	0.0000	25.000	0.20000	0.0000
	0.0000	1.0000	-1.0000	-0.50000E-01	0.50000
	0.65140	0.35000	0.0000	2.0000	0.16000E-02
	3.0000	1.4500	/		
82	'IEEEEX1' 1	0.0000	50.000	0.60000E-01	0.0000
	0.0000	1.0000	-1.0000	-0.40000E-01	0.50000
	0.80000E-01	1.0000	0.0000	2.0000	0.16000E-02
	3.0000	1.4500	/		

1.8.3 CURENT WECC Verification

Prepared by [Hantao Cui](#). Last revised 23 May 2020.

Background

The **CURENT** WECC system contains 179 buses and 263 branches. Two line trip scenarios are created to verify ANDES simulation results with DSATools TSAT and Siemens PTI PSS/E.

Dynamic data is based on the CURENT WECC 179-Bus test system, which uses models GENROU, TGOV1, IEEEG1, EXST2, EXDC2, ESST3A, IEEEEST, ST2CUT and ESDC2A, the saturation of which could be implemented differently across software.

Simulation Parameters

Integretion method: Trapezidal Rule (ANDES and TSAT), the default second order Adams-Bashforth method (AB-2) (PSS/E)

Time step size: 1/120 sec. (Note: step size between 1/30 to 1/120 has little impact on the ANDES results. One can use `tstep=1/30` to obtain almost the same results.)

Load conversion: static loads are converted to 100% constant impedances for both P and Q.

TSAT automatic parameter correction is disabled.

Initialization

Power flow solutions are identical across all the three software.

GENROU initialization ($\$E_{\{FD\}}\$, \$E_{\{TERM\}}\$, \$P\$, \$Q\$, \$\delta\$, \$I_d\$$ and $\$I_q\$$) is identical to that from PSS/E for all cases (with and without generator saturation). Note that $\$I_d\$$ and $\$I_q\$$ are in machine base in PSS/E but in system base in ANDES.

GENROU initialization (including all the internal variables $\$E'd\$, \$E'q\$, \$\psi_{kd}\$, \$\psi_{kq}\$, \$\psi''_d\$,$ and ψ''_q) is identical to that from **OpenIPSL**.

No controller limit violation occurs during initialization.

Conclusion

The finding is that, **for particular disturbances in large systems, neither two of ANDES, TSAT and PSS/E could match**. Implementation details in commercial software are lacking. Thus, it could be futile to insist on obtaining the same results for large systems, especially with several complex models.

Nevertheless, Scenario 2 shows that ANDES results are trustworthy. **In fact, ANDES is open-source with all the implemented equations clearly documented, which makes the results highly credible for research and education purposes.**

```
import andes
import numpy as np
from andes.utils.tsat import tsat_to_df, psse_to_df, plot_comparison, run_cmp

andes.config_logger(stream_level=30)
```

Scenario 1

Line 38-39 trips and reconnects after 0.1 sec. This branch is a transformer branch that connects generator #11 on Bus 39 to Bus 38. It is the only link to Bus 39.

```
ss = run_cmp('wecc.raw', dyr='wecc.dyr', fault_line='Line_221',
            t1=1.0, t2=1.1, tstep=1/120)
```

```
<Toggle Toggle_1>: Line.Line_221 status changed to 0.0 at t=1.0 sec.
<Toggle Toggle_2>: Line.Line_221 status changed to 1.0 at t=1.1 sec.
100%|████████████████████████████████████████| 100/100 [00:16<00:00, 5.89%/s]
```

```
# Line_221 information
ss.Line.cache.df_in.iloc[220]
```

```
idx      Line_221
u         1
name      Line_221
bus1      38
```

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```

bus2          39
Sn            100
fn            60
Vn1           230
Vn2           18
r             0.0005
x             0.0238
b             0
g             0
b1            0
g1            0
b2            0
g2            0
trans         1
tap           1
phi           0
owner         None
xcoord        None
ycoord        None
Name: 220, dtype: object

```

```

# Load TSAT and PSSE Outputs
omega2 = tsat_to_df('omega2.xls')
v2 = tsat_to_df('v2.xls')

omega2_psse = psse_to_df('omega2_psse.xlsx')
v2_psse = psse_to_df('v2_psse.xlsx')
omega2_psse.iloc[:, 1:] += 1
omega2_psse.iloc[:, 1:] *= 60

# prepare variable headers for TSAT and PSSE
def header_replace(fname, idx, offset, old_str, new_str):
    """
    Utility function for replacing strings in variable header
    """
    old_headers = [fname[i + offset] for i in idx]
    return [i.replace(old_str, new_str) for i in old_headers]

fname = ss.TDS.plt._fname
tsat_omega_headers = header_replace(fname, ss.GENROU.omega.a, 1, "GENROU",
    ↪ "TSAT")
tsat_v_headers = header_replace(fname, ss.GENROU.v.a, 1 + ss.dae.n, "Bus",
    ↪ "TSAT")

psse_omega_headers = header_replace(fname, ss.GENROU.omega.a, 1, "GENROU",
    ↪ "PSSE")
psse_v_headers = header_replace(fname, ss.GENROU.v.a, 1 + ss.dae.n, "Bus",
    ↪ "PSSE")

```

```

fig, ax = plot_comparison(ss, ss.GENROU.omega, omega2,
    a=(10,), a_tsat=[10], a_psse=[10],

```

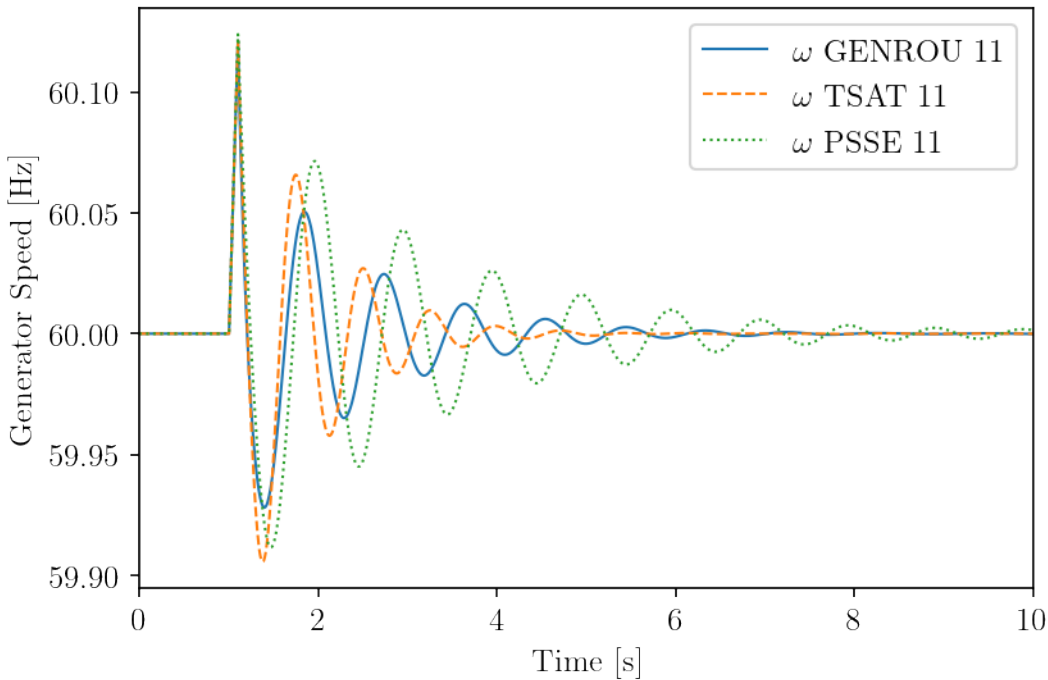
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```

ylabel="Generator Speed [Hz]",
tsat_header=tsat_omega_headers,
psse_data = omega2_psse,
psse_header = psse_omega_headers,
scale=60, right=10,
legend=True,
show=False,
)

```



```

fig, ax = plot_comparison(ss, ss.GENROU.v, v2,
    a=(10,), a_tsat=[10], a_psse=[10],
    ylabel="Terminal Voltage [p.u.]",
    tsat_header=tsat_v_headers,
    psse_data = v2_psse,
    psse_header = psse_v_headers,
    scale=1, right=10,
    legend=True,
    show=False
)

```

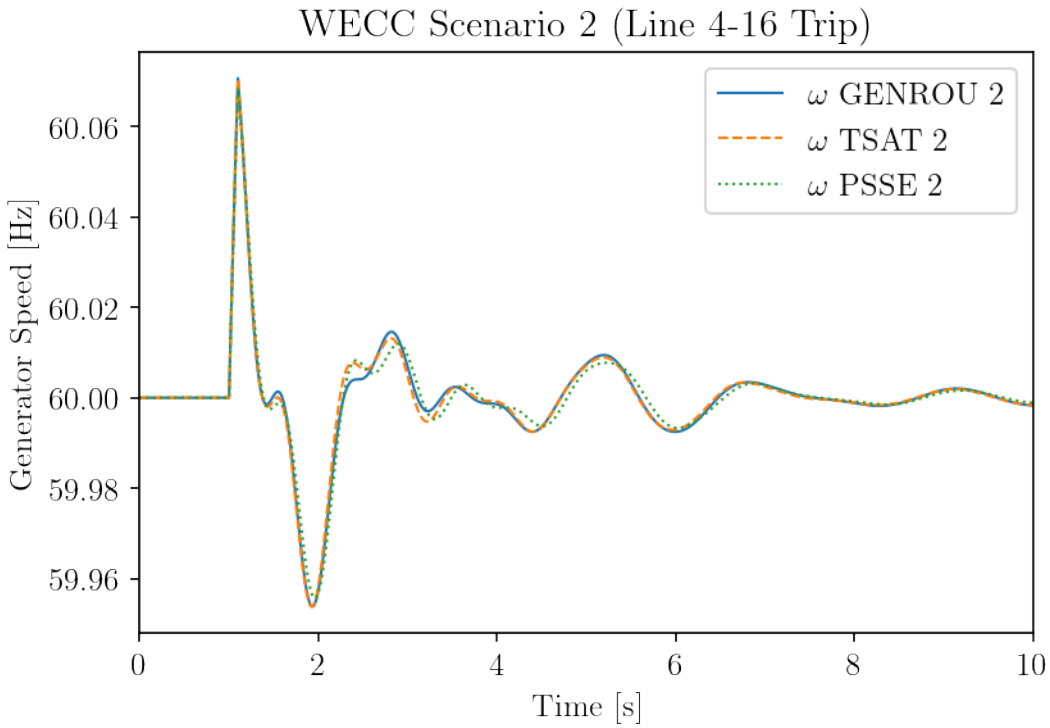

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```
g                0
b1               0
g1               0
b2               0
g2               0
trans            0
tap              1
phi              0
owner            None
xcoord           None
ycoord           None
Name: 1, dtype: object
```

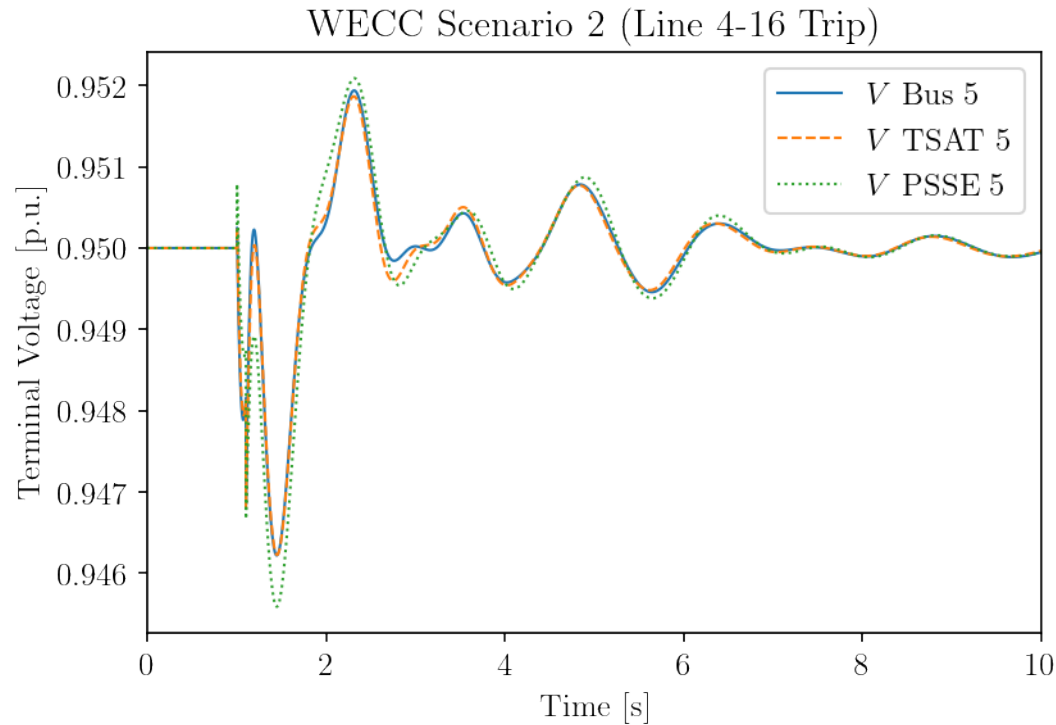
```
# load data
omega = tsat_to_df('omega.xls')
v = tsat_to_df('v.xls')

omega_psse = psse_to_df('omega_psse.xlsx')
v_psse = psse_to_df('v_psse.xlsx')
omega_psse.iloc[:, 1:] += 1
omega_psse.iloc[:, 1:] *= 60

fig, ax = plot_comparison(ss2, ss2.GENROU.omega, omega,
                        a=(1,), a_tsat=[1], a_psse=[1],
                        ylabel="Generator Speed [Hz]",
                        title="WECC Scenario 2 (Line 4-16 Trip)",
                        tsat_header=tsat_omega_headers,
                        psse_data = omega_psse,
                        psse_header = psse_omega_headers,
                        scale=60, right=10,
                        legend=True,
                        show=False
                        )
```



```
fig, ax = plot_comparison(ss2, ss2.GENROU.v, v,
                        a=(1,), a_tsat=[1], a_psse=[1],
                        ylabel="Terminal Voltage [p.u.]",
                        title="WECC Scenario 2 (Line 4-16 Trip)",
                        tsat_header=tsat_v_headers,
                        psse_data = v_psse,
                        psse_header = psse_v_headers,
                        scale=1, right=10,
                        legend=True,
                        show=False
                    )
```



Appendix: CURENT WECC 179-Bus System Data

Power Flow Data (PSS/E RAW format)

```
data = !cat wecc.raw
print('\n'.join(data))
```

```
0, 100.00, 32, 0, 1, 60.00 / PSS(R)E 32 RAW created by rawd32 THU,
↪MAY 21 2020 10:24
WESTERN ELECTRICITY COORDINATING COUNCIL 179-BUS SYSTEM (MOD
DISTRIBUTED WITH ANDES (HTTPS://GITHUB.COM/CUIHANTAO/ANDES)
1, 'CORONADO ', 500.0000,1, 1, 1, 1,0.97947, -26.1745
2, 'CHOLLA ', 345.0000,1, 1, 1, 1,0.97744, -16.9603
3, 'CORONADO ', 20.0000,2, 1, 1, 1,1.04000, -19.6589
4, 'CRAIG ', 345.0000,1, 1, 1, 1,0.97518, 16.2755
5, 'CRAIG ', 22.0000,2, 1, 1, 1,0.95000, 23.5536
6, 'FOURCORN ', 500.0000,1, 1, 1, 1,1.06814, -7.9038
7, 'FOURCORN ', 345.0000,1, 1, 1, 1,1.00914, -4.6874
8, 'FCNGN4CC ', 22.0000,2, 1, 1, 1,1.00000, 2.2301
9, 'FOURCORN ', 230.0000,1, 1, 1, 1,1.00726, -5.2308
10, 'HAYDEN ', 20.0000,2, 1, 1, 1,1.00000, 33.7299
11, 'NAVAJO ', 500.0000,1, 2, 1, 1,1.07205, -23.9351
12, 'NAVAJO 2 ', 26.0000,2, 2, 1, 1,1.00000, -17.8112
13, 'MOENKOPI ', 500.0000,1, 2, 1, 1,1.06735, -24.8548
14, 'PALOVRD2 ', 24.0000,2, 2, 1, 1,0.96000, -21.7139
15, 'PALOVRDE ', 500.0000,1, 2, 1, 1,1.04856, -29.6406
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16, 'SAN JUAN	,	345.0000,1,	1,	1,	1,1.03559,	-3.8744
17, 'SJUAN G4	,	22.0000,2,	1,	1,	1,1.00000,	-0.8871
18, 'WESTWING	,	500.0000,1,	2,	1,	1,1.05593,	-29.5910
19, 'NAVAJO1	,	500.0000,1,	2,	1,	1,1.07025,	-22.8500
20, 'NAVAJO2	,	500.0000,1,	2,	1,	1,1.06042,	-25.9522
21, 'NAVAJO3	,	500.0000,1,	2,	1,	1,1.04693,	-22.1208
22, 'NAVAJO4	,	500.0000,1,	2,	1,	1,1.02564,	-31.4586
23, 'MOENKOP1	,	500.0000,1,	2,	1,	1,1.05571,	-23.3906
24, 'MOENKOP2	,	500.0000,1,	2,	1,	1,1.04116,	-31.0832
25, 'MOENKOP3	,	500.0000,1,	2,	1,	1,1.05132,	-15.5499
26, 'MOENKOP4	,	500.0000,1,	2,	1,	1,1.04671,	-42.3967
27, 'FOURCOR1	,	500.0000,1,	1,	1,	1,1.06585,	-5.7792
28, 'FOURCOR2	,	500.0000,1,	1,	1,	1,1.06933,	-27.9822
29, 'CANAD G1	,	20.0000,2,	1,	1,	1,1.00000,	24.7380
30, 'CANADA	,	500.0000,1,	1,	1,	1,1.03634,	20.9474
31, 'CANALB	,	500.0000,1,	1,	1,	1,1.07861,	49.2370
32, 'CA230TO	,	230.0000,1,	1,	1,	1,0.97855,	53.8260
33, 'CA230	,	230.0000,1,	1,	1,	1,1.00114,	62.8749
34, 'CMAIN GM	,	20.0000,2,	1,	1,	1,1.02000,	67.7961
35, 'BRIDGER2	,	22.0000,2,	1,	1,	1,1.00900,	2.4615
36, 'ADELANTO	,	500.0000,1,	2,	1,	1,1.06032,	-42.1554
37, 'ADELAN&1	,	500.0000,1,	2,	1,	1,1.08090,	-46.2256
38, 'CASTAIC	,	230.0000,1,	2,	1,	1,1.03195,	-47.2901
39, 'CASTAI4G	,	18.0000,2,	2,	1,	1,1.02000,	-45.9803
40, 'GLENDAI	,	230.0000,1,	2,	1,	1,1.02337,	-50.9223
41, 'HAYNES	,	230.0000,1,	2,	1,	1,1.03129,	-50.6520
42, 'HAYNES3G	,	18.0000,2,	2,	1,	1,1.00000,	-47.3488
43, 'INTERMT	,	345.0000,1,	1,	1,	1,1.05257,	-4.3661
44, 'INTERM1G	,	26.0000,2,	1,	1,	1,1.05000,	0.2811
45, 'OLIVE	,	230.0000,1,	2,	1,	1,1.03475,	-47.6289
46, 'OWENS G	,	11.5000,2,	2,	1,	1,1.02000,	-47.2682
47, 'RINALDI	,	230.0000,1,	2,	1,	1,1.03402,	-47.8387
48, 'RINALDI	,	500.0000,1,	2,	1,	1,1.07212,	-45.4811
49, 'RIVER	,	230.0000,1,	2,	1,	1,1.02362,	-51.8438
50, 'STA B	,	138.0000,1,	2,	1,	1,1.03256,	-51.9003
51, 'STA B1	,	287.0000,1,	2,	1,	1,1.03663,	-50.7167
52, 'STA B2	,	287.0000,1,	2,	1,	1,1.03663,	-50.7167
53, 'STA BLD	,	230.0000,1,	2,	1,	1,1.02728,	-52.1086
54, 'STA E	,	230.0000,1,	2,	1,	1,1.02516,	-50.0567
55, 'STA E	,	500.0000,1,	2,	1,	1,1.04304,	-47.6632
56, 'STA F	,	230.0000,1,	2,	1,	1,1.02484,	-51.8789
57, 'STA G	,	230.0000,1,	2,	1,	1,1.02394,	-51.1740
58, 'STA J	,	230.0000,1,	2,	1,	1,1.03112,	-48.9133
59, 'SYLMARLA	,	230.0000,1,	2,	1,	1,1.03832,	-47.1488
60, 'SYLMAR S	,	230.0000,1,	2,	1,	1,1.02073,	-48.2552
61, 'VALLEY	,	230.0000,1,	2,	1,	1,1.02930,	-49.0304
62, 'VICTORVL	,	287.0000,1,	2,	1,	1,1.05209,	-44.4925
63, 'VICTORVL	,	500.0000,1,	2,	1,	1,1.05866,	-42.4751
64, 'MONTA G1	,	20.0000,2,	1,	1,	1,1.00000,	56.5947
65, 'MONTANA	,	500.0000,1,	1,	1,	1,1.04928,	48.2022
66, 'BIG EDDY	,	115.0000,1,	1,	1,	1,1.06863,	-16.9326
67, 'BIG EDDY	,	230.0000,1,	1,	1,	1,1.06592,	-14.5699

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68, 'BIG EDDY	,	500.0000,1,	1,	1,	1,1.08919,	-13.3098
69, 'DALLES21	,	13.8000,2,	1,	1,	1,1.05500,	-7.9400
70, 'CELILO	,	230.0000,1,	1,	1,	1,1.06159,	-15.0760
71, 'CELILOCA	,	500.0000,1,	1,	1,	1,1.08964,	-13.4178
72, 'COLSTRP	,	500.0000,1,	1,	1,	1,1.07839,	-1.3595
73, 'COULEE	,	500.0000,1,	1,	1,	1,1.07000,	0.1645
74, 'GARRISON	,	500.0000,1,	1,	1,	1,1.03705,	-12.1586
75, 'JOHN DAY	,	500.0000,1,	1,	1,	1,1.08283,	-11.1230
76, 'JOHN DAY	,	13.8000,3,	1,	1,	1,1.00000,	0.0000
77, 'HANFORD	,	500.0000,1,	1,	1,	1,1.04947,	0.2258
78, 'NORTH G3	,	20.0000,2,	1,	1,	1,1.00000,	26.5872
79, 'NORTH	,	500.0000,1,	1,	1,	1,1.04993,	12.1085
80, 'BURNS	,	500.0000,1,	1,	1,	1,1.05295,	-19.5513
81, 'GRIZZLY	,	500.0000,1,	1,	1,	1,1.06740,	-17.1477
82, 'MALIN	,	500.0000,1,	1,	1,	1,1.05433,	-23.3455
83, 'MIDPOINT	,	500.0000,1,	1,	1,	1,1.06195,	-5.1981
84, 'MIDPOINT	,	345.0000,1,	1,	1,	1,0.99845,	-1.5707
85, 'SUMMER L	,	500.0000,1,	1,	1,	1,1.05818,	-18.2347
86, 'GRIZZLY1	,	500.0000,1,	1,	1,	1,1.06533,	-18.7474
87, 'GRIZZLY2	,	500.0000,1,	1,	1,	1,1.07143,	-16.0156
88, 'MALIN1	,	500.0000,1,	1,	1,	1,1.05062,	-14.1380
89, 'MALIN2	,	500.0000,1,	1,	1,	1,1.06088,	-19.8058
90, 'GRIZZLY3	,	500.0000,1,	1,	1,	1,1.07997,	-21.7956
91, 'GRIZZLY4	,	500.0000,1,	1,	1,	1,1.06943,	-17.2249
92, 'GRIZZLY5	,	500.0000,1,	1,	1,	1,1.06860,	-22.4488
93, 'GRIZZLY6	,	500.0000,1,	1,	1,	1,1.07170,	-17.8609
94, 'GRIZZLY7	,	500.0000,1,	1,	1,	1,1.07926,	-22.0559
95, 'GRIZZLY8	,	500.0000,1,	1,	1,	1,1.06917,	-17.2247
96, 'GRIZZLY9	,	500.0000,1,	1,	1,	1,1.06761,	-22.7454
97, 'GRIZZLYA	,	500.0000,1,	1,	1,	1,1.07104,	-17.8942
98, 'BURNS1	,	500.0000,1,	1,	1,	1,0.97284,	8.0442
99, 'CORTINA	,	200.0000,1,	3,	1,	1,1.13097,	-34.9741
100, 'COTWDPGE	,	200.0000,1,	3,	1,	1,1.13613,	-30.4883
101, 'DIABLO	,	500.0000,1,	2,	1,	1,1.05298,	-46.1260
102, 'DIABLO1	,	25.0000,2,	2,	1,	1,0.98000,	-42.3238
103, 'GATES	,	500.0000,1,	2,	1,	1,1.04707,	-47.6820
104, 'GLENN	,	200.0000,1,	3,	1,	1,1.14090,	-34.1986
105, 'LOGAN CR	,	200.0000,1,	3,	1,	1,1.14016,	-34.5836
106, 'LOSBANOS	,	500.0000,1,	2,	1,	1,1.04927,	-49.5273
107, 'MIDWAY	,	500.0000,1,	2,	1,	1,1.05934,	-48.6051
108, 'MIDWAY	,	200.0000,1,	2,	1,	1,1.16705,	-51.4430
109, 'MOSSLAND	,	500.0000,1,	2,	1,	1,1.04639,	-49.7921
110, 'OLINDA	,	500.0000,1,	3,	1,	1,1.03727,	-31.0686
111, 'ROUND MT	,	20.0000,2,	3,	1,	1,1.02000,	-15.0791
112, 'ROUND MT	,	200.0000,1,	3,	1,	1,1.12385,	-25.1402
113, 'ROUND MT	,	500.0000,1,	3,	1,	1,1.03454,	-27.9316
114, 'TABLE MT	,	500.0000,1,	3,	1,	1,1.01342,	-32.0699
115, 'TEVATR	,	20.0000,2,	3,	1,	1,1.05000,	-35.6850
116, 'TEVATR	,	200.0000,1,	3,	1,	1,1.12744,	-39.6332
117, 'TEVATR2	,	20.0000,2,	3,	1,	1,1.00000,	-30.7816
118, 'TEVATR	,	500.0000,1,	3,	1,	1,0.99816,	-38.9938
119, 'OLINDA1	,	500.0000,1,	3,	1,	1,1.05026,	-24.0934

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120, 'OLINDA2	,	500.0000,1,	3,	1,	1,1.01142,	-38.0294
121, 'OLINDA3	,	500.0000,1,	3,	1,	1,1.02786,	-30.7891
122, 'OLINDA4	,	500.0000,1,	3,	1,	1,0.98098,	-46.5990
123, 'ROUND1	,	500.0000,1,	3,	1,	1,1.04054,	-22.0273
124, 'ROUND2	,	500.0000,1,	3,	1,	1,1.01079,	-36.1445
125, 'ROUND3	,	500.0000,1,	3,	1,	1,1.04054,	-22.0273
126, 'ROUND4	,	500.0000,1,	3,	1,	1,1.01079,	-36.1445
127, 'TABLE1	,	500.0000,1,	3,	1,	1,1.01257,	-25.8067
128, 'TABLE2	,	500.0000,1,	3,	1,	1,0.99882,	-45.3405
129, 'TABLE3	,	500.0000,1,	3,	1,	1,1.01755,	-27.3173
130, 'TABLE4	,	500.0000,1,	3,	1,	1,0.99876,	-41.4218
131, 'TEVATR1	,	500.0000,1,	2,	1,	1,0.97999,	-36.9419
132, 'TEVATR2	,	500.0000,1,	2,	1,	1,1.07047,	-51.7010
133, 'TEVATR3	,	500.0000,1,	2,	1,	1,0.97141,	-35.0590
134, 'GATES1	,	500.0000,1,	2,	1,	1,1.06807,	-49.9922
135, 'DEVERS	,	500.0000,1,	2,	1,	1,1.03539,	-43.5212
136, 'EAGLROCK	,	230.0000,1,	2,	1,	1,1.01010,	-52.7598
137, 'ELDORADO	,	20.0000,2,	2,	1,	1,1.02000,	-25.9732
138, 'ELDORADO	,	500.0000,1,	2,	1,	1,1.05122,	-33.0947
139, 'LITEHIPE	,	20.0000,2,	2,	1,	1,1.02000,	-49.6246
140, 'LITEHIPE	,	230.0000,1,	2,	1,	1,1.01186,	-55.7741
141, 'LUGO	,	500.0000,1,	2,	1,	1,1.05498,	-46.0893
142, 'MESA CAL	,	230.0000,1,	2,	1,	1,1.00705,	-55.0594
143, 'MIRALOMA	,	20.0000,2,	2,	1,	1,1.05000,	-45.4414
144, 'MIRALOMA	,	500.0000,1,	2,	1,	1,1.04087,	-49.6789
145, 'MIRALOMA	,	230.0000,1,	2,	1,	1,1.03821,	-50.1247
146, 'MOHAVE	,	500.0000,1,	2,	1,	1,1.06999,	-29.3603
147, 'MOHAV1CC	,	22.0000,2,	2,	1,	1,1.05000,	-21.0397
148, 'PARDEE	,	20.0000,2,	2,	1,	1,1.01000,	-39.5994
149, 'PARDEE	,	230.0000,1,	2,	1,	1,1.00600,	-51.6818
150, 'SERRANO	,	500.0000,1,	2,	1,	1,1.04129,	-50.0775
151, 'VALLEY	,	500.0000,1,	2,	1,	1,1.03694,	-47.7607
152, 'VINCENT	,	500.0000,1,	2,	1,	1,1.06119,	-48.9450
153, 'VINCENT	,	230.0000,1,	2,	1,	1,0.99489,	-51.6324
154, 'CAMP WIL	,	345.0000,1,	1,	1,	1,1.04289,	-2.4160
155, 'BENLOMND	,	345.0000,1,	1,	1,	1,1.04464,	-3.3929
156, 'BENLOMND	,	230.0000,1,	1,	1,	1,1.04624,	-3.9585
157, 'EMERY	,	345.0000,1,	1,	1,	1,1.03705,	4.8898
158, 'EMERY	,	20.0000,2,	1,	1,	1,1.05000,	9.6052
159, 'MONA	,	345.0000,1,	1,	1,	1,1.05596,	-2.0072
160, 'NAUGHTON	,	230.0000,1,	1,	1,	1,1.04453,	0.6143
161, 'NAUGHT	,	20.0000,2,	1,	1,	1,1.00000,	3.4140
162, 'PINTO PS	,	345.0000,1,	1,	1,	1,1.03679,	-2.4413
163, 'PINTO	,	345.0000,1,	1,	1,	1,1.04044,	-1.4027
164, 'SPAN FRK	,	345.0000,1,	1,	1,	1,1.03514,	-1.0920
165, 'SIGURD	,	345.0000,1,	1,	1,	1,1.05190,	-0.5455
166, 'TERMINAL	,	345.0000,1,	1,	1,	1,1.03911,	-3.4207
167, 'MALIN3	,	500.0000,1,	3,	1,	1,1.06106,	-19.7689
168, 'MALIN4	,	500.0000,1,	3,	1,	1,1.02557,	-31.6678
169, 'MALIN5	,	500.0000,1,	3,	1,	1,1.06179,	-19.0138
170, 'MALIN6	,	500.0000,1,	3,	1,	1,1.02702,	-31.6971
171, 'MALIN7	,	500.0000,1,	3,	1,	1,1.05696,	-17.4396

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172, 'MALIN8	,	500.0000,1,	3,	1,	1,1.03194,	-37.1499		
173, 'MIDWAY1	,	500.0000,1,	2,	1,	1,1.04651,	-48.2385		
174, 'MIDWAY2	,	500.0000,1,	2,	1,	1,1.05458,	-49.3078		
175, 'MIDWAY3	,	500.0000,1,	2,	1,	1,1.04625,	-48.2334		
176, 'MIDWAY4	,	500.0000,1,	2,	1,	1,1.05470,	-49.3092		
177, 'MIDWAY5	,	500.0000,1,	2,	1,	1,1.04598,	-48.2211		
178, 'MIDWAY6	,	500.0000,1,	2,	1,	1,1.05705,	-49.2854		
179, 'BURNS2	,	500.0000,1,	1,	1,	1,0.98437,	-6.6858		
0 /End of Bus data, Begin Load data								
1, 'BL',1,	1,	1,	1750.000,	-56.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
3, 'BL',1,	1,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
4, 'BL',1,	1,	1,	2350.000,	-127.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
5, 'BL',1,	1,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
7, 'BL',1,	1,	1,	239.000,	-56.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
8, 'BL',1,	1,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
9, 'BL',1,	1,	1,	139.700,	23.800,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
10, 'BL',1,	1,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
11, 'BL',1,	2,	1,	90.000,	70.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
12, 'BL',1,	2,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
14, 'BL',1,	2,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
15, 'BL',1,	2,	1,	793.400,	207.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
16, 'BL',1,	1,	1,	840.000,	5.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
17, 'BL',1,	1,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
18, 'BL',1,	2,	1,	617.000,	-69.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
29, 'BL',1,	1,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
30, 'BL',1,	1,	1,	4400.000,	1000.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
33, 'BL',1,	1,	1,	3600.000,	700.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
34, 'BL',1,	1,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
35, 'BL',1,	1,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
36, 'BL',1,	2,	1,	-1862.000,	971.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
39, 'BL',1,	2,	1,	100.000,	0.000,	0.000,	0.000,	0.	

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↪000,	0.000,	1,1						
40, 'BL',	1, 2,	1,	135.000,	27.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
42, 'BL',	1, 2,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
43, 'BL',	1, 1,	1,	2053.000,	907.100,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
44, 'BL',	1, 1,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
45, 'BL',	1, 2,	1,	-72.800,	-17.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
46, 'BL',	1, 2,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
47, 'BL',	1, 2,	1,	121.000,	25.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
49, 'BL',	1, 2,	1,	320.000,	65.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
50, 'BL',	1, 2,	1,	237.200,	-63.200,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
53, 'BL',	1, 2,	1,	138.000,	28.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
54, 'BL',	1, 2,	1,	807.800,	132.100,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
56, 'BL',	1, 2,	1,	117.000,	24.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
57, 'BL',	1, 2,	1,	121.000,	25.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
58, 'BL',	1, 2,	1,	887.700,	-6.200,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
59, 'BL',	1, 2,	1,	-2771.000,	1654.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
60, 'BL',	1, 2,	1,	401.000,	80.600,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
61, 'BL',	1, 2,	1,	205.200,	17.600,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
62, 'BL',	1, 2,	1,	-129.000,	32.200,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
64, 'BL',	1, 1,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
65, 'BL',	1, 1,	1,	1700.000,	300.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
66, 'BL',	1, 1,	1,	160.000,	31.250,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
67, 'BL',	1, 1,	1,	-67.500,	160.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
68, 'BL',	1, 1,	1,	-44.200,	22.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
69, 'BL',	1, 1,	1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
70, 'BL',	1, 1,	1,	3137.000,	1681.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
72, 'BL',	1, 1,	1,	-1525.000,	-50.000,	0.000,	0.000,	0.	

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↪000,	0.000,	1,1						
74, 'BL',	1, 1,	1, 1,	2584.000,	394.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
75, 'BL',	1, 1,	1, 1,	3200.000,	1100.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
76, 'BL',	1, 1,	1, 1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
77, 'BL',	1, 1,	1, 1,	3500.000,	500.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
78, 'BL',	1, 1,	1, 1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
79, 'BL',	1, 1,	1, 1,	5000.000,	400.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
81, 'BL',	1, 1,	1, 1,	-66.600,	-97.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
82, 'BL',	1, 1,	1, 1,	-339.000,	-119.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
84, 'BL',	1, 1,	1, 1,	610.000,	-414.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
99, 'BL',	1, 3,	1, 1,	-43.300,	20.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
100, 'BL',	1, 3,	1, 1,	210.400,	-77.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
101, 'BL',	1, 2,	1, 1,	50.000,	25.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
102, 'BL',	1, 2,	1, 1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
103, 'BL',	1, 2,	1, 1,	305.000,	-7.600,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
104, 'BL',	1, 3,	1, 1,	27.500,	-0.100,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
105, 'BL',	1, 3,	1, 1,	8.010,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
106, 'BL',	1, 2,	1, 1,	265.000,	14.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
107, 'BL',	1, 2,	1, 1,	55.600,	-329.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
108, 'BL',	1, 2,	1, 1,	777.600,	32.600,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
109, 'BL',	1, 2,	1, 1,	40.000,	21.500,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
110, 'BL',	1, 3,	1, 1,	-189.000,	61.500,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
111, 'BL',	1, 3,	1, 1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
112, 'BL',	1, 3,	1, 1,	148.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
114, 'BL',	1, 3,	1, 1,	-0.700,	118.500,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
115, 'BL',	1, 3,	1, 1,	100.000,	0.000,	0.000,	0.000,	0.	
↪000,	0.000,	1,1						
116, 'BL',	1, 3,	1, 1,	884.000,	54.800,	0.000,	0.000,	0.	

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→000,	0.000,	1,1						
117,'BL',1,	3,	1,	100.000,	0.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
118,'BL',1,	3,	1,	5661.000,	3491.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
135,'BL',1,	2,	1,	856.000,	19.600,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
136,'BL',1,	2,	1,	175.000,	18.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
137,'BL',1,	2,	1,	100.000,	0.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
138,'BL',1,	2,	1,	902.300,	-11.400,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
139,'BL',1,	2,	1,	100.000,	0.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
140,'BL',1,	2,	1,	3191.000,	630.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
141,'BL',1,	2,	1,	204.200,	-28.200,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
142,'BL',1,	2,	1,	377.400,	64.500,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
143,'BL',1,	2,	1,	100.000,	0.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
144,'BL',1,	2,	1,	3098.000,	1189.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
147,'BL',1,	2,	1,	100.000,	0.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
148,'BL',1,	2,	1,	100.000,	0.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
149,'BL',1,	2,	1,	3118.000,	78.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
150,'BL',1,	2,	1,	1230.000,	72.800,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
151,'BL',1,	2,	1,	406.000,	41.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
153,'BL',1,	2,	1,	1066.000,	-10.800,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
154,'BL',1,	1,	1,	457.700,	81.700,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
155,'BL',1,	1,	1,	33.900,	11.900,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
156,'BL',1,	1,	1,	148.000,	-7.900,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
157,'BL',1,	1,	1,	116.100,	38.400,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
158,'BL',1,	1,	1,	100.000,	0.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
159,'BL',1,	1,	1,	-62.000,	12.800,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
160,'BL',1,	1,	1,	255.000,	100.000,	0.000,	0.000,	0.	
→000,	0.000,	1,1						
161,'BL',1,	1,	1,	100.000,	0.000,	0.000,	0.000,	0.	

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↪000,      0.000,      1,1
  163,'BL',1,      1,      31.600,      11.500,      0.000,      0.000,      0.
↪000,      0.000,      1,1
  164,'BL',1,      1,      141.200,      71.400,      0.000,      0.000,      0.
↪000,      0.000,      1,1
  165,'BL',1,      1,      379.000,      -43.000,      0.000,      0.000,      0.
↪000,      0.000,      1,1
  166,'BL',1,      1,      185.000,      78.500,      0.000,      0.000,      0.
↪000,      0.000,      1,1
0 /End of Load data, Begin Fixed shunt data
   6,'1 ',1,      0.000, -113.000
   7,'1 ',1,      0.000, -155.000
  11,'1 ',1,      0.000, -190.000
  13,'1 ',1,      0.000, -391.000
  15,'1 ',1,      0.000, -146.000
  16,'1 ',1,      0.000,  390.000
  18,'1 ',1,      0.000, -427.000
  36,'1 ',1,      0.000,  912.000
  43,'1 ',1,      0.000,  430.000
  48,'1 ',1,      0.000,  -80.000
  59,'1 ',1,      0.000, 2146.000
  62,'1 ',1,      0.000, -108.000
  67,'1 ',1,      0.000,  576.850
  70,'1 ',1,      0.000,  792.000
  71,'1 ',1,      0.000,  462.000
  75,'1 ',1,      0.000, 1019.350
  77,'1 ',1,      0.000,  550.000
  79,'1 ',1,      0.000, 1200.000
  80,'1 ',1,      0.000, -220.000
  81,'1 ',1,      0.000, -674.000
  82,'1 ',1,      0.000, -110.000
  83,'1 ',1,      0.000, -220.000
  84,'1 ',1,      0.000, -870.000
 103,'1 ',1,      0.000,  -91.000
 107,'1 ',1,      0.000, -327.000
 108,'1 ',1,      0.000, -130.000
 112,'1 ',1,      0.000, -128.000
 113,'1 ',1,      0.000,  -91.000
 114,'1 ',1,      0.000,  -91.000
 116,'1 ',1,      0.000,  -32.000
 118,'1 ',1,      0.000, 1500.000
 138,'1 ',1,      0.000, -319.000
 144,'1 ',1,      0.000,  400.000
 146,'1 ',1,      0.000, -196.000
 153,'1 ',1,      0.000, -190.000
 154,'1 ',1,      0.000,  -60.000
 157,'1 ',1,      0.000, -220.000
 163,'1 ',1,      0.000,  -18.000
 165,'1 ',1,      0.000,  -50.000
 179,'1 ',1,      0.000, -220.000
0 /End of Fixed shunt data, Begin Generator data
   3,'1 ',      800.000,  123.043,  300.000, -300.000,1.04000,      0,  1600.

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→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
5,'1 ', 1048.000, -132.905, 400.000, -400.000,0.95000, 0, 2100.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
8,'1 ', 2160.000, -30.469, 700.000, -500.000,1.00000, 0, 4300.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
10,'1 ', 2050.000, 464.829, 900.000, -900.000,1.00000, 0, 4100.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
12,'1 ', 1690.000, 195.571, 700.000, -280.000,1.00000, 0, 3400.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
14,'1 ', 2640.000, 378.080, 1300.000, -900.000,0.96000, 0, 5300.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
17,'1 ', 962.000, 148.778, 300.000, -300.000,1.00000, 0, 2000.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
29,'1 ', 4450.000, 1011.075, 4000.000, -4000.000,1.00000, 0, 8900.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
34,'1 ', 4480.000, 1150.177, 5320.000, -3500.000,1.02000, 0, 9000.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
35,'1 ', 1640.000, 285.666, 600.000, -525.000,1.00900, 0, 3300.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
39,'1 ', 200.000, -52.159, 268.000, -134.000,1.02000, 0, 400.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
42,'1 ', 325.000, 68.266, 300.000, -220.000,1.00000, 0, 650.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
44,'1 ', 1780.000, 534.593, 850.000, -440.000,1.05000, 0, 3600.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
46,'1 ', 110.000, 29.078, 100.000, -100.000,1.02000, 0, 220.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
64,'1 ', 2910.000, 953.299, 1500.000, -1000.000,1.00000, 0, 5800.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
69,'1 ', 1301.000, 431.493, 692.000, -711.000,1.05500, 0, 2600.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
76,'1 ', 5174.765, 855.276, 2649.000, -1850.000,1.00000, 0, 10400.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1
→9999.000, 0.000, 1,1.0000
78,'1 ', 9950.000, 1854.073, 5780.000, -2000.000,1.00000, 0, 20000.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1, 100.0, 1

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→9999.000,      0.000,      1,1.0000
  102,'1 ',      765.000,    -206.264,    330.000,   -310.000,0.98000,      0,  1500.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  _
→9999.000,      0.000,      1,1.0000
  111,'1 ',    1057.000,     25.675,    400.000,   -400.000,1.02000,      0,  2100.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  _
→9999.000,      0.000,      1,1.0000
  115,'1 ',     594.000,    192.348,    300.000,   -300.000,1.05000,      0,  1200.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  _
→9999.000,      0.000,      1,1.0000
  117,'1 ',    3467.000,   1654.420,   2500.000,  -1000.000,1.00000,      0,  6900.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  _
→9999.000,      0.000,      1,1.0000
  137,'1 ',     982.700,   -128.764,    300.000,   -300.000,1.02000,      0,  2000.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  _
→9999.000,      0.000,      1,1.0000
  139,'1 ',    3195.000,   1032.512,   2000.000,   -900.000,1.02000,      0,  6400.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  _
→9999.000,      0.000,      1,1.0000
  143,'1 ',    1690.000,    593.821,    900.000,   -400.000,1.05000,      0,  3400.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  _
→9999.000,      0.000,      1,1.0000
  147,'1 ',    1680.000,    446.627,    700.000,   -300.000,1.05000,      0,  3400.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  _
→9999.000,      0.000,      1,1.0000
  148,'1 ',    2200.000,    393.721,    600.000,   -600.000,1.01000,      0,  4400.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  _
→9999.000,      0.000,      1,1.0000
  158,'1 ',    1665.000,    -31.368,   9999.000,  -9999.000,1.05000,      0,  3300.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  _
→9999.000,      0.000,      1,1.0000
  161,'1 ',     445.000,     91.733,   9999.000,  -9999.000,1.00000,      0,   900.
→000, 0.00000E+0, 2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  _
→9999.000,      0.000,      1,1.0000
0 /End of Generator data, Begin Branch data
  2,      7,'1 ',  1.79000E-3, 1.98800E-2,   2.57600,      0.00,      0.00,  _
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1,   0.00,      1,1.0000
  4,     16,'1 ',  9.77000E-3, 1.10000E-1,   2.00000,      0.00,      0.00,  _
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2,   0.00,      1,1.0000
  4,    159,'1 ',  8.11000E-3, 1.36900E-1,   2.43480,      0.00,      0.00,  _
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1,   0.00,      1,1.0000
  6,     27,'1 ', -0.00000E+0,-4.08000E-3,   0.00000,      0.00,      0.00,  _
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1,   0.00,      1,1.0000
  7,     16,'1 ',  5.00000E-4, 5.30000E-3,   0.08820,      0.00,      0.00,  _
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1,   0.00,      1,1.0000
  7,    162,'1 ',  4.80000E-3, 4.36000E-2,   0.70780,      0.00,      0.00,  _
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2,   0.00,      1,1.0000
 11,     19,'1 ', -0.00000E+0,-6.34000E-3,   0.00000,      0.00,      0.00,  _
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1,   0.00,      1,1.0000
 11,     21,'1 ', -0.00000E+0,-1.18800E-2,   0.00000,      0.00,      0.00,  _
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1,   0.00,      1,1.0000
 11,    138,'1 ',  2.80000E-3, 2.11000E-2,   1.01940,      0.00,      0.00,  _

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→1630.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
13, 20,'1 ', -0.00000E+0, -6.34000E-3, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
13, 23,'1 ', -0.00000E+0, -8.26000E-3, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
13, 25,'1 ', -0.00000E+0, -1.79500E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
13, 28,'1 ', -0.00000E+0, -6.12000E-3, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
15, 18,'1 ', 4.00000E-4, 9.60000E-3, 0.90380, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
15, 18,'2 ', 4.00000E-4, 9.60000E-3, 0.90380, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
15, 135,'1 ', 2.59000E-3, 2.96700E-2, 2.15300, 0.00, 0.00,
→1800.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
15, 135,'2 ', 2.59000E-3, 2.96700E-2, 2.15300, 0.00, 0.00,
→1800.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
18, 22,'1 ', -0.00000E+0, -1.18800E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
18, 24,'1 ', -0.00000E+0, -8.26000E-3, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
19, 20,'1 ', 7.70000E-4, 1.80400E-2, 1.39842, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
21, 22,'1 ', 2.41000E-3, 5.86500E-2, 4.86560, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
23, 24,'1 ', 1.79000E-3, 4.24400E-2, 3.39220, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
25, 26,'1 ', 2.07000E-3, 4.95900E-2, 3.95160, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
26, 138,'1 ', -0.00000E+0, -1.79500E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
27, 28,'1 ', 1.77000E-3, 4.18900E-2, 3.34460, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
30, 31,'1 ', 3.50000E-3, 7.00000E-2, 4.60600, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
30, 79,'1 ', 8.30000E-4, 2.39000E-2, 3.30000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
32, 33,'1 ', 2.00000E-3, 2.00000E-2, 0.80000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
36, 37,'1 ', 7.40000E-4, 1.86100E-2, 1.40264, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
36, 55,'1 ', 8.20000E-4, 1.66800E-2, 1.18802, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
36, 63,'1 ', -0.00000E+0, 1.59000E-3, 0.12002, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
36, 63,'2 ', -0.00000E+0, 1.59000E-3, 0.12002, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
38, 45,'1 ', 2.21000E-3, 3.34600E-2, 0.07338, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
38, 47,'1 ', 2.90000E-3, 3.80000E-2, 0.08240, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
38, 58,'1 ', 3.09000E-3, 4.67700E-2, 0.10080, 0.00, 0.00,

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→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
38,	59,'1	',	2.26000E-3,	3.42200E-2,	0.07506,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
40,	54,'1	',	4.70000E-4,	7.23000E-3,	0.01624,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
40,	57,'1	',	3.50000E-4,	5.36000E-3,	0.01204,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
41,	49,'1	',	2.20000E-3,	3.42200E-2,	0.07716,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
41,	49,'2	',	2.38000E-3,	3.66900E-2,	0.08284,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
41,	56,'1	',	2.01000E-3,	3.07400E-2,	0.06886,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
41,	57,'1	',	2.81000E-3,	4.29600E-2,	0.09648,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
43,	159,'1	',	1.80000E-3,	2.45000E-2,	0.43920,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
43,	159,'2	',	1.80000E-3,	2.45000E-2,	0.43920,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
45,	47,'1	',	2.90000E-4,	4.34000E-3,	0.00950,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
47,	54,'1	',	2.29000E-3,	1.58300E-2,	0.03060,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
47,	54,'2	',	2.29000E-3,	1.58300E-2,	0.03060,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
47,	58,'1	',	1.41000E-3,	9.67000E-3,	0.01940,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
47,	58,'2	',	1.41000E-3,	9.67000E-3,	0.01940,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
47,	58,'3	',	1.61000E-3,	9.71000E-3,	0.01928,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
47,	58,'4	',	1.61000E-3,	9.71000E-3,	0.01928,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
47,	59,'1	',	2.70000E-4,	3.93000E-3,	0.00918,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
47,	59,'2	',	2.70000E-4,	3.93000E-3,	0.00918,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
47,	59,'3	',	2.70000E-4,	3.93000E-3,	0.00918,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
47,	61,'1	',	1.38000E-3,	1.11600E-2,	0.02470,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
47,	61,'2	',	1.38000E-3,	1.11600E-2,	0.02470,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
48,	63,'1	',	8.30000E-4,	1.88400E-2,	1.66668,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,2,	0.00,	1,1.0000	
49,	56,'1	',	3.70000E-4,	3.66000E-3,	0.00830,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
49,	57,'1	',	5.50000E-4,	5.86000E-3,	0.01246,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
51,	62,'1	',	1.07000E-2,	7.90500E-2,	0.36670,	0.00,	0.00,	└
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,	1,1,	0.00,	1,1.0000	
52,	62,'1	',	1.07000E-2,	7.90500E-2,	0.36670,	0.00,	0.00,	└

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→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
53, 56,'1 ', 7.30000E-4, 1.02500E-2, 0.02558, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
53, 56,'2 ', 7.30000E-4, 1.02500E-2, 0.02558, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
54, 57,'1 ', 1.19000E-3, 1.24400E-2, 0.02798, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
54, 57,'2 ', 1.19000E-3, 1.24400E-2, 0.02798, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
54, 61,'1 ', 1.28000E-3, 9.79000E-3, 0.02120, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
56, 57,'1 ', 1.10000E-3, 1.18900E-2, 0.02514, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
60, 136,'1 ', 1.40000E-3, 2.64000E-2, 0.10200, 0.00, 0.00,
→3070.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
60, 149,'1 ', 6.50000E-4, 1.18700E-2, 0.04672, 0.00, 0.00,
→3070.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
60, 149,'2 ', 6.50000E-4, 1.18700E-2, 0.04672, 0.00, 0.00,
→3070.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
63, 138,'1 ', 1.79000E-3, 2.52400E-2, 0.53546, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
63, 138,'2 ', 1.79000E-3, 2.52400E-2, 0.53546, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
63, 141,'1 ', 2.00000E-4, 4.10000E-3, 0.29620, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
65, 77,'1 ', 7.00000E-4, 7.40000E-2, 4.87000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
67, 70,'1 ', 6.00000E-5, 1.31000E-3, 0.00378, 0.00, 0.00,
→3020.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
67, 70,'2 ', 6.00000E-5, 1.16000E-3, 0.00332, 0.00, 0.00,
→3020.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
68, 71,'1 ', 1.00000E-5, 3.00000E-4, 0.01434, 0.00, 0.00,
→3450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
68, 71,'2 ', 1.00000E-5, 3.00000E-4, 0.01844, 0.00, 0.00,
→3450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
68, 75,'1 ', 2.30000E-4, 4.51000E-3, 0.33320, 0.00, 0.00,
→2175.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
68, 75,'2 ', 2.00000E-4, 4.46000E-3, 0.30500, 0.00, 0.00,
→2175.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
72, 74,'1 ', 1.79000E-3, 1.40500E-2, 3.68000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
73, 77,'1 ', 1.13000E-3, 2.06900E-2, 1.85526, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
74, 75,'1 ', 1.96000E-3, 3.30400E-2, 1.88000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
74, 77,'1 ', 1.42000E-3, 2.25800E-2, 1.88000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
75, 77,'1 ', 1.20000E-3, 2.31600E-2, 1.71520, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
75, 77,'2 ', 3.00000E-4, 2.00000E-2, 3.60000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
75, 81,'1 ', 6.30000E-4, 1.41200E-2, 1.09756, 0.00, 0.00,

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→3450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
75, 81,'2 ', 1.09000E-3, 2.40800E-2, 1.55542, 0.00, 0.00,
→3020.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
75, 81,'3 ', 1.08000E-3, 2.40900E-2, 1.55348, 0.00, 0.00,
→3020.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
77, 79,'1 ', 2.00000E-4, 8.20000E-3, 1.30000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
77, 79,'2 ', 2.00000E-4, 8.20000E-3, 1.30000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
80, 98,'1 ', 2.64000E-3, 5.35600E-2, 5.29066, 0.00, 0.00,
→3600.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
80, 179,'1 ', -0.00000E+0, -2.66700E-2, 0.00000, 0.00, 0.00,
→1732.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
81, 86,'1 ', 4.10000E-4, 7.37000E-3, 0.72694, 0.00, 0.00,
→3450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
81, 90,'1 ', 6.60000E-4, 1.26600E-2, 0.95976, 0.00, 0.00,
→3020.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
81, 94,'1 ', 6.60000E-4, 1.26600E-2, 0.95976, 0.00, 0.00,
→3020.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
82, 88,'1 ', 7.20000E-4, 1.38200E-2, 1.27572, 0.00, 0.00,
→3600.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
82, 93,'1 ', 7.80000E-4, 1.50200E-2, 1.13810, 0.00, 0.00,
→3020.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
82, 97,'1 ', 7.40000E-4, 1.41300E-2, 1.06634, 0.00, 0.00,
→3020.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
82, 167,'1 ', -0.00000E+0, -7.20000E-3, 0.00000, 0.00, 0.00,
→1800.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
82, 169,'1 ', -0.00000E+0, -8.64000E-3, 0.00000, 0.00, 0.00,
→1800.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
82, 171,'1 ', -0.00000E+0, -1.00000E-2, 0.00000, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
83, 98,'1 ', -0.00000E+0, -2.66700E-2, 0.00000, 0.00, 0.00,
→1732.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
84, 155,'1 ', 6.20000E-3, 6.73000E-2, 1.11560, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
85, 87,'1 ', 6.00000E-4, 1.03600E-2, 1.01456, 0.00, 0.00,
→3450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
85, 89,'1 ', 1.20000E-4, 2.38000E-3, 0.21926, 0.00, 0.00,
→3600.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
85, 179,'1 ', 1.22000E-3, 2.37300E-2, 2.20710, 0.00, 0.00,
→3600.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
86, 87,'1 ', -0.00000E+0, -1.26300E-2, 0.00000, 0.00, 0.00,
→2000.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
88, 89,'1 ', -0.00000E+0, -8.58000E-3, 0.00000, 0.00, 0.00,
→2000.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
90, 91,'1 ', -0.00000E+0, -1.26300E-2, 0.00000, 0.00, 0.00,
→2400.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
91, 92,'1 ', 7.40000E-4, 1.42800E-2, 1.08220, 0.00, 0.00,
→3020.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
92, 93,'1 ', -0.00000E+0, -1.26300E-2, 0.00000, 0.00, 0.00,
→2400.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
94, 95,'1 ', -0.00000E+0, -1.26300E-2, 0.00000, 0.00, 0.00,

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→2000.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 95, 96,'1 ', 7.40000E-4, 1.42800E-2, 1.08220, 0.00, 0.00,
→3020.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 96, 97,'1 ',-0.00000E+0,-1.26300E-2, 0.00000, 0.00, 0.00,
→2000.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 99, 100,'1 ', 2.48200E-2, 1.69380E-1, 0.20232, 0.00, 0.00,
→838.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 99, 116,'1 ', 1.48000E-2, 1.01010E-1, 0.12066, 0.00, 0.00,
→838.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 100, 104,'1 ', 1.38200E-2, 9.26800E-2, 0.11060, 0.00, 0.00,
→747.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 100, 105,'1 ', 1.66800E-2, 1.13810E-1, 0.13608, 0.00, 0.00,
→838.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 100, 112,'1 ', 1.11300E-2, 6.67800E-2, 0.07286, 0.00, 0.00,
→752.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 100, 112,'2 ', 1.05000E-2, 6.54000E-2, 0.06860, 0.00, 0.00,
→602.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 100, 112,'3 ', 1.10500E-2, 6.64200E-2, 0.07160, 0.00, 0.00,
→752.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 100, 116,'1 ', 3.90300E-2, 2.74030E-1, 0.31072, 0.00, 0.00,
→747.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 101, 103,'1 ', 7.90000E-4, 1.93700E-2, 1.32850, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 101, 107,'1 ', 8.70000E-4, 2.08700E-2, 1.45710, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 101, 107,'2 ', 8.70000E-4, 2.08700E-2, 1.45710, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 103, 106,'1 ', 8.30000E-4, 1.98500E-2, 0.00000, 0.00, 0.00,
→2450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 103, 133,'1 ', 9.30000E-4, 3.64400E-2, 1.38950, 0.00, 0.00,
→2450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 103, 134,'1 ', 7.20000E-4, 1.60000E-2, 1.08790, 0.00, 0.00,
→2450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 104, 116,'1 ', 3.05800E-2, 2.04600E-1, 0.24472, 0.00, 0.00,
→747.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 105, 116,'1 ', 2.23500E-2, 1.61060E-1, 0.18342, 0.00, 0.00,
→838.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 106, 107,'1 ', 1.53000E-3, 1.47000E-2, 0.00000, 0.00, 0.00,
→1560.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 106, 109,'1 ', 5.30000E-4, 1.29700E-2, 0.00000, 0.00, 0.00,
→2450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 107, 132,'1 ', 2.00000E-5,-1.33100E-2, 0.00000, 0.00, 0.00,
→1800.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 107, 134,'1 ', 2.00000E-5,-9.98000E-3, 0.00000, 0.00, 0.00,
→2450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 107, 173,'1 ',-0.00000E+0,-9.35000E-3, 0.00000, 0.00, 0.00,
→2134.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 107, 175,'1 ',-0.00000E+0,-9.44000E-3, 0.00000, 0.00, 0.00,
→2134.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 107, 177,'1 ',-0.00000E+0,-9.35000E-3, 0.00000, 0.00, 0.00,
→2134.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 110, 119,'1 ',-0.00000E+0,-1.00000E-2, 0.00000, 0.00, 0.00,

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→2667.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 110, 172,'1 ', -0.00000E+0, -1.00000E-2, 0.00000, 0.00, 0.00, _
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 113, 123,'1 ', 2.00000E-5, -9.98000E-3, 0.00000, 0.00, 0.00, _
→1800.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 113, 125,'1 ', 2.00000E-5, -9.98000E-3, 0.00000, 0.00, 0.00, _
→1800.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 113, 168,'1 ', -0.00000E+0, -7.20000E-3, 0.00000, 0.00, 0.00, _
→1800.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 113, 170,'1 ', -0.00000E+0, -7.20000E-3, 0.00000, 0.00, 0.00, _
→1800.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 114, 124,'1 ', 1.00000E-5, -6.66000E-3, 0.00000, 0.00, 0.00, _
→1800.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 114, 126,'1 ', 1.00000E-5, -6.66000E-3, 0.00000, 0.00, 0.00, _
→1800.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 114, 127,'1 ', 1.00000E-5, -1.12000E-2, 0.00000, 0.00, 0.00, _
→2667.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 114, 129,'1 ', 1.00000E-5, -7.20000E-3, 0.00000, 0.00, 0.00, _
→2667.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 118, 122,'1 ', -0.00000E+0, -1.00000E-2, 0.00000, 0.00, 0.00, _
→2667.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 118, 128,'1 ', 1.00000E-5, -1.12000E-2, 0.00000, 0.00, 0.00, _
→2667.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 118, 130,'1 ', 1.00000E-5, -3.60000E-3, 0.00000, 0.00, 0.00, _
→2667.00, 0.00000, 0.00000, 0.00000, 0.00000,1,2, 0.00, 1,1.0000
 118, 131,'1 ', 1.00000E-5, -7.55000E-3, 0.00000, 0.00, 0.00, _
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 118, 133,'1 ', 1.00000E-5, -1.09800E-2, 0.00000, 0.00, 0.00, _
→2450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 119, 120,'1 ', 7.60000E-4, 1.95200E-2, 1.82450, 0.00, 0.00, _
→2894.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 120, 121,'1 ', -0.00000E+0, -1.00000E-2, 0.00000, 0.00, 0.00, _
→2667.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 121, 122,'1 ', 8.20000E-4, 2.11900E-2, 1.98420, 0.00, 0.00, _
→2894.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 123, 124,'1 ', 1.40000E-3, 2.33800E-2, 1.47500, 0.00, 0.00, _
→2396.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 125, 126,'1 ', 1.40000E-3, 2.33800E-2, 1.47500, 0.00, 0.00, _
→2396.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 127, 128,'1 ', 1.54000E-3, 3.40900E-2, 2.31140, 0.00, 0.00, _
→2450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 129, 130,'1 ', 9.50000E-4, 2.10200E-2, 1.42520, 0.00, 0.00, _
→2450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 131, 132,'1 ', 1.65000E-3, 5.71900E-2, 2.47740, 0.00, 0.00, _
→2450.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 135, 151,'1 ', 4.20000E-4, 9.05000E-3, 0.66794, 0.00, 0.00, _
→3600.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 136, 142,'1 ', 1.90000E-3, 2.58000E-2, 0.09840, 0.00, 0.00, _
→2320.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 136, 149,'1 ', 8.45000E-3, 7.03400E-2, 0.15954, 0.00, 0.00, _
→1160.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
 138, 141,'1 ', 1.93000E-3, 2.77900E-2, 4.67120, 0.00, 0.00, _

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→3600.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
138,	146,'1 '	5.60000E-4,	1.41500E-2,	1.04290,	0.00,	0.00,	→
→3600.00,	0.00000,	0.00000,	0.00000,	0.00000,1,2,	0.00,	1,1.0000	
140,	142,'1 '	1.10000E-3,	1.27000E-2,	0.04800,	0.00,	0.00,	→
→2320.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
141,	144,'1 '	2.80000E-4,	7.53000E-3,	0.51736,	0.00,	0.00,	→
→3600.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
141,	144,'2 '	3.50000E-4,	7.50000E-3,	0.55360,	0.00,	0.00,	→
→3600.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
141,	146,'1 '	1.90000E-3,	3.10000E-2,	4.14020,	0.00,	0.00,	→
→3600.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
141,	150,'1 '	6.00000E-4,	1.28000E-2,	0.94620,	0.00,	0.00,	→
→3600.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
141,	152,'1 '	4.40000E-4,	1.12500E-2,	0.82920,	0.00,	0.00,	→
→3600.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
141,	152,'2 '	4.40000E-4,	1.12500E-2,	0.82920,	0.00,	0.00,	→
→3600.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
142,	145,'1 '	1.38000E-3,	5.39900E-2,	0.15252,	0.00,	0.00,	→
→2320.00,	0.00000,	0.00000,	0.00000,	0.00000,1,2,	0.00,	1,1.0000	
142,	153,'1 '	3.20000E-3,	3.95000E-2,	0.14400,	0.00,	0.00,	→
→2320.00,	0.00000,	0.00000,	0.00000,	0.00000,1,2,	0.00,	1,1.0000	
144,	150,'1 '	2.10000E-4,	4.57000E-3,	0.32336,	0.00,	0.00,	→
→3600.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
149,	153,'1 '	2.85000E-3,	3.64900E-2,	0.12656,	0.00,	0.00,	→
→2320.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
149,	153,'2 '	1.38000E-3,	3.39900E-2,	0.11252,	0.00,	0.00,	→
→2320.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
150,	151,'1 '	4.00000E-4,	9.30000E-3,	0.68560,	0.00,	0.00,	→
→3600.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
152,	174,'1 '	-0.00000E+0,	-9.35000E-3,	0.00000,	0.00,	0.00,	→
→2134.00,	0.00000,	0.00000,	0.00000,	0.00000,1,2,	0.00,	1,1.0000	
152,	176,'1 '	-0.00000E+0,	-9.35000E-3,	0.00000,	0.00,	0.00,	→
→2134.00,	0.00000,	0.00000,	0.00000,	0.00000,1,2,	0.00,	1,1.0000	
152,	178,'1 '	-0.00000E+0,	-8.40000E-3,	0.00000,	0.00,	0.00,	→
→2100.00,	0.00000,	0.00000,	0.00000,	0.00000,1,2,	0.00,	1,1.0000	
154,	155,'1 '	2.40000E-3,	3.32000E-2,	0.58490,	0.00,	0.00,	→
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,1,2,	0.00,	1,1.0000	
154,	157,'1 '	5.20000E-3,	6.02000E-2,	1.01000,	0.00,	0.00,	→
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
154,	157,'2 '	4.90000E-3,	5.37000E-2,	0.88430,	0.00,	0.00,	→
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
154,	159,'1 '	1.70000E-3,	2.25000E-2,	0.39920,	0.00,	0.00,	→
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
154,	159,'2 '	2.10000E-3,	2.38000E-2,	0.38450,	0.00,	0.00,	→
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
154,	164,'1 '	1.20000E-3,	1.72000E-2,	0.29870,	0.00,	0.00,	→
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
154,	166,'1 '	8.00000E-4,	1.06000E-2,	0.20390,	0.00,	0.00,	→
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
155,	166,'1 '	1.60000E-3,	2.26000E-2,	0.38100,	0.00,	0.00,	→
→0.00,	0.00000,	0.00000,	0.00000,	0.00000,1,1,	0.00,	1,1.0000	
156,	160,'1 '	1.08000E-2,	9.65000E-2,	0.32960,	0.00,	0.00,	→

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→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
157, 163,'1 ', 9.60000E-3, 8.78000E-2, 1.42650, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
157, 164,'1 ', 3.40000E-3, 3.92000E-2, 0.65240, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
157, 165,'1 ', 3.40000E-3, 3.74000E-2, 0.62080, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
157, 165,'2 ', 3.40000E-3, 3.72000E-2, 0.61820, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
159, 165,'1 ', 3.80000E-3, 3.40000E-2, 0.58240, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
159, 165,'2 ', 3.20000E-3, 3.49000E-2, 0.57220, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
167, 168,'1 ', 1.03000E-3, 2.33800E-2, 1.58040, 0.00, 0.00,
→3020.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
169, 170,'1 ', 1.07000E-3, 2.47000E-2, 1.52700, 0.00, 0.00,
→3020.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
171, 172,'1 ', 1.03000E-3, 3.23000E-2, 2.79600, 0.00, 0.00,
→0.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
173, 174,'1 ', 1.23000E-3, 2.65900E-2, 1.98702, 0.00, 0.00,
→3600.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
175, 176,'1 ', 1.23000E-3, 2.66200E-2, 1.98880, 0.00, 0.00,
→3600.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
177, 178,'1 ', 1.12000E-3, 2.51700E-2, 1.83586, 0.00, 0.00,
→3600.00, 0.00000, 0.00000, 0.00000, 0.00000,1,1, 0.00, 1,1.0000
0 /End of Branch data, Begin Transformer data
1, 2, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→
',1, 1,1.0000
0.00000E+0, 1.46000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
1, 3, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→
',1, 1,1.0000
0.00000E+0, 1.73000E-2, 100.00
0.95450, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
4, 5, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→
',1, 1,1.0000
0.00000E+0, 1.23800E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
4, 10, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→
',1, 1,1.0000
0.00000E+0, 1.50000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
6, 7, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→
',1, 1,1.0000

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0.00000E+0, 1.10000E-2, 100.00
1.06300, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
↪0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
6, 7, 0,'2 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↪ ',1, 1,1.0000
0.00000E+0, 1.10000E-2, 100.00
1.06300, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
↪0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
7, 8, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↪ ',1, 1,1.0000
0.00000E+0, 5.90000E-3, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 3000.00, 0, 0, 1.50000,
↪0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
7, 9, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↪ ',1, 1,1.0000
2.80000E-4, 1.38000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 430.00, 0, 0, 1.50000,
↪0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
7, 9, 0,'2 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↪ ',1, 1,1.0000
2.90000E-4, 1.39000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 430.00, 0, 0, 1.50000,
↪0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
11, 12, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↪ ',1, 1,1.0000
0.00000E+0, 6.66000E-3, 100.00
1.08000, 0.000, 0.000, 0.00, 0.00, 2000.00, 0, 0, 1.50000,
↪0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
15, 14, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↪ ',1, 1,1.0000
6.00000E-5, 4.95000E-3, 100.00
1.10610, 0.000, 0.000, 0.00, 0.00, 3066.00, 0, 0, 1.50000,
↪0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
16, 17, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↪ ',1, 1,1.0000
0.00000E+0, 6.00000E-3, 100.00
1.04350, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
↪0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
30, 29, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↪ ',1, 1,1.0000
0.00000E+0, 1.50000E-3, 100.00
1.05000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
↪0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000

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31, 32, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↳ ',1, 1,1.0000
0.00000E+0, 1.00000E-2, 100.00
1.10000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,↳
↳0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
33, 34, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↳ ',1, 1,1.0000
0.00000E+0, 2.00000E-3, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,↳
↳0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
84, 35, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↳ ',1, 1,1.0000
0.00000E+0, 4.60000E-3, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 2000.00, 0, 0, 1.50000,↳
↳0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
37, 47, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↳ ',1, 1,1.0000
1.30000E-4, 6.93000E-3, 100.00
1.05000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,↳
↳0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
38, 39, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↳ ',1, 1,1.0000
5.00000E-4, 2.38000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,↳
↳0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
41, 42, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↳ ',1, 1,1.0000
5.80000E-4, 2.53500E-2, 100.00
1.04910, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,↳
↳0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
43, 44, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↳ ',1, 1,1.0000
0.00000E+0, 5.20000E-3, 100.00
1.02500, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,↳
↳0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
47, 46, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↳ ',1, 1,1.0000
4.99000E-3, 1.14730E-1, 100.00
1.04780, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,↳
↳0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
48, 47, 0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
↳ ',1, 1,1.0000
2.60000E-4, 1.38600E-2, 100.00
1.05000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,↳

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→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
  51, 50, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→      ', 1, 1, 1.0000
  5.90000E-4, 1.49100E-2, 100.00
1.00170, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
  52, 50, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→      ', 1, 1, 1.0000
  5.90000E-4, 1.49100E-2, 100.00
1.00170, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
  53, 50, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→      ', 1, 1, 1.0000
  3.00000E-4, 1.33000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
  53, 50, 0, '2 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→      ', 1, 1, 1.0000
  3.00000E-4, 1.34000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
  55, 54, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→      ', 1, 1, 1.0000
  1.30000E-4, 1.38600E-2, 100.00
1.01060, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
  55, 54, 0, '2 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→      ', 1, 1, 1.0000
  1.30000E-4, 1.38600E-2, 100.00
1.01060, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
  59, 60, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→      ', 1, 1, 1.0000
  0.00000E+0, 1.15000E-3, 100.00
1.01330, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
  63, 62, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→      ', 1, 1, 1.0000
  2.00000E-4, 2.33800E-2, 100.00
0.97890, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
  65, 64, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→      ', 1, 1, 1.0000

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0.00000E+0, 5.00000E-3, 100.00
1.09000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
67, 66, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→', 1, 1, 1.0000
8.90000E-4, 2.99000E-2, 100.00
0.98730, 0.000, 0.000, 0.00, 0.00, 250.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
68, 67, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→', 1, 1, 1.0000
2.00000E-4, 1.18100E-2, 100.00
1.02380, 0.000, 0.000, 0.00, 0.00, 1008.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
68, 67, 0, '2 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→', 1, 1, 1.0000
9.00000E-5, 7.35000E-3, 100.00
1.02380, 0.000, 0.000, 0.00, 0.00, 1300.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
67, 69, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→', 1, 1, 1.0000
0.00000E+0, 1.03400E-2, 100.00
1.04550, 0.000, 0.000, 0.00, 0.00, 2000.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
71, 70, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→', 1, 1, 1.0000
0.00000E+0, 2.21000E-3, 100.00
1.02340, 0.000, 0.000, 0.00, 0.00, 2500.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
75, 76, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→', 1, 1, 1.0000
0.00000E+0, 3.75000E-3, 100.00
1.09770, 0.000, 0.000, 0.00, 0.00, 5000.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
79, 78, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→', 1, 1, 1.0000
0.00000E+0, 2.50000E-3, 100.00
1.06600, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
83, 84, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→', 1, 1, 1.0000
0.00000E+0, 7.20000E-3, 100.00
1.05000, 0.000, 0.000, 0.00, 0.00, 1500.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000

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101, 102, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
↳ ', 1, 1, 1.0000
0.00000E+0, 9.80000E-3, 100.00
1.05000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
↳ 0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
108, 107, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
↳ ', 1, 1, 1.0000
3.00000E-4, 1.74000E-2, 100.00
1.11900, 0.000, 0.000, 0.00, 0.00, 840.00, 0, 0, 1.50000,
↳ 0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
108, 107, 0, '2 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
↳ ', 1, 1, 1.0000
2.00000E-4, 1.19000E-2, 100.00
1.11900, 0.000, 0.000, 0.00, 0.00, 1120.00, 0, 0, 1.50000,
↳ 0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
111, 112, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
↳ ', 1, 1, 1.0000
0.00000E+0, 2.28100E-2, 100.00
0.91740, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
↳ 0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
112, 113, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
↳ ', 1, 1, 1.0000
1.00000E-4, 1.74000E-2, 100.00
1.11900, 0.000, 0.000, 0.00, 0.00, 840.00, 0, 0, 1.50000,
↳ 0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
115, 116, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
↳ ', 1, 1, 1.0000
0.00000E+0, 1.81500E-2, 100.00
0.90910, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
↳ 0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
116, 118, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
↳ ', 1, 1, 1.0000
2.00000E-4, 1.25000E-2, 100.00
1.11900, 0.000, 0.000, 0.00, 0.00, 1120.00, 0, 0, 1.50000,
↳ 0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
117, 118, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
↳ ', 1, 1, 1.0000
0.00000E+0, 4.48000E-3, 100.00
0.94520, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
↳ 0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
137, 138, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
↳ ', 1, 1, 1.0000
0.00000E+0, 1.51200E-2, 100.00
0.99600, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,

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→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    139,    140,        0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→                                ',1,    1,1.0000
    0.00000E+0, 3.65000E-3, 100.00
0.97870, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    143,    144,        0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→                                ',1,    1,1.0000
    0.00000E+0, 5.16000E-3, 100.00
0.98430, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    144,    145,        0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→                                ',1,    1,1.0000
    0.00000E+0, 5.00000E-3, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    146,    147,        0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→                                ',1,    1,1.0000
    0.00000E+0, 9.80000E-3, 100.00
1.05000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    148,    149,        0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→                                ',1,    1,1.0000
    0.00000E+0, 1.02600E-2, 100.00
0.98710, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    152,    153,        0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→                                ',1,    1,1.0000
    0.00000E+0, 1.14900E-2, 100.00
1.06310, 0.000, 0.000, 0.00, 0.00, 1120.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    152,    153,        0,'2 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→                                ',1,    1,1.0000
    0.00000E+0, 1.14900E-2, 100.00
1.06310, 0.000, 0.000, 0.00, 0.00, 1120.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    152,    153,        0,'3 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→                                ',1,    1,1.0000
    0.00000E+0, 1.14900E-2, 100.00
1.06310, 0.000, 0.000, 0.00, 0.00, 1120.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
    155,    156,        0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'
→                                ',1,    1,1.0000

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3.00000E-4, 1.81000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
157, 158, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→', 1, 1, 1.0000
2.00000E-4, 5.80000E-3, 100.00
0.98550, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
160, 161, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→', 1, 1, 1.0000
5.00000E-4, 1.41000E-2, 100.00
1.05880, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
163, 162, 0, '1 ', 1, 1, 1, 0.00000E+0, 0.00000E+0, 2, '
→', 1, 1, 1.0000
0.00000E+0, 1.95000E-2, 100.00
1.00000, 0.000, 0.000, 0.00, 0.00, 0.00, 0, 0, 1.50000,
→0.51000, 1.50000, 0.51000, 159, 0, 0.00000, 0.00000, 0.000
1.00000, 0.000
0 /End of Transformer data, Begin Area interchange data
0 /End of Area interchange data, Begin Two-terminal dc line data
0 /End of Two-terminal dc line data, Begin VSC dc line data
0 /End of VSC dc line data, Begin Impedance correction table data
0 /End of Impedance correction table data, Begin Multi-terminal dc line data
0 /End of Multi-terminal dc line data, Begin Multi-section line data
0 /End of Multi-section line data, Begin Zone data
1, '1 '
0 /End of Zone data, Begin Inter-area transfer data
0 /End of Inter-area transfer data, Begin Owner data
1, '1 '
0 /End of Owner data, Begin FACTS device data
0 /End of FACTS device data, Begin Switched shunt data
0 /End of Switched shunt data, Begin GNE device data
0 /End of GNE device data
Q

```

Dynamic Data (PSS/E DYN format)

```

data = !cat wecc.dyn
print('\n'.join(data))

```

3	'GENROU'	1	3.9000	0.32000E-01	0.54000	0.62000E-01	
			2.6400	5.0000	1.8600	1.7800	0.25000
			0.45300	0.19500	0.14500	1.9714	6.9000 /
3	'IEEEEST'	1	3	0	0.0000	0.0000	
			0.0000	0.0000	0.0000	0.0000	0.0000

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	0.0000	0.0000	0.75000	1.0000	4.2000	
	-2.0000	0.10000	-0.10000	0.0000	0.0000	/
3 'ESST3A' 1	0.20000E-01	0.30000	-0.20000	8.0000		
	1.0000	5.0000	20.000	0.0000	99.000	
	-99.000	1.0000	3.6700	0.43500	6.4800	
	0.10000E-01	0.98000E-02	4.8600	3.3300	0.40000	
	99.000	0.0000	/			
3 'IEEEG1' 1	0	0	20.000	0.10000		
	0.0000	0.20000	1.0000	-1.0000	0.95000	
	0.0000	0.10000	0.0000	0.0000	0.0000	
	0.0000	0.0000	0.0000	0.30000	0.0000	
	8.7200	0.70000	0.0000	/		
5 'GENROU' 1	4.0000	0.32000E-01	0.52000	0.63000E-01		
	2.6100	0.0000	1.8100	1.7300	0.24500	
	0.51000	0.19000	0.14000	1.7850	7.1400	/
5 'ST2CUT' 1	1	0	0	0		
	5.5000	0.0000	0.30000E-01	0.0000	10.000	
	10.000	0.40000	0.40000E-01	0.0000	0.0000	
	0.0000	0.0000	0.50000E-01	-0.50000E-01	0.0000	
	0.0000	/				
5 'ESST3A' 1	0.20000E-01	0.20000	-0.20000	8.2000		
	1.0000	5.0000	50.000	0.0000	99.000	
	-99.000	1.0000	3.5600	0.33500	5.8100	
	0.10000E-01	0.77000E-02	5.6000	3.7500	0.40000	
	99.000	0.0000	/			
5 'IEEEG1' 1	0	0	20.000	0.10000		
	0.0000	0.20000	1.0000	-1.0000	0.95000	
	0.0000	0.10000	0.0000	0.0000	0.0000	
	0.0000	0.0000	0.0000	0.30000	0.0000	
	8.7200	0.70000	0.0000	/		
8 'GENROU' 1	8.4000	0.35000E-01	0.46000	0.70000E-01		
	3.4200	0.0000	1.7600	1.5800	0.28500	
	0.48500	0.20500	0.15500	1.8429	6.4500	/
8 'ST2CUT' 1	1	0	0	0		
	10.000	0.0000	0.0000	0.0000	3.0000	
	3.0000	0.15000	0.50000E-01	0.15000	0.50000E-01	
	0.15000	0.50000E-01	0.50000E-01	-0.50000E-01	0.0000	
	0.0000	/				
8 'EXST1' 1	0.20000E-01	99.000	-99.000	0.0000		
	0.20000E-01	50.000	0.20000E-01	9999.0	-9999.0	
	0.0000	0.10000E-01	1.0000	/		
8 'IEEEG1' 1	0	0	20.000	0.10000		
	0.0000	0.20000	1.0000	-1.0000	0.95000	
	0.0000	0.10000	0.0000	0.0000	0.0000	
	0.0000	0.0000	0.0000	0.30000	0.0000	
	8.7200	0.70000	0.0000	/		
10 'GENROU' 1	4.5000	0.40000E-01	0.50000	0.60000E-01		
	2.4500	0.0000	1.7000	1.6500	0.25000	
	0.50000	0.19000	0.14000	1.7850	7.1400	/
10 'ST2CUT' 1	1	0	0	0		
	0.0000	0.0000	0.25000E-01	0.0000	0.16000E-01	
	0.16000E-01	0.26000	0.26000E-01	0.26000	0.26000E-01	

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	0.0000	0.0000	0.10000	-0.10000	0.0000
	0.0000	/			
10 'ESDC2A' 1	0.20000E-01	50.000	0.50000E-01	0.20000E-01	
	0.0000	3.0000	-3.0000	0.0000	0.51200
	0.70000E-01	1.3000	0.0000	3.9825	0.50000
	5.3100	1.0490	/		
10 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
12 'GENROU' 1	4.2000	0.32000E-01	0.60000	0.66000E-01	
	3.5900	0.0000	1.7600	1.6800	0.22000
	0.40000	0.17500	0.13000	1.9225	7.6900 /
12 'ST2CUT' 1	1	0	0	0	
	10.000	0.0000	0.0000	0.0000	3.0000
	3.0000	0.15000	0.50000E-01	0.15000	0.50000E-01
	0.15000	0.50000E-01	0.50000E-01	-0.50000E-01	0.0000
	0.0000	/			
12 'EXST1' 1	0.20000E-01	99.000	-99.000	1.0000	
	10.000	75.000	0.20000E-01	9999.0	-9999.0
	0.0000	0.10000E-01	1.0000	/	
12 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
14 'GENROU' 1	8.2000	0.33000E-01	0.48000	0.55000E-01	
	3.8300	0.0000	1.9800	1.8500	0.37500
	0.56700	0.28500	0.22500	1.4800	4.4400 /
14 'ST2CUT' 1	1	0	0	0	
	10.000	0.0000	0.0000	0.0000	3.0000
	3.0000	0.15000	0.50000E-01	0.15000	0.50000E-01
	0.15000	0.50000E-01	0.50000E-01	-0.50000E-01	0.0000
	0.0000	/			
14 'ESST3A' 1	0.20000E-01	0.20000	-0.20000	6.8000	
	1.0000	5.0000	50.000	0.0000	99.000
	-99.000	1.0000	3.7700	0.12400	6.5200
	0.10000E-01	0.50000E-02	6.7700	0.0000	0.40000
	99.000	0.0000	/		
14 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
17 'GENROU' 1	3.8000	0.31000E-01	0.49000	0.58000E-01	
	2.6300	0.0000	1.6700	0.61000	0.26000
	0.45300	0.20500	0.14500	1.9714	6.9000 /
17 'ST2CUT' 1	1	0	0	0	
	0.0000	0.0000	0.0000	0.0000	30.000
	30.000	0.23000	0.25000E-01	0.23000	0.25000E-01
	0.0000	0.0000	0.60000E-01	-0.60000E-01	0.0000

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	0.0000	/			
17 'ESDC2A' 1	0.20000E-01	25.000	0.20000E-01	0.20000E-01	
	0.0000	3.0000	-3.0000	0.0000	0.64200
	0.10300	0.99400	0.0000	2.5950	0.35600
	3.4600	1.0000	/		
17 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
29 'GENROU' 1	8.0000	0.50000E-01	0.20000	0.80000E-01	
	4.3400	0.0000	0.90000	0.60000	0.25000
	0.60000	0.15000	0.90000E-01	2.2000	11.000 /
29 'ST2CUT' 1	3	0	0	0	
	-3.5000	0.0000	0.0000	0.0000	1.0000
	1.0000	0.0000	3.0000	0.80000E-01	0.27000E-01
	0.80000E-01	0.27000E-01	0.10000	-0.10000	0.0000
	0.0000	/			
29 'EXST1' 1	0.20000E-01	99.000	-99.000	0.0000	
	0.20000E-01	72.500	0.20000E-01	9999.0	-9999.0
	0.0000	0.10000E-01	1.5000	/	
29 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
34 'GENROU' 1	4.6000	0.40000E-01	0.37000	0.10000	
	2.9500	0.0000	1.8250	1.7800	0.29100
	0.44000	0.25000	0.23900	1.3933	4.1800 /
34 'ST2CUT' 1	1	0	0	0	
	10.000	0.0000	0.10000	0.0000	1.0000
	1.0000	0.20000	0.10000E-01	0.0000	0.0000
	0.0000	0.0000	0.50000E-01	-0.50000E-01	0.0000
	0.0000	/			
34 'EXST1' 1	0.20000E-01	99.000	-99.000	0.0000	
	0.20000E-01	50.000	0.80000E-01	9999.0	-9999.0
	0.0000	0.15000E-01	1.0000	/	
34 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
35 'GENROU' 1	4.1000	0.33000E-01	0.56000	0.62000E-01	
	2.3200	0.0000	2.0700	1.9900	0.28000
	0.49000	0.21500	0.15500	1.8429	6.4500 /
35 'ST2CUT' 1	1	0	0	0	
	10.000	0.0000	0.0000	0.0000	3.0000
	3.0000	0.15000	0.50000E-01	0.15000	0.50000E-01
	0.15000	0.50000E-01	0.50000E-01	-0.50000E-01	0.0000
	0.0000	/			
35 'EXST1' 1	0.20000E-01	99.000	-99.000	0.0000	
	0.20000E-01	50.000	0.36000	9999.0	-9999.0

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	0.0000	0.30000E-01	1.0000	/	
35 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
39 'GENROU' 1	9.8000	0.28000E-01	0.20000	0.16000	
	6.4100	0.0000	0.99500	0.56800	0.19500
	0.56800	0.10000	0.89000E-01	2.2400	11.200 /
39 'ST2CUT' 1	1	0	0	0	
	0.0000	0.0000	0.0000	0.0000	15.000
	15.000	0.0000	0.53000E-01	0.0000	0.53000E-01
	0.0000	0.0000	0.50000E-01	-0.50000E-01	0.0000
	0.0000	/			
39 'EXST1' 1	0.20000E-01	99.000	-99.000	0.0000	
	0.20000E-01	75.000	0.16000	9999.0	-9999.0
	0.0000	0.10000E-01	1.0000	/	
39 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.30000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	10.000	0.70000	0.0000	/	
42 'GENROU' 1	4.8000	0.37000E-01	0.50000	0.75000E-01	
	4.1300	0.0000	1.7000	1.6200	0.25600
	0.41000	0.10000	0.85000E-01	1.8429	6.4500 /
42 'ST2CUT' 1	3	0	0	0	
	0.0000	0.0000	0.30000E-01	0.0000	1.5000
	1.5000	0.37500	12.000	0.0000	0.0000
	0.0000	0.0000	0.50000E-01	-0.50000E-01	0.0000
	0.0000	/			
42 'ESDC2A' 1	0.20000E-01	20.000	0.20000	0.20000E-01	
	0.0000	2.0000	-2.0000	0.0000	0.54500
	0.90000E-01	1.0000	0.0000	3.0975	0.41000
	4.1300	1.0000	/		
42 'IEEEG1' 1	0	0	20.000	0.80000E-01	
	0.0000	0.15000	1.0000	-1.0000	0.95000
	0.0000	0.50000E-01	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.28000	0.0000
	10.000	0.72000	0.0000	/	
44 'GENROU' 1	4.7000	0.31000E-01	0.67000	0.61000E-01	
	2.8800	0.0000	1.9900	1.9000	0.24500
	0.42000	0.10000	0.85000E-01	1.9057	6.6700 /
44 'ST2CUT' 1	1	0	0	0	
	3.0000	0.0000	0.0000	0.0000	10.000
	10.000	0.30000	0.30000E-01	0.30000	0.30000E-01
	0.0000	0.0000	0.10000	-0.10000	0.0000
	0.0000	/			
44 'ESST3A' 1	0.20000E-01	0.20000	-0.20000	7.2000	
	1.0000	4.0000	50.000	0.0000	99.000
	-99.000	1.0000	4.3500	0.24300	8.4000
	0.10000E-01	0.50000E-02	6.3600	20.000	0.60000
	99.000	0.0000	/		

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44	'IEEEG1'	1	0	0	20.000	0.10000
			0.20000	1.0000	-1.0000	0.95000
			0.0000	0.10000	0.0000	0.0000
			0.0000	0.0000	0.0000	0.30000
			8.7200	0.70000	0.0000	/
46	'GENROU'	1	7.4000	0.30000E-01	0.20000	0.16000
			3.8000	0.0000	0.61900	0.36500
			0.36500	0.10000	0.85000E-01	1.7850
						7.1400
46	'ST2CUT'	1	1	0	0	0
			10.000	0.0000	0.0000	0.0000
			3.0000	0.15000	0.50000E-01	0.15000
			0.15000	0.50000E-01	0.50000E-01	-0.50000E-01
			0.0000	/		0.0000
46	'EXST1'	1	0.20000E-01	99.000	-99.000	0.0000
			0.20000E-01	50.000	0.16000	9999.0
			0.0000	0.15000E-01	1.0000	/
46	'IEEEG1'	1	0	0	20.000	0.90000E-01
			0.0000	0.20000	1.0000	-1.0000
			0.0000	0.30000	0.10000	0.0000
			0.0000	0.0000	0.0000	0.0000
			0.0000	0.90000	0.0000	/
64	'GENROU'	1	4.7800	0.41000E-01	0.53000	0.67000E-01
			3.3800	0.0000	1.6026	1.5818
			0.45122	0.23079	0.16596	1.9475
						7.7900
64	'ST2CUT'	1	1	0	0	0
			3.0000	0.0000	0.30000E-01	0.0000
			20.000	6.7200	0.67200	0.0000
			0.0000	0.0000	0.10000	-0.10000
			0.0000	/		0.0000
64	'EXST1'	1	0.20000E-01	99.000	-99.000	0.0000
			0.20000E-01	47.500	0.13000	9999.0
			0.0000	0.20000E-01	1.0000	/
64	'IEEEG1'	1	0	0	20.000	0.10000
			0.0000	0.20000	1.0000	-1.0000
			0.0000	0.50000	0.0000	0.0000
			0.0000	0.0000	0.0000	0.30000
			8.7200	0.70000	0.0000	/
69	'GENROU'	1	4.0000	0.20000E-01	0.20000	0.50000E-01
			3.0000	0.0000	1.4846	0.83403
			0.83403	0.47870	0.40033	1.3900
						4.1700
69	'ST2CUT'	1	1	0	0	0
			10.000	0.0000	0.0000	0.0000
			3.0000	0.15000	0.50000E-01	0.15000
			0.15000	0.50000E-01	0.50000E-01	-0.50000E-01
			0.0000	/		0.0000
69	'EXST1'	1	0.20000E-01	99.000	-99.000	0.0000
			0.20000E-01	50.000	0.16000	9999.0
			0.0000	0.26000E-01	1.0000	/
69	'IEEEG1'	1	0	0	20.000	0.10000
			0.0000	0.20000	1.0000	-1.0000
			0.0000	0.10000	0.30000	0.0000
			0.0000	0.0000	0.0000	0.30000

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	8.7200	0.40000	0.0000	/	
76 'GENROU' 1	8.0000	0.30000E-01	0.20000	0.60000E-01	
	3.6700	0.0000	1.2009	0.84062	0.46099
	0.84062	0.32024	0.30991	1.3900	4.1700 /
76 'ST2CUT' 1	3	0	0	0	
-0.40000E-01	0.0000	0.0000	0.0000	29.500	
	29.500	1.5000	0.15000	1.5000	0.15000
	0.0000	0.0000	0.90000E-01	-0.90000E-01	0.0000
	0.0000	/			
76 'ESDC2A' 1	0.20000E-01	20.000	0.60000E-01	0.20000E-01	
	0.0000	3.0000	-3.0000	0.0000	0.13000
	0.50000E-01	1.3000	0.0000	3.3750	0.30000
	4.5000	1.0000 /			
76 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	1.0500
	0.0000	0.80000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
78 'GENROU' 1	7.2000	0.43000E-01	0.20000	0.79000E-01	
	3.4600	0.0000	0.63800	0.42400	0.22800
	0.42400	0.16100	0.12700	1.9675	7.8700 /
78 'ST2CUT' 1	3	0	0	0	
-0.60000E-01	0.0000	0.0000	0.0000	29.500	
	29.500	1.5000	0.15000	1.5000	0.15000
	0.0000	0.0000	0.90000E-01	-0.90000E-01	0.0000
	0.0000	/			
78 'ESDC2A' 1	0.20000E-01	20.000	0.10000	0.20000E-01	
	0.0000	3.0000	-3.0000	0.0000	0.57000
	0.50000E-01	1.2000	0.0000	3.3750	0.30000
	4.5000	1.0000 /			
78 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
102 'GENROU' 1	6.1200	0.52000E-01	1.5000	0.14400	
	3.4600	0.0000	2.1290	2.0740	0.46700
	1.2700	0.31100	0.25000	1.3333	4.0000 /
102 'ST2CUT' 1	1	0	0	0	
	10.000	0.0000	0.0000	0.0000	3.0000
	3.0000	0.15000	0.50000E-01	0.15000	0.50000E-01
	0.15000	0.50000E-01	0.50000E-01	-0.50000E-01	0.0000
	0.0000	/			
102 'EXST1' 1	0.20000E-01	99.000	-99.000	0.20000E-01	
	0.20000E-01	40.000	0.20000E-01	9999.0	-9999.0
	0.0000	0.10000E-01	1.0000	/	
102 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
111 'GENROU' 1	4.0000	0.51000E-01	0.20000	0.33000E-01	

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	4.3900	5.0000	2.0548	1.3111	0.62622	
	1.3111	0.51468	0.27397	1.7850	7.1400	/
111	'IEEEEST' 1	3	0	0.0000	0.0000	
	0.0000	0.0000	0.0000	0.0000	0.0000	
	0.0000	0.0000	0.75000	1.0000	4.2000	
	-2.0000	0.10000	-0.10000	0.0000	0.0000	/
111	'ESDC2A' 1	0.20000E-01	40.500	0.60000E-01	0.20000E-01	
	0.0000	2.0000	-2.0000	0.0000	0.50000	
	0.50000E-01	1.0000	0.0000	2.6250	0.54000	
	20.000	1.0000	/			
111	'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000	
	0.0000	0.10000	0.10000	0.0000	0.0000	
	0.0000	0.0000	0.0000	0.30000	0.0000	
	8.7200	0.60000	0.0000	/		
115	'GENROU' 1	7.8000	0.60000E-01	0.20000	0.11000	
	4.1600	0.0000	0.75000	0.53000	0.32000	
	0.53000	0.30000	0.21500	1.5500	4.6500	/
115	'IEEEEST' 1	3	0	0.0000	0.0000	
	0.0000	0.0000	0.0000	0.0000	0.0000	
	0.0000	0.0000	0.75000	1.0000	4.2000	
	-2.0000	0.10000	-0.10000	0.0000	0.0000	/
115	'EXST1' 1	0.20000E-01	99.000	-99.000	0.0000	
	0.20000E-01	40.000	0.20000E-01	9999.0	-9999.0	
	0.0000	0.10000E-01	1.2000	/		
115	'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000	
	0.0000	0.10000	0.0000	0.0000	0.0000	
	0.0000	0.0000	0.0000	0.30000	0.0000	
	8.7200	0.70000	0.0000	/		
117	'GENROU' 1	4.5000	0.40000E-01	0.50000	0.60000E-01	
	3.8200	0.0000	1.7000	1.6500	0.25000	
	0.50000	0.19000	0.14000	1.7850	7.1400	/
117	'IEEEEST' 1	3	0	0.0000	0.0000	
	0.0000	0.0000	0.0000	0.0000	0.0000	
	0.0000	0.0000	0.75000	1.0000	4.2000	
	-2.0000	0.10000	-0.10000	0.0000	0.0000	/
117	'ESDC2A' 1	0.20000E-01	40.000	0.50000E-01	0.20000E-01	
	0.0000	3.0000	-3.0000	0.0000	0.51200	
	0.70000E-01	1.3000	0.0000	3.9825	0.50000	
	5.3100	1.0490	/			
117	'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000	
	0.0000	0.10000	0.0000	0.0000	0.0000	
	0.0000	0.0000	0.0000	0.30000	0.0000	
	8.7200	0.70000	0.0000	/		
137	'GENROU' 1	7.8000	0.60000E-01	0.20000	0.11000	
	6.0700	0.0000	0.75000	0.53000	0.32000	
	0.53000	0.30000	0.21500	1.5500	4.6500	/
137	'ST2CUT' 1	1	0	0	0	
	10.000	0.0000	0.0000	0.0000	3.0000	
	3.0000	0.15000	0.50000E-01	0.15000	0.50000E-01	

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	0.15000	0.50000E-01	0.50000E-01	-0.50000E-01	0.0000
	0.0000	/			
137 'EXST1' 1	0.20000E-01	99.000	-99.000	0.0000	
	0.20000E-01	50.000	0.20000E-01	9999.0	-9999.0
	0.0000	0.10000E-01	1.2000	/	
137 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
139 'GENROU' 1	5.3000	0.35000E-01	0.50000	0.77000E-01	
	2.8200	0.0000	1.6200	1.5700	0.24500
	0.37600	0.10000	0.95000E-01	2.1060	10.530 /
139 'ST2CUT' 1	3	0	0	0	
	0.0000	0.0000	0.0000	0.0000	29.500
	29.500	1.5000	0.15000	1.5000	0.15000
	0.0000	0.0000	0.90000E-01	-0.90000E-01	0.0000
	0.0000	/			
139 'ESDC2A' 1	0.20000E-01	20.000	0.50000E-01	0.20000E-01	
	0.0000	3.0000	-3.0000	0.0000	0.60000
	0.70000E-01	1.3000	0.0000	2.8200	0.32000
	3.7600	1.0000	/		
139 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
143 'GENROU' 1	8.0000	0.50000E-01	1.5000	0.60000E-01	
	2.7500	0.0000	1.9500	1.8700	0.34000
	1.0000	0.29000	0.24000	1.3900	4.1700 /
143 'ST2CUT' 1	1	0	0	0	
	0.50000	0.0000	0.42000E-01	0.0000	10.000
	10.000	1.0000	0.80000E-01	1.7000	0.80000E-01
	0.0000	0.0000	0.50000E-01	-0.50000E-01	0.0000
	0.0000	/			
143 'EXST1' 1	0.20000E-01	99.000	-99.000	0.0000	
	0.20000E-01	50.000	0.19000	9999.0	-9999.0
	0.0000	0.15000E-01	1.0000	/	
143 'IEEEG1' 1	0	0	20.000	0.10000	
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
147 'GENROU' 1	8.4000	0.35000E-01	0.46000	0.70000E-01	
	3.4900	0.0000	1.7600	1.5800	0.28500
	0.48500	0.20500	0.15500	1.8429	6.4500 /
147 'ST2CUT' 1	1	0	0	0	
	5.0000	0.0000	0.29000E-01	0.0000	2.4000
	2.4000	0.14400	0.40000E-01	0.37700	0.10500
	0.0000	0.0000	0.50000E-01	-0.50000E-01	0.0000
	0.0000	/			
147 'EXST1' 1	0.20000E-01	99.000	-99.000	0.0000	

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	0.20000E-01	40.000	0.20000E-01	9999.0	-9999.0
	0.0000	0.10000E-01	1.0000	/	
147	'IEEEG1' 1	0	0	20.000	0.10000
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
148	'GENROU' 1	4.3000	0.32000E-01	0.43000	0.66000E-01
	3.0300	0.0000	1.7900	1.7150	0.22000
	0.44000	0.10000	0.85000E-01	1.8525	7.4100 /
148	'ST2CUT' 1	1	0	0	0
	10.000	0.0000	0.0000	0.0000	3.0000
	3.0000	0.15000	0.50000E-01	0.15000	0.50000E-01
	0.15000	0.50000E-01	0.50000E-01	-0.50000E-01	0.0000
	0.0000	/			
148	'EXST1' 1	0.20000E-01	99.000	-99.000	0.0000
	0.20000E-01	40.000	0.20000	9999.0	-9999.0
	0.0000	0.35000E-01	1.7500	/	
148	'IEEEG1' 1	0	0	20.000	0.10000
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
158	'GENROU' 1	3.9000	0.32000E-01	0.49000	0.62000E-01
	2.8200	0.0000	1.6400	1.5700	0.24000
	0.43000	0.18500	0.13000	1.9225	7.6900 /
158	'ST2CUT' 1	1	0	0	0
	8.0800	0.0000	0.30000E-01	0.0000	10.000
	10.000	0.15000	0.50000E-01	0.15000	0.50000E-01
	0.0000	0.0000	0.50000E-01	-0.50000E-01	0.0000
	0.0000	/			
158	'EXST1' 1	0.20000E-01	99.000	-99.000	1.0000
	10.000	40.000	0.20000E-01	9999.0	-9999.0
	0.0000	0.10000E-01	1.0000	/	
158	'IEEEG1' 1	0	0	20.000	0.10000
	0.0000	0.20000	1.0000	-1.0000	0.95000
	0.0000	0.10000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.30000	0.0000
	8.7200	0.70000	0.0000	/	
161	'GENROU' 1	5.2100	0.42000E-01	1.5000	0.42000E-01
	3.0100	0.0000	1.7980	1.7780	0.32400
	0.45000	0.26000	0.19300	1.4800	5.1800 /
161	'ST2CUT' 1	1	0	0	0
	10.000	0.0000	0.30000E-01	0.0000	30.000
	30.000	0.40000	0.50000E-01	0.40000	0.50000E-01
	0.0000	0.0000	0.40000E-01	-0.40000E-01	0.0000
	0.0000	/			
161	'EXST1' 1	0.20000E-01	99.000	-99.000	0.0000
	0.20000E-01	50.000	0.10000	9999.0	-9999.0
	0.0000	0.12000E-01	1.0000	/	
161	'IEEEG1' 1	0	0	20.000	0.10000
	0.0000	0.20000	1.0000	-1.0000	0.95000

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0.0000	0.10000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.30000	0.0000
8.7200	0.70000	0.0000	/	

1.9 Miscellaneous

1.9.1 Per Unit System

The bases for AC system are

- S_b^{ac} : three-phase power in MVA. By default, $S_b^{ac} = 100MVA$ (set by `System.config.mva`).
- V_b^{ac} : phase-to-phase voltage in kV.
- I_b^{ac} : current base $I_b^{ac} = \frac{S_b^{ac}}{\sqrt{3}V_b^{ac}}$

The bases for DC system are

- S_b^{dc} : power in MVA. It is assumed to be the same as S_b^{ac} .
- V_b^{dc} : voltage in kV.

Some device parameters are given as per unit values under the device base power and voltage (if applicable). For example, the Line model `andes.models.line.Line` has parameters `r`, `x` and `b` as per unit values in the device bases `Sn`, `Vn1`, and `Vn2`. It is up to the user to check data consistency. For example, line voltage bases are typically the same as bus nominal values. If the `r`, `x`, and `b` are meant to be per unit values under the system base, each Line device should use an `Sn` equal to the system base `mva`.

Parameters in the device base will have a property value in the Model References page. For example, `Line.r` has a property `z`, which means it is a per unit impedance in the device base. To find out all applicable properties, refer to the "Other Parameters" section of `andes.core.param.NumParam`.

After setting up the system, these parameters will be converted to per-units in the bases of system base MVA and bus nominal voltages. The parameter values in the system base will be stored to the `v` attribute of the `NumParam`. The original inputs in the device base will be moved to the `vin` attribute. For example, after setting up the system, `Line.x.v` is the line reactances in per unit under the system base.

Values in the `v` attribute is what get utilized in computation. Writing new values directly to `vin` will not affect the values in `v` afterward. To alter parameters after setting up, refer to example notebook 2.

1.9.2 Notes

Modeling Blocks

State Freeze

State freeze is used by converter controllers during fault transients to fix a variable at the pre-fault values. The concept of state freeze applies to both state and algebraic variables. For example, in the renewable energy electric control model (REECA), the proportional-integral controllers for reactive power error and voltage error are subject to state freeze when voltage dip is observed. The internal and output states should be frozen when the freeze signal turns one and frees when the signal turns back to zero.

Freezing a state variable can be easily implemented by multiplying the freeze signal with the right-hand side (RHS) of the differential equation:

$$T\dot{x} = (1 - z_f) \times f(x)$$

where $f(x)$ is the original RHS of the differential equation, and z_f is the freeze signal. When z_f becomes zero the differential equation will evaluate to zero, making the increment zero.

Freezing an algebraic variable is more difficult to implement. One might consider a similar solution to freezing a differential variable by constructing a piecewise equation, for example,

$$0 = (1 - z_f) \times g(y)$$

where $g(y)$ is the original RHS of the algebraic equation. One might also need to add a small value to the diagonals of `dae.gv` associated with the algebraic variable to avoid singularity. The rationale behind this implementation is to zero out the algebraic equation mismatch and thus stop incremental correction: in the frozen state, since z_f switches to zero, the algebraic increment should be forced to zero. This method, however, would not work when a dishonest Newton method is used.

If the Jacobian matrix is not updated after z_f switches to one, in the row associated with the equation, the derivatives will remain the same. For the algebraic equation of the PI controller given by

$$0 = (K_p u + x_i) - y$$

where K_p is the proportional gain, u is the input, x_i is the integrator output, and y is the PI controller output, the derivatives w.r.t u , x_i and y are nonzero in the pre-frozen state. These derivative corrects y following the changes of u and x . Although x has been frozen, if the Jacobian is not rebuilt, the correction will still be made due to the change of u . Since this equation is linear, only one iteration is needed to let y track the changes of u . For nonlinear algebraic variables, this approach will likely give the wrong results, since the residual is pegged at zero.

To correctly freeze an algebraic variable, the freezing signal needs to be passed to an `EventFlag`, which will set an `custom_event` flag if any input changes. `EventFlag` is a `VarService` that will be evaluated at each iteration after discrete components and before equations.

1.9.3 Profiling Import

To speed up the command-line program, import profiling is used to break down the program loading time.

With tool `profimp`, `andes` can be profiled with `profimp "import andes" --html > andes_import.htm`. The report can be viewed in any web browser.

1.9.4 What won't work

You might have heard that PyPy is faster than CPython due to a built-in JIT compiler. Before you spend an hour compiling the dependencies, here is the fact: PyPy won't work for speeding up ANDES.

PyPy is often much slower than CPython when using CPython extension modules (see the [PyPy_FAQ](#)). Unfortunately, NumPy is one of the highly optimized libraries that heavily use CPython extension modules.

1.10 Frequently Asked Questions

1.10.1 Program Startup

1.10.2 General

Q: What is the Hybrid Symbolic-Numeric Framework in ANDES?

A: It is a modeling and simulation framework that uses symbolic computation for descriptive modeling and code generation for fast numerical simulation. The goal of the framework is to reduce the programming efforts associated with implementing complex models and automate the research workflow of modeling, simulation, and documentation.

The framework reduces the modeling efforts from two aspects: (1) allowing modeling by typing in equations, and (2) allowing modeling using modularized control blocks and discontinuous components. One only needs to describe the model using equations and blocks without having to write the numerical code to implement the computation. The framework automatically generate symbolic expressions, computes partial derivatives, and generates vectorized numerical code.

1.10.3 Modeling

Admittance matrix

Q: Where to find the line admittance matrix?

A: ANDES does not build line admittance matrix for computing line power injections. Instead, line power injections are computed as vectors on the two line terminal. This approach generalizes line as a power injection model.

Q: Without admittance matrix, how to switch out lines?

A: Lines can be switched out and in by using `Toggle`. See the example in `cases/kundur/kundur_full.xlsx`. One does not need to manually trigger a Jacobian matrix rebuild because `Toggle` automatically triggers it using the new connectivity status.

Reference of the existing model

Q: Is there any further reference of the existing model?

A: Most of them can be found online, such as ESIG and PowerWorld.

1.11 License

1.11.1 GNU Public License v3

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1.12 Quick install

Working with Conda?

ANDES is available on conda-forge and can be installed with Anaconda, Miniconda, and Mambaforge:

```
conda install -c conda-forge andes
```

Prefer pip?

ANDES can be installed via pip from [PyPI](#).

```
pip install andes
```

New to Python?

Set up a Mambaforge environment by following [Setting Up Mambaforge](#). We recommend Mambaforge on Windows and Apple Silicon for new users.

Are you a developer?

Installing from source? Looking to develop models? Check the guide in [Develop Install](#).

EXAMPLES

A collection of examples are presented to supplement the tutorial. The examples below are identical to the Jupyter Notebook in the `examples` folder of the repository [here](#). You can run the examples in a live Jupyter Notebook online using [Binder](#).

2.1 Simulate and Plot

2.1.1 Import and Setting the Verbosity Level

We first import the `andes` library and the `get_case` function that for loading test cases shipped with ANDES.

```
import andes

from andes.utils.paths import get_case
```

We can configure the verbosity level for logging (output messages) by passing a verbosity level (10-DEBUG, 20-INFO, 30-WARNING, 40-ERROR, 50-CRITICAL) to the `stream_level` argument of `andes.main.config_logger()`. Verbose level 10 is useful for getting debug output.

The logging level can be altered (as of v1.4.3) by calling `config_logger` again with new `stream_level` and `file_level`.

```
andes.config_logger(stream_level=20)
```

Note that the above `andes.config_logger()` is a shorthand to `andes.main.config_logger()`. If this step is omitted, the default INFO level (`stream_level=20`) will be used.

2.1.2 Run Time-Domain Simulation

Run power flow by default

`get_case` takes a relative path to `ANDES_ROOT/andes/cases` and returns the full path, where `ANDES_ROOT` is the root folder of ANDES.

`andes.run` is the entrypoint function for loading files and running routines. It runs power flow by default and returns a `System` object.

Note: if `default_config=True`, the default config will be used. To use your own config, remove `default_config=True`.

See the tutorial for saving and editing ANDES config.

```
ss = andes.run(get_case('kundur/kundur_full.xlsx'), default_config=True)
```

```
Working directory: "/home/hacui/repos/andes/examples"
> Loaded generated Python code in "/home/hacui/.andes/pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/kundur/kundur_full.
→xlsx"...
Input file parsed in 0.2775 seconds.
System internal structure set up in 0.0322 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0039 seconds.
0: |F(x)| = 14.9282832
1: |F(x)| = 3.608627841
2: |F(x)| = 0.1701107882
3: |F(x)| = 0.002038626956
4: |F(x)| = 3.745104027e-07
Converged in 5 iterations in 0.0084 seconds.
Report saved to "kundur_full_out.txt" in 0.0020 seconds.
```

```
-> Single process finished in 0.5018 seconds.
```

Run time-domain simulation

Run TDS by calling `TDS.run()` on the system. Note that the call must follow the power flow immediately.

The default simulation is for 20 seconds. To change it, change `config.tf` to the desired value.

```
ss.TDS.config.tf = 10 # simulate for 10 seconds
```

```
ss.TDS.run()
```

```
-> Time Domain Simulation Summary:
Sparse Solver: KLU
Simulation time: 0.0-10 s.
Fixed step size: h=33.33 ms. Shrink if not converged.
Initialization for dynamics completed in 0.0490 seconds.
Initialization was successful.
```

```
0%|          | 0/100 [00:00<?, ?%/s]
```

```
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
```

```
Simulation completed in 0.5985 seconds.
Outputs to "kundur_full_out.lst" and "kundur_full_out.npz".
Outputs written in 0.0104 seconds.
```

```
True
```

To check if all operations completed successfully, check `ss.exit_code`. `exit_code == 0` means that all operations were successful.

If not zero, `exit_code` indicates the number of errors caught. One will need to check output messages for errors.

```
ss.exit_code
```

```
0
```

2.1.3 Export and Plot Results

If you are using ANDES interactively from Jupyter Notebook or IPython, at the end of a time-domain simulation, a plotter object `ss.TDS.plt` will automatically be created.

To check if that has been created successfully (in case the detection of an interactive environment fails), check the type of `ss.TDS.plt`.

```
ss.TDS.plt
```

```
<andes.plot.TDSData at 0x7fb229d9ff70>
```

If `ss.TDS.plt` is `None`, it can be manually loaded with `ss.TDS.load_plotter()`. Otherwise, `load_plotter()` can be safely skipped.

```
ss.TDS.load_plotter()
```

Exporting simulation data to csv

To export simulation results to a CSV file, one can use `ss.TDS.plt.export_csv()`, which takes an optional argument of the file name.

If not provided, a default file name will be assigned.

```
ss.TDS.plt.export_csv()
```

```
CSV data saved to "/home/hacui/repos/andes/examples/kundur_full_out.csv".
```

Index-based Plotting

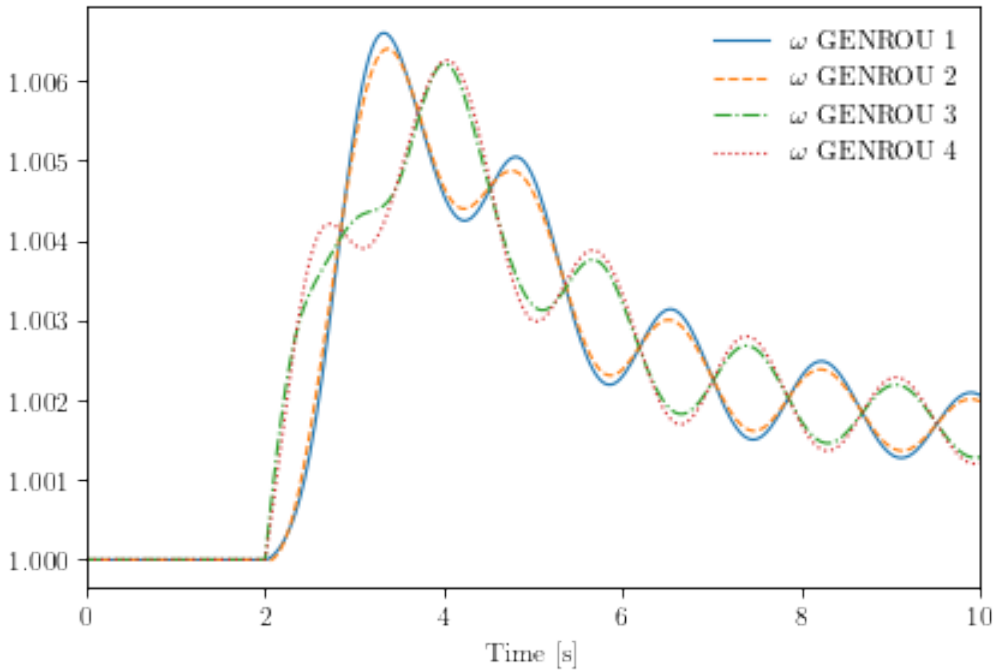
`plotter.plot()` is the entry point for plotting. It is the backend of the command-line `andes plot`.

Before plotting, open the `kundur_full_out.lst` to find the indices (first column) for the variables to plot.

For example, if we want to plot all generator speed, which is the `omega` variable of `GENROU`. By inspect, we found the indices as 5, 6, 7, 8.

Pass them in a tuple or a list to `ss.TDS.plt.plot`.

```
fig, ax = ss.TDS.plt.plot((5, 6, 7, 8))
```



`plot()` returns a figure object and an axis object.

Find index by variable name

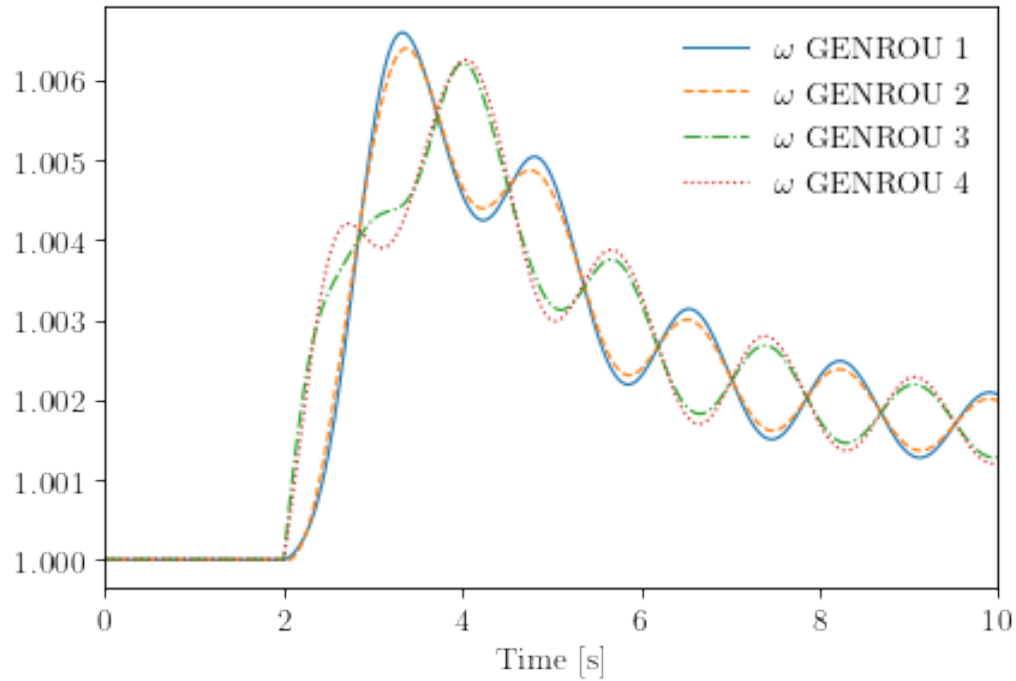
`plotter.find()` is a method for finding indices based on variable name.

The first argument is the pattern to find. An optional argument `exclude` is the pattern to exclude. Regular expression is supported for both.

```
ss.TDS.plt.find('omega')
```

```
([5, 6, 7, 8],
 ['omega GENROU 1', 'omega GENROU 2', 'omega GENROU 3', 'omega GENROU 4'])
```

```
fig, ax = ss.TDS.plotter.plot(ss.TDS.plotter.find('omega')[0])
```

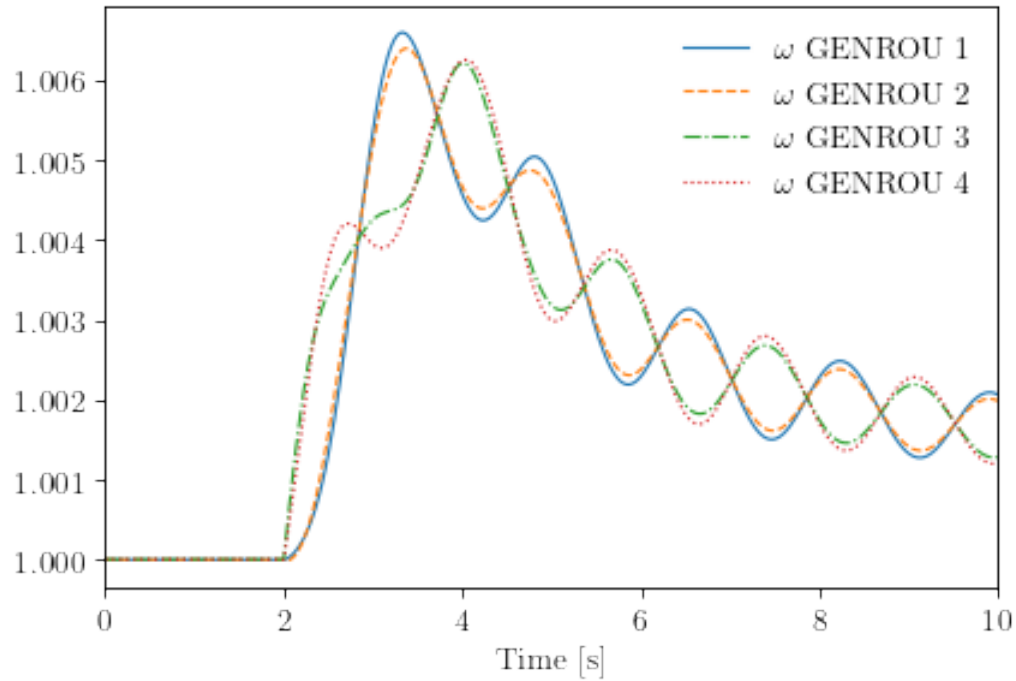


Plotting by variable

Looking up indices from the 1st file can be tedious.

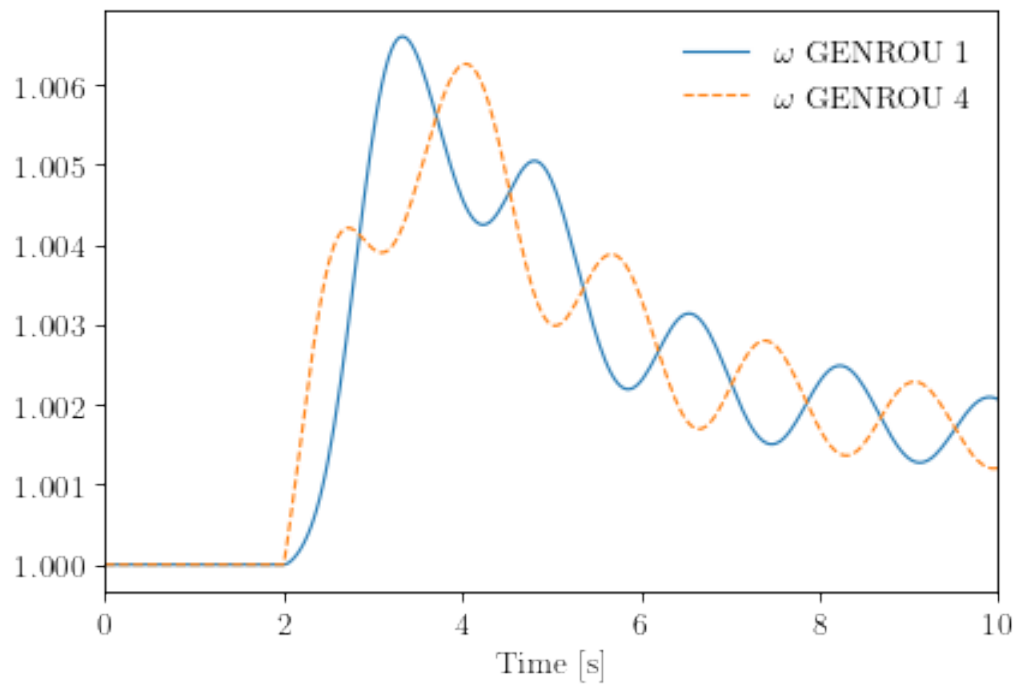
Instead, one can pass a variable in a model to `ss.TDS.plt.plot`. For example, to plot `ss.GENROU.omega`, do

```
fig, ax = ss.TDS.plt.plot(ss.GENROU.omega)
```

To plot a subset of the variables, pass the 0-indexed selection indices in a tuple through argument `a` of `ss.TDS.plt.plot`. For example, to plot the 0-th and the 3-th GENROU `omega`, do

```
fig, ax = ss.TDS.plt.plot(ss.GENROU.omega, a=(0, 3))
```



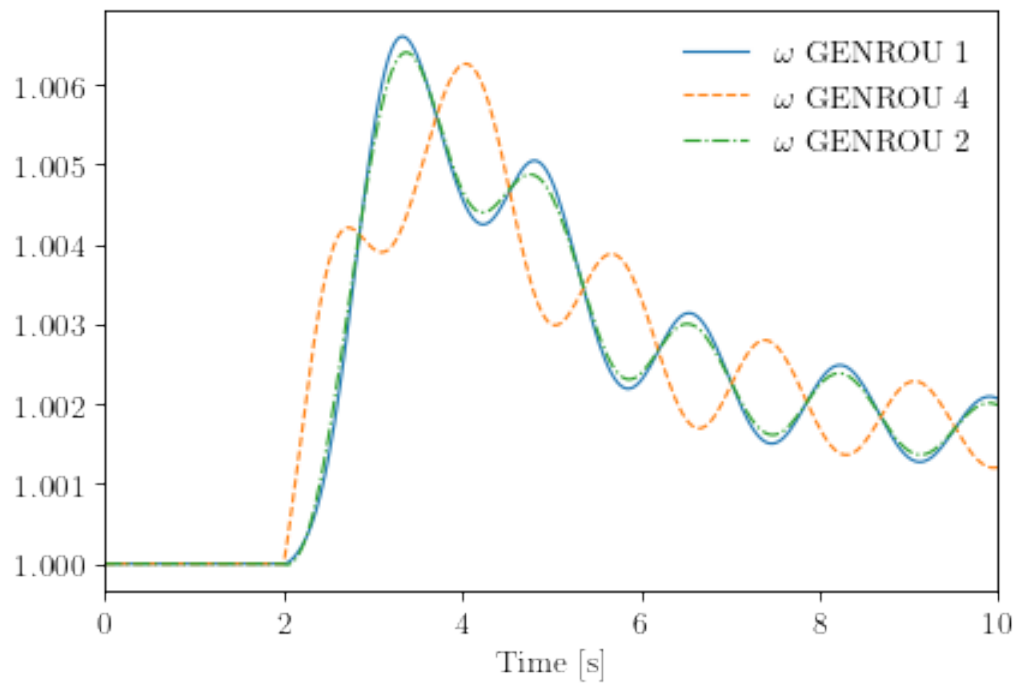
Adding curves to an existing figure

Plotting curves into an existing figure allows easy comparison of results. It can be done by passing a figure and an axis object of `plot()`.

For example, to plot the speed of the second generator ($a=1$) on the figure above, do

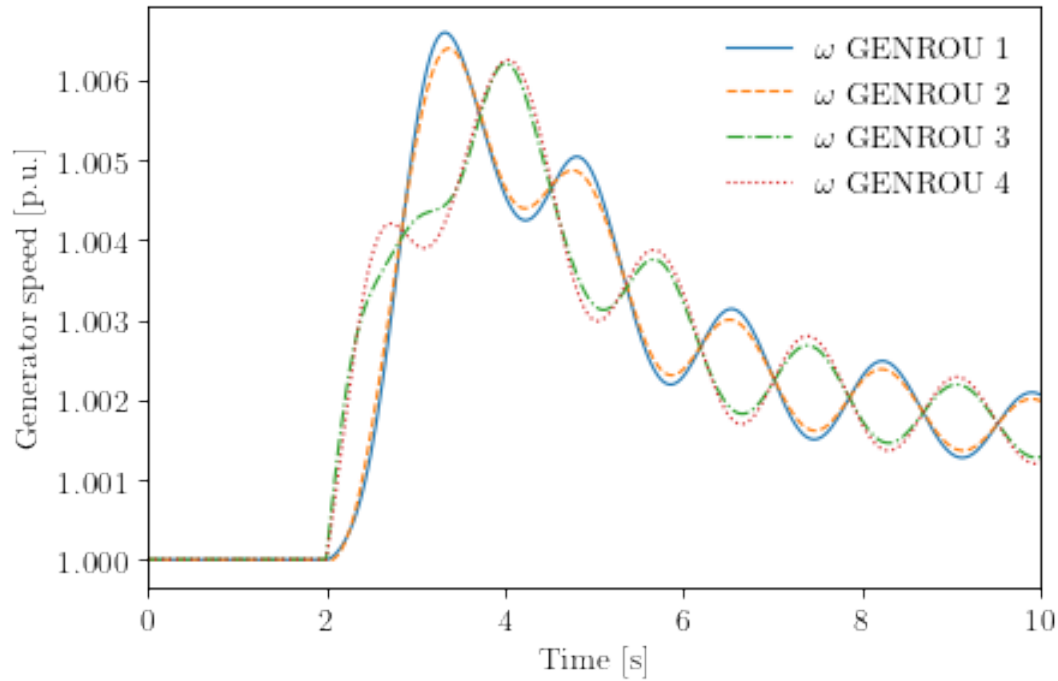
```
fig, ax = ss.TDS.plt.plot(ss.GENROU.omega, a=(1, ), fig=fig, ax=ax,
↳linestyles=['-.-'])
fig
```

<Figure size 432x288 with 0 Axes>



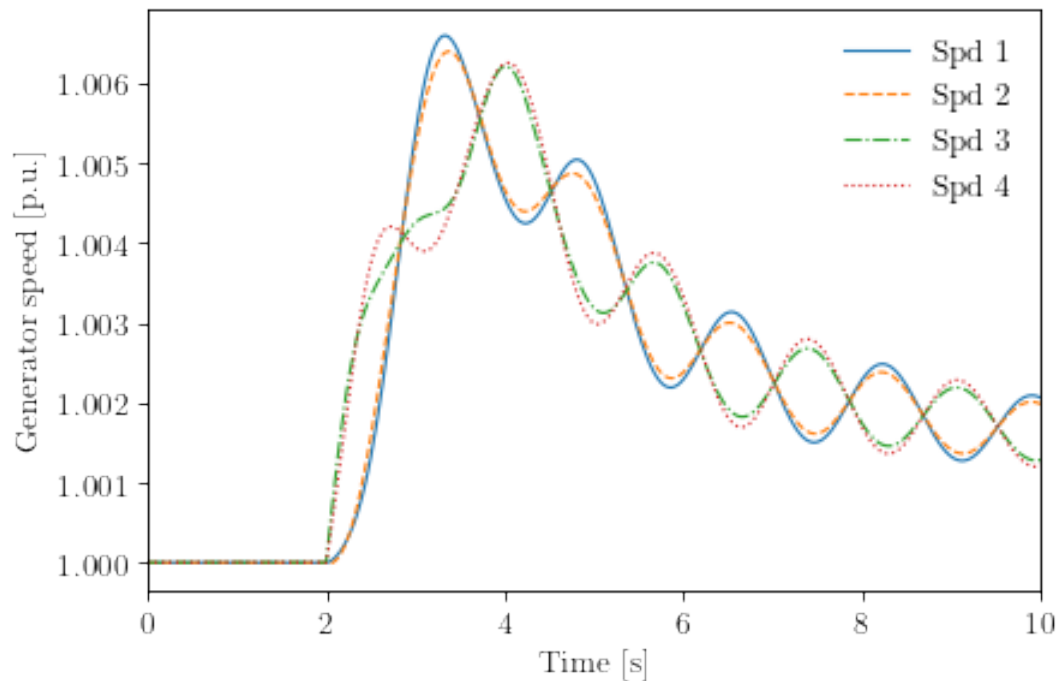
Y-axis label

```
fig, ax = ss.TDS.plotter.plot((5, 6, 7, 8), ylabel='Generator speed [p.u.]')
```



Legend names (yheader)

```
fig, ax = ss.TDS.plotter.plot((5, 6, 7, 8), ylabel='Generator speed [p.u.]',
                              yheader=['Spd 1', 'Spd 2', 'Spd 3', 'Spd 4'])
```



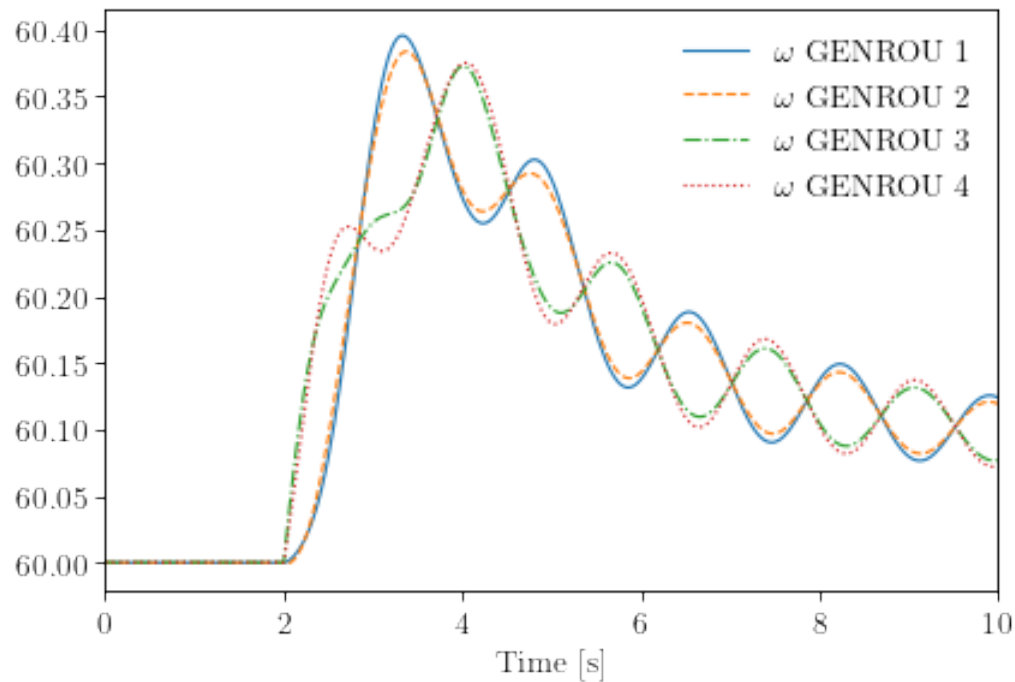
Note that the number of elements passed to `yheader` should match the number of variables. `yheader` only

applies to new curves and cannot be used to modify existing legends.

Scaling

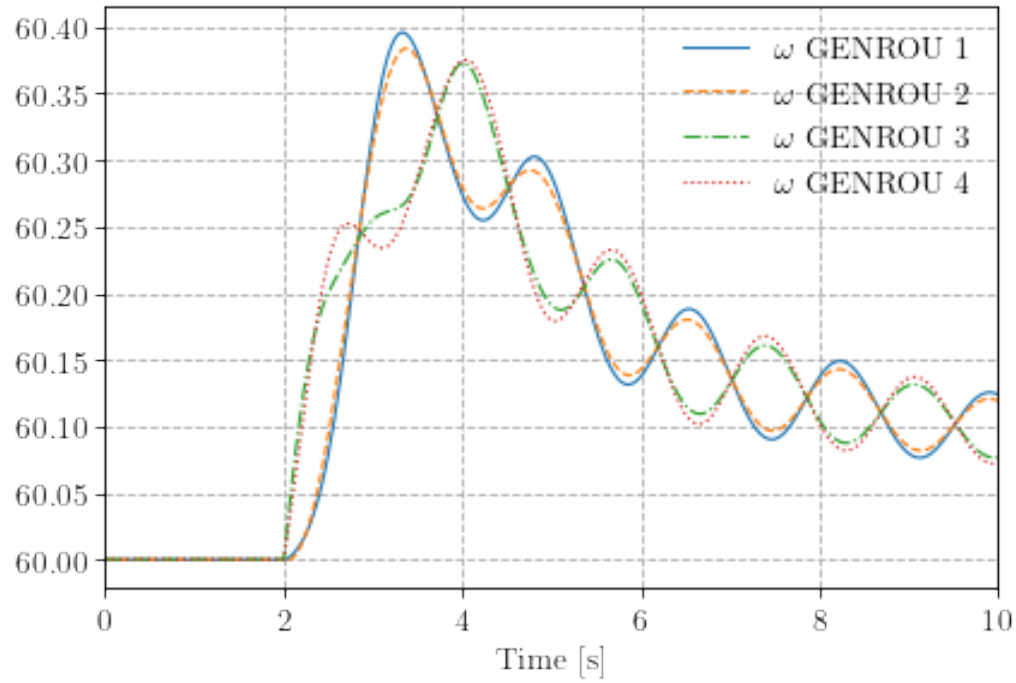
A lambda function can be passed to `ycalc` to scale the value. To scale the frequency from per unit to 60 Hz nominal values, use

```
fig, ax = ss.TDS.plotter.plot((5, 6, 7, 8), ycalc=lambda x: 60 * x)
```



Greyscale and Grid

```
fig, ax = ss.TDS.plotter.plot((5, 6, 7, 8),  
                               ycalc=lambda x: 60 * x,  
                               greyscale=True,  
                               grid=True)
```

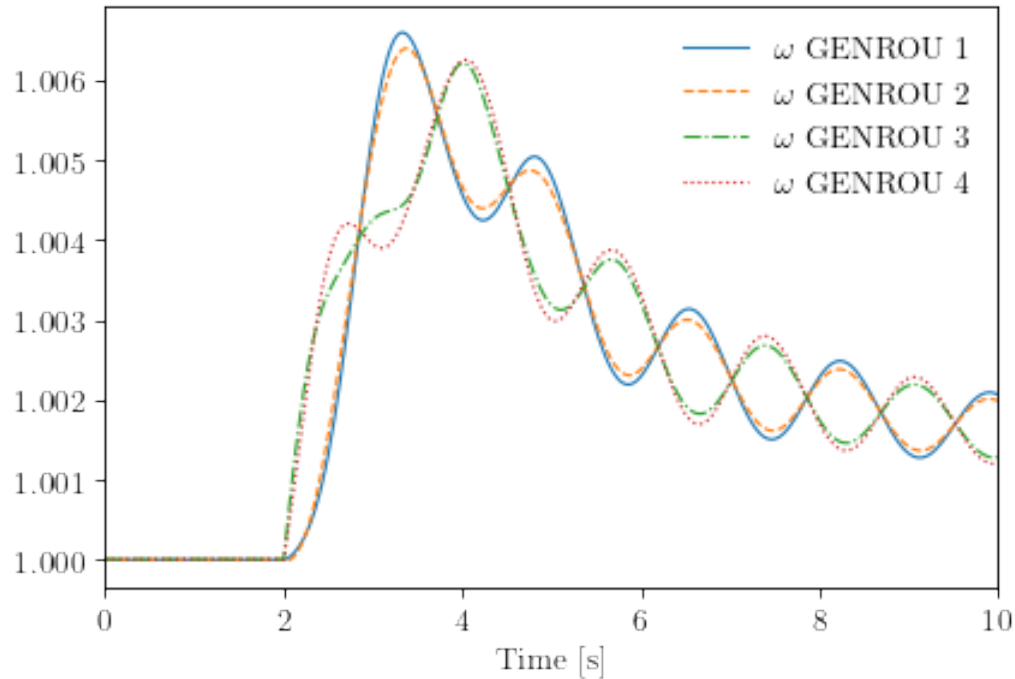


Save figure

Pass `savefig = True` to save the figure to a png file.

```
fig, ax = ss.TDS.plotter.plot((5, 6, 7, 8), savefig=True)
```

Figure saved to "kundur_full_out_1.png".



Additional arguments

`plotter.plot` takes additional arguments. To check additional arguments, please use `help` or refer to the source code.

```
help(ss.TDS.plotter.plot)
```

Help on method `plot` in module `andes.plot`:

```
plot(yidx, xidx=(0,), *, a=None, ytimes=None, ycalc=None, left=None,
    ↳right=None, ymin=None, ymax=None, xlabel=None, ylabel=None, xheader=None,
    ↳yheader=None, legend=None, grid=False, greyscale=False, latex=True, dpi=80,
    ↳line_width=1.0, font_size=12, savefig=None, save_format=None, show=True,
    ↳title=None, linestyle=None, use_bqplot=False, hline1=None, hline2=None,
    ↳vline1=None, vline2=None, hline=None, vline=None, fig=None, ax=None,
    ↳backend=None, set_xlim=True, set_ylim=True, autoscale=False, legend_
    ↳bbox=None, legend_loc=None, legend_ncol=1, figsize=None, color=None,
    ↳**kwargs) method of andes.plot.TDSData instance
    Entry function for plotting.
```

```
    This function retrieves the x and y values based on the `xidx` and
    `yidx` inputs, applies scaling functions `ytimes` and `ycalc`
    ↳sequentially,
    and delegates the plotting to the backend.
```

Parameters

`yidx` : list or int

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```

    The indices for the y-axis variables
xidx : tuple or int, optional
    The index for the x-axis variable
a : tuple or list, optional
    The 0-indexed sub-indices into `yidx` to plot.
ytimes : float, optional
    A scaling factor to apply to all y values.
left : float
    The starting value of the x axis
right : float
    The ending value of the x axis
ymin : float
    The minimum value of the y axis
ymax : float
    The maximum value of the y axis
ylabel : str
    Text label for the y axis
yheader : list
    A list containing the variable names for the y-axis variable
title : str
    Title string to be shown at the top
fig
    Existing figure object to draw the axis on.
ax
    Existing axis object to draw the lines on.

Other Parameters
-----
ycalc: callable, optional
    A callable to apply to all y values after scaling with `ytimes`.
xlabel : str
    Text label for the x axis
xheader : list
    A list containing the variable names for the x-axis variable
legend : bool
    True to show legend and False otherwise
legend_ncol : int
    Number of columns in legend
legend_bbox : tuple of two floats
    legend box to anchor
grid : bool
    True to show grid and False otherwise
latex : bool
    True to enable latex and False to disable
greyscale : bool
    True to use greyscale, False otherwise
savefig : bool or str
    True to save to png figure file.
    str is treated as the output file name.
save_format : str
    File extension string (pdf, png or jpg) for the savefig format
dpi : int

```

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```

    Dots per inch for screen print or save.
    `savefig` uses a minimum of 200 dpi
line_width : float
    Plot line width
font_size : float
    Text font size (labels and legends)
figsize : tuple
    Figure size passed when creating new figure
show : bool
    True to show the image
backend : str or None
    `bqplot` to use the bqplot backend in notebook.
    None for matplotlib.
hline1: float, optional
    Dashed horizontal line 1
hline2: float, optional
    Dashed horizontal line 2
vline1: float, optional
    Dashed horizontal line 1
vline2: float, optional
    Dashed vertical line 2
hline: float or Iterable
    y-axis location of horizontal line(s)
vline: float or Iterable
    x-axis location of vertical line(s)

Returns
-----
(fig, ax)
    Figure and axis handles for matplotlib backend.
fig
    Figure object for bqplot backend.

```

2.1.4 Cleanup

```
! andes misc -C
```

```

"/home/hacui/repos/andes/examples/kundur_full_out.npz" removed.
"/home/hacui/repos/andes/examples/kundur_full_out.txt" removed.
"/home/hacui/repos/andes/examples/kundur_full_out.lst" removed.
"/home/hacui/repos/andes/examples/kundur_full_out.csv" removed.

```

```
!rm kundur_full_out_1.png
```


2.2 Working with Data

This example shows how to work with the data of a loaded test system, including parameters and variables.

```
import andes
from andes.utils.paths import get_case

andes.config_logger()
```

To show all the rows and columns, change the pandas configuration with

```
import pandas as pd

pd.options.display.max_columns = None
pd.options.display.max_rows = None
```

Let's load the Kundur's system.

2.2.1 Load System from an ANDES XLSX File

The ANDES xlsx file is the best supported format. Other formats can be converted to the xlsx format.

See the link below for more about format conversion. <https://github.com/cuihantao/andes/blob/master/README.md#format-converter>

As previously shown, test cases can be loaded with `andes.run()`:

```
ss = andes.run(get_case('kundur/kundur_full.xlsx'),
               default_config=True) # one can remove `default_config=True`
↳to use custom config file
```

```
Working directory: "/home/hacui/repos/andes/examples"
> Loaded generated Python code in "/home/hacui/.andes/pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/kundur/kundur_full.
↳xlsx"...
Input file parsed in 0.1394 seconds.
System internal structure set up in 0.0319 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0036 seconds.
0: |F(x)| = 14.9282832
1: |F(x)| = 3.608627841
2: |F(x)| = 0.1701107882
3: |F(x)| = 0.002038626956
```

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```
4: |F(x)| = 3.745104027e-07
Converged in 5 iterations in 0.0074 seconds.
Report saved to "kundur_full_out.txt" in 0.0010 seconds.
```

```
-> Single process finished in 0.3582 seconds.
```

Alternatively, one can load a test case *without setting up* using `andes.load(..., setup=False)`. Note that `setup=False` option. It is useful to apply parameter changes to an existing test case.

```
ss = andes.load(get_case('kundur/kundur_full.xlsx'),
                default_config=True,
                setup=False)
```

```
Working directory: "/home/hacui/repos/andes/examples"
> Reloaded generated Python code of module "pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/kundur/kundur_full.
->xlsx"...
Input file parsed in 0.1263 seconds.
```

For example, we can toggle the connectivity status `u` of `Line_3` to 0 using

```
ss.Line.alter('u', 'Line_3', 0)
```

When done, remember to set up the system before running calculation routines:

```
ss.setup()

ss.PFlow.run()
```

```
System internal structure set up in 0.0366 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0049 seconds.
0: |F(x)| = 14.9282832
1: |F(x)| = 3.579044433
2: |F(x)| = 0.119268955
3: |F(x)| = 0.03278820195
4: |F(x)| = 2.880943096e-05
5: |F(x)| = 3.93747257e-11
Converged in 6 iterations in 0.0122 seconds.
Report saved to "kundur_full_out.txt" in 0.0016 seconds.
```

```
True
```

After setting up the system, adding or removing devices are not yet allowed.

2.2.2 Load System from PSS/E RAW and DYR Files

ANDES supports loading systems from PSS/E RAW and DYR files.

The PSS/E v32 raw format is best supported.

Note that this feature is experimental. We try out best to support this format, but the compatibility is not guaranteed.

```
raw_path = get_case('kundur/kundur.raw')
dyr_path = get_case('kundur/kundur_full.dyr')
```

The raw file is passed to the positional argument, whereas the dyr file is passed to addfile.

```
ss = andes.run(raw_path, addfile=dyr_path, default_config=True)
```

```
Working directory: "/home/hacui/repos/andes/examples"
> Reloaded generated Python code of module "pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/kundur/kundur.raw"...
  MODIFIED KUNDUR'S TWO-AREA TEST SYSTEM, DISTRIBUTED WITH ANDES
  SEE THE BOOK "POWER SYSTEM STABILITY AND CONTROL" FOR ORIGINAL DATA
Input file parsed in 0.0047 seconds.
Parsing additional file "/home/hacui/repos/andes/andes/cases/kundur/kundur_
→full.dyr"...
Addfile parsed in 0.0912 seconds.
System internal structure set up in 0.0310 seconds.
-> System connectivity check results:
  No islanded bus detected.
  System is interconnected.
  Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
  Numba: Off
  Sparse solver: KLU
  Solution method: NR method
Power flow initialized in 0.0037 seconds.
0: |F(x)| = 3.175850023
1: |F(x)| = 3.176155228e-08
Converged in 2 iterations in 0.0044 seconds.
Report saved to "kundur_out.txt" in 0.0006 seconds.
```

```
-> Single process finished in 0.2371 seconds.
```

Attributes for storing values

Parameters are stored as attributes of the model. For example, `ss.GENROU.M`, the machine starting time constant (2H), is stored in `ss.GENROU.M`.

```
ss.GENROU.M
```

```
NumParam: GENROU.M, v=[117.    117.    111.15 111.15], vin=[13.    13.    12.35,
↪12.35]
```

It is an instance of `NumParam`, which contains fields `v` for the values after converting to system-base per unit values.

```
ss.GENROU.M.v
```

```
array([117.    , 117.    , 111.15, 111.15])
```

And field `vin` is for the original input data.

```
ss.GENROU.M.vin
```

```
array([13.    , 13.    , 12.35, 12.35])
```

Tabulated view

ANDES provides tabulated **view** of model parameters by using `DataFrame`. Each model object has an attribute called `cache` for caching the parameter dataframes.

The original parameters from the input file are stored in `cache.df_in` of the model object. For `GENROU`, do

```
ss.GENROU.cache.df_in
```

	idx	u	name	bus	gen	coi	coi2	Sn	Vn	fn	D	\
uid												
0	GENROU_1	1.0	GENROU_1	1	1	None	None	900.0	20.0	60.0	0.0	
1	GENROU_2	1.0	GENROU_2	2	2	None	None	900.0	20.0	60.0	0.0	
2	GENROU_3	1.0	GENROU_3	3	3	None	None	900.0	20.0	60.0	0.0	
3	GENROU_4	1.0	GENROU_4	4	4	None	None	900.0	20.0	60.0	0.0	
	M	ra	x1	xd1	kp	kw	S10	S12	gammap	gammaq	xd	xq \
uid												
0	13.00	0.0	0.06	0.3	0.0	0.0	0.0	0.0	1.0	1.0	1.8	1.7
1	13.00	0.0	0.06	0.3	0.0	0.0	0.0	0.0	1.0	1.0	1.8	1.7
2	12.35	0.0	0.06	0.3	0.0	0.0	0.0	0.0	1.0	1.0	1.8	1.7
3	12.35	0.0	0.06	0.3	0.0	0.0	0.0	0.0	1.0	1.0	1.8	1.7
	xd2	xq1	xq2	Td10	Td20	Tq10	Tq20					
uid												

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0	0.25	0.55	0.25	8.0	0.03	0.4	0.05
1	0.25	0.55	0.25	8.0	0.03	0.4	0.05
2	0.25	0.55	0.25	8.0	0.03	0.4	0.05
3	0.25	0.55	0.25	8.0	0.03	0.4	0.05

Parameters will be **converted** to per-unit in the system base after loading. This process have been done if `andes.run` is used for loading the data file.

To inspect the converted parameters, check the `cache.df` parameter.

```
ss.GENROU.cache.df
```

	idx	u	name	bus	gen	coi	coi2	Sn	Vn	fn	D	\
uid												
0	GENROU_1	1.0	GENROU_1	1	1	None	None	900.0	20.0	60.0	0.0	
1	GENROU_2	1.0	GENROU_2	2	2	None	None	900.0	20.0	60.0	0.0	
2	GENROU_3	1.0	GENROU_3	3	3	None	None	900.0	20.0	60.0	0.0	
3	GENROU_4	1.0	GENROU_4	4	4	None	None	900.0	20.0	60.0	0.0	
	M	ra	x1	xd1	kp	kw	S10	S12	gammap	gammaq	xd	\
uid												
0	117.00	0.0	0.006667	0.033333	0.0	0.0	0.0	0.0	1.0	1.0	0.2	
1	117.00	0.0	0.006667	0.033333	0.0	0.0	0.0	0.0	1.0	1.0	0.2	
2	111.15	0.0	0.006667	0.033333	0.0	0.0	0.0	0.0	1.0	1.0	0.2	
3	111.15	0.0	0.006667	0.033333	0.0	0.0	0.0	0.0	1.0	1.0	0.2	
	xq	xd2	xq1	xq2	Td10	Td20	Tq10	Tq20				
uid												
0	0.188889	0.027778	0.061111	0.027778	8.0	0.03	0.4	0.05				
1	0.188889	0.027778	0.061111	0.027778	8.0	0.03	0.4	0.05				
2	0.188889	0.027778	0.061111	0.027778	8.0	0.03	0.4	0.05				
3	0.188889	0.027778	0.061111	0.027778	8.0	0.03	0.4	0.05				

One will notice the converted parameters such as `M`, `x1`, and all other impedances.

It is very important to notice that `cache.df` and `cache.df_in` are both views. Altering data in these views will NOT alter the underlying parameter values.

To alter values, see the example below.

One may have noticed that `ss.GENROU.cache.df` and `ss.GENROU.as_df()` returns the same dataframe. The difference is that the latter creates a new dataframe everytime it is called, but the former caches the dataframe when it is initially accessed.

Altering parameters

Parameters can be altered by calling the `alter` method on a model instance.

We first look up the original value through `get`.

Either `v` or `vin` can be passed to argument `attr` to retrieve the converted or the original data. Here we are retrieving the original input data. If `attr` is not provided, `get` returns the value after per-unit conversion, which is the value used for calculation, by default.

```
ss.GENROU.get("M", "GENROU_1", attr='vin')
```

```
13.0
```

To change the `M` of `GENROU_1` to 10, do

```
ss.GENROU.alter("M", "GENROU_1", 10)
```

The value set through `alter` is always the data before per-unit conversion - just like it should have been in an input file. ANDES will perform the conversion and set `vin` and `v` correctly.

Parameters altered through `Model.alter()` can be saved as a new system using

```
andes.io.xlsx.write(ss, 'new_system.xlsx', overwrite=True)
```

```
xlsx file written to "new_system.xlsx"
```

```
True
```

In-place update

`alter()` can be used to change the value of `ConstService` to modify the equation that depend on such `ConstService`. For example, the distributed PV model `PVD1` implements a `ConstService` called `pref0` to store the initial value of the power reference. An equation associated with variable `Pref` enforces that $0 = \text{Pref} - \text{pref0}$.

If one needs to modify `Pref`, it has to be done through modifying `pref0`. Modifying `Pref` directly will not take any effect since the variable will be overwritten by the solution of equations.

To update `pref0` for a `PVD1` device with `idx = "PVD_1"`, one can do

```
ss.PVD1.alter('pref0', 'PVD_1', 0.005)
```

or, using keyword arguments in any order,

```
ss.PVD1.alter(src='pref0', idx='PVD_1', value=0.005)
```

If `PVD_1` is the first (i.e., 0-th in the Python indexing) in the `idx` list, this modification is equivalent to setting

```
ss.PVD1.pref0.v[0] = 0.005.
```

Since index 0 is given, the array `ss.PVD1.pref0.v` is updated in-place.

When one needs to modify the `pref0` of all PVD1 devices to 0.005, one can do

```
ss.PVD1.alter('pref0', ss.PVD1.idx.v, 0.005)
```

This is equivalent to

```
ss.PVD1.pref0.v[:] = 0.005
```

Note the `[:]` in the above line. This is a slice operation so that the assignment happens in-place.

One must never do out-of-place assignment, i.e.,

```
ss.PVD1.pref0.v = 0.005
```

or

```
ss.PVD1.pref0.v = 0.005 * np.ones_line(ss.PVD1.pref0.v)
```

because the assignment will point `ss.PVD1.pref0.v` to a new array. Internally, ANDES reuses the memory for all arrays, meaning that their addresses are assumed to be constant. If one modifies `ss.PVD1.pref0.v` out of place, the previous memory will no longer be accessible through `ss.PVD1.pref0.v`.

On the safe side, one should modify variables using `alter()` or, at least, always use in-place assignment to internal arrays.

Refreshing the view

As mentioned, `cache.df` and `cache.df_in` are *cached* views and will not be automatically updated for inspection.

This is generally not an issue if one performs the simulation after altering data. However, if one needs to inspect the data again, `cache.refresh()` needs to be called manually.

```
ss.GENROU.cache.refresh()
```

```
ss.GENROU.cache.df_in
```

	idx	u	name	bus	gen	coi	coi2	Sn	Vn	fn	D	\	
uid													
0	GENROU_1	1.0	GENROU_1	1	1	None	None	900.0	20.0	60.0	0.0		
1	GENROU_2	1.0	GENROU_2	2	2	None	None	900.0	20.0	60.0	0.0		
2	GENROU_3	1.0	GENROU_3	3	3	None	None	900.0	20.0	60.0	0.0		
3	GENROU_4	1.0	GENROU_4	4	4	None	None	900.0	20.0	60.0	0.0		
	M	ra	xl	xd1	kp	kw	S10	S12	gammap	gammaq	xd	xq	\
uid													
0	10.00	0.0	0.06	0.3	0.0	0.0	0.0	0.0	1.0	1.0	1.8	1.7	
1	13.00	0.0	0.06	0.3	0.0	0.0	0.0	0.0	1.0	1.0	1.8	1.7	
2	12.35	0.0	0.06	0.3	0.0	0.0	0.0	0.0	1.0	1.0	1.8	1.7	
3	12.35	0.0	0.06	0.3	0.0	0.0	0.0	0.0	1.0	1.0	1.8	1.7	
	xd2	xq1	xq2	Td10	Td20	Tq10	Tq20						
uid													

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0	0.25	0.55	0.25	8.0	0.03	0.4	0.05
1	0.25	0.55	0.25	8.0	0.03	0.4	0.05
2	0.25	0.55	0.25	8.0	0.03	0.4	0.05
3	0.25	0.55	0.25	8.0	0.03	0.4	0.05

Alternatively, one can call the `as_df()` function to build a new dataframe *without overwriting* the cache:

```
ss.GENROU.as_df()
```

uid	idx	u	name	bus	gen	coi	coi2	Sn	Vn	fn	D	\
0	GENROU_1	1.0	GENROU_1	1	1	None	None	900.0	20.0	60.0	0.0	
1	GENROU_2	1.0	GENROU_2	2	2	None	None	900.0	20.0	60.0	0.0	
2	GENROU_3	1.0	GENROU_3	3	3	None	None	900.0	20.0	60.0	0.0	
3	GENROU_4	1.0	GENROU_4	4	4	None	None	900.0	20.0	60.0	0.0	

	M	ra	xl	xd1	kp	kw	S10	S12	gammap	gammaq	xd	\
0	90.00	0.0	0.006667	0.033333	0.0	0.0	0.0	0.0	1.0	1.0	0.2	
1	117.00	0.0	0.006667	0.033333	0.0	0.0	0.0	0.0	1.0	1.0	0.2	
2	111.15	0.0	0.006667	0.033333	0.0	0.0	0.0	0.0	1.0	1.0	0.2	
3	111.15	0.0	0.006667	0.033333	0.0	0.0	0.0	0.0	1.0	1.0	0.2	

uid	xq	xd2	xq1	xq2	Td10	Td20	Tq10	Tq20
0	0.188889	0.027778	0.061111	0.027778	8.0	0.03	0.4	0.05
1	0.188889	0.027778	0.061111	0.027778	8.0	0.03	0.4	0.05
2	0.188889	0.027778	0.061111	0.027778	8.0	0.03	0.4	0.05
3	0.188889	0.027778	0.061111	0.027778	8.0	0.03	0.4	0.05

2.2.3 Variables

Snapshots

One might also want to check the variable values in a similar way to that for a parameter. Certainly, a variable has a `v` attribute which stores values.

It is important to note that `v` only holds the values at the last program state. Such program state could be the solution of power flow, the initialization of time-domain simulation, or the end of a simulation disturbances.

Since we have only ran power flow for `ss`, `ss.Bus.v.v` are the voltage magnitude solutions, where the first `v` is for "voltage", and the second `v` is the first `v`'s value attribute.

```
ss.Bus.v.v
```

```
array([1.          , 1.          , 1.          , 1.          , 0.98337472,
        0.96908585, 0.9562181 , 0.95400018, 0.96856366, 0.98377143])
```


Variables hold more than values. They have an attribute `a` for the addresses indexing into the corresponding type of array.

There are two system-level arrays, `ss.dae.x` and `ss.dae.y` for the right-hand-side of the differential and algebraic equations, respectively.

```
type(ss.Bus.v)
```

```
andes.core.var.Algeb
```

`ss.Bus.v` is an algebraic variable, thus `ss.Bus.v.a` holds the indices into `ss.dae.g`.

```
ss.dae.y[ss.Bus.v.a]
```

```
array([1.          , 1.          , 1.          , 1.          , 0.98337472,
        0.96908585, 0.9562181 , 0.95400018, 0.96856366, 0.98377143])
```

We can see that these two values are the same.

Time series

After a time-domain simulation, the time series of the variables can be retrieved through `ss.dae.ts`. Let's first run a simulation.

```
ss.TDS.run()
```

```
-> Time Domain Simulation Summary:
Sparse Solver: KLU
Simulation time: 0.0-20.0 s.
Fixed step size: h=33.33 ms. Shrink if not converged.
Initialization for dynamics completed in 0.0489 seconds.
Initialization was successful.
```

```
0%|          | 0/100 [00:00<?, ?%/s]
```

```
<Toggle Toggle_1>: Line.Line_8 status changed to 0 at t=2.0 sec.
```

```
Simulation completed in 1.1192 seconds.
Outputs to "kundur_out.lst" and "kundur_out.npz".
Outputs written in 0.0226 seconds.
```

```
True
```

```
ss.dae.ts
```

```
<andes.variables.dae.DAETimeSeries at 0x7f7bc75c1b50>
```

`ss.dae.ts` has four commonly used attributes: `t` for time stamps, `xy` for variables (differential and then algebraic), `z` for discontinuous states, and `df` for the dataframe of all.

- Each point in `ss.dae.ts.t` correspond to a row in `ss.dae.ts.xy`.
- Each column in `ss.dae.ts.xy` correspond to a variable, whose name can be located in `ss.dae.xy_name`, for all timestamps.
- `z` is not stored by default unless one enables it before simulation by setting `ss.TDS.config.store_z = 1`.
- `df` is not built by default but can be manually triggered after simulation by calling `ss.dae.ts.unpack(df=True)`

The following are some statistics of the shapes of arrays:

```
ss.dae.ts.t.shape
```

```
(603,)
```

```
ss.dae.ts.xy.shape  # x-axis is for time stamps, and y-axis is for variables
```

```
(603, 201)
```

```
len(ss.dae.xy_name)
```

```
201
```

Extracting Variable Data

Let's extract the data for rotor speed (variable `omega`) of GENROU generators. The first step to extract variable data is to determine the type of the variable: differential or algebraic. One can print the variable to see the type:

```
ss.GENROU.omega
```

```
State: GENROU.omega, a=[4 5 6 7], v=[1.00165687 1.00166417 1.00182915 1.  
↪00184744], e=[-0.00251535 -0.00375723 0.00131868 0.00182826]
```

The output shows that `omega` is a state (differential variable), which should be looked up in `ss.dae.x`. For algebraic variables such as `ss.Bus.v`, they should be looked up in `ss.dae.y`.

Therefore, all `omega` variables can be extracted as follows:

```
omega = ss.dae.ts.x[:, ss.GENROU.omega.a]
```

where the `:` in the first axis will access such data for all time stamps, and `ss.GENROU.omega.a` stores the addresses of all `omega` into `ss.dae.x`.

To access all bus voltages (algebraic variable `v`) of the generators, one can use:

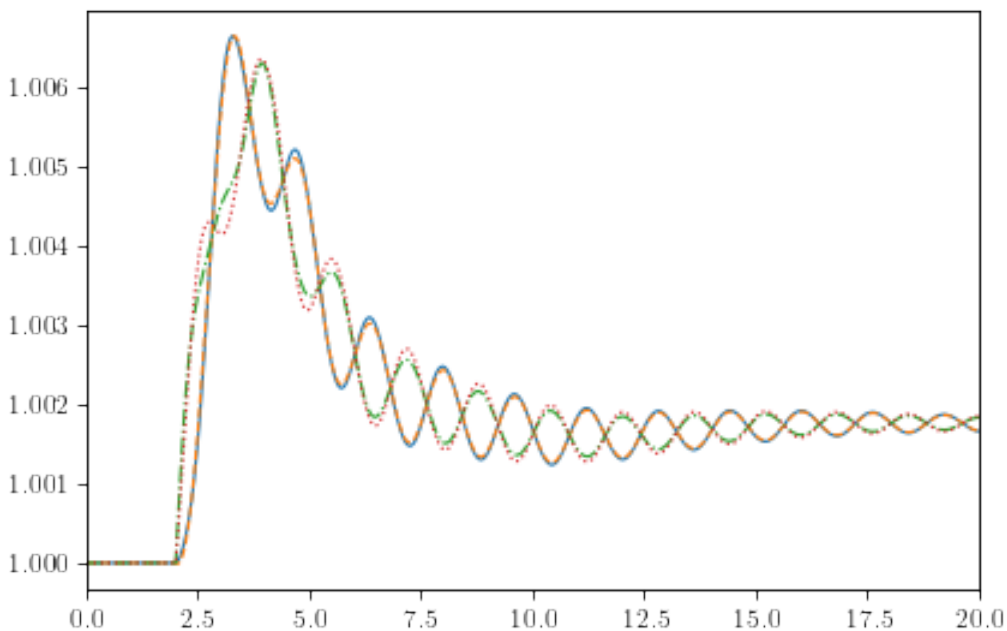
```
ss.dae.ts.y[:, ss.GENROU.v.a]
```

```
array([[1.          , 1.          , 1.          , 1.          ],
       [1.          , 1.          , 1.          , 1.          ],
       [1.          , 1.          , 1.          , 1.          ],
       ...,
       [1.00240968, 1.00148908, 0.99526693, 1.00007159],
       [1.00249935, 1.00159007, 0.99515528, 0.99997846],
       [1.00259067, 1.0016924 , 0.99504062, 0.999883   ]])
```

These data correspond to the timestamps stored in `ss.dae.ts.t`. One can process such data as necessary.

To show verify the extracted data, we plot them with `ss.TDS.plt.plot_data`.

```
ss.TDS.plt.plot_data(ss.dae.ts.t, omega )
```



```
(<Figure size 480x320 with 1 Axes>, <AxesSubplot:>)
```

2.2.4 Altering Fault duration

`Alter` can be used for updating any model parameter. We show another example of updating the duration of a fault. Using the `ieee14_fault.xlsx` test case, we have

```
ss = andes.run(get_case("ieee14/ieee14_fault.xlsx"))
```

```
Working directory: "/home/hacui/repos/andes/examples"
> Loaded config from file "/home/hacui/.andes/andes.rc"
> Reloaded generated Python code of module "pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/ieee14/ieee14_fault.
  ↳xlsx"...
```

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```

Input file parsed in 0.0546 seconds.
System internal structure set up in 0.0348 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0037 seconds.
0: |F(x)| = 0.5605182134
1: |F(x)| = 0.006202200332
2: |F(x)| = 5.819382824e-06
3: |F(x)| = 6.96508129e-12
Converged in 4 iterations in 0.0047 seconds.
Initialization for dynamics completed in 0.0353 seconds.
Initialization was successful.
Report saved to "ieee14_fault_out.txt" in 0.0021 seconds.

```

```

-> Single process finished in 0.3141 seconds.

```

Again, if you need to add devices, you should use `ss = andes.load(..., setup=False)` and `ss.setup()` instead of `andes.run()`.

List the existing Fault devices:

```
ss.Fault.as_df()
```

	idx	u	name	bus	tf	tc	xf	rf
uid								
0	1	1.0	Fault_1	9	1.0	1.1	0.0001	0.0

One fault on Bus 9 is applied at $t=1.0$ sec and cleared at $t=1.1$ sec. Suppose that we want to clear the fault at $t = 1.05$ sec, we can do

```
ss.Fault.alter('tc', 1, 1.05) # arguments are `src`, `idx`, `value`
```

where `tc` is the parameter to alter, `1` is the `idx` of the Fault to find, and `1.05` is the new value. Inspect the Fault devices to see the updated value. The simulation for the new system can be performed next.

```
ss.Fault.as_df()
```

	idx	u	name	bus	tf	tc	xf	rf
uid								
0	1	1.0	Fault_1	9	1.0	1.05	0.0001	0.0

2.2.5 Cleanup

```
!andes misc -C
```

```
"/home/hacui/repos/andes/examples/kundur_full_out.txt" removed.
"/home/hacui/repos/andes/examples/kundur_out.lst" removed.
"/home/hacui/repos/andes/examples/kundur_out.npz" removed.
"/home/hacui/repos/andes/examples/ieee14_fault_out.txt" removed.
"/home/hacui/repos/andes/examples/kundur_out.txt" removed.
```

```
!rm new_system.xlsx
```

2.3 Inspecting Models

First of all, import `andes` and configure the logger to the `WARNING` level (30).

```
import andes
andes.config_logger(30)
```

2.3.1 Inspect Model Equations

Create an empty `andes.System` object and call `prepare(nomp=True)` to generate equations and pretty print, where `nomp` disables multiprocessing so that equations can be properly returned. This operation may take a moment.

To only generate equations for a specific model, such as `GENCLS`, do:

```
ss = andes.System()
ss.GENCLS.prepare()
```

List all models

```
print(ss.supported_models())
```

Supported Groups and Models

Group	Models
ACLine	Line
ACShort	Jumper
ACTopology	Bus
Calculation	ACE, ACEc, COI
Collection	Area
DCLink	Ground, R, L, C, RCp, RCs, RLs, RLCs, RLCp

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DCTopology	Node
DG	PVD1, ESD1, EV1, EV2
DGProtection	DGPRCT1, DGPRCTExt
DynLoad	ZIP, FLoad
Exciter	EXDC2, IEEEEX1, ESDC2A, EXST1, ESST3A, SEXS, IEEEET1, EXAC1, EXAC4, ESST4B, AC8B, IEEEET3, ESAC1A, ESST1A
FreqMeasurement	BusFreq, BusROCOF
Information	Summary
Motor	Motor3, Motor5
PLL	PLL1
PSS	IEEEEST, ST2CUT
PhasorMeasurement	PMU
RenAerodynamics	WTARA1, WTARV1
RenExciter	REECA1, REECA1E, REECA1G
RenGen	REGCA1, REGCP1, REGCV1, REGCV2
RenGovernor	WTDTA1, WTDS
RenPitch	WTPTA1
RenPlant	REPCA1
RenTorque	WTTQA1
StaticACDC	VSCShunt
StaticGen	PV, Slack
StaticLoad	PQ
StaticShunt	Shunt, ShuntTD, ShuntSw
SynGen	GENCLS, GENROU, PLBVFU1, GENROUOS
TimedEvent	Toggle, Fault, Alter
TurbineGov	TG2, TGOV1, TGOV1DB, TGOV1N, TGOV1NDB, IEEEG1, IEESGO, GAST, HYGOV, HYGOVDB
Undefined	TimeSeries
VoltComp	IEEEVC

2.3.2 Check model documentation

To check the documentation for the model, print the return of `doc()` for the model instance.

For example, the documentation for GENCLS can be printed with

```
print(ss.GENCLS.doc())
```

Model <GENCLS> in Group <SynGen>
Classical generator model.

Parameters

Name	Description	Default	Unit	Properties
idx	unique device idx			
u	connection status	1	bool	
name	device name			
bus	interface bus id			mandatory
gen	static generator index			mandatory

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coi	center of inertia index			
coi2	center of inertia index			
Sn	Power rating	100	MVA	
Vn	AC voltage rating	110		
fn	rated frequency	60		
D	Damping coefficient	0		power
M	machine start up time	6		non_zero, non_negative, power
	(2H)			
ra	armature resistance	0		z
xl	leakage reactance	0		z
xd1	d-axis transient reactance	0.302		z
kp	active power feedback gain	0		
kw	speed feedback gain	0		
S10	first saturation factor	0		
S12	second saturation factor	1		
gammap	P ratio of linked static gen	1		
gammaq	Q ratio of linked static gen	1		
subidx	Generator idx in plant; only used by PSS/E data	0		

Variables

Name	Type	Description	Unit	Properties
delta	State	rotor angle	rad	v_str
omega	State	rotor speed	pu (Hz)	v_str
Id	Algeb	d-axis current		v_str
Iq	Algeb	q-axis current		v_str
vd	Algeb	d-axis voltage		v_str
vq	Algeb	q-axis voltage		v_str
tm	Algeb	mechanical torque		v_str
te	Algeb	electric torque		v_str
vf	Algeb	excitation voltage	pu	v_str
XadIfd	Algeb	d-axis armature excitation current	p.u (kV)	v_str
Pe	Algeb	active power injection		v_str
Qe	Algeb	reactive power injection		v_str
psid	Algeb	d-axis flux		v_str
psiq	Algeb	q-axis flux		v_str
a	ExtAlgeb	Bus voltage phase angle		
v	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Type	Initial Value
delta	State	delta0
omega	State	u

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Id	Algeb	u * Id0
Iq	Algeb	u * Iq0
vd	Algeb	u * vd0
vq	Algeb	u * vq0
tm	Algeb	tm0
te	Algeb	u * tm0
vf	Algeb	u * vf0
XadIfd	Algeb	u * vf0
Pe	Algeb	u * (vd0 * Id0 + vq0 * Iq0)
Qe	Algeb	u * (vq0 * Id0 - vd0 * Iq0)
psid	Algeb	u * psid0
psiq	Algeb	u * psiq0
a	ExtAlgeb	
v	ExtAlgeb	

Differential Equations

Name	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
-----+-----+-----+-----			
delta	State	u * (2 * pi * fn) * (omega - 1)	
omega	State	u * (tm - te - D * (omega - 1))	M

Algebraic Equations

Name	Type	RHS of Equation "0 = g(x, y)"
-----+-----+-----		
Id	Algeb	+ xq * Id - vf+ psid
Iq	Algeb	+ xq * Iq+ psiq
vd	Algeb	u * v * sin(delta - a) - vd
vq	Algeb	u * v * cos(delta - a) - vq
tm	Algeb	tm0 - tm
te	Algeb	u * (psid * Iq - psiq * Id) - te
vf	Algeb	u * vf0 - vf
XadIfd	Algeb	u * vf0 - XadIfd
Pe	Algeb	u * (vd * Id + vq * Iq) - Pe
Qe	Algeb	u * (vq * Id - vd * Iq) - Qe
psid	Algeb	u * (ra*Iq + vq) - psid
psiq	Algeb	u * (ra*Id + vd) + psiq
a	ExtAlgeb	-u * (vd * Id + vq * Iq)
v	ExtAlgeb	-u * (vq * Id - vd * Iq)

Services

Name	Equation	Type
-----+-----+-----		
p0	p0s * gammap	ConstService
q0	q0s * gammaq	ConstService
_V	v * exp(1j * a)	ConstService
_S	p0 - 1j * q0	ConstService
_I	_S / conj(_V)	ConstService
_E	_V + _I * (ra + 1j * xq)	ConstService
_deltac	log(_E / abs(_E))	ConstService

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delta0	u * im(_deltac)	ConstService
vdq	u * (_V * exp(1j * 0.5 * pi - _deltac))	ConstService
Idq	u * (_I * exp(1j * 0.5 * pi - _deltac))	ConstService
Id0	re(Idq)	ConstService
Iq0	im(Idq)	ConstService
vd0	re(vdq)	ConstService
vq0	im(vdq)	ConstService
tm0	u * ((vq0 + ra * Iq0) * Iq0 + (vd0 + ra * Id0) * Id0)	ConstService
psid0	u * (ra * Iq0) + vq0	ConstService
psiq0	-u * (ra * Id0) - vd0	ConstService
vf0	(vq0 + ra * Iq0) + xq * Id0	ConstService

Config Fields in [GENCLS]

Option	Value	Info	Acceptable values
allow_adjust	1	allow adjusting upper or lower limits	(0, 1)
adjust_lower	0	adjust lower limit	(0, 1)
adjust_upper	1	adjust upper limit	(0, 1)
vf_lower	1	lower limit for vf warning	
vf_upper	5	upper limit for vf warning	

Pretty print of variables

All symbols are stored in the attributes of `Model.syms`. For example,

```
ss.GENCLS.syms.xy
```

$$\begin{bmatrix} \delta \\ \omega \\ I_d \\ I_q \\ V_d \\ V_q \\ \tau_m \\ \tau_e \\ v_f \\ X_{ad}I_{fd} \\ P_e \\ Q_e \\ \psi_d \\ \psi_q \\ \theta \\ V \end{bmatrix}$$

Differential variables comes before algebraic variables.

```
ss.GENCLS.states
```

```
OrderedDict([('delta', State: GENCLS.delta, []),
             ('omega', State: GENCLS.omega, [])])
```

```
ss.GENCLS.algebs
```

```
OrderedDict([('Id', Algeb: GENCLS.Id, []),
             ('Iq', Algeb: GENCLS.Iq, []),
             ('vd', Algeb: GENCLS.vd, []),
             ('vq', Algeb: GENCLS.vq, []),
             ('tm', Algeb: GENCLS.tm, []),
             ('te', Algeb: GENCLS.te, []),
             ('vf', Algeb: GENCLS.vf, []),
             ('XadIfd', Algeb: GENCLS.XadIfd, []),
             ('Pe', Algeb: GENCLS.Pe, []),
             ('Qe', Algeb: GENCLS.Qe, []),
             ('psid', Algeb: GENCLS.psid, []),
             ('psiq', Algeb: GENCLS.psiq, [])])
```

Pretty print of equations

Formatted equations are stored in each model. The following attributes of `Model.syms` are available for equation printing.

- `f`: differential equations
- `g`: algebraic equations
- `df`: df/dxy
- `dg`: dg/dxy

```
ss.GENCLS.syms.f
```

$$\begin{bmatrix} 2\pi fu(\omega - 1) \\ u(-D(\omega - 1) - \tau_e + \tau_m) \end{bmatrix}$$

```
ss.GENCLS.syms.g
```

$$\begin{bmatrix} I_d x_q + \psi_d - v_f \\ I_q x_q + \psi_q \\ V u \sin(\delta - \theta) - V_d \\ V u \cos(\delta - \theta) - V_q \\ -\tau_m + \tau_{m0} \\ -\tau_e + u(-I_d \psi_q + I_q \psi_d) \\ u v_{f0} - v_f \\ -X_{ad} I_{fd} + u v_{f0} \\ -P_e + u(I_d V_d + I_q V_q) \\ -Q_e + u(I_d V_q - I_q V_d) \\ -\psi_d + u(I_q r_a + V_q) \\ \psi_q + u(I_d r_a + V_d) \\ -u(I_d V_d + I_q V_q) \\ -u(I_d V_q - I_q V_d) \end{bmatrix}$$

```
ss.GENCLS.syms.df
```

$$\begin{bmatrix} 0 & 2\pi f u & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -D u & 0 & 0 & 0 & 0 & u & -u & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

```
ss.GENCLS.syms.dg
```

$$\begin{bmatrix} 0 & 0 & x_q & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & x_q & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ V u \cos(\delta - \theta) & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -V u \cos(\delta - \theta) \\ -V u \sin(\delta - \theta) & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & V u \sin(\delta - \theta) \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -\psi_q u & \psi_d u & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & I_q u & -I_d u & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & V_d u & V_q u & I_d u & I_q u & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & V_q u & -V_d u & -I_q u & I_d u & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & r_a u & 0 & u & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & r_a u & 0 & u & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -V_d u & -V_q u & -I_d u & -I_q u & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -V_q u & V_d u & I_q u & -I_d u & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Pretty print of services

The list of services is in `services`.

```
ss.GENCLS.services
```

```
OrderedDict([('p0', ConstService: GENCLS.p0, v=0.0),
             ('q0', ConstService: GENCLS.q0, v=0.0),
             ('_V', ConstService: GENCLS._V, v=0.0),
             ('_S', ConstService: GENCLS._S, v=0.0),
             ('_I', ConstService: GENCLS._I, v=0.0),
             ('_E', ConstService: GENCLS._E, v=0.0),
             ('_deltac', ConstService: GENCLS._deltac, v=0.0),
             ('delta0', ConstService: GENCLS.delta0, v=0.0),
             ('vdq', ConstService: GENCLS.vdq, v=0.0),
             ('Idq', ConstService: GENCLS.Idq, v=0.0),
             ('Id0', ConstService: GENCLS.Id0, v=0.0),
             ('Iq0', ConstService: GENCLS.Iq0, v=0.0),
             ('vd0', ConstService: GENCLS.vd0, v=0.0),
             ('vq0', ConstService: GENCLS.vq0, v=0.0),
             ('tm0', ConstService: GENCLS.tm0, v=0.0),
             ('psid0', ConstService: GENCLS.psid0, v=0.0),
             ('psi0', ConstService: GENCLS.psi0, v=0.0),
             ('vf0', ConstService: GENCLS.vf0, v=0.0)])
```

Service equations are in `Model.syms.s`. For example, services of GENCLS is in

```
ss.GENCLS.syms.s
```

```
[P_{0s}*\gamma_P,
 Q_{0s}*\gamma_Q,
 V*exp(I*\theta),
 P_0 - I*Q_0,
 S/conj(V_c),
 I_c*(r_a + I*xq) + V_c,
 log(E/Abs(E)),
 u*im(\delta_c),
 V_c*u*exp(-\delta_c + 0.5*I*pi),
 I_c*u*exp(-\delta_c + 0.5*I*pi),
 re(I_{dq}),
 im(I_{dq}),
 re(V_{dq}),
 im(V_{dq}),
 u*(I_{d0}*(I_{d0}*r_a + V_{d0}) + I_{q0}*(I_{q0}*r_a + V_{q0})),
 I_{q0}*r_a*u + V_{q0},
 -I_{d0}*r_a*u - V_{d0},
 I_{d0}*xq + I_{q0}*r_a + V_{q0}]
```

2.4 Eigenvalue Analysis

2.4.1 Run Eigenvalue Analysis

```
import numpy as np

import andes
from andes.utils.paths import list_cases, get_case
```

```
case_path = get_case('kundur/kundur_full.xlsx')
```

Pass the routine name EIG or eig to `andes.run`.

```
ss = andes.run(case_path, routine='eig')
```

```
Working directory: "/home/hacui/repos/andes/examples"
> Loaded config from file "/home/hacui/.andes/andes.rc"
> Loaded generated Python code in "/home/hacui/.andes/pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/kundur/kundur_full.
→xlsx"...
Input file parsed in 0.1985 seconds.
System internal structure set up in 0.0309 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

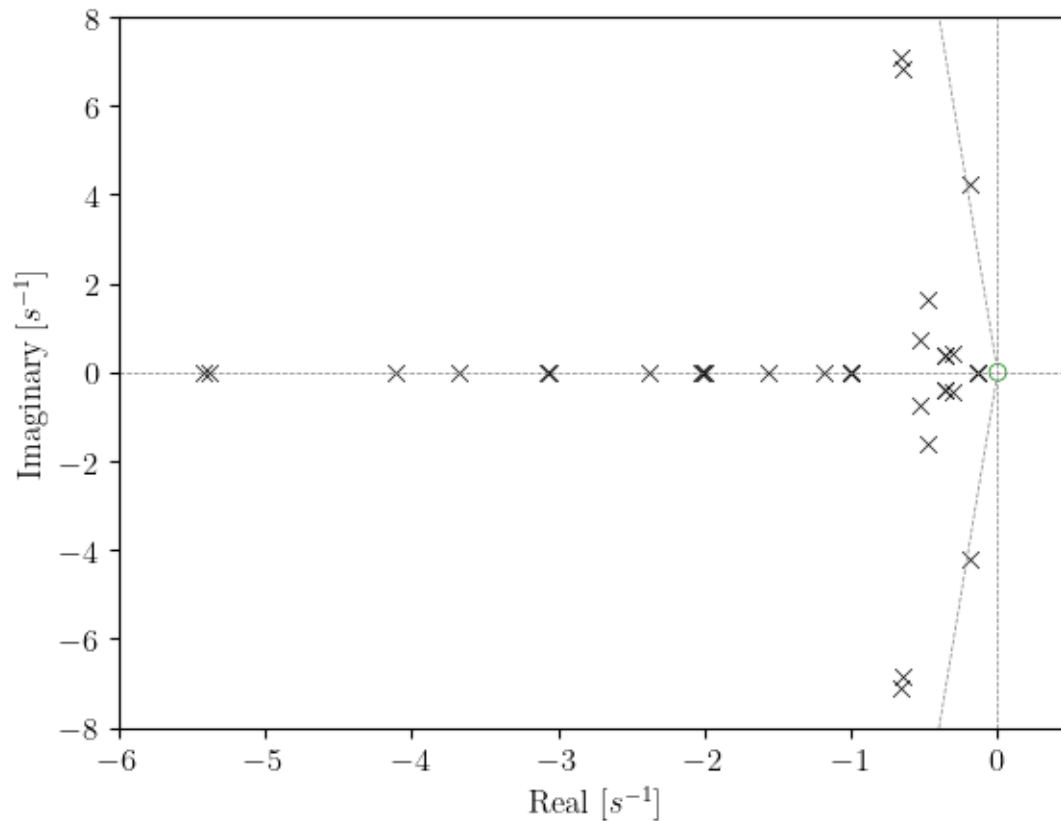
-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0042 seconds.
0: |F(x)| = 14.9282832
1: |F(x)| = 3.608627841
2: |F(x)| = 0.1701107882
3: |F(x)| = 0.002038626956
4: |F(x)| = 3.745104027e-07
Converged in 5 iterations in 0.0070 seconds.
Report saved to "kundur_full_out.txt" in 0.0010 seconds.
Initialization for dynamics completed in 0.0301 seconds.
Initialization was successful.

-> Eigenvalue Analysis:
    Positive      0
    Zeros         1
    Negative     52
Eigenvalue analysis finished in 0.0051 seconds.
Report saved to "kundur_full_eig.txt".
```

```
-> Single process finished in 0.5363 seconds.
```

2.4.2 Plotting in S-Domain

```
ss.EIG.plot()
```



```
(<Figure size 640x480 with 1 Axes>,  
<AxesSubplot:xlabel='Real [s-1]', ylabel='Imaginary [s-1]'>)
```

2.4.3 Report

Report is saved to the file and can be loaded into the notebook.

```
with open('kundur_full_eig.txt', 'r') as f:  
    print(f.read())
```

```
ANDES 1.7.5.post2.dev0+ga53a31fa  
Copyright (C) 2015-2022 Hantao Cui
```

```
ANDES comes with ABSOLUTELY NO WARRANTY  
Case file: /home/hacui/repos/andes/andes/cases/kundur/kundur_full.xlsx  
Report time: 07/05/2022 08:57:50 PM
```

```
Power flow converged in 5 iterations.  
Flat-start: No
```

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EIGENVALUE ANALYSIS REPORT

Positives 0
 Zeros 1
 Negatives 52

STATISTICS

	↪Damped Freq.	Most Associated Frequency	Damping [%]	Real	Imag.	
#1		LL_x EXDC2 1		-1	0	↪
↪	0	0	0			
#2		LL_x EXDC2 2		-1	0	↪
↪	0	0	0			
#3		LL_x EXDC2 3		-1	0	↪
↪	0	0	0			
#4		LL_x EXDC2 4		-1	0	↪
↪	0	0	0			
#5		LS_y EXDC2 3		-49.191	0.64233	↪
↪	0.10223	7.8296	99.991			
#6		LS_y EXDC2 3		-49.191	-0.64233	↪
↪	0.10223	7.8296	99.991			
#7		LS_y EXDC2 1		-49.535	0	↪
↪	0	0	0			
#8		LS_y EXDC2 4		-49.515	0	↪
↪	0	0	0			
#9		LA_y EXDC2 2		-49.202	0.39349	↪
↪	0.062627	7.831	99.997			
#10		LA_y EXDC2 2		-49.202	-0.39349	↪
↪	0.062627	7.831	99.997			
#11		LA_y EXDC2 1		-48.885	0	↪
↪	0	0	0			
#12		LA_y EXDC2 4		-48.905	0	↪
↪	0	0	0			
#13		e2d GENROU 2		-36.896	0	↪
↪	0	0	0			
#14		e2d GENROU 4		-36.75	0	↪
↪	0	0	0			
#15		e2d GENROU 1		-34.732	0	↪
↪	0	0	0			
#16		e2q GENROU 3		-33.89	0	↪
↪	0	0	0			
#17		e2q GENROU 2		-33.526	0	↪
↪	0	0	0			
#18		e2d GENROU 3		-31.242	0	↪
↪	0	0	0			
#19		e2q GENROU 4		-27.613	0	↪
↪	0	0	0			
#20		e2q GENROU 1		-24.954	0	↪
↪	0	0	0			

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#21		delta GENROU 3	-0.6564	7.086	└
↳	1.1278	1.1326	9.224		
#22		delta GENROU 3	-0.6564	-7.086	└
↳	1.1278	1.1326	9.224		
#23		delta GENROU 2	-0.65252	6.8343	└
↳	1.0877	1.0927	9.5046		
#24		delta GENROU 2	-0.65252	-6.8343	└
↳	1.0877	1.0927	9.5046		
#25		delta GENROU 1	-0.19177	4.2247	└
↳	0.67239	0.67308	4.5346		
#26		delta GENROU 1	-0.19177	-4.2247	└
↳	0.67239	0.67308	4.5346		
#27		e1d GENROU 2	-5.4189	0	└
↳	0	0	0		
#28		e1d GENROU 3	-5.3729	0	└
↳	0	0	0		
#29		e1d GENROU 4	-4.1119	0	└
↳	0	0	0		
#30		e1d GENROU 2	-3.6722	0	└
↳	0	0	0		
#31		vp EXDC2 2	-0.48245	1.628	└
↳	0.25911	0.27025	28.413		
#32		vp EXDC2 2	-0.48245	-1.628	└
↳	0.25911	0.27025	28.413		
#33		vp EXDC2 4	-3.0736	0	└
↳	0	0	0		
#34		vp EXDC2 1	-3.0635	0	└
↳	0	0	0		
#35		vp EXDC2 1	-2.3787	0	└
↳	0	0	0		
#36		LAG_y TGOV1 1	-1.5702	0	└
↳	0	0	0		
#37		LAG_y TGOV1 4	-1.9922	0	└
↳	0	0	0		
#38		LAG_y TGOV1 2	-2.0109	0	└
↳	0	0	0		
#39		LAG_y TGOV1 3	-2.0194	0	└
↳	0	0	0		
#40		W_x EXDC2 2	-1.1816	0	└
↳	0	0	0		
#41		W_x EXDC2 4	-0.53573	0.73459	└
↳	0.11691	0.1447	58.924		
#42		W_x EXDC2 4	-0.53573	-0.73459	└
↳	0.11691	0.1447	58.924		
#43*		delta GENROU 3	-1.1783e-14	0	└
↳	0	0	0		
#44		LL_x TGOV1 2	-0.30739	0.44664	└
↳	0.071085	0.086293	56.693		
#45		LL_x TGOV1 2	-0.30739	-0.44664	└
↳	0.071085	0.086293	56.693		
#46		W_x EXDC2 1	-0.36003	0.38874	└
↳	0.061869	0.084328	67.95		

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#47		W_x EXDC2 1	-0.36003	-0.38874	
↪	0.061869	0.084328	67.95		
#48		W_x EXDC2 3	-0.35993	0.37956	
↪	0.060409	0.083251	68.81		
#49		W_x EXDC2 3	-0.35993	-0.37956	
↪	0.060409	0.083251	68.81		
#50		LL_x TGOV1 1	-0.14157	0	
↪	0	0	0		
#51		LL_x TGOV1 2	-0.14203	0	
↪	0	0	0		
#52		LL_x TGOV1 3	-0.14202	0	
↪	0	0	0		
EIGENVALUE DATA					
		#1	#2	#3	
↪	#4	#5	#6	#7	
delta GENROU 1		0	0	0	
↪	0	0	0	4e-05	
delta GENROU 2		0	0	0	
↪	0	0	0	6e-05	
delta GENROU 3		0	0	0	
↪	0	0	0	2e-05	
delta GENROU 4		0	0	0	
↪	0	0	0	1e-05	
omega GENROU 1		0	0	0	
↪	0	0	0	2e-05	
omega GENROU 2		0	0	0	
↪	0	0	0	3e-05	
omega GENROU 3		0	0	0	
↪	0	0	0	1e-05	
omega GENROU 4		0	0	0	
↪	0	0	0	0	
e1q GENROU 1		0	0	0	
↪	0	0.00084	0.00084	0.00306	
e1q GENROU 2		0	0	0	
↪	0	0.0019	0.0019	0.00224	
e1q GENROU 3		0	0	0	
↪	0	0.0026	0.0026	0.00069	
e1q GENROU 4		0	0	0	
↪	0	0.00118	0.00118	0.00063	
e1d GENROU 1		0	0	0	
↪	0	0	0	0	
e1d GENROU 2		0	0	0	
↪	0	0	0	0	
e1d GENROU 3		0	0	0	
↪	0	0	0	0	
e1d GENROU 4		0	0	0	
↪	0	0	0	0	
e2d GENROU 1		0	0	0	
↪	0	0.00839	0.00839	0.02012	
e2d GENROU 2		0	0	0	

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→	0	0.01824		0.01824		0.01364	
e2d GENROU 3	0		0		0	0	┌
→	0	0.02784		0.02784		0.00467	
e2d GENROU 4	0		0		0	0	┌
→	0	0.01361		0.01361		0.00474	
e2q GENROU 1	0		0		0	0	┌
→	0	0.00096		0.00096		0.00036	
e2q GENROU 2	0		0		0	0	┌
→	0	0.00026		0.00026		0.00114	
e2q GENROU 3	0		0		0	0	┌
→	0	3e-05		3e-05		0.00031	
e2q GENROU 4	0		0		0	0	┌
→	0	0.00118		0.00118		9e-05	
LAG_y TGOV1 1	0		0		0	0	┌
→	0	0		0		0	
LAG_y TGOV1 2	0		0		0	0	┌
→	0	0		0		0	
LAG_y TGOV1 3	0		0		0	0	┌
→	0	0		0		0	
LAG_y TGOV1 4	0		0		0	0	┌
→	0	0		0		0	
LL_x TGOV1 1	0		0		0	0	┌
→	0	0		0		0	
LL_x TGOV1 2	0		0		0	0	┌
→	0	0		0		0	
LL_x TGOV1 3	0		0		0	0	┌
→	0	0		0		0	
LL_x TGOV1 4	0		0		0	0	┌
→	0	0		0		0	
vp EXDC2 1	0		0		0	0	┌
→	0	0.00157		0.00157		0.00231	
vp EXDC2 2	0		0		0	0	┌
→	0	0.00352		0.00352		0.00168	
vp EXDC2 3	0		0		0	0	┌
→	0	0.00346		0.00346		0.00037	
vp EXDC2 4	0		0		0	0	┌
→	0	0.00202		0.00202		0.00043	
LS_y EXDC2 1	0		0		0	0	┌
→	0	0.06526		0.06526		0.53032	
LS_y EXDC2 2	0		0		0	0	┌
→	0	0.14386		0.14386		0.37893	
LS_y EXDC2 3	0		0		0	0	┌
→	0	0.30715		0.30715		0.18162	
LS_y EXDC2 4	0		0		0	0	┌
→	0	0.08575		0.08575		0.10168	
LL_x EXDC2 1	0	0.66046		0		0	┌
→	0	0		0		0	
LL_x EXDC2 2	0		0	0.66046		0	┌
→	0	0		0		0	
LL_x EXDC2 3	0		0	0		1	┌
→	0	0		0		0	
LL_x EXDC2 4			0	0		0	┌

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↪	0.65832	0	0	0	
LA_y EXDC2 1		0	0	0	↪
↪	0	0.06704	0.06704	0.22072	0
LA_y EXDC2 2		0	0	0	↪
↪	0	0.20271	0.20271	0.21636	0
LA_y EXDC2 3		0	0	0	↪
↪	0	0.30051	0.30051	0.072	0
LA_y EXDC2 4		0	0	0	↪
↪	0	0.1453	0.1453	0.06982	0
W_x EXDC2 1		0	0	0	↪
↪	0	5e-05	5e-05	0.00015	0
W_x EXDC2 2		0	0	0	↪
↪	0	0.00012	0.00012	0.00013	0
W_x EXDC2 3		0	0	0	↪
↪	0	0.00017	0.00017	4e-05	0
W_x EXDC2 4		0	0	0	↪
↪	0	8e-05	8e-05	4e-05	
PARTICIPATION FACTORS [1/8]					
		#8	#9	#10	
↪	#11	#12	#13	#14	↪
delta GENROU 1		2e-05	1e-05	1e-05	↪
↪	5e-05	2e-05	0.00044	0.00047	
delta GENROU 2		1e-05	0	0	↪
↪	6e-05	1e-05	0.00078	0.00049	
delta GENROU 3		5e-05	0	0	↪
↪	2e-05	6e-05	0.00062	0.00061	
delta GENROU 4		5e-05	1e-05	1e-05	↪
↪	1e-05	6e-05	0.00032	0.00067	
omega GENROU 1		1e-05	1e-05	1e-05	↪
↪	3e-05	1e-05	0.00025	0.00027	
omega GENROU 2		1e-05	0	0	↪
↪	4e-05	1e-05	0.00045	0.00028	
omega GENROU 3		2e-05	0	0	↪
↪	1e-05	2e-05	0.00025	0.00024	
omega GENROU 4		2e-05	0	0	↪
↪	0	2e-05	0.00012	0.00025	
e1q GENROU 1		0.00117	0.00225	0.00225	↪
↪	0.0031	0.00115	0.0003	0.00033	
e1q GENROU 2		0.00043	0.00285	0.00285	↪
↪	0.00224	0.00041	0.00042	0.00021	
e1q GENROU 3		0.00184	0.00167	0.00167	↪
↪	0.00067	0.00185	0.00028	0.00027	
e1q GENROU 4		0.00329	0.00134	0.00134	↪
↪	0.00061	0.00333	0.00019	0.00041	
e1d GENROU 1		0	0	0	↪
↪	0	0	2e-05	1e-05	
e1d GENROU 2		0	0	0	↪
↪	0	0	7e-05	2e-05	
e1d GENROU 3		0	0	0	↪
↪	0	0	5e-05	5e-05	

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e1d GENROU 4	0	0	0	↪
↪ 0	0	2e-05	1e-05	↪
e2d GENROU 1	0.00784	0.01923	0.01923	↪
↪ 0.02323	0.00867	0.23812	0.24595	↪
e2d GENROU 2	0.00261	0.02337	0.02337	↪
↪ 0.01559	0.00284	0.33371	0.16432	↪
e2d GENROU 3	0.01258	0.01507	0.01507	↪
↪ 0.00518	0.01432	0.2465	0.23261	↪
e2d GENROU 4	0.02533	0.01309	0.01309	↪
↪ 0.00526	0.02886	0.17228	0.34779	↪
e2q GENROU 1	0.00015	0.0011	0.0011	↪
↪ 0.00039	0.00016	0.00111	0.00037	↪
e2q GENROU 2	0.00038	0.00045	0.00045	↪
↪ 0.00121	0.00039	0.0033	0.00106	↪
e2q GENROU 3	0.00116	7e-05	7e-05	↪
↪ 0.00032	0.00123	0.00241	0.00234	↪
e2q GENROU 4	0.00041	0.00079	0.00079	↪
↪ 9e-05	0.00044	0.00069	0.00043	↪
LAG_y TGOV1 1	0	0	0	↪
↪ 0	0	0	0	↪
LAG_y TGOV1 2	0	0	0	↪
↪ 0	0	0	0	↪
LAG_y TGOV1 3	0	0	0	↪
↪ 0	0	0	0	↪
LAG_y TGOV1 4	0	0	0	↪
↪ 0	0	0	0	↪
LL_x TGOV1 1	0	0	0	↪
↪ 0	0	0	0	↪
LL_x TGOV1 2	0	0	0	↪
↪ 0	0	0	0	↪
LL_x TGOV1 3	0	0	0	↪
↪ 0	0	0	0	↪
LL_x TGOV1 4	0	0	0	↪
↪ 0	0	0	0	↪
vp EXDC2 1	0.00094	0.00415	0.00415	↪
↪ 0.01364	0.00476	0.00032	0.00034	↪
vp EXDC2 2	0.00034	0.00522	0.00522	↪
↪ 0.00979	0.00169	0.00042	0.0002	↪
vp EXDC2 3	0.00105	0.0022	0.0022	↪
↪ 0.0021	0.00546	0.0002	0.00019	↪
vp EXDC2 4	0.00242	0.00226	0.00226	↪
↪ 0.00246	0.01263	0.00018	0.00038	↪
LS_y EXDC2 1	0.19482	0.203	0.203	↪
↪ 0.22143	0.08347	0.00069	0.00074	↪
LS_y EXDC2 2	0.06924	0.25052	0.25052	↪
↪ 0.15607	0.02909	0.0009	0.00042	↪
LS_y EXDC2 3	0.46474	0.22878	0.22878	↪
↪ 0.07262	0.2043	0.00092	0.00088	↪
LS_y EXDC2 4	0.51255	0.11281	0.11281	↪
↪ 0.04075	0.22639	0.00041	0.00085	↪
LL_x EXDC2 1	0	0	0	↪
↪ 0	0	0	0	↪

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LL_x EXDC2 2	0	0	0	0	↩
↩ 0	0	0	0	0	
LL_x EXDC2 3	0	0	0	0	↩
↩ 0	0	0	0	0	
LL_x EXDC2 4	0	0	0	0	↩
↩ 0	0	0	0	0	
LA_y EXDC2 1	0.08621	0.2062	0.2062		↩
↩ 0.53692	0.19058	0.00079	0.00084		
LA_y EXDC2 2	0.04203	0.34908	0.34908		↩
↩ 0.51915	0.09112	0.00141	0.00066		
LA_y EXDC2 3	0.19588	0.22134	0.22134		↩
↩ 0.16772	0.44428	0.001	0.00095		
LA_y EXDC2 4	0.37416	0.18904	0.18904		↩
↩ 0.16302	0.85269	0.00077	0.0016		
W_x EXDC2 1	6e-05	0.00014	0.00014		↩
↩ 0.00038	0.00014	0	0		
W_x EXDC2 2	2e-05	0.00021	0.00021		↩
↩ 0.00031	5e-05	0	0		
W_x EXDC2 3	0.00011	0.00013	0.00013		↩
↩ 0.0001	0.00026	0	0		
W_x EXDC2 4	0.00021	0.00011	0.00011		↩
↩ 0.0001	0.0005	0	0		

PARTICIPATION FACTORS [2/8]

	#15	#16	#17	
↩ #18	#19	#20	#21	↩
delta GENROU 1	0.0013	0.00058	0.00086	↩
↩ 4e-05	1e-05	0.00014	0.04024	
delta GENROU 2	0.00034	0.00024	0.00268	↩
↩ 6e-05	7e-05	2e-05	0.08541	
delta GENROU 3	0.00011	0.00276	0.00076	↩
↩ 5e-05	5e-05	0.0002	0.23816	
delta GENROU 4	0.00079	0.00199	1e-05	↩
↩ 0.00011	1e-05	1e-05	0.16086	
omega GENROU 1	0.00075	0.00034	0.0005	↩
↩ 3e-05	0	8e-05	0.02377	
omega GENROU 2	0.0002	0.00014	0.00155	↩
↩ 3e-05	4e-05	1e-05	0.05045	
omega GENROU 3	4e-05	0.00109	0.0003	↩
↩ 2e-05	2e-05	8e-05	0.0965	
omega GENROU 4	0.00029	0.00074	1e-05	↩
↩ 4e-05	0	0	0.06107	
e1q GENROU 1	0.00054	6e-05	0.00042	↩
↩ 0.00094	4e-05	0.0003	0.00067	
e1q GENROU 2	0.00065	0.00022	2e-05	↩
↩ 0.00115	0.00016	0.00097	0.00141	
e1q GENROU 3	0.00038	0.00019	0.00019	↩
↩ 0.00144	0.00011	0.00123	0.00194	
e1q GENROU 4	0.00034	1e-05	0.0003	↩
↩ 0.00112	2e-05	0.00045	0.0034	
e1d GENROU 1	0.00197	0.00266	0.00808	↩

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↪ 1e-05	0.02906	0.04674	0.00263	
e1d GENROU 2	0.0033	0.00186	0.01412	↪
↪ 0.00441	0.01327	0.03129	0.00637	
e1d GENROU 3	0.00138	0.01461	0.00314	↪
↪ 0.00479	0.0177	0.02276	0.02746	
e1d GENROU 4	0.00094	0.01041	0.00046	↪
↪ 5e-05	0.03673	0.03898	0.00549	
e2d GENROU 1	0.25874	0.03867	0.05142	↪
↪ 0.14321	0.00031	0.0033	0.00066	
e2d GENROU 2	0.16397	0.03747	0.0468	↪
↪ 0.20085	0.00352	0.02285	0.00139	
e2d GENROU 3	0.11321	0.0137	0.07851	↪
↪ 0.27348	0.00187	0.03733	0.00213	
e2d GENROU 4	0.18053	0.00845	0.08023	↪
↪ 0.18763	0.00026	0.00906	0.00371	
e2q GENROU 1	0.05939	0.06822	0.19355	↪
↪ 0.00017	0.23112	0.22378	0.00134	
e2q GENROU 2	0.09922	0.04763	0.3366	↪
↪ 0.06848	0.10503	0.1491	0.00325	
e2q GENROU 3	0.04116	0.36911	0.07409	↪
↪ 0.07356	0.13858	0.10724	0.01383	
e2q GENROU 4	0.028	0.26219	0.0109	↪
↪ 0.00082	0.28669	0.18311	0.00276	
LAG_y TGOV1 1	0	0	0	↪
↪ 0	0	0	0.00067	
LAG_y TGOV1 2	0	0	0	↪
↪ 0	0	0	0.00142	
LAG_y TGOV1 3	0	0	0	↪
↪ 0	0	0	0.00355	
LAG_y TGOV1 4	0	0	0	↪
↪ 0	0	0	0.00239	
LL_x TGOV1 1	0	0	0	↪
↪ 0	0	0	3e-05	
LL_x TGOV1 2	0	0	0	↪
↪ 0	0	0	7e-05	
LL_x TGOV1 3	0	0	0	↪
↪ 0	0	0	0.00014	
LL_x TGOV1 4	0	0	0	↪
↪ 0	0	0	9e-05	
vp EXDC2 1	0.00033	3e-05	0.00062	↪
↪ 0.00077	9e-05	0.00049	6e-05	
vp EXDC2 2	0.00084	0.0003	0.00017	↪
↪ 0.00073	0.00025	0.00122	0.00018	
vp EXDC2 3	0.00034	0.00023	6e-05	↪
↪ 0.00069	0.00014	0.00101	0.00069	
vp EXDC2 4	0.00022	4e-05	0.00029	↪
↪ 0.0009	3e-05	0.00061	0.00083	
LS_y EXDC2 1	0.0006	5e-05	0.00101	↪
↪ 0.00103	9e-05	0.00039	1e-05	
LS_y EXDC2 2	0.00149	0.00049	0.00026	↪
↪ 0.00095	0.00024	0.00095	3e-05	
LS_y EXDC2 3	0.00129	0.00084	0.0002	↪

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↪	0.00197	0.0003	0.00172	0.00021	
LS_y EXDC2 4		0.00041	6e-05	0.00048	↪
↪	0.00123	3e-05	0.00049	0.00012	
LL_x EXDC2 1		0	0	0	↪
↪	0	0	0	0	
LL_x EXDC2 2		0	0	0	↪
↪	0	0	0	0	
LL_x EXDC2 3		0	0	0	↪
↪	0	0	0	0	
LL_x EXDC2 4		0	0	0	↪
↪	0	0	0	0	
LA_y EXDC2 1		0.00067	6e-05	0.00113	↪
↪	0.00114	0.0001	0.00042	1e-05	
LA_y EXDC2 2		0.00229	0.00074	0.0004	↪
↪	0.00144	0.00037	0.00143	3e-05	
LA_y EXDC2 3		0.00137	0.00089	0.00021	↪
↪	0.00207	0.00031	0.00179	0.00018	
LA_y EXDC2 4		0.00076	0.00011	0.00089	↪
↪	0.00224	6e-05	0.00089	0.00018	
W_x EXDC2 1		0	0	0	↪
↪	0	0	0	0	
W_x EXDC2 2		0	0	0	↪
↪	0	0	1e-05	1e-05	
W_x EXDC2 3		0	0	0	↪
↪	0	0	1e-05	3e-05	
W_x EXDC2 4		0	0	0	↪
↪	1e-05	0	0	3e-05	
PARTICIPATION FACTORS [3/8]					
		#22	#23	#24	↪
↪	#25	#26	#27	#28	
delta GENROU 1		0.04024	0.17926	0.17926	↪
↪	0.17245	0.17245	0.01877	0.00547	
delta GENROU 2		0.08541	0.21636	0.21636	↪
↪	0.08005	0.08005	0.02617	0.00332	
delta GENROU 3		0.23816	0.04918	0.04918	↪
↪	0.09817	0.09817	0.00681	0.02482	
delta GENROU 4		0.16086	0.08069	0.08069	↪
↪	0.14333	0.14333	0.00315	0.02115	
omega GENROU 1		0.02377	0.10604	0.10604	↪
↪	0.10491	0.10491	0.01037	0.00302	
omega GENROU 2		0.05045	0.12794	0.12794	↪
↪	0.04872	0.04872	0.01445	0.00183	
omega GENROU 3		0.0965	0.01995	0.01995	↪
↪	0.04102	0.04102	0.00257	0.00936	
omega GENROU 4		0.06107	0.03068	0.03068	↪
↪	0.05611	0.05611	0.00111	0.00747	
e1q GENROU 1		0.00067	0.00511	0.00511	↪
↪	0.00596	0.00596	0.00153	0.00043	
e1q GENROU 2		0.00141	0.00145	0.00145	↪
↪	0.00491	0.00491	0.00172	0.00027	

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e1q GENROU 3	0.00194	0.00018	0.00018	└
→ 0.00041	0.00041	0.00039	0.0016	
e1q GENROU 4	0.0034	0.00215	0.00215	└
→ 0.00091	0.00091	0.00022	0.00155	
e1d GENROU 1	0.00263	0.00462	0.00462	└
→ 0.00044	0.00044	0.36152	0.09703	
e1d GENROU 2	0.00637	0.02796	0.02796	└
→ 0.00049	0.00049	0.49924	0.07963	
e1d GENROU 3	0.02746	0.00894	0.00894	└
→ 0.00335	0.00335	0.12193	0.48105	
e1d GENROU 4	0.00549	0.00157	0.00157	└
→ 0.00281	0.00281	0.05818	0.38742	
e2d GENROU 1	0.00066	0.0043	0.0043	└
→ 0.00204	0.00204	0.00033	8e-05	
e2d GENROU 2	0.00139	0.00146	0.00146	└
→ 0.00158	0.00158	0.00074	0.00013	
e2d GENROU 3	0.00213	0.00012	0.00012	└
→ 0.00027	0.00027	0.00018	0.00073	
e2d GENROU 4	0.00371	0.00209	0.00209	└
→ 0.00056	0.00056	6e-05	0.0004	
e2q GENROU 1	0.00134	0.00229	0.00229	└
→ 0.00017	0.00017	0.01819	0.00503	
e2q GENROU 2	0.00325	0.01381	0.01381	└
→ 0.00019	0.00019	0.02501	0.00411	
e2q GENROU 3	0.01383	0.00437	0.00437	└
→ 0.00129	0.00129	0.00604	0.02453	
e2q GENROU 4	0.00276	0.00076	0.00076	└
→ 0.00109	0.00109	0.00287	0.01969	
LAG_y TGOV1 1	0.00067	0.0032	0.0032	└
→ 0.00728	0.00728	0.00125	0.00038	
LAG_y TGOV1 2	0.00142	0.00386	0.00386	└
→ 0.00338	0.00338	0.00175	0.00023	
LAG_y TGOV1 3	0.00355	0.00079	0.00079	└
→ 0.00371	0.00371	0.00041	0.00152	
LAG_y TGOV1 4	0.00239	0.00129	0.00129	└
→ 0.0054	0.0054	0.00019	0.00129	
LL_x TGOV1 1	3e-05	0.00016	0.00016	└
→ 0.00064	0.00064	6e-05	2e-05	
LL_x TGOV1 2	7e-05	0.0002	0.0002	└
→ 0.00031	0.00031	8e-05	1e-05	
LL_x TGOV1 3	0.00014	3e-05	3e-05	└
→ 0.00026	0.00026	1e-05	5e-05	
LL_x TGOV1 4	9e-05	5e-05	5e-05	└
→ 0.00038	0.00038	1e-05	5e-05	
vp EXDC2 1	6e-05	0.00162	0.00162	└
→ 0.00482	0.00482	0.00739	0.002	
vp EXDC2 2	0.00018	0.00133	0.00133	└
→ 0.00482	0.00482	0.01079	0.00183	
vp EXDC2 3	0.00069	0.00024	0.00024	└
→ 0.00056	0.00056	0.00174	0.00719	
vp EXDC2 4	0.00083	0.00076	0.00076	└
→ 0.00082	0.00082	0.00101	0.00706	

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LS_y EXDC2 1	1e-05	0.00022	0.00022	↵
↵ 0.00047	0.00047	0.00037	0.0001	
LS_y EXDC2 2	3e-05	0.00018	0.00018	↵
↵ 0.00046	0.00046	0.00052	9e-05	
LS_y EXDC2 3	0.00021	7e-05	7e-05	↵
↵ 0.00012	0.00012	0.00018	0.00074	
LS_y EXDC2 4	0.00012	0.00011	0.00011	↵
↵ 8e-05	8e-05	5e-05	0.00035	
LL_x EXDC2 1	0	0	0	↵
↵ 0	0	0	0	
LL_x EXDC2 2	0	0	0	↵
↵ 0	0	0	0	
LL_x EXDC2 3	0	0	0	↵
↵ 0	0	0	0	
LL_x EXDC2 4	0	0	0	↵
↵ 0	0	0	0	
LA_y EXDC2 1	1e-05	0.00021	0.00021	↵
↵ 0.00039	0.00039	0.00064	0.00017	
LA_y EXDC2 2	3e-05	0.00023	0.00023	↵
↵ 0.00052	0.00052	0.00126	0.00021	
LA_y EXDC2 3	0.00018	6e-05	6e-05	↵
↵ 9e-05	9e-05	0.00031	0.00125	
LA_y EXDC2 4	0.00018	0.00016	0.00016	↵
↵ 0.00011	0.00011	0.00015	0.00102	
W_x EXDC2 1	0	5e-05	5e-05	↵
↵ 0.00038	0.00038	0.00056	0.00015	
W_x EXDC2 2	1e-05	5e-05	5e-05	↵
↵ 0.00044	0.00044	0.00093	0.00016	
W_x EXDC2 3	3e-05	1e-05	1e-05	↵
↵ 7e-05	7e-05	0.00022	0.00094	
W_x EXDC2 4	3e-05	3e-05	3e-05	↵
↵ 9e-05	9e-05	0.00011	0.00076	
PARTICIPATION FACTORS [4/8]				
	#29	#30	#31	↵
↵ #32	#33	#34	#35	
delta GENROU 1	0.00184	0.00076	0.0105	↵
↵ 0.0105	0.00211	0.00572	0.00175	
delta GENROU 2	0.00619	0.00021	8e-05	↵
↵ 8e-05	0.0019	0.00509	0.00601	
delta GENROU 3	0.00524	0.00086	0.00348	↵
↵ 0.00348	0.00522	0.00212	0.00608	
delta GENROU 4	0.00254	0	0.00062	↵
↵ 0.00062	0.00562	0.00191	0.00119	
omega GENROU 1	0.00097	0.00039	0.00811	↵
↵ 0.00811	0.00097	0.00262	0.00049	
omega GENROU 2	0.00326	0.00011	0.00024	↵
↵ 0.00024	0.00087	0.00234	0.00176	
omega GENROU 3	0.00188	0.0003	0.00176	↵
↵ 0.00176	0.00163	0.00066	0.00119	
omega GENROU 4	0.00086	0	0.00023	↵

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↪	0.00023	0.00164	0.00056	0.0002	
e1q GENROU 1		0.00024	0.00202	0.07076	↪
↪	0.07076	0.00382	0.01402	0.05544	
e1q GENROU 2		0.0016	0.0052	0.0874	↪
↪	0.0874	0.00481	0.01018	0.04937	
e1q GENROU 3		0.00126	0.00534	0.07194	↪
↪	0.07194	0.01035	0.00282	0.04397	
e1q GENROU 4		0.00048	0.00212	0.0524	↪
↪	0.0524	0.01026	0.00535	0.04396	
e1d GENROU 1		0.22346	0.14687	0.02655	↪
↪	0.02655	0.0065	0.02563	0.01032	
e1d GENROU 2		0.16265	0.15839	0.02676	↪
↪	0.02676	0.00999	0.01879	0.00058	
e1d GENROU 3		0.1893	0.12278	0.02515	↪
↪	0.02515	0.02218	0.00485	0.00021	
e1d GENROU 4		0.28887	0.12266	0.02446	↪
↪	0.02446	0.02447	0.0144	0.00922	
e2d GENROU 1		1e-05	0.00011	0.00296	↪
↪	0.00296	0.00013	0.0005	0.00144	
e2d GENROU 2		9e-05	0.00027	0.00367	↪
↪	0.00367	0.00016	0.00032	0.00127	
e2d GENROU 3		8e-05	0.0003	0.00331	↪
↪	0.00331	0.00037	0.0001	0.00124	
e2d GENROU 4		4e-05	0.00013	0.0025	↪
↪	0.0025	0.00042	0.00022	0.00131	
e2q GENROU 1		0.02215	0.0174	0.00812	↪
↪	0.00812	0.00095	0.00378	0.00189	
e2q GENROU 2		0.01605	0.01868	0.00815	↪
↪	0.00815	0.00146	0.00276	0.00011	
e2q GENROU 3		0.01847	0.01432	0.00757	↪
↪	0.00757	0.00321	0.0007	4e-05	
e2q GENROU 4		0.0281	0.01426	0.00734	↪
↪	0.00734	0.00353	0.00208	0.00165	
LAG_y TGOV1 1		0.0003	0.00019	0.0023	↪
↪	0.0023	0.00118	0.00327	0.00534	
LAG_y TGOV1 2		0.00103	5e-05	7e-05	↪
↪	7e-05	0.00107	0.00292	0.0193	
LAG_y TGOV1 3		0.00077	0.0002	0.00065	↪
↪	0.00065	0.0026	0.00108	0.01706	
LAG_y TGOV1 4		0.00037	0	9e-05	↪
↪	9e-05	0.00279	0.00096	0.00309	
LL_x TGOV1 1		1e-05	1e-05	0.00065	↪
↪	0.00065	5e-05	0.00015	0.00014	
LL_x TGOV1 2		5e-05	0	2e-05	↪
↪	2e-05	5e-05	0.00014	0.00054	
LL_x TGOV1 3		3e-05	1e-05	0.00015	↪
↪	0.00015	0.0001	4e-05	0.00037	
LL_x TGOV1 4		1e-05	0	2e-05	↪
↪	2e-05	0.0001	4e-05	7e-05	
vp EXDC2 1		0.0018	0.02792	0.0755	↪
↪	0.0755	0.08166	0.28549	0.19372	
vp EXDC2 2		0.01151	0.07037	0.09369	↪

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↪	0.09369	0.10072	0.20041	0.17109	
vp EXDC2 3		0.00659	0.05154	0.05539	↪
↪	0.05539	0.15513	0.03978	0.10881	
vp EXDC2 4		0.00328	0.02678	0.05123	↪
↪	0.05123	0.20162	0.10006	0.1402	
LS_y EXDC2 1		4e-05	0.00026	0.00452	↪
↪	0.00452	0.00039	0.00144	0.00445	
LS_y EXDC2 2		0.00022	0.00065	0.00551	↪
↪	0.00551	0.00047	0.00099	0.00386	
LS_y EXDC2 3		0.00027	0.00103	0.00707	↪
↪	0.00707	0.00158	0.00043	0.00532	
LS_y EXDC2 4		7e-05	0.00026	0.00313	↪
↪	0.00313	0.00099	0.00052	0.00329	
LL_x EXDC2 1		0	0	0	↪
↪	0	0	0	0	
LL_x EXDC2 2		0	0	0	↪
↪	0	0	0	0	
LL_x EXDC2 3		0	0	0	↪
↪	0	0	0	0	
LL_x EXDC2 4		0	0	0	↪
↪	0	0	0	0	
LA_y EXDC2 1		0.0001	0.00137	0.0025	↪
↪	0.0025	0.00299	0.0104	0.00439	
LA_y EXDC2 2		0.0009	0.00465	0.00418	↪
↪	0.00418	0.00497	0.00984	0.00523	
LA_y EXDC2 3		0.00078	0.00513	0.00372	↪
↪	0.00372	0.01154	0.00294	0.00501	
LA_y EXDC2 4		0.00032	0.00221	0.00285	↪
↪	0.00285	0.01245	0.00614	0.00536	
W_x EXDC2 1		0.00026	0.00528	0.03995	↪
↪	0.03995	0.02435	0.08588	0.11819	
W_x EXDC2 2		0.00188	0.01518	0.05653	↪
↪	0.05653	0.03424	0.06873	0.119	
W_x EXDC2 3		0.00159	0.01641	0.04933	↪
↪	0.04933	0.07785	0.02014	0.11172	
W_x EXDC2 4		0.00065	0.00702	0.03754	↪
↪	0.03754	0.08326	0.04168	0.11845	

PARTICIPATION FACTORS [5/8]

		#36	#37	#38	
↪	#39	#40	#41	#42	
delta GENROU 1		0.00239	0.01045	0.00051	↪
↪	0.00201	0.00333	0.00065	0.00065	
delta GENROU 2		0.00236	0.00093	0.00922	↪
↪	0.00128	0.00055	0.00047	0.00047	
delta GENROU 3		0.00232	0.00157	0.00622	↪
↪	0.00373	0.00374	0.00048	0.00048	
delta GENROU 4		0.00245	0.0139	0.00281	↪
↪	0.00283	8e-05	0.00065	0.00065	
omega GENROU 1		0.05646	0.00087	2e-05	↪
↪	7e-05	0.00453	0.00107	0.00107	

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omega GENROU 2	0.05461	8e-05	0.00045	└
↪ 4e-05	0.00192	0.00065	0.00065	
omega GENROU 3	0.03522	8e-05	0.0002	└
↪ 8e-05	0.00528	0.0005	0.0005	
omega GENROU 4	0.03404	0.0007	8e-05	└
↪ 6e-05	0.00043	0.00073	0.00073	
e1q GENROU 1	0.00021	0.01108	0.00476	└
↪ 0.00142	0.03388	0.08211	0.08211	
e1q GENROU 2	0.00026	0.00532	0.00231	└
↪ 0.00021	0.04408	0.06594	0.06594	
e1q GENROU 3	0.0001	0.00154	0.00122	└
↪ 0.0004	0.03867	0.06805	0.06805	
e1q GENROU 4	7e-05	0.00458	0.00375	└
↪ 0.0018	0.02724	0.07576	0.07576	
e1d GENROU 1	0.00019	0.00414	0.00056	└
↪ 0.00018	0.02258	0.00026	0.00026	
e1d GENROU 2	0.0002	0.00398	0.0024	└
↪ 0.00016	0.02473	0.00126	0.00126	
e1d GENROU 3	0.0001	0.00324	0.00173	└
↪ 0.00029	0.02321	0.00142	0.00142	
e1d GENROU 4	0.0001	0.0042	0.00103	└
↪ 0.00044	0.02112	0.00043	0.00043	
e2d GENROU 1	0	0.00015	0.00011	└
↪ 2e-05	0.00025	0.00119	0.00119	
e2d GENROU 2	0	6e-05	2e-05	└
↪ 2e-05	0.00035	0.00092	0.00092	
e2d GENROU 3	0	2e-05	1e-05	└
↪ 6e-05	0.00034	0.00105	0.00105	
e2d GENROU 4	0	2e-05	7e-05	└
↪ 2e-05	0.00024	0.00127	0.00127	
e2q GENROU 1	4e-05	0.00084	0.00011	└
↪ 4e-05	0.00566	8e-05	8e-05	
e2q GENROU 2	4e-05	0.00081	0.00049	└
↪ 3e-05	0.00617	0.00037	0.00037	
e2q GENROU 3	2e-05	0.00065	0.00034	└
↪ 6e-05	0.00573	0.00041	0.00041	
e2q GENROU 4	2e-05	0.00084	0.00021	└
↪ 9e-05	0.0052	0.00012	0.00012	
LAG_y TGOV1 1	0.28771	0.44443	0.03358	└
↪ 0.18229	0.00614	0.0005	0.0005	
LAG_y TGOV1 2	0.27828	0.03862	0.60969	└
↪ 0.11639	0.0026	0.0003	0.0003	
LAG_y TGOV1 3	0.23415	0.05545	0.34788	└
↪ 0.28645	0.00933	0.0003	0.0003	
LAG_y TGOV1 4	0.24068	0.49682	0.15655	└
↪ 0.21672	0.0008	0.00047	0.00047	
LL_x TGOV1 1	0.02949	0.00262	0.00012	└
↪ 0.00046	0.00245	0.00046	0.00046	
LL_x TGOV1 2	0.02951	0.00024	0.00224	└
↪ 0.0003	0.00107	0.00029	0.00029	
LL_x TGOV1 3	0.01928	0.00026	0.00099	└
↪ 0.00058	0.00299	0.00022	0.00022	

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LL_x TGOV1 4	0.0199	0.00236	0.00045	↩
↩ 0.00044	0.00026	0.00035	0.00035	
vp EXDC2 1	0.00028	0.01851	0.01021	↩
↩ 0.00225	0.02054	0.04771	0.04771	
vp EXDC2 2	0.00034	0.00805	0.00341	↩
↩ 0.00124	0.02771	0.03765	0.03765	
vp EXDC2 3	0.00019	0.0005	0.00126	↩
↩ 0.00202	0.01745	0.02788	0.02788	
vp EXDC2 4	0.00016	0.00385	0.00608	↩
↩ 0.00268	0.01504	0.0403	0.0403	
LS_y EXDC2 1	2e-05	0.00065	0.00035	↩
↩ 8e-05	0.00189	0.00251	0.00251	
LS_y EXDC2 2	2e-05	0.00028	0.00012	↩
↩ 4e-05	0.00251	0.00194	0.00194	
LS_y EXDC2 3	2e-05	4e-05	9e-05	↩
↩ 0.00015	0.00343	0.00312	0.00312	
LS_y EXDC2 4	1e-05	0.00014	0.00021	↩
↩ 9e-05	0.00142	0.00216	0.00216	
LL_x EXDC2 1	0	0	0	↩
↩ 0	0	0	0	
LL_x EXDC2 2	0	0	0	↩
↩ 0	0	0	0	
LL_x EXDC2 3	0	0	0	↩
↩ 0	0	0	0	
LL_x EXDC2 4	0	0	0	↩
↩ 0	0	0	0	
LA_y EXDC2 1	0	0.00028	0.00016	↩
↩ 4e-05	1e-05	0.00088	0.00088	
LA_y EXDC2 2	0	0.00016	7e-05	↩
↩ 3e-05	2e-05	0.00094	0.00094	
LA_y EXDC2 3	0	2e-05	4e-05	↩
↩ 6e-05	2e-05	0.00105	0.00105	
LA_y EXDC2 4	0	0.0001	0.00016	↩
↩ 7e-05	1e-05	0.00125	0.00125	
W_x EXDC2 1	0.0007	0.01967	0.01051	↩
↩ 0.00229	0.2114	0.11396	0.11396	
W_x EXDC2 2	0.00099	0.00975	0.004	↩
↩ 0.00144	0.32512	0.10252	0.10252	
W_x EXDC2 3	0.0008	0.00089	0.00219	↩
↩ 0.00345	0.30227	0.11206	0.11206	
W_x EXDC2 4	0.00057	0.00566	0.00867	↩
↩ 0.00377	0.21431	0.13329	0.13329	

PARTICIPATION FACTORS [6/8]

	#43*	#44	#45	↩
↩ #46	#47	#48	#49	
delta GENROU 1	0.23884	0.00446	0.00446	↩
↩ 5e-05	5e-05	4e-05	4e-05	
delta GENROU 2	0.24952	0.00469	0.00469	↩
↩ 2e-05	2e-05	3e-05	3e-05	
delta GENROU 3	0.26107	0.00465	0.00465	↩

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↪	2e-05	2e-05	7e-05	7e-05	
delta GENROU 4		0.25057	0.00449	0.00449	↪
↪	7e-05	7e-05	5e-05	5e-05	
omega GENROU 1		0	0.10227	0.10227	↪
↪	0.00063	0.00063	0.00032	0.00032	
omega GENROU 2		0	0.10619	0.10619	↪
↪	0.00022	0.00022	0.00028	0.00028	
omega GENROU 3		0	0.07177	0.07177	↪
↪	0.00013	0.00013	0.00029	0.00029	
omega GENROU 4		0	0.06484	0.06484	↪
↪	0.00031	0.00031	0.0002	0.0002	
e1q GENROU 1		0	2e-05	2e-05	↪
↪	0.07049	0.07049	0.04381	0.04381	
e1q GENROU 2		0	2e-05	2e-05	↪
↪	0.05619	0.05619	0.05594	0.05594	
e1q GENROU 3		0	3e-05	3e-05	↪
↪	0.0392	0.0392	0.06379	0.06379	
e1q GENROU 4		0	4e-05	4e-05	↪
↪	0.04984	0.04984	0.04973	0.04973	
e1d GENROU 1		0	0	0	↪
↪	0.00451	0.00451	0.00282	0.00282	
e1d GENROU 2		0	0	0	↪
↪	0.00354	0.00354	0.00354	0.00354	
e1d GENROU 3		0	0	0	↪
↪	0.00267	0.00267	0.00435	0.00435	
e1d GENROU 4		0	1e-05	1e-05	↪
↪	0.00388	0.00388	0.0039	0.0039	
e2d GENROU 1		0	0	0	↪
↪	0.00069	0.00069	0.00042	0.00042	
e2d GENROU 2		0	0	0	↪
↪	0.00051	0.00051	0.0005	0.0005	
e2d GENROU 3		0	0	0	↪
↪	0.00039	0.00039	0.00063	0.00063	
e2d GENROU 4		0	0	0	↪
↪	0.00056	0.00056	0.00055	0.00055	
e2q GENROU 1		0	0	0	↪
↪	0.00136	0.00136	0.00085	0.00085	
e2q GENROU 2		0	0	0	↪
↪	0.00106	0.00106	0.00106	0.00106	
e2q GENROU 3		0	0	0	↪
↪	0.00079	0.00079	0.00129	0.00129	
e2q GENROU 4		0	0	0	↪
↪	0.00115	0.00115	0.00116	0.00116	
LAG_y TGOV1 1		0	0.04715	0.04715	↪
↪	0.00028	0.00028	0.00015	0.00015	
LAG_y TGOV1 2		0	0.04895	0.04895	↪
↪	0.0001	0.0001	0.00013	0.00013	
LAG_y TGOV1 3		0	0.04317	0.04317	↪
↪	7e-05	7e-05	0.00017	0.00017	
LAG_y TGOV1 4		0	0.04147	0.04147	↪
↪	0.0002	0.0002	0.00012	0.00012	
LL_x TGOV1 1		0	0.12629	0.12629	↪

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↪	0.00092	0.00092	0	0.00049	0.00049	
LL_x TGOV1 2			0	0.13567	0.13567	↪
↪	0.00033	0.00033	0	0.00045	0.00045	
LL_x TGOV1 3			0	0.0929	0.0929	↪
↪	0.00019	0.00019	0	0.00047	0.00047	
LL_x TGOV1 4			0	0.08958	0.08958	↪
↪	0.00052	0.00052	0	0.00034	0.00034	
vp EXDC2 1			0	8e-05	8e-05	↪
↪	0.02856	0.02856	0	0.01757	0.01757	
vp EXDC2 2			0	7e-05	7e-05	↪
↪	0.02194	0.02194	0	0.02157	0.02157	
vp EXDC2 3			0	6e-05	6e-05	↪
↪	0.01098	0.01098	0	0.01765	0.01765	
vp EXDC2 4			0	8e-05	8e-05	↪
↪	0.01848	0.01848	0	0.01825	0.01825	
LS_y EXDC2 1			0	0	0	↪
↪	0.00105	0.00105	0	0.00064	0.00064	
LS_y EXDC2 2			0	0	0	↪
↪	0.00079	0.00079	0	0.00077	0.00077	
LS_y EXDC2 3			0	0	0	↪
↪	0.00086	0.00086	0	0.00136	0.00136	
LS_y EXDC2 4			0	0	0	↪
↪	0.00069	0.00069	0	0.00068	0.00068	
LL_x EXDC2 1			0	0	0	↪
↪	0	0	0	0	0	
LL_x EXDC2 2			0	0	0	↪
↪	0	0	0	0	0	
LL_x EXDC2 3			0	0	0	↪
↪	0	0	0	0	0	
LL_x EXDC2 4			0	0	0	↪
↪	0	0	0	0	0	
LA_y EXDC2 1			0	0	0	↪
↪	0.00049	0.00049	0	0.0003	0.0003	
LA_y EXDC2 2			0	0	0	↪
↪	0.00051	0.00051	0	0.0005	0.0005	
LA_y EXDC2 3			0	0	0	↪
↪	0.00038	0.00038	0	0.00061	0.00061	
LA_y EXDC2 4			0	0	0	↪
↪	0.00054	0.00054	0	0.00053	0.00053	
W_x EXDC2 1			0	0.00025	0.00025	↪
↪	0.11968	0.11968	0	0.07515	0.07515	
W_x EXDC2 2			0	0.00028	0.00028	↪
↪	0.10481	0.10481	0	0.10518	0.10518	
W_x EXDC2 3			0	0.00032	0.00032	↪
↪	0.07742	0.07742	0	0.12701	0.12701	
W_x EXDC2 4			0	0.00035	0.00035	↪
↪	0.10724	0.10724		0.1081	0.1081	
PARTICIPATION FACTORS [7/8]						
		#50		#51		#52
delta GENROU 1		0.00304		0.00244		4e-05

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delta GENROU 2	0.00157	0.00344	8e-05
delta GENROU 3	0.00179	6e-05	0.00325
delta GENROU 4	0.00266	0	0.00268
omega GENROU 1	0	0	0
omega GENROU 2	0	0	0
omega GENROU 3	0	0	0
omega GENROU 4	0	0	0
e1q GENROU 1	0	3e-05	0
e1q GENROU 2	2e-05	7e-05	0
e1q GENROU 3	0	0	6e-05
e1q GENROU 4	0	0	3e-05
e1d GENROU 1	1e-05	2e-05	0
e1d GENROU 2	0	5e-05	0
e1d GENROU 3	1e-05	0	4e-05
e1d GENROU 4	1e-05	0	3e-05
e2d GENROU 1	0	0	0
e2d GENROU 2	0	0	0
e2d GENROU 3	0	0	0
e2d GENROU 4	0	0	0
e2q GENROU 1	0	1e-05	0
e2q GENROU 2	0	1e-05	0
e2q GENROU 3	0	0	1e-05
e2q GENROU 4	0	0	1e-05
LAG_y TGOV1 1	0.00021	0.00017	0
LAG_y TGOV1 2	0.00011	0.00023	1e-05
LAG_y TGOV1 3	0.0001	0	0.00019
LAG_y TGOV1 4	0.00015	0	0.00015
LL_x TGOV1 1	0.30765	0.38484	0.0055
LL_x TGOV1 2	0.16372	0.56187	0.01273
LL_x TGOV1 3	0.12342	0.00631	0.34609
LL_x TGOV1 4	0.1836	0.00014	0.28568
vp EXDC2 1	3e-05	8e-05	0
vp EXDC2 2	2e-05	6e-05	0
vp EXDC2 3	1e-05	0	4e-05
vp EXDC2 4	2e-05	0	6e-05
LS_y EXDC2 1	0	0	0
LS_y EXDC2 2	0	0	0
LS_y EXDC2 3	0	0	0
LS_y EXDC2 4	0	0	0
LL_x EXDC2 1	0	0	0
LL_x EXDC2 2	0	0	0
LL_x EXDC2 3	0	0	0
LL_x EXDC2 4	0	0	0
LA_y EXDC2 1	0	0	0
LA_y EXDC2 2	0	0	0
LA_y EXDC2 3	0	0	0
LA_y EXDC2 4	0	0	0
W_x EXDC2 1	9e-05	0.00026	0
W_x EXDC2 2	9e-05	0.00023	1e-05
W_x EXDC2 3	5e-05	0	0.00021
W_x EXDC2 4	7e-05	0	0.00029

2.4.4 Parameter Sweep and Root Loci Plot

Parameter sweep allows automatically applying a set of parameters to compute the eigenvalues. It is useful to plot the root loci of the system.

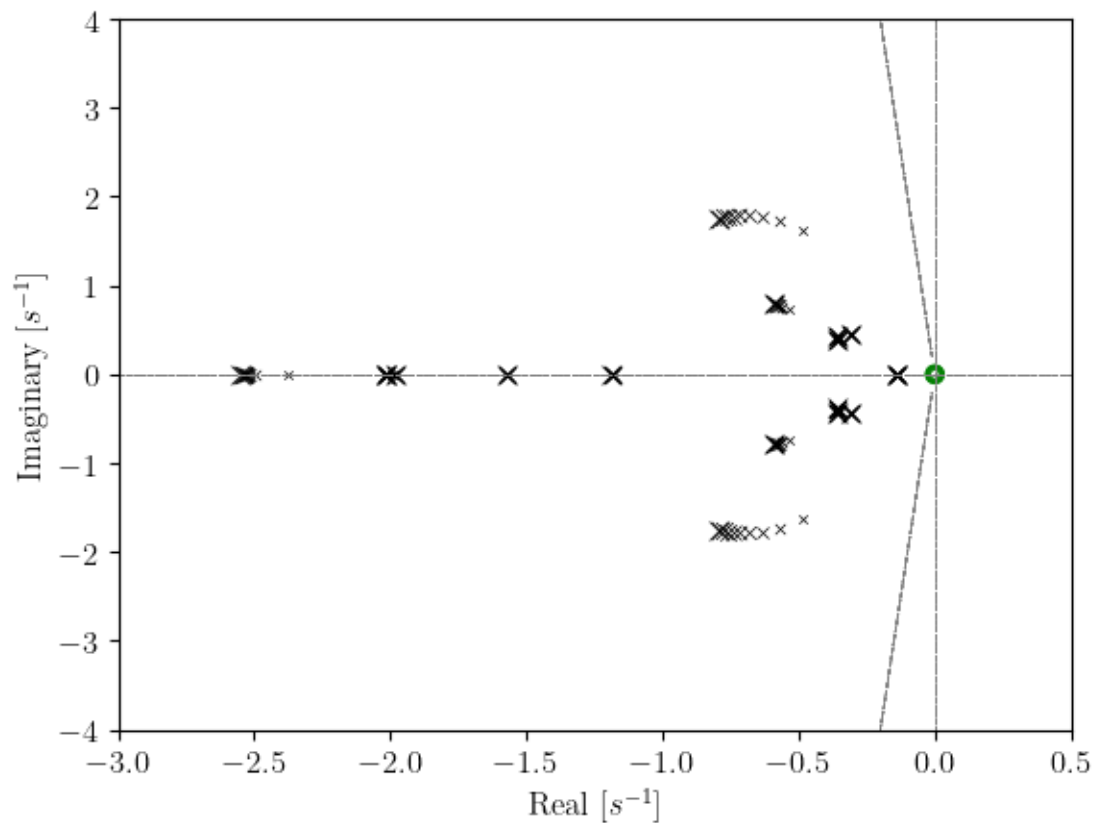
In this example, we will study the impact of `EXDC2.KA` of the device 1 on the system stability. Let its `KA` vary evenly between 20 to 200 in 10 steps.

```
ret = ss.EIG.sweep(ss.EXDC2.KA, 1, np.linspace(20, 200, 10))
```

Plot the 30th to the 50-th eigenvalues (0-based index) on the s-plane:

```
ss.EIG.plot_root_loci(ret, range(30, 51), left=-3, ymax=4, ymin=-4)
```

```
(<Figure size 640x480 with 1 Axes>,  
<AxesSubplot:xlabel='Real [ $s^{-1}$ ]', ylabel='Imaginary [ $s^{-1}$ ]'>)
```



Note that the marker size increases linearly as the parameters sweep from the first to the last. We recommend sweeping the parameter in an ascending order so that the larger marker size correspond to a larger parameter.

2.4.5 Cleanup

```
!andes misc -C
```

```
"/home/hacui/repos/andes/examples/kundur_full_out.txt" removed.  
"/home/hacui/repos/andes/examples/kundur_full_eig.txt" removed.
```

2.5 Using CLI from Notebook

This example notebook is a supplement to the ANDES tutorial. Make sure you have read the tutorial on using the CLI first.

A brief version can be found at <https://github.com/cuihantao/andes/blob/master/README.md#run-simulations>

2.5.1 The ! magic in iPython

This example shows how to use the ANDES CLI from Jupyter Notebook.

It is based on the iPython magic `!`. To run a command *from within* IPython or Jupyter, place a `!` immediately before the command.

Conversely, all commands demonstrated in this notebook can be used in a terminal/shell by removing the preceding `!` sign.

2.5.2 Set up on Windows

Windows users will need to install [MSYS2](#) to support most of the Linux shell commands.

To install MSYS2-base, uncomment the following line and run it:

```
# !conda install -c msys2 -n base --yes m2-base
```

2.5.3 Running Shell Commands

For example, to list the directory, use `!ls`. This is equivalent to executing `ls` from the terminal.

```
!ls
```

demonstration	ex1.ipynb	ex3.ipynb	ex5.ipynb	ex7.ipynb	ex9.ipynb
ex10.ipynb	ex2.ipynb	ex4.ipynb	ex6.ipynb	ex8.ipynb	verification

Likewise, to run `andes`, use `!andes`. Addition arguments can be passed as usual.

2.5.4 Run a simulation

```
!andes run ../andes/cases/kundur/kundur_full.xlsx -r tds
```

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```

0: |F(x)| = 14.9282832
1: |F(x)| = 3.608627841
2: |F(x)| = 0.1701107882
3: |F(x)| = 0.002038626956
4: |F(x)| = 3.745104027e-07
Converged in 5 iterations in 0.0032 seconds.
Initialization for dynamics completed in 0.0278 seconds.
Initialization was successful.
Report saved to "kundur_full_out.txt" in 0.0016 seconds.

-> Time Domain Simulation Summary:
Sparse Solver: KLU
Simulation time: 0.0-20.0 s.
Fixed step size: h=33.33 ms. Shrink if not converged.
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
100%|#####| 100.0/100 [00:01<00:00, 86.61%/
↪s]
Simulation completed in 1.1546 seconds.
Outputs to "kundur_full_out.lst" and "kundur_full_out.npz".
Outputs written in 0.0235 seconds.
-> Single process finished in 1.6411 seconds.

```

Case file names can be separated from the path, which can be passed to `-p`. The above command is equivalent to

```
!andes run kundur_full.xlsx -p "../andes/cases/kundur/" -r tds
```

```

_ _ _ _ _ | Version 1.6.4.post10.dev0+gd1a4589d
/_\ _ _ _ | |___ | Python 3.9.10 on Linux, 04/19/2022 08:30:43 PM
/_\ | ' \/_\ / -|_-< |
/_\ \_\_|_|_\_,_\_\_/___/ | This program comes with ABSOLUTELY NO WARRANTY.

Working directory: "/home/hacui/repos/andes/examples"
> Loaded config from file "/home/hacui/.andes/andes.rc"
> Loaded generated Python code in "/home/hacui/.andes/pycode".
Parsing input file "../andes/cases/kundur/kundur_full.xlsx"...
Input file parsed in 0.2501 seconds.
System internal structure set up in 0.0305 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0029 seconds.
0: |F(x)| = 14.9282832
1: |F(x)| = 3.608627841
2: |F(x)| = 0.1701107882

```

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```

3: |F(x)| = 0.002038626956
4: |F(x)| = 3.745104027e-07
Converged in 5 iterations in 0.0032 seconds.
Initialization for dynamics completed in 0.0277 seconds.
Initialization was successful.
Report saved to "kundur_full_out.txt" in 0.0016 seconds.

-> Time Domain Simulation Summary:
Sparse Solver: KLU
Simulation time: 0.0-20.0 s.
Fixed step size: h=33.33 ms. Shrink if not converged.
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
100%|#####| 100.0/100 [00:01<00:00, 86.32%/
↪s]
Simulation completed in 1.1584 seconds.
Outputs to "kundur_full_out.lst" and "kundur_full_out.npz".
Outputs written in 0.0237 seconds.
-> Single process finished in 1.6446 seconds.

```

```
!pwd
```

```
/home/hacui/repos/andes/examples
```

```
import os

os.path.isfile('../andes/cases/kundur/kundur_full.xlsx')
```

```
True
```

PSS/E RAW and DYR Files

To run a simulation using PSS/E raw and dyr files, pass the dyr file to argument `--addfile`.

For example:

```
!andes run ../andes/cases/kundur/kundur.raw --addfile ../andes/cases/kundur/
↪kundur_full.dyr -r tds
```

```

_          _          | Version 1.6.4.post10.dev0+gd1a4589d
/_\ _ _ _ _| | _ _ _ | Python 3.9.10 on Linux, 04/19/2022 08:30:46 PM
/_ \| ' \/_ / -|_-< |
/_/ \_\_|_|_\_,_\_/ _/ | This program comes with ABSOLUTELY NO WARRANTY.

Working directory: "/home/hacui/repos/andes/examples"
> Loaded config from file "/home/hacui/.andes/andes.rc"
> Loaded generated Python code in "/home/hacui/.andes/pycode".
Parsing input file "../andes/cases/kundur/kundur.raw"...
MODIFIED KUNDUR'S TWO-AREA TEST SYSTEM, DISTRIBUTED WITH ANDES

```

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```

SEE THE BOOK "POWER SYSTEM STABILITY AND CONTROL" FOR ORIGINAL DATA
Input file parsed in 0.0024 seconds.
Parsing additional file "../andes/cases/kundur/kundur_full.dyr"...
Addfile parsed in 0.2239 seconds.
System internal structure set up in 0.0297 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0028 seconds.
0: |F(x)| = 3.175850023
1: |F(x)| = 3.176155228e-08
Converged in 2 iterations in 0.0014 seconds.
Initialization for dynamics completed in 0.0276 seconds.
Initialization was successful.
Report saved to "kundur_out.txt" in 0.0014 seconds.

-> Time Domain Simulation Summary:
Sparse Solver: KLU
Simulation time: 0.0-20.0 s.
Fixed step size: h=33.33 ms. Shrink if not converged.
<Toggle Toggle_1>: Line.Line_8 status changed to 0 at t=2.0 sec.
100%|#####| 100.0/100 [00:01<00:00, 86.44%/
↪s]
Simulation completed in 1.1569 seconds.
Outputs to "kundur_out.lst" and "kundur_out.npz".
Outputs written in 0.0235 seconds.
-> Single process finished in 1.6165 seconds.

```

2.5.5 Check the output 1st file

```
!cat kundur_full_out.lst
```

0,	Time [s],	Time [s]
1,	delta GENROU 1,	δ GENROU 1
2,	delta GENROU 2,	δ GENROU 2
3,	delta GENROU 3,	δ GENROU 3
4,	delta GENROU 4,	δ GENROU 4
5,	omega GENROU 1,	ω GENROU 1
6,	omega GENROU 2,	ω GENROU 2
7,	omega GENROU 3,	ω GENROU 3
8,	omega GENROU 4,	ω GENROU 4
9,	e1q GENROU 1,	e_{1q} GENROU 1
10,	e1q GENROU 2,	e_{1q} GENROU 2

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11,	e1q GENROU 3,	\$e' _q\$ GENROU 3
12,	e1q GENROU 4,	\$e' _q\$ GENROU 4
13,	e1d GENROU 1,	\$e' _d\$ GENROU 1
14,	e1d GENROU 2,	\$e' _d\$ GENROU 2
15,	e1d GENROU 3,	\$e' _d\$ GENROU 3
16,	e1d GENROU 4,	\$e' _d\$ GENROU 4
17,	e2d GENROU 1,	\$e' ' _d\$ GENROU 1
18,	e2d GENROU 2,	\$e' ' _d\$ GENROU 2
19,	e2d GENROU 3,	\$e' ' _d\$ GENROU 3
20,	e2d GENROU 4,	\$e' ' _d\$ GENROU 4
21,	e2q GENROU 1,	\$e' ' _q\$ GENROU 1
22,	e2q GENROU 2,	\$e' ' _q\$ GENROU 2
23,	e2q GENROU 3,	\$e' ' _q\$ GENROU 3
24,	e2q GENROU 4,	\$e' ' _q\$ GENROU 4
25,	LAG_y TGOV1 1,	\$y_{LAG}\$ TGOV1 1
26,	LAG_y TGOV1 2,	\$y_{LAG}\$ TGOV1 2
27,	LAG_y TGOV1 3,	\$y_{LAG}\$ TGOV1 3
28,	LAG_y TGOV1 4,	\$y_{LAG}\$ TGOV1 4
29,	LL_x TGOV1 1,	\$x' _{LL}\$ TGOV1 1
30,	LL_x TGOV1 2,	\$x' _{LL}\$ TGOV1 2
31,	LL_x TGOV1 3,	\$x' _{LL}\$ TGOV1 3
32,	LL_x TGOV1 4,	\$x' _{LL}\$ TGOV1 4
33,	vp EXDC2 1,	\$V_p\$ EXDC2 1
34,	vp EXDC2 2,	\$V_p\$ EXDC2 2
35,	vp EXDC2 3,	\$V_p\$ EXDC2 3
36,	vp EXDC2 4,	\$V_p\$ EXDC2 4
37,	LS_y EXDC2 1,	\$y_{LS}\$ EXDC2 1
38,	LS_y EXDC2 2,	\$y_{LS}\$ EXDC2 2
39,	LS_y EXDC2 3,	\$y_{LS}\$ EXDC2 3
40,	LS_y EXDC2 4,	\$y_{LS}\$ EXDC2 4
41,	LL_x EXDC2 1,	\$x' _{LL}\$ EXDC2 1
42,	LL_x EXDC2 2,	\$x' _{LL}\$ EXDC2 2
43,	LL_x EXDC2 3,	\$x' _{LL}\$ EXDC2 3
44,	LL_x EXDC2 4,	\$x' _{LL}\$ EXDC2 4
45,	LA_y EXDC2 1,	\$y_{LA}\$ EXDC2 1
46,	LA_y EXDC2 2,	\$y_{LA}\$ EXDC2 2
47,	LA_y EXDC2 3,	\$y_{LA}\$ EXDC2 3
48,	LA_y EXDC2 4,	\$y_{LA}\$ EXDC2 4
49,	W_x EXDC2 1,	\$x' _{W}\$ EXDC2 1
50,	W_x EXDC2 2,	\$x' _{W}\$ EXDC2 2
51,	W_x EXDC2 3,	\$x' _{W}\$ EXDC2 3
52,	W_x EXDC2 4,	\$x' _{W}\$ EXDC2 4
53,	a Bus 1,	\$\theta\$ Bus 1
54,	a Bus 2,	\$\theta\$ Bus 2
55,	a Bus 3,	\$\theta\$ Bus 3
56,	a Bus 4,	\$\theta\$ Bus 4
57,	a Bus 5,	\$\theta\$ Bus 5
58,	a Bus 6,	\$\theta\$ Bus 6
59,	a Bus 7,	\$\theta\$ Bus 7
60,	a Bus 8,	\$\theta\$ Bus 8
61,	a Bus 9,	\$\theta\$ Bus 9
62,	a Bus 10,	\$\theta\$ Bus 10

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63,	v Bus 1,	\$V\$ Bus 1
64,	v Bus 2,	\$V\$ Bus 2
65,	v Bus 3,	\$V\$ Bus 3
66,	v Bus 4,	\$V\$ Bus 4
67,	v Bus 5,	\$V\$ Bus 5
68,	v Bus 6,	\$V\$ Bus 6
69,	v Bus 7,	\$V\$ Bus 7
70,	v Bus 8,	\$V\$ Bus 8
71,	v Bus 9,	\$V\$ Bus 9
72,	v Bus 10,	\$V\$ Bus 10
73,	q PV 2,	\$q\$ PV 2
74,	q PV 3,	\$q\$ PV 3
75,	q PV 4,	\$q\$ PV 4
76,	q Slack 1,	\$q\$ Slack 1
77,	p Slack 1,	\$p\$ Slack 1
78,	Id GENROU 1,	\$I_d\$ GENROU 1
79,	Id GENROU 2,	\$I_d\$ GENROU 2
80,	Id GENROU 3,	\$I_d\$ GENROU 3
81,	Id GENROU 4,	\$I_d\$ GENROU 4
82,	Iq GENROU 1,	\$I_q\$ GENROU 1
83,	Iq GENROU 2,	\$I_q\$ GENROU 2
84,	Iq GENROU 3,	\$I_q\$ GENROU 3
85,	Iq GENROU 4,	\$I_q\$ GENROU 4
86,	vd GENROU 1,	\$V_d\$ GENROU 1
87,	vd GENROU 2,	\$V_d\$ GENROU 2
88,	vd GENROU 3,	\$V_d\$ GENROU 3
89,	vd GENROU 4,	\$V_d\$ GENROU 4
90,	vq GENROU 1,	\$V_q\$ GENROU 1
91,	vq GENROU 2,	\$V_q\$ GENROU 2
92,	vq GENROU 3,	\$V_q\$ GENROU 3
93,	vq GENROU 4,	\$V_q\$ GENROU 4
94,	tm GENROU 1,	\$\tau_m\$ GENROU 1
95,	tm GENROU 2,	\$\tau_m\$ GENROU 2
96,	tm GENROU 3,	\$\tau_m\$ GENROU 3
97,	tm GENROU 4,	\$\tau_m\$ GENROU 4
98,	te GENROU 1,	\$\tau_e\$ GENROU 1
99,	te GENROU 2,	\$\tau_e\$ GENROU 2
100,	te GENROU 3,	\$\tau_e\$ GENROU 3
101,	te GENROU 4,	\$\tau_e\$ GENROU 4
102,	vf GENROU 1,	\$v_f\$ GENROU 1
103,	vf GENROU 2,	\$v_f\$ GENROU 2
104,	vf GENROU 3,	\$v_f\$ GENROU 3
105,	vf GENROU 4,	\$v_f\$ GENROU 4
106,	XadIfd GENROU 1,	\$X_{ad}I_{fd}\$ GENROU 1
107,	XadIfd GENROU 2,	\$X_{ad}I_{fd}\$ GENROU 2
108,	XadIfd GENROU 3,	\$X_{ad}I_{fd}\$ GENROU 3
109,	XadIfd GENROU 4,	\$X_{ad}I_{fd}\$ GENROU 4
110,	Pe GENROU 1,	\$P_e\$ GENROU 1
111,	Pe GENROU 2,	\$P_e\$ GENROU 2
112,	Pe GENROU 3,	\$P_e\$ GENROU 3
113,	Pe GENROU 4,	\$P_e\$ GENROU 4
114,	Qe GENROU 1,	\$Q_e\$ GENROU 1

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115,	Qe GENROU 2,	\$Q_e\$ GENROU 2
116,	Qe GENROU 3,	\$Q_e\$ GENROU 3
117,	Qe GENROU 4,	\$Q_e\$ GENROU 4
118,	psid GENROU 1,	\$\psi_d\$ GENROU 1
119,	psid GENROU 2,	\$\psi_d\$ GENROU 2
120,	psid GENROU 3,	\$\psi_d\$ GENROU 3
121,	psid GENROU 4,	\$\psi_d\$ GENROU 4
122,	psiq GENROU 1,	\$\psi_q\$ GENROU 1
123,	psiq GENROU 2,	\$\psi_q\$ GENROU 2
124,	psiq GENROU 3,	\$\psi_q\$ GENROU 3
125,	psiq GENROU 4,	\$\psi_q\$ GENROU 4
126,	psi2q GENROU 1,	\$\psi_{aq}\$ GENROU 1
127,	psi2q GENROU 2,	\$\psi_{aq}\$ GENROU 2
128,	psi2q GENROU 3,	\$\psi_{aq}\$ GENROU 3
129,	psi2q GENROU 4,	\$\psi_{aq}\$ GENROU 4
130,	psi2d GENROU 1,	\$\psi_{ad}\$ GENROU 1
131,	psi2d GENROU 2,	\$\psi_{ad}\$ GENROU 2
132,	psi2d GENROU 3,	\$\psi_{ad}\$ GENROU 3
133,	psi2d GENROU 4,	\$\psi_{ad}\$ GENROU 4
134,	psi2 GENROU 1,	\$\psi_a\$ GENROU 1
135,	psi2 GENROU 2,	\$\psi_a\$ GENROU 2
136,	psi2 GENROU 3,	\$\psi_a\$ GENROU 3
137,	psi2 GENROU 4,	\$\psi_a\$ GENROU 4
138,	Se GENROU 1,	\$S_e(\psi_a)\$ GENROU 1
139,	Se GENROU 2,	\$S_e(\psi_a)\$ GENROU 2
140,	Se GENROU 3,	\$S_e(\psi_a)\$ GENROU 3
141,	Se GENROU 4,	\$S_e(\psi_a)\$ GENROU 4
142,	XaqI1q GENROU 1,	\$X_{aq}I_{1q}\$ GENROU 1
143,	XaqI1q GENROU 2,	\$X_{aq}I_{1q}\$ GENROU 2
144,	XaqI1q GENROU 3,	\$X_{aq}I_{1q}\$ GENROU 3
145,	XaqI1q GENROU 4,	\$X_{aq}I_{1q}\$ GENROU 4
146,	paux TGOV1 1,	\$P_{aux}\$ TGOV1 1
147,	paux TGOV1 2,	\$P_{aux}\$ TGOV1 2
148,	paux TGOV1 3,	\$P_{aux}\$ TGOV1 3
149,	paux TGOV1 4,	\$P_{aux}\$ TGOV1 4
150,	pout TGOV1 1,	\$P_{out}\$ TGOV1 1
151,	pout TGOV1 2,	\$P_{out}\$ TGOV1 2
152,	pout TGOV1 3,	\$P_{out}\$ TGOV1 3
153,	pout TGOV1 4,	\$P_{out}\$ TGOV1 4
154,	wref TGOV1 1,	\$\omega_{ref}\$ TGOV1 1
155,	wref TGOV1 2,	\$\omega_{ref}\$ TGOV1 2
156,	wref TGOV1 3,	\$\omega_{ref}\$ TGOV1 3
157,	wref TGOV1 4,	\$\omega_{ref}\$ TGOV1 4
158,	pref TGOV1 1,	\$P_{ref}\$ TGOV1 1
159,	pref TGOV1 2,	\$P_{ref}\$ TGOV1 2
160,	pref TGOV1 3,	\$P_{ref}\$ TGOV1 3
161,	pref TGOV1 4,	\$P_{ref}\$ TGOV1 4
162,	wd TGOV1 1,	\$\omega_{dev}\$ TGOV1 1
163,	wd TGOV1 2,	\$\omega_{dev}\$ TGOV1 2
164,	wd TGOV1 3,	\$\omega_{dev}\$ TGOV1 3
165,	wd TGOV1 4,	\$\omega_{dev}\$ TGOV1 4
166,	pd TGOV1 1,	\$P_d\$ TGOV1 1

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167,	pd TGOV1 2,	\$P_d\$ TGOV1 2
168,	pd TGOV1 3,	\$P_d\$ TGOV1 3
169,	pd TGOV1 4,	\$P_d\$ TGOV1 4
170,	LL_y TGOV1 1,	\$y_{LL}\$ TGOV1 1
171,	LL_y TGOV1 2,	\$y_{LL}\$ TGOV1 2
172,	LL_y TGOV1 3,	\$y_{LL}\$ TGOV1 3
173,	LL_y TGOV1 4,	\$y_{LL}\$ TGOV1 4
174,	v EXDC2 1,	\$E_{term}\$ EXDC2 1
175,	v EXDC2 2,	\$E_{term}\$ EXDC2 2
176,	v EXDC2 3,	\$E_{term}\$ EXDC2 3
177,	v EXDC2 4,	\$E_{term}\$ EXDC2 4
178,	vout EXDC2 1,	\$v_{out}\$ EXDC2 1
179,	vout EXDC2 2,	\$v_{out}\$ EXDC2 2
180,	vout EXDC2 3,	\$v_{out}\$ EXDC2 3
181,	vout EXDC2 4,	\$v_{out}\$ EXDC2 4
182,	vref EXDC2 1,	\$V_{ref}\$ EXDC2 1
183,	vref EXDC2 2,	\$V_{ref}\$ EXDC2 2
184,	vref EXDC2 3,	\$V_{ref}\$ EXDC2 3
185,	vref EXDC2 4,	\$V_{ref}\$ EXDC2 4
186,	Se EXDC2 1,	\$S_e(V_{out})\$ EXDC2 1
187,	Se EXDC2 2,	\$S_e(V_{out})\$ EXDC2 2
188,	Se EXDC2 3,	\$S_e(V_{out})\$ EXDC2 3
189,	Se EXDC2 4,	\$S_e(V_{out})\$ EXDC2 4
190,	vi EXDC2 1,	\$V_i\$ EXDC2 1
191,	vi EXDC2 2,	\$V_i\$ EXDC2 2
192,	vi EXDC2 3,	\$V_i\$ EXDC2 3
193,	vi EXDC2 4,	\$V_i\$ EXDC2 4
194,	LL_y EXDC2 1,	\$y_{LL}\$ EXDC2 1
195,	LL_y EXDC2 2,	\$y_{LL}\$ EXDC2 2
196,	LL_y EXDC2 3,	\$y_{LL}\$ EXDC2 3
197,	LL_y EXDC2 4,	\$y_{LL}\$ EXDC2 4
198,	W_y EXDC2 1,	\$y_{W}\$ EXDC2 1
199,	W_y EXDC2 2,	\$y_{W}\$ EXDC2 2
200,	W_y EXDC2 3,	\$y_{W}\$ EXDC2 3
201,	W_y EXDC2 4,	\$y_{W}\$ EXDC2 4

2.5.6 Plot and save to file

We found a limitation of using `andes plot` from within Notebook/iPython. The figure won't be displayed correctly. The workaround is to save the image as a file and display it from the notebook.

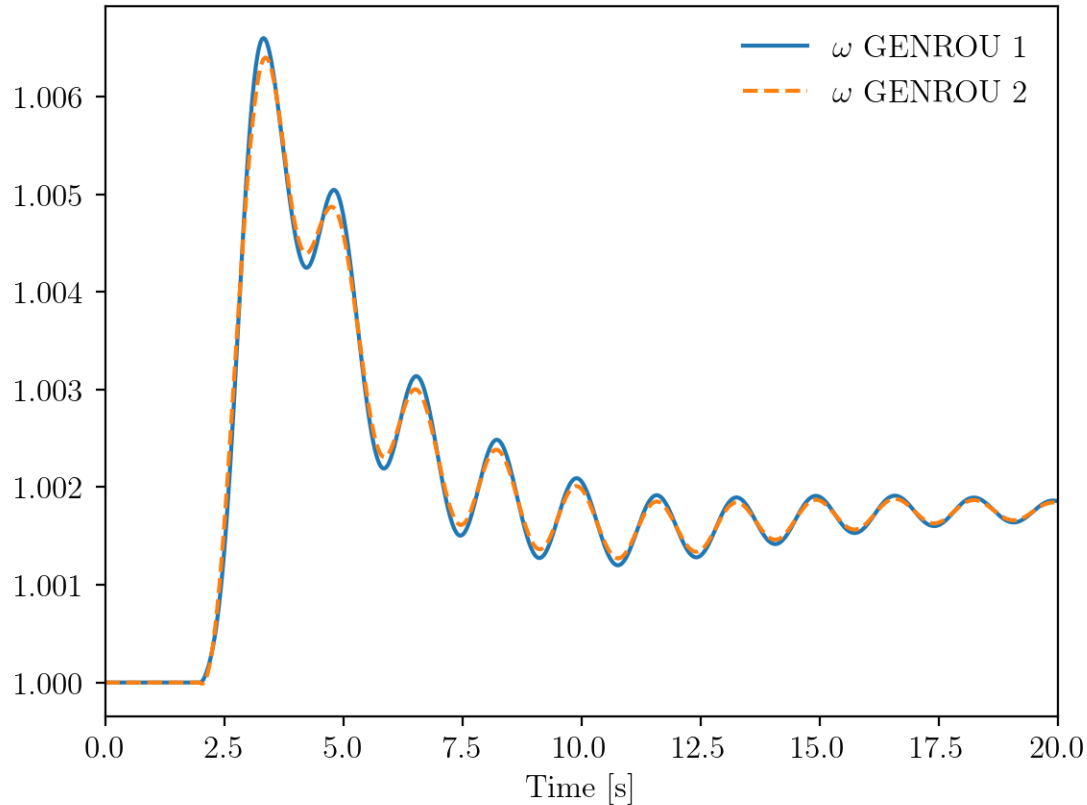
Please let us know if you have better solutions.

```
!andes plot kundur_full_out.lst 0 5 6 --save
```

```
Figure saved to "kundur_full_out_1.png".
Figure(640x480)
```

2.5.7 Display image

```
from IPython.display import Image
Image("kundur_full_out_1.png")
```



2.5.8 Using xargs for index lookup

A convenient tool in Linux/macOS is `xargs`, which turns the standard output of one program into arguments for another.

`andes plot --xargs` accepts an input of search pattern for variable names and returns a list of arguments, including the matched indices, that can be understood by `andes plot`.

To illustrate, let's look at an example output of `andes plot --xargs`.

```
!andes plot kundur_full_out.lst --xargs "omega GENROU"
```

```
kundur_full_out.lst 0 5 6 7 8
```

The output consists of the `lst` file name, the default x-axis index 0, and the indices for the found variables. The full output can be passed to `andes plot` without modification.

We use the following command to pass the arguments:

```
!andes plot kundur_full_out.lst --xargs "omega GENROU" | xargs andes plot
```

Figure (640x480)

where `|` is the pipe operator in shell for piping the standard output of the left-hand side to the right-hand side, `xargs` captures the pipe-in and appends it to `andes plot`.

The command is equivalent to manually running

```
!andes plot kundur_full_out.lst 5 6 7 8
```

Figure (640x480)

2.5.9 Cleanup

Remove the saved png image files.

```
!rm -v *.png
```

removed 'kundur_full_out_1.png'

```
!andes misc -C
```

```
"/home/hacui/repos/andes/examples/kundur_full_out.npz" removed.  
"/home/hacui/repos/andes/examples/kundur_full_out.txt" removed.  
"/home/hacui/repos/andes/examples/kundur_out.lst" removed.  
"/home/hacui/repos/andes/examples/kundur_out.npz" removed.  
"/home/hacui/repos/andes/examples/kundur_full_out.lst" removed.  
"/home/hacui/repos/andes/examples/kundur_out.txt" removed.
```

2.6 Batch Processing - Generate Cases

This notebook demonstrates creating cases in batch and running them in parallel.

2.6.1 Create Cases in Batch

The approach to create cases in batch following this procedure:

- Load the base case from file
- For each desired case output:
 - Alter parameters to the desired value
 - Save each system to a new case file

```
import andes
import numpy as np
from andes.utils.paths import get_case

andes.config_logger(stream_level=30)  # brief logging
```

```
# create directory for output cases
!rm -rf batch_cases
!mkdir -p batch_cases
```

```
kundur = get_case('kundur/kundur_full.xlsx')
ss = andes.load(kundur)
```

We demonstrate running the Kundur's system under different loading conditions.

Cases are created by modifying the `p0` of `PQ` with `idx == PQ_0`.

As always, input parameters can be inspected by accessing `Model.as_df(vin=True)`.

```
p0_base = ss.PQ.get('p0', "PQ_0")
```

Create 3 cases so that the load increases from `p0_base` to `1.2 * p0_base`.

```
N_CASES = 3  # Note: increase `N_CASES` as necessary
p0_values = np.linspace(p0_base, 1.2 * p0_base, N_CASES)
```

```
for value in p0_values:
    ss.PQ.alter('p0', 'PQ_0', value)
    file_name = f'batch_cases/kundur_p_{value:.2f}.xlsx'

    andes.io.dump(ss, 'xlsx', file_name, overwrite=True)
```

2.6.2 Parallel Simulation

Parallel simulation is easy with the command line tool.

Change directory to `batch_cases`:

```
import os

# change the Python working directory
os.chdir('batch_cases')
```

```
!ls -la
```

```
total 56
drwxr-xr-x 2 hacui hacui 4096 Apr 19 20:31 .
drwxr-xr-x 6 hacui hacui 4096 Apr 19 20:31 ..
```

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```
-rw-r--r-- 1 hacui hacui 14841 Apr 19 20:31 kundur_p11.59.xlsx
-rw-r--r-- 1 hacui hacui 14842 Apr 19 20:31 kundur_p12.75.xlsx
-rw-r--r-- 1 hacui hacui 14840 Apr 19 20:31 kundur_p13.91.xlsx
```

Running from Command line

```
!andes run *.xlsx -r tds
```

```

  _ _ _ _ _ | Version 1.6.4.post10.dev0+gd1a4589d
 / _ \ _ _ | Python 3.9.10 on Linux, 04/19/2022 08:31:06 PM
/_ _ \ _ _ |
/_ _ \ _ _ | This program comes with ABSOLUTELY NO WARRANTY.

```

```
Working directory: "/home/hacui/repos/andes/examples/batch_cases"
-> Processing 3 jobs on 12 CPUs.
Process 0 for "kundur_p_11.59.xlsx" started.
Process 1 for "kundur_p_12.75.xlsx" started.
Process 2 for "kundur_p_13.91.xlsx" started.
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
100%|#####| 100.0/100 [00:01<00:00, 89.55%/
↪s]
100%|#####| 100.0/100 [00:01<00:00, 87.15%/
↪s]
100%|#####| 100.0/100 [00:01<00:00, 83.73%/
↪s]
Log saved to "/tmp/andes-4fbaduja/andes.log".
-> Multiprocessing finished in 1.7566 seconds.
```

Number of CPUs

In some cases, you don't want the simulator to use up all resources.

ANDES allows to control the number of processes to run in parallel through `--ncpu NCPU`, where `NCPU` is the maximum number of processes (equivalent to the number of CPU cores) allowed.

```
!andes run *.xlsx -r tds --ncpu 4
```

[illegible]

```
Working directory: "/home/hacui/repos/andes/examples/batch_cases"
-> Processing 3 jobs on 4 CPUs.
Process 0 for "kundur_p_11.59.xlsx" started.
```

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```

Process 1 for "kundur_p_12.75.xlsx" started.
Process 2 for "kundur_p_13.91.xlsx" started.
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
100%|#####| 100.0/100 [00:01<00:00, 88.46%/
↪s]
100%|#####| 100.0/100 [00:01<00:00, 86.36%/
↪s]
100%|#####| 100.0/100 [00:01<00:00, 83.39%/
↪s]
Log saved to "/tmp/andes-rlpeyx09/andes.log".
-> Multiprocessing finished in 1.7693 seconds.

```

Running with APIs

Setting `pool = True` allows returning all system instances in a list.

This comes with a penalty in computation time but can be helpful if you want to extract data directly.

```
systems = andes.run('*.*xlsx', routine='tds', pool=True, verbose=10)
```

```

Working directory: "/home/hacui/repos/andes/examples/batch_cases"
Found files: ['kundur_p_11.59.xlsx', 'kundur_p_12.75.xlsx', 'kundur_p_13.91.
↪xlsx']
-> Processing 3 jobs on 12 CPUs.

```

```

Cases are processed in the following order:
"kundur_p_11.59.xlsx"
"kundur_p_12.75.xlsx"
"kundur_p_13.91.xlsx"
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.<Toggle 1>: Line.
↪Line_8 status changed to 0 at t=2.0 sec.

<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
Log saved to "/tmp/andes-lmohp4sw/andes.log".
-> Multiprocessing finished in 3.2217 seconds.

```

```
systems[0]
```

```
<andes.system.System at 0x7fbaa050a070>
```

```
systems
```

```

[<andes.system.System at 0x7fbaa050a070>,
<andes.system.System at 0x7fba7bca2c70>,
<andes.system.System at 0x7fba7bc9db80>]

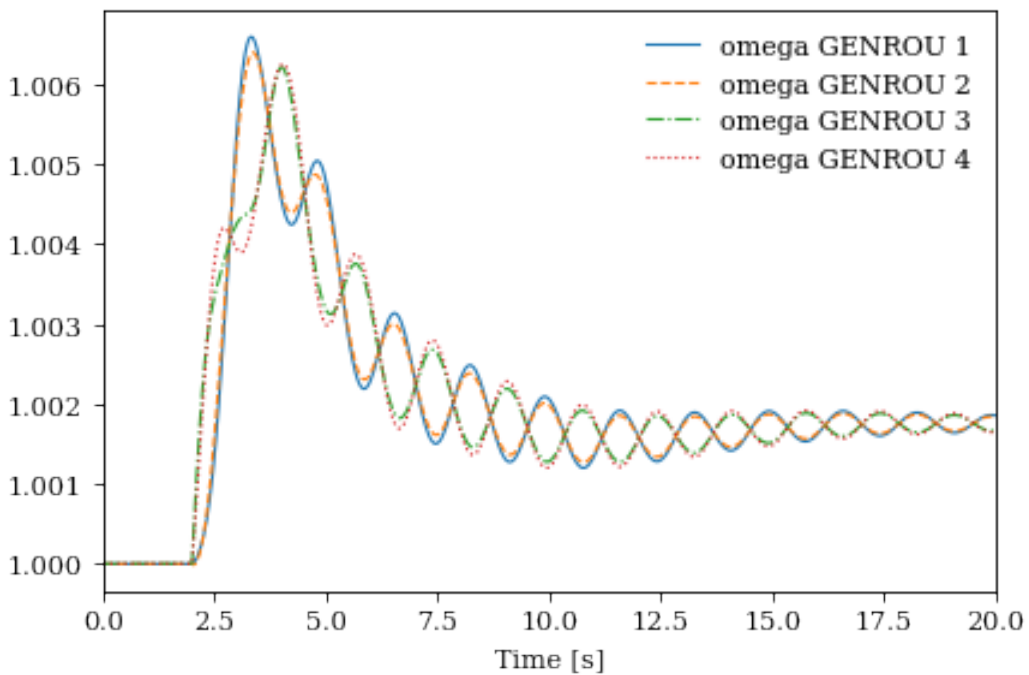
```

Example plots

Plotting or data analyses can be carried out as usual.

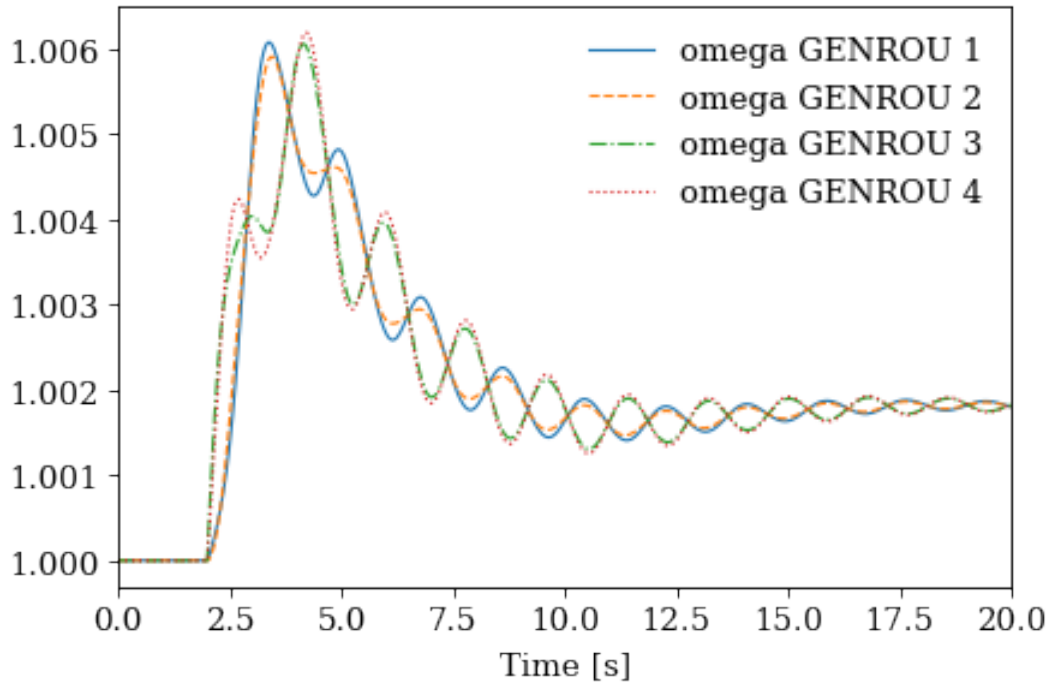
```
ss = systems[0]
```

```
systems[0].TDS.plotter.plot(ss.GENROU.omega, latex=False)
```



```
(<Figure size 480x320 with 1 Axes>, <AxesSubplot:xlabel='Time [s] '>)
```

```
systems[2].TDS.plotter.plot(ss.GENROU.omega, latex=False)
```

```
(<Figure size 480x320 with 1 Axes>, <AxesSubplot:xlabel='Time [s] '>)
```

```
!andes misc -C
!rm -rf batch_cases
```

```
No output file found in the working directory.
```

2.7 Batch Processing - in Memory

This notebook shows examples for batch power flow and time-domain calculations. Readers are supposed to have read the previous examples, especially Example 7 for parallel simulations.

```
import andes
import numpy as np

from matplotlib import pyplot as plt
```

2.7.1 Batch Power Flow Calculation

Use the Kundur's system as the example. Suppose we want to calculate power flow for the same system structure but for different load levels.

```
kundur = andes.utils.get_case('kundur/kundur_full.xlsx')
```

```
ss = andes.run(kundur,
               no_output=True,
               default_config=True,
               verbose=30, # set logging level to WARNING
               )
```

```
-> Single process finished in 0.4701 seconds.
```

There are two PQ loads in the Kundur's system with idxes of PQ_0 and PQ_1.

```
ss.PQ.as_df(vin=True)
```

	idx	u	name	bus	Vn	p0	q0	vmax	vmin	owner
uid										
0	PQ_0	1.0	PQ_0	7	230.0	11.59	-0.735	1.1	0.9	1
1	PQ_1	1.0	PQ_1	8	230.0	15.75	-0.899	1.1	0.9	1

If we have a range of active power for each load, such as

```
n_samples = 3 # Note: increase `n_samples` for higher data resolution

pq0_values = np.linspace(10, 12, n_samples)
pq1_values = np.linspace(12, 18, n_samples)
```

where there are 3 samples for PQ_0.p0 between [10, 12] and 3 samples for PQ_1.p0 between (12, 18).

We can use a for loop to set the load values and calculate power flow for each point.

Suppose we want to retrieve the voltage magnitude for each case, we use `v_results` the voltage results. Results that are not saved will be discarded.

```
v_results = np.zeros((ss.Bus.n, n_samples ** 2))
idx = 0

for ii in pq0_values:
    ss.PQ.alter("p0", "PQ_0", ii)
    for jj in pq1_values:
        ss.PQ.alter("p0", "PQ_1", jj)

        ss.PFlow.run()
        v_results[:, idx] = ss.dae.y[ss.Bus.v.a]

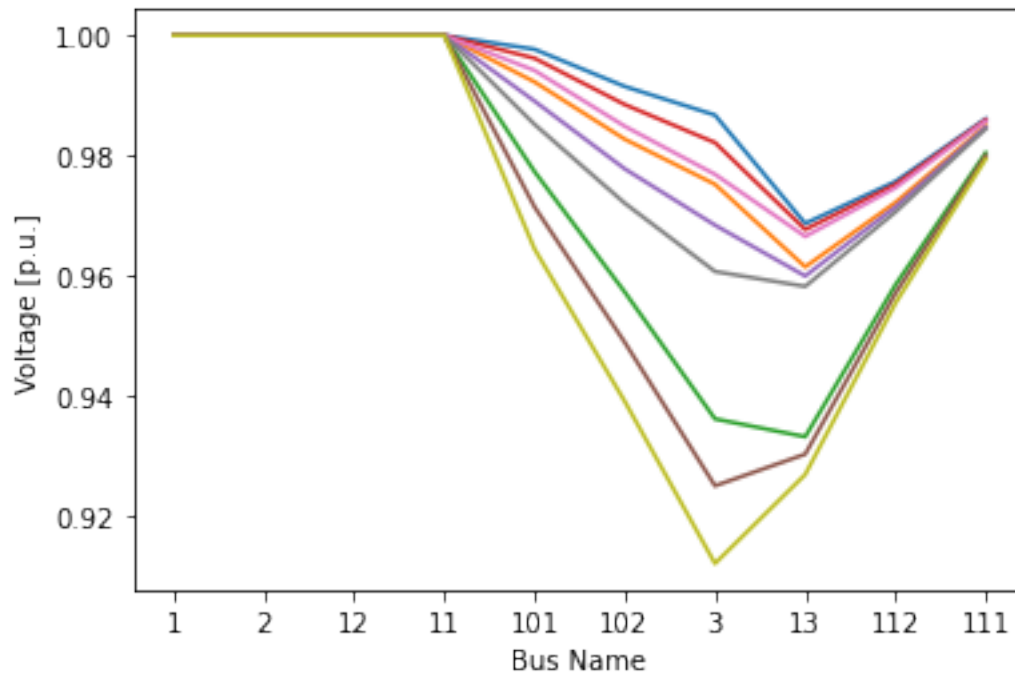
        idx += 1
```

Let's plot the results.

```
lines = plt.plot(v_results)

xl = plt.xlabel('Bus Name')
yl = plt.ylabel('Voltage [p.u.]')

tk = plt.xticks(np.arange(ss.Bus.n), ss.Bus.name.v)
```



One should be aware that the for-loop based approach is single-threaded. It does not take advantage of multi-core processors.

If the total number of scenarios are huge, one should refer to Example 7 to save all scenarios to excel files and use multi-processing.

2.7.2 Batch Time-Domain Simulation

The next example shows how to run batch time-domain simulations for different events.

Suppose we want to create one scenario for each line trip event, which is actuated through `Toggle`. For the same system, we want to add `Toggles` for each line, run the simulation, and save results.

```
kundur = andes.utils.get_case('kundur/kundur_full.xlsx')
```

We use `andes.load()` with `setup=False` to load the test case.

It is important to note that one must pass `setup=False` so that adding `Toggles` can be allowed.

```
ss = andes.load(kundur, setup=False)
```

The `idx`s of all available lines to trip are in `ss.Line.idx.v`:

```
idxes = ss.Line.idx.v
```

```
ss.Toggle.as_df()
```

```

      idx  u      name model      dev  t
uid
0      1  1  Toggle_1  Line  Line_8  2

```

We use `ss.add()` to add two Toggles for each line at 1 second and 1.1 seconds to simulate a line opening and closing. `ss.add()` takes a model name, "Toggle", as the positional argument, and a dictionary for the Toggle device parameters.

A note for this particular test case is that `kundur_full.xlsx` already comes with a Toggle with `idx==1`. To not to interfere with our scenarios, we need to disable it using `ss.Toggle.alter`.

After adding Toggle devices, we need to manually call `ss.setup()` to finish the data structure setup. Then, power flow and time-domain simulation can be performed.

We store the results in a dictionary where keys are the line names and values are the systems. Code is as follows.

```

results = dict()

for idx in idxes:
    ss = andes.load(kundur, setup=False)

    ss.add('Toggle', dict(model="Line", dev=idx, t=1.0))
    ss.add('Toggle', dict(model="Line", dev=idx, t=1.1))

    ss.setup()                                # no `ss.add()` calls are allowed after
↪setup()
    ss.Toggle.alter('u', 1, 0.0) # disable the existing Toggle with idx=1
↪(this is for the particular case)

    ss.PFlow.run()
    ss.TDS.config.tf = 5                # simulate for 5 seconds to save time
    ss.TDS.config.no_tqdm = 1          # disable progres bar printing
    ss.TDS.run()

    results[idx] = ss

```

```

<Toggle Toggle_2>: Line.Line_0 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_0 status changed to 1 at t=1.1 sec.
<Toggle Toggle_2>: Line.Line_1 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_1 status changed to 1 at t=1.1 sec.
<Toggle Toggle_2>: Line.Line_2 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_2 status changed to 1 at t=1.1 sec.
<Toggle Toggle_2>: Line.Line_3 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_3 status changed to 1 at t=1.1 sec.
<Toggle Toggle_2>: Line.Line_4 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_4 status changed to 1 at t=1.1 sec.

```

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```

<Toggle Toggle_2>: Line.Line_5 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_5 status changed to 1 at t=1.1 sec.
<Toggle Toggle_2>: Line.Line_6 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_6 status changed to 1 at t=1.1 sec.
<Toggle Toggle_2>: Line.Line_7 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_7 status changed to 1 at t=1.1 sec.
<Toggle Toggle_2>: Line.Line_8 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_8 status changed to 1 at t=1.1 sec.
<Toggle Toggle_2>: Line.Line_9 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_9 status changed to 1 at t=1.1 sec.
<Toggle Toggle_2>: Line.Line_10 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_10 status changed to 1 at t=1.1 sec.

```

Time step reduced to zero. Convergence is not likely.
Simulation terminated at t=1.1001 s.

```

<Toggle Toggle_2>: Line.Line_11 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_11 status changed to 1 at t=1.1 sec.
<Toggle Toggle_2>: Line.Line_12 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_12 status changed to 1 at t=1.1 sec.
<Toggle Toggle_2>: Line.Line_13 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_13 status changed to 1 at t=1.1 sec.
<Toggle Toggle_2>: Line.Line_14 status changed to 0 at t=1.0 sec.
<Toggle Toggle_3>: Line.Line_14 status changed to 1 at t=1.1 sec.

```

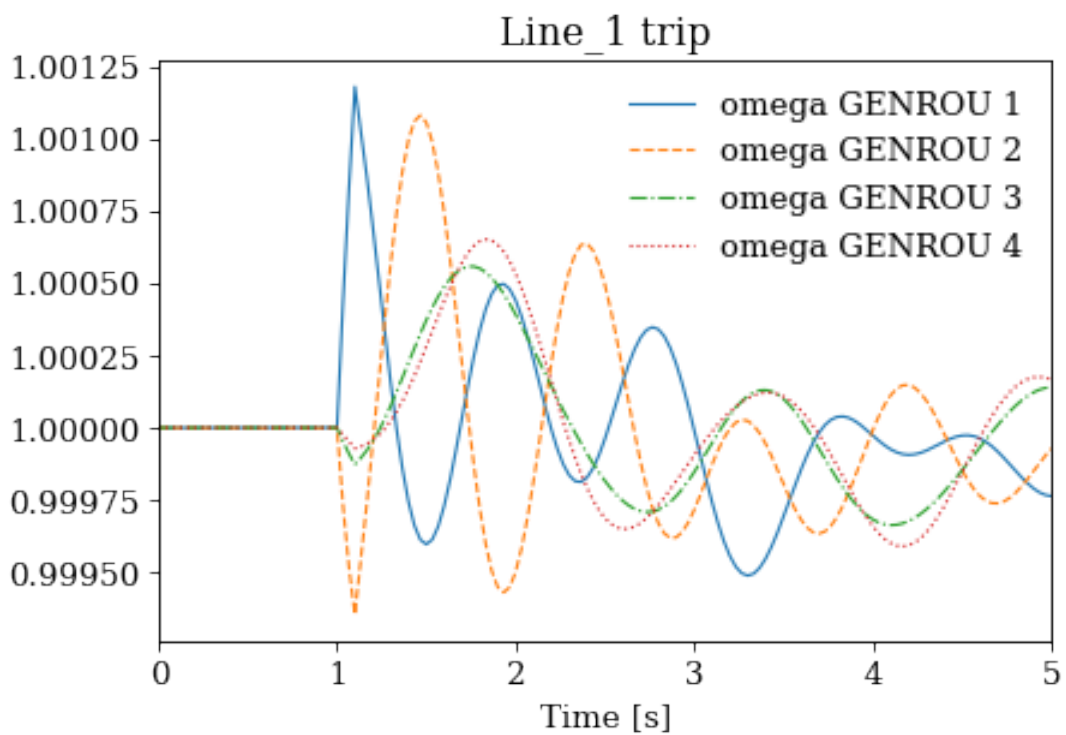
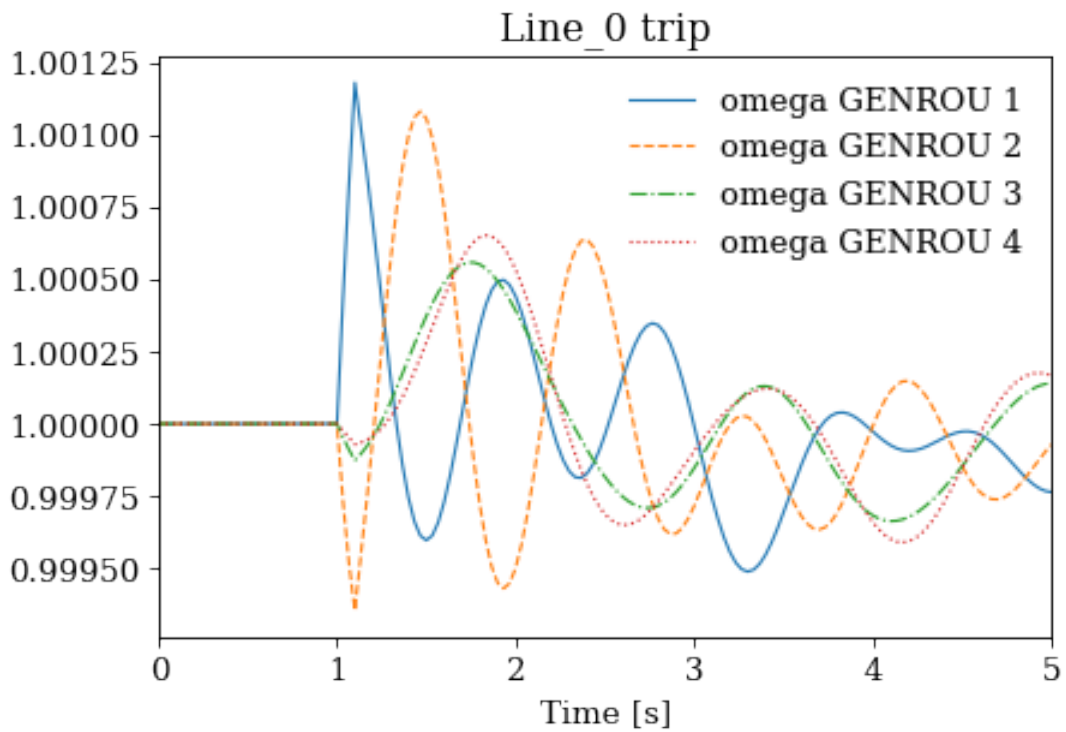
Jacobian matrix is singular.
Suspect diagonal elements: [55, 61]
NaN found in solution. Convergence is not likely
Simulation terminated at t=1.5808 s.

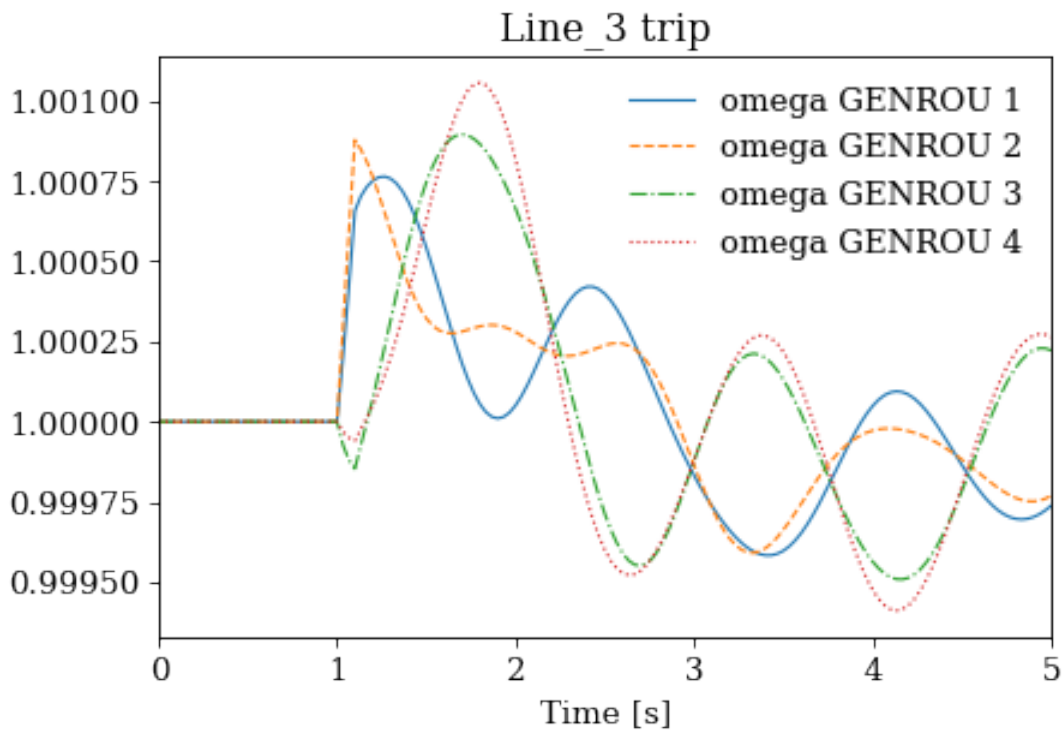
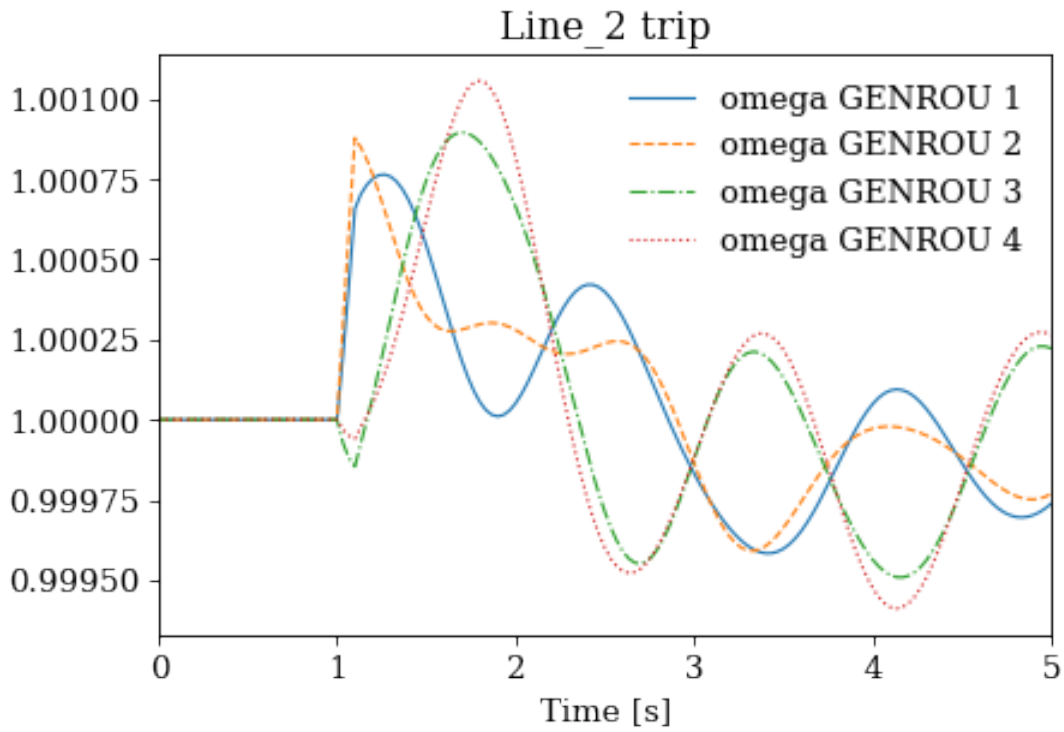
Not all cases will solve due to system instability. For the converged cases, one can export the data or plot results following Example 1.

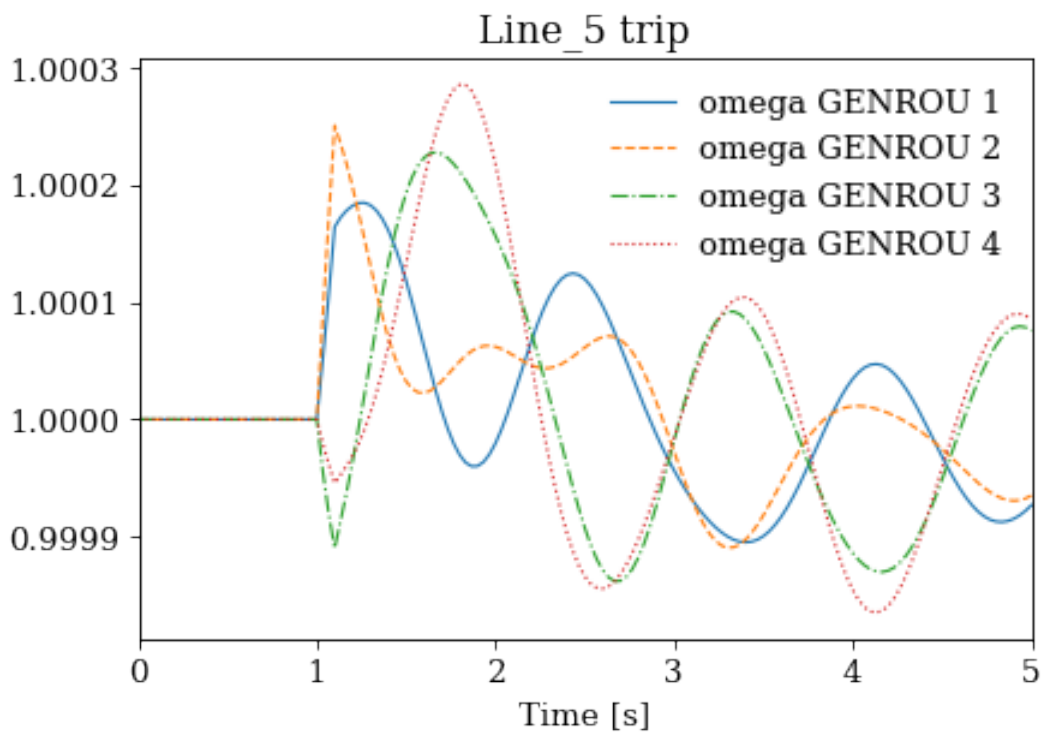
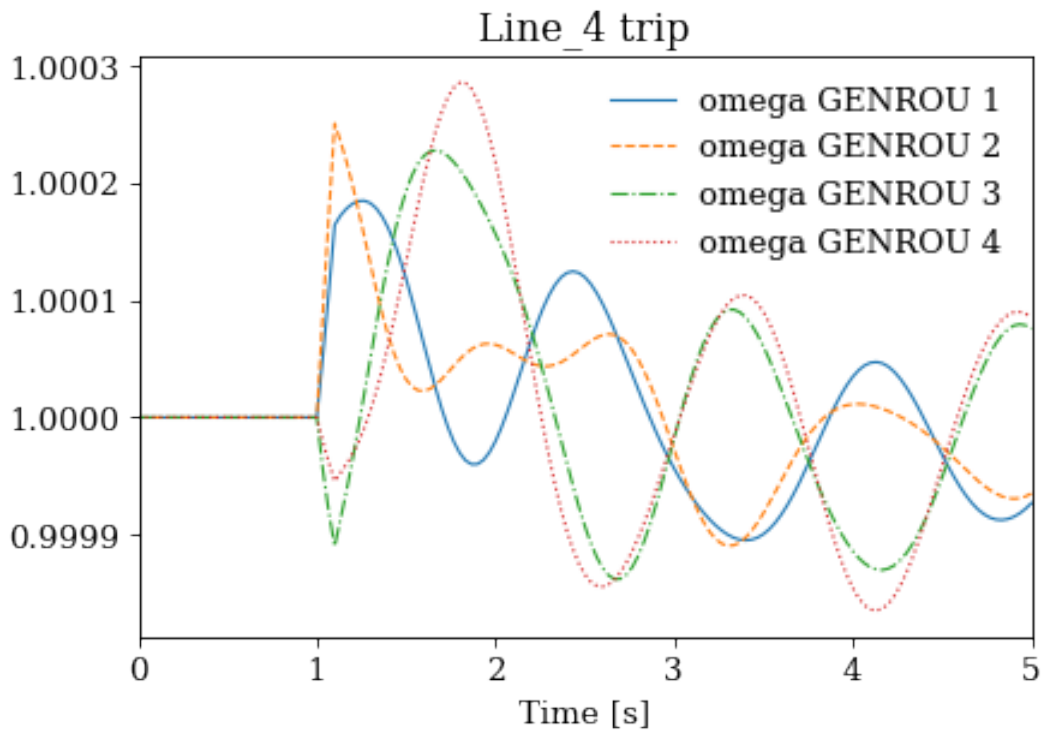
```

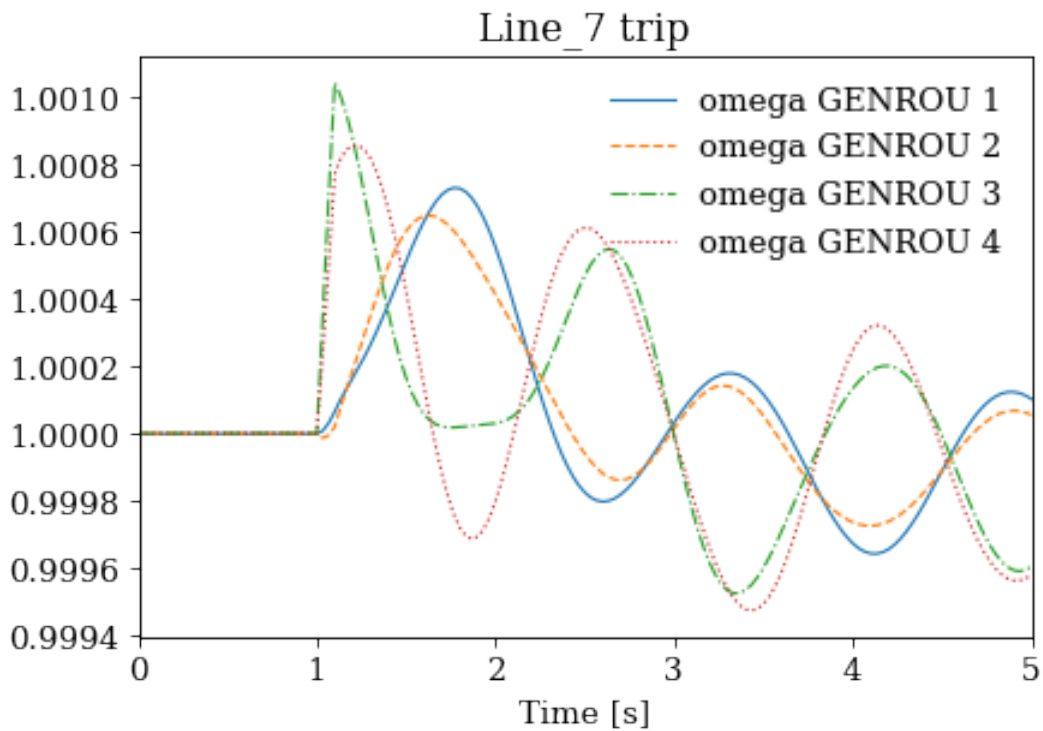
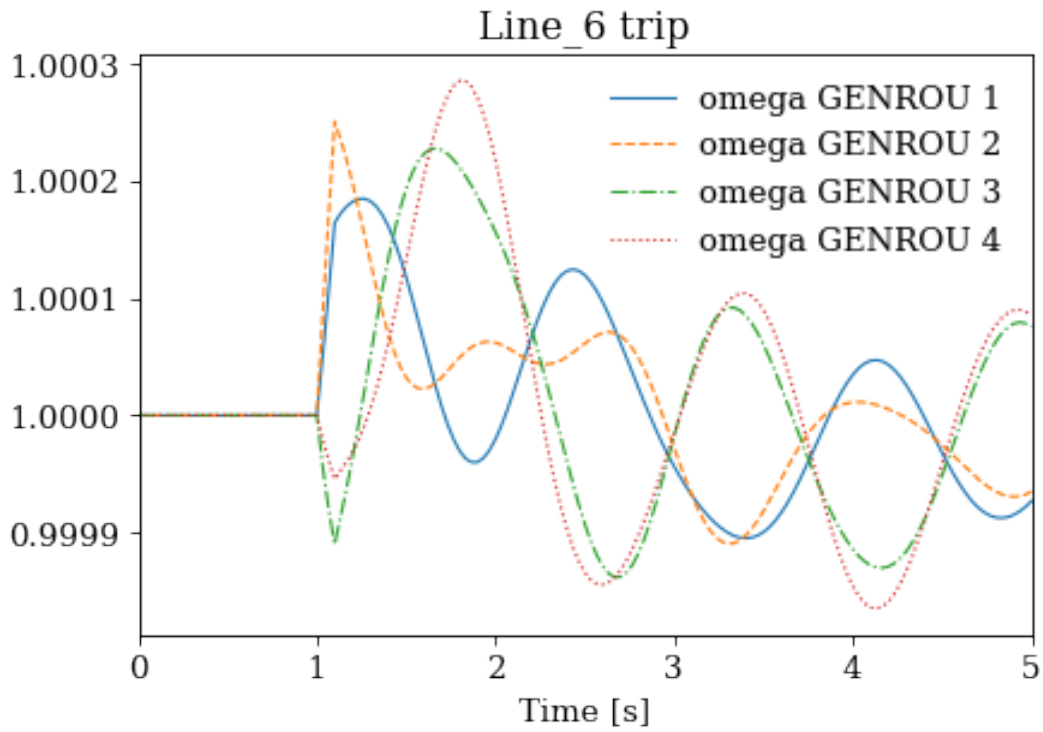
for idx, ss in results.items():
    ss.TDS.plt.plot(ss.GENROU.omega, title=f'{idx} trip', latex=False, dpi=80)

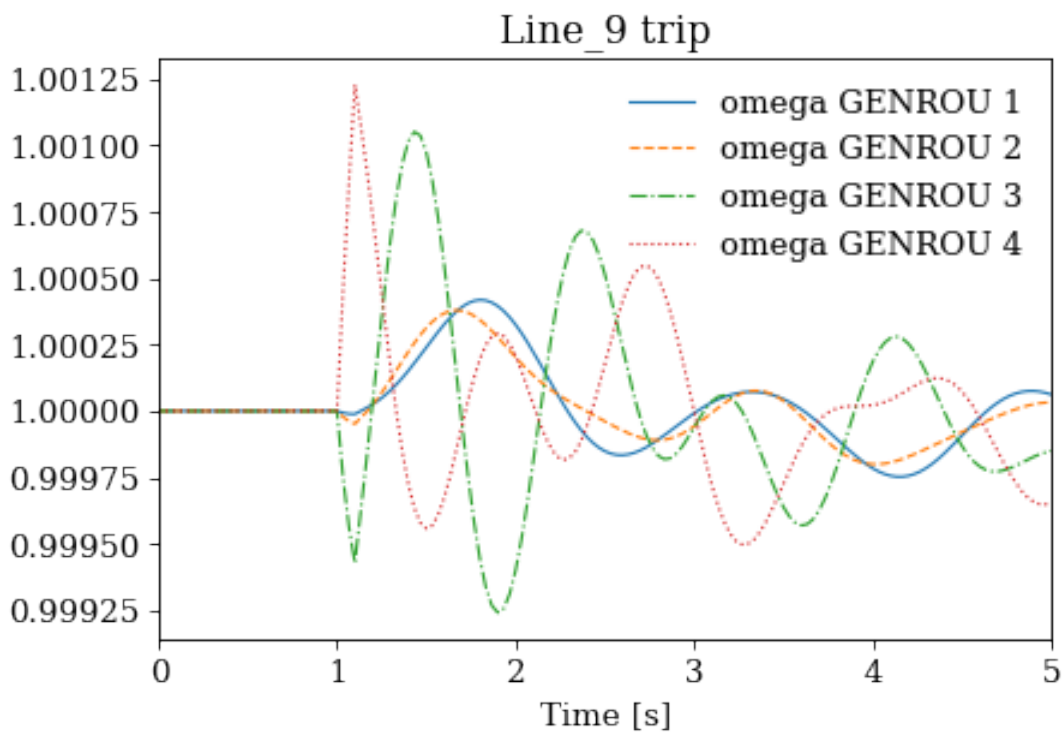
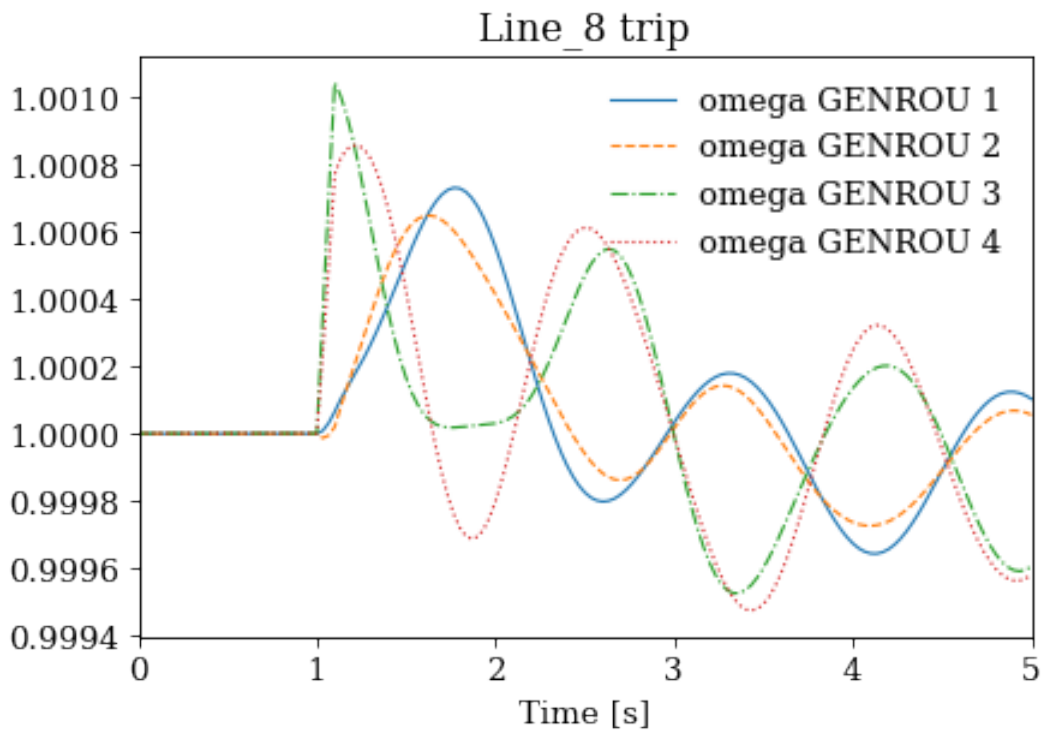
```

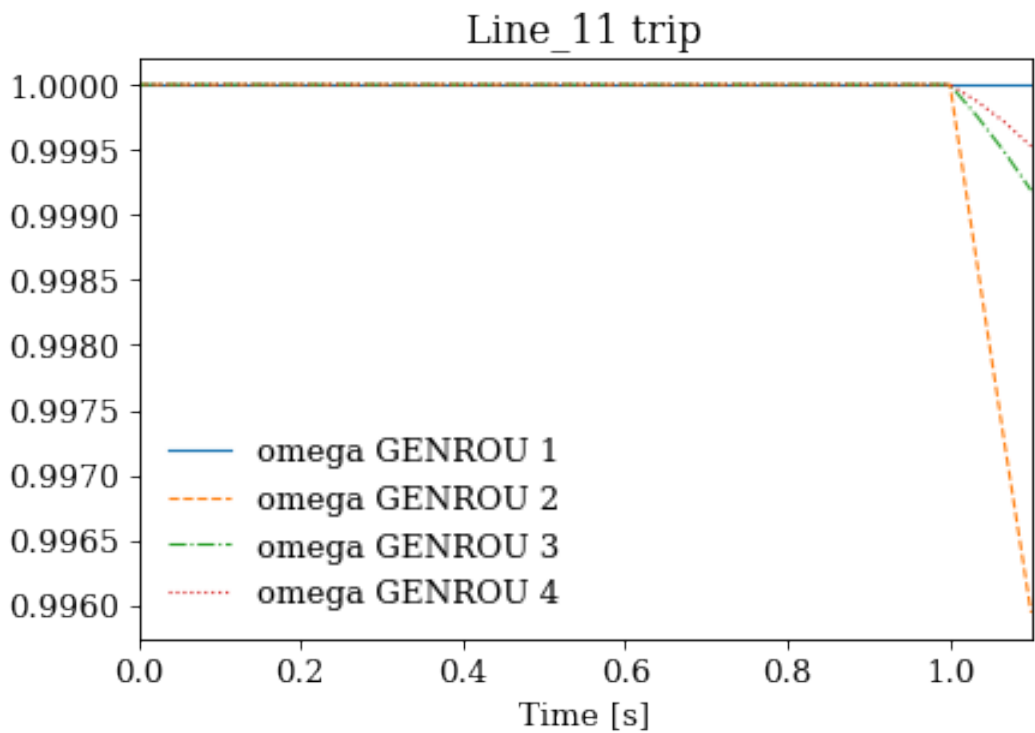
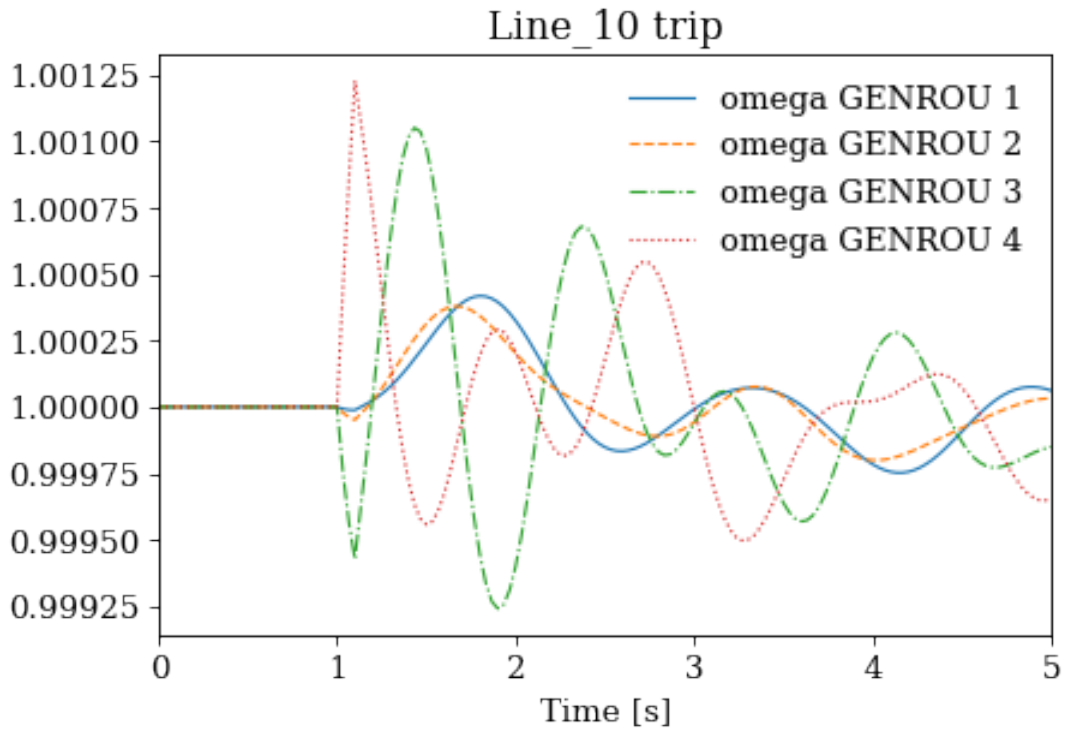


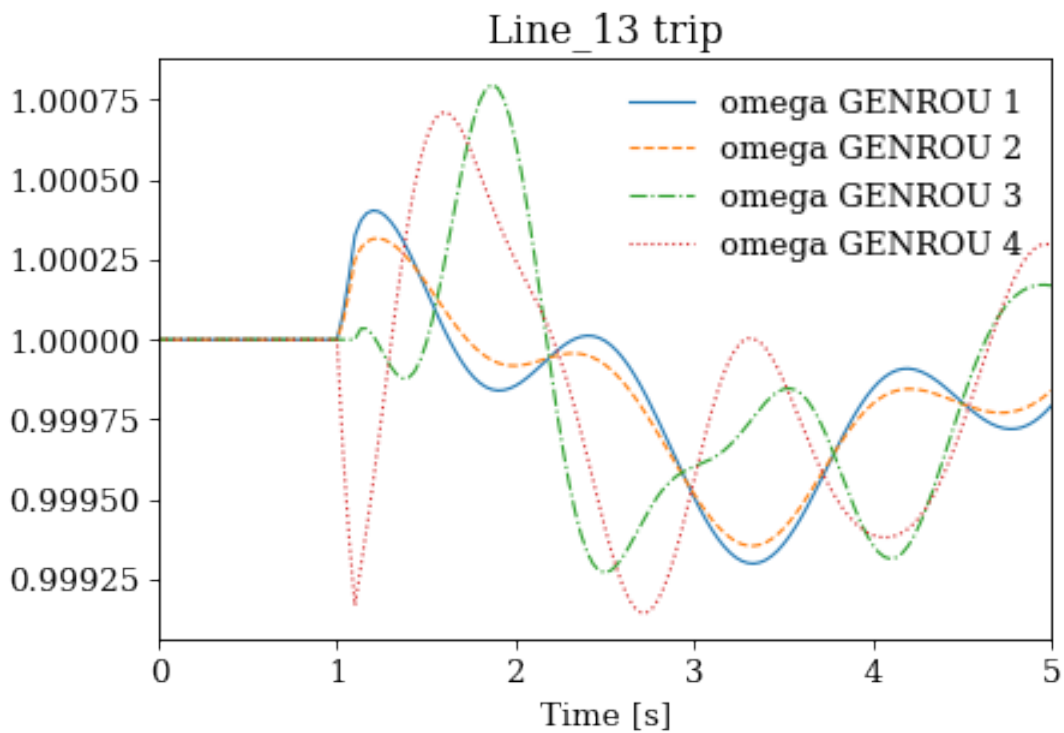
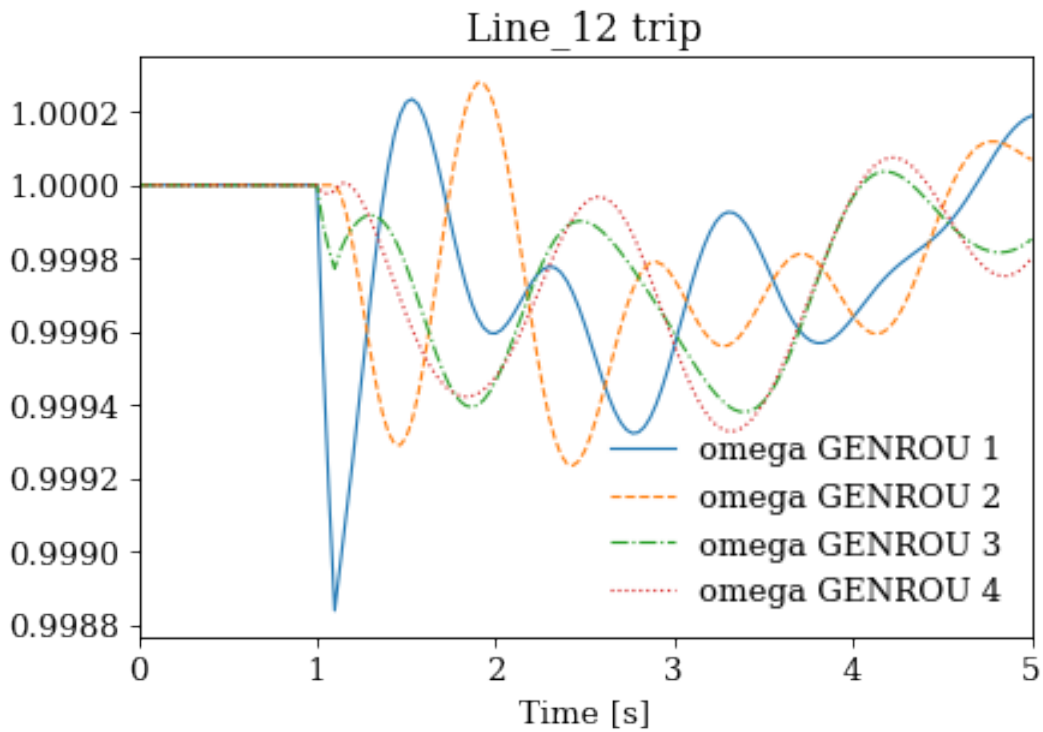


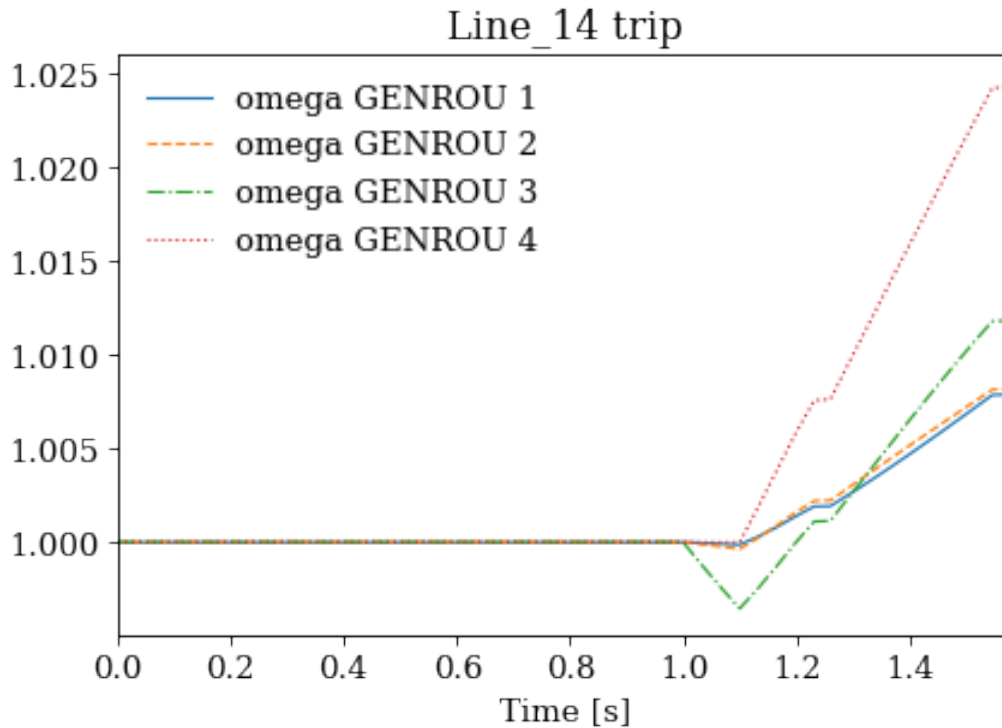












```
!rm -rf batch_cases/
```

2.8 Changing Setpoints

This notebook shows an example of changing the generator setpoints in a time-domain simulation. Data in this example is trivial, but the example can be retrofitted for scenarios such as economic dispatch incorporation or reinforcement learning.

Steps are the follwing:

1. Initialize a system by running the power flow,
2. Set the first simulation stop time in `TDS.config.tf`,
3. Run the simulation,
4. Update the setpoints,
5. Set the new simulation stop time and repeat from 3 until the end.

2.8.1 Step 1: Case Setup

```
import andes
from andes.utils import get_case
```

```
kundur = get_case('kundur/kundur_full.xlsx')

ss = andes.run(kundur)
```

```
Working directory: "/home/hacui/repos/andes/examples"
> Loaded config from file "/home/hacui/.andes/andes.rc"
> Loaded generated Python code in "/home/hacui/.andes/pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/kundur/kundur_full.
↳xlsx"...
Input file parsed in 0.2635 seconds.
System internal structure set up in 0.0315 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0087 seconds.
0: |F(x)| = 14.9282832
1: |F(x)| = 3.608627841
2: |F(x)| = 0.1701107882
3: |F(x)| = 0.002038626956
4: |F(x)| = 3.745104027e-07
Converged in 5 iterations in 0.0108 seconds.
Initialization for dynamics completed in 0.0395 seconds.
Initialization was successful.
Report saved to "kundur_full_out.txt" in 0.0023 seconds.
```

```
-> Single process finished in 0.5215 seconds.
```

```
# disable the Toggle in this case
ss.Toggle.alter('u', 1, 0)
```

2.8.2 Step 2: Set the First Stop Time

```
# simulate to t=1 sec

# specify the first stop in `ss.TDS.config.tf`
ss.TDS.config.tf = 1
```

2.8.3 Step 3: Run Simulation

```
ss.TDS.run()
```

```
-> Time Domain Simulation Summary:
Sparse Solver: KLU
Simulation time: 0.0-1 s.
Fixed step size: h=33.33 ms. Shrink if not converged.
```

```
0%|          | 0/100 [00:00<?, ?%/s]
```

```
Simulation completed in 0.0245 seconds.
Outputs to "kundur_full_out.lst" and "kundur_full_out.npz".
Outputs written in 0.0039 seconds.
```

```
True
```

2.8.4 Step 4. Apply the auxiliary power setpoints to TGOV1.paux0.v

First, let's check the equations of TGOV1. `ss.TGOV1.paux0` is associated with equation `0 = paux - paux0`, in which `paux` is added to the power input equation.

```
print(ss.TGOV1.doc())
```

```
Model <TGOV1> in Group <TurbineGov>
TGOV1 turbine governor model.
```

```
Implements the PSS/E TGOV1 model without deadband.
```

```
Parameters
```

Name	Description	Default	Unit	Properties
idx	unique device idx			
u	connection status	1	bool	
name	device name			
syn	Synchronous generator idx			mandatory, unique
Tn	Turbine power rating. Equal to `Sn` if not provided.		MVA	

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wref0	Base speed reference	1	p.u.	
R	Speed regulation gain (mach. base default)	0.050	p.u.	ipower
VMAX	Maximum valve position	1.200	p.u.	power
VMIN	Minimum valve position	0	p.u.	power
T1	Valve time constant	0.100		
T2	Lead-lag lead time constant	0.200		
T3	Lead-lag lag time constant	10		
Dt	Turbine damping coefficient	0		power
Sg	Rated power from generator	0	MVA	
ug	Generator connection status	0	bool	
Vn	Rated voltage from generator	0	kV	

Variables

Name	Type	Description	Unit	Properties
LAG_y	State	State in lag TF		v_str
LL_x	State	State in lead-lag		v_str
omega	ExtState	Generator speed	p.u.	
paux	Algeb	Auxiliary power input		v_str
pout	Algeb	Turbine final output power		v_str
wref	Algeb	Speed reference variable		v_str
pref	Algeb	Reference power input		v_str
wd	Algeb	Generator speed deviation	p.u.	v_str
pd	Algeb	Pref plus speed deviation times gain	p.u.	v_str
LL_y	Algeb	Output of lead-lag		v_str
tm	ExtAlgeb	Mechanical power interface to SynGen		

Initialization Equations

Name	Type	Initial Value
LAG_y	State	pd * 1 / 1
LL_x	State	LAG_y
omega	ExtState	
paux	Algeb	paux0
pout	Algeb	ue * tm0
wref	Algeb	wref0
pref	Algeb	tm0 * R
wd	Algeb	0
pd	Algeb	ue * tm0
LL_y	Algeb	LAG_y
tm	ExtAlgeb	

Differential Equations

Name	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LAG_y	State	1 * pd - 1 * LAG_y	T1
LL_x	State	(LAG_y - LL_x)	T3
omega	ExtState		

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Algebraic Equations

Name	Type	RHS of Equation "0 = g(x, y)"
paux	Algeb	paux0 - paux
pout	Algeb	ue * (LL_y - Dt * wd) - pout
wref	Algeb	wref0 - wref
pref	Algeb	pref0 * R - pref
wd	Algeb	ue * (omega - wref) - wd
pd	Algeb	ue*(- wd + pref + paux) * gain - pd
LL_y	Algeb	1 * T2 * (LAG_y - LL_x) + 1 * LL_x * T3 - LL_y * T3 + LL_LT1_z1 * LL_LT2_z1 * (LL_y - 1 * LL_x)
tm	ExtAlgeb	ue * (pout - tm0)

Services

Name	Equation	Type
ue	u * ug	ConstService
pref0	tm0	ConstService
paux0	0	ConstService
gain	ue/R	ConstService

Discretes

Name	Type	Info
LAG_lim	AntiWindup	Limiter in Lag
LL_LT1	LessThan	
LL_LT2	LessThan	

Blocks

Name	Type	Info
LAG	LagAntiWindup	
LL	LeadLag	

Config Fields in [TGOV1]

Option	Value	Info	Acceptable values
allow_adjust	1	allow adjusting upper or lower limits	(0, 1)
adjust_lower	0	adjust lower limit	(0, 1)
adjust_upper	1	adjust upper limit	(0, 1)

ss.TGOV1.paux0.v

```
array([0., 0., 0., 0.])
```

```
# look up the original values of TGOV1 make sure they are as expected  
ss.TGOV1.paux0.v
```

```
array([0., 0., 0., 0.])
```

```
# MUST use in-place assignments.  
# Here, we increase the setpoint of the 0-th generator  
  
# method 1: use in-place assignment again  
ss.TGOV1.paux0.v[0] = 0.05  
  
# method 2: use ``ss.TGOV1.alter()``  
# ss.TGOV1.alter('paux0', 1, 0.05)
```

```
ss.TGOV1.paux0.v
```

```
array([0.05, 0. , 0. , 0. ])
```

Continue to simulate to 2 seconds.

```
ss.TDS.config.tf = 2
```

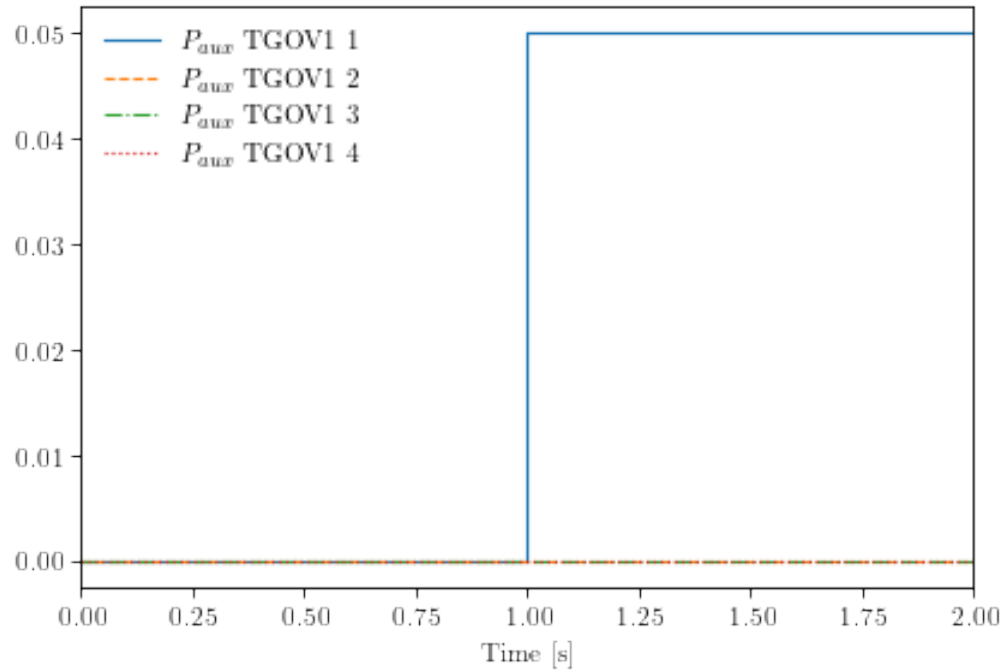
```
ss.TDS.run()
```

```
0%|          | 0/100 [00:00<?, ?%/s]
```

```
Simulation completed in 0.0916 seconds.  
Outputs to "kundur_full_out.lst" and "kundur_full_out.npz".  
Outputs written in 0.0032 seconds.
```

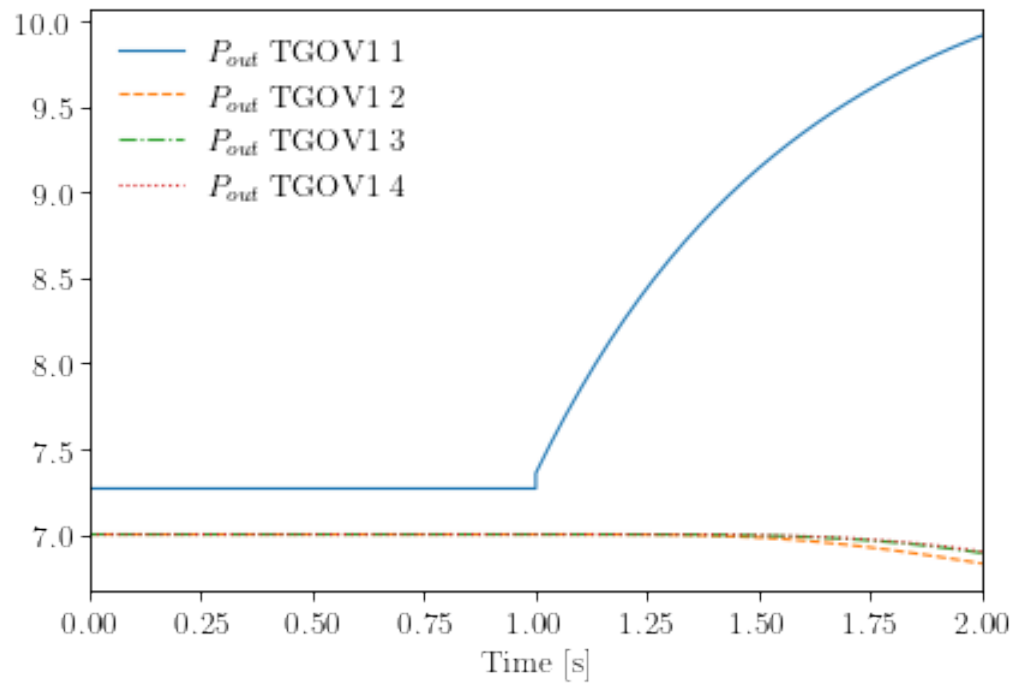
```
True
```

```
ss.TDS.plotter.plot(ss.TGOV1.paux)
```



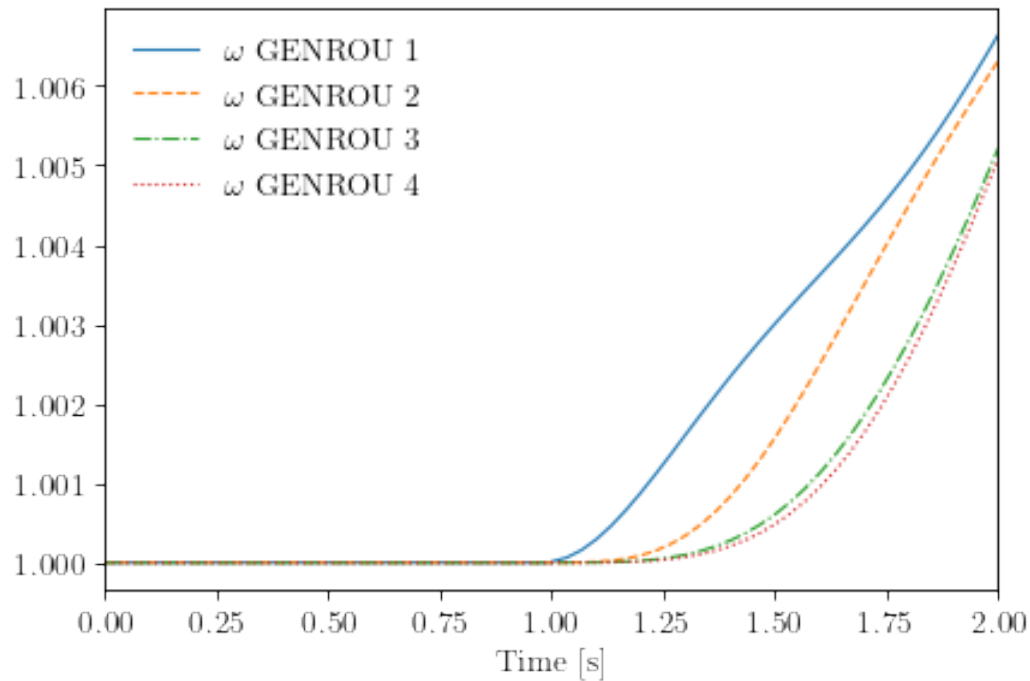
```
(<Figure size 480x320 with 1 Axes>, <AxesSubplot:xlabel='Time [s] '>)
```

```
ss.TDS.plotter.plot(ss.TGOV1.pout)
```



```
(<Figure size 480x320 with 1 Axes>, <AxesSubplot:xlabel='Time [s] '>)
```

```
ss.TDS.plotter.plot(ss.GENROU.omega)
```



```
(<Figure size 480x320 with 1 Axes>, <AxesSubplot:xlabel='Time [s] '>)
```

2.8.5 Step 5: Set Another New Setpoints and New Ending Time.

In this example, we clear the auxiliary power previously set to `TGOV1.paux0.v`

```
# method 1: use in-place assignment again
ss.TGOV1.paux0.v[0] = 0.

# method 2: use ``ss.TGOV1.alter()``
# ss.TGOV1.alter('paux0', 1, 0)

# set the new ending time to 10 sec.
ss.TDS.config.tf = 10
```

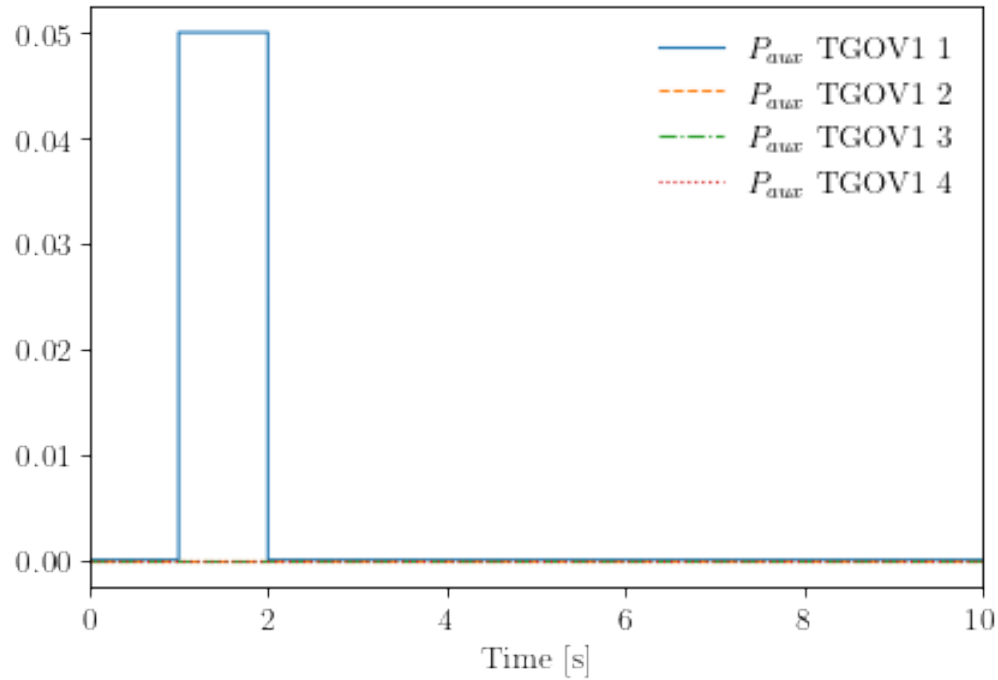
```
ss.TDS.run()
```

```
0%|          | 0/100 [00:00<?, ?%/s]
```

```
Simulation completed in 0.6068 seconds.
Outputs to "kundur_full_out.lst" and "kundur_full_out.npz".
Outputs written in 0.0275 seconds.
```

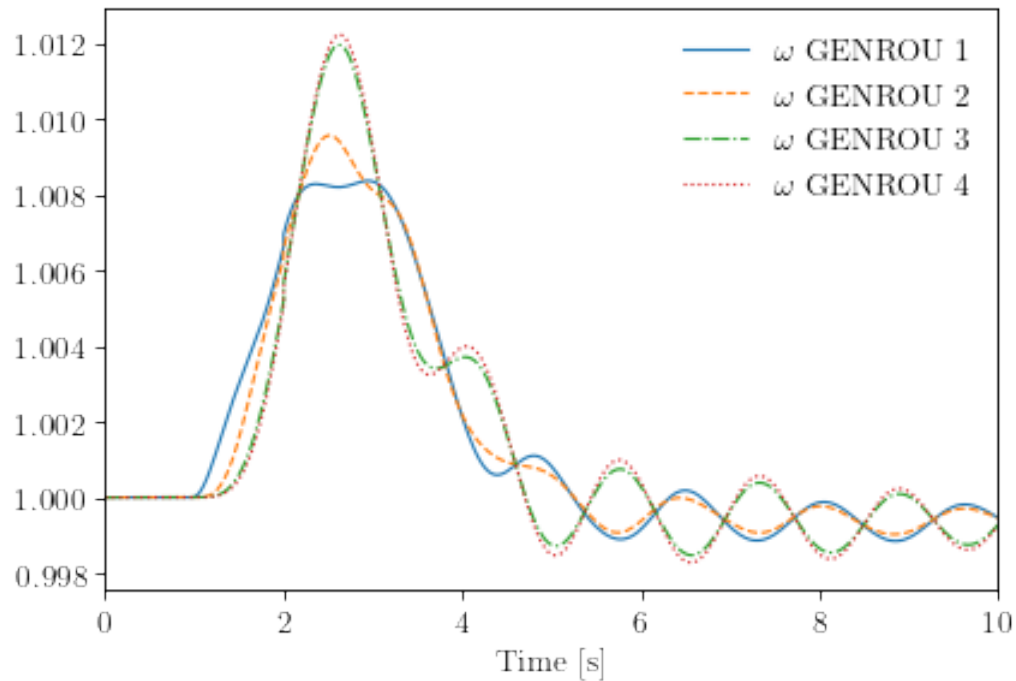
```
True
```

```
ss.TDS.plotter.plot(ss.TGOV1.paux)
```



```
(<Figure size 480x320 with 1 Axes>, <AxesSubplot:xlabel='Time [s] '>)
```

```
ss.TDS.plotter.plot(ss.GENROU.omega)
```



```
(<Figure size 480x320 with 1 Axes>, <AxesSubplot:xlabel='Time [s] '>)
```

```
!andes misc -C
```

```
"/home/hacui/repos/andes/examples/kundur_full_out.npz" removed.  
"/home/hacui/repos/andes/examples/kundur_full_out.txt" removed.  
"/home/hacui/repos/andes/examples/kundur_full_out.lst" removed.
```

2.9 Load Frequency Control

This examples shows (1) how to trip a generator, and (2) how to drive frequency back by load shedding.

```
import andes  
import numpy as np  
  
andes.config_logger(stream_level=20)
```

2.9.1 Tripping a Generator in the IEEE 14-Bus System

```
# using the IEEE 14-bus model as an example.
# The example here contains a variety of models: generators, exciters,
↳ turbine governors, and PSS
# To speed up, one can remove unneeded ones, e.g., PSS

ieee14_raw = andes.get_case("ieee14/ieee14.raw")
ieee14_dyr = andes.get_case("ieee14/ieee14.dyr")
```

```
# use `andes.load` to load the test system
# Need to set `setup=False` to be able to add new Toggles that turns off
↳ generators.

ss = andes.load(ieee14_raw, addfile=ieee14_dyr, setup=False)
```

```
Working directory: "/home/hacui/repos/andes/examples"
> Loaded config from file "/home/hacui/.andes/andes.rc"
> Loaded generated Python code in "/home/hacui/.andes/pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/ieee14/ieee14.raw"...
  IEEE 14 BUS TEST CASE
    03/06/14 CONTO           100.0  1962 W
Input file parsed in 0.0119 seconds.
Parsing additional file "/home/hacui/repos/andes/andes/cases/ieee14/ieee14.dyr
↳ "...
Addfile parsed in 0.2965 seconds.
```

```
# Add a Toggle that disconnects `GENROU_2` at t=1 s

ss.add("Toggle", dict(model='SynGen', dev="GENROU_2", t=1.0))
```

```
'Toggle_3'
```

```
# Call setup manually

ss.setup()
```

```
IEEEEST <IEEEEST_1> added BusFreq <BusFreq_1> linked to bus <3.0>
ST2CUT <ST2CUT_2> added BusFreq <BusFreq_2> linked to bus <1.0>
ST2CUT <ST2CUT_3> added BusFreq <BusFreq_3> linked to bus <2.0>
System internal structure set up in 0.0750 seconds.
```

```
True
```

```
# double check that Toggles are set up correctly
# Check `u` of the Toggles - the first two line switches are disabled, and
↳ the generator trip is enabled

ss.Toggle.as_df()
```

	idx	u	name	model	dev	t
uid						
0	Toggle_1	1.0	Toggle_1	Line	Line_1	1.0
1	Toggle_2	1.0	Toggle_2	Line	Line_1	1.1
2	Toggle_3	1.0	Toggle_3	SynGen	GENROU_2	1.0

```
# disable existing line switches
# The IEEE 14-bus system contains predefined line switches. Disabling them to
→study generator trip only.

ss.Toggle.u.v[[0, 1]] = 0
```

```
# calculate power flow

# use constant power model for PQ (we will come back to this later)

ss.PQ.config.p2p = 1
ss.PQ.config.q2q = 1
ss.PQ.config.p2z = 0
ss.PQ.config.q2z = 0

# turn off under-voltage PQ-to-Z conversion
ss.PQ.pq2z = 0

ss.PFlow.run()
```

```
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0101 seconds.
0: |F(x)| = 0.5605182134
1: |F(x)| = 0.006202200332
2: |F(x)| = 5.819382824e-06
3: |F(x)| = 6.96508129e-12
Converged in 4 iterations in 0.0111 seconds.
Initialization for dynamics completed in 0.0575 seconds.
Initialization was successful.
Report saved to "ieee14_out.txt" in 0.0083 seconds.
```

```
True
```

```
# set the first simulation stop and run it

ss.TDS.config.tf = 20
```

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```
ss.TDS.config.criteria = 0 # temporarily turn off stability criteria based
↪on angle separation
ss.TDS.run()
```

```
-> Time Domain Simulation Summary:
Sparse Solver: KLU
Simulation time: 0.0-20 s.
Fixed step size: h=33.33 ms. Shrink if not converged.
```

```
0%|          | 0/100 [00:00<?, ?%/s]
```

```
<Toggle Toggle_3>: SynGen.GENROU_2 status changed to 0 at t=1.0 sec.
```

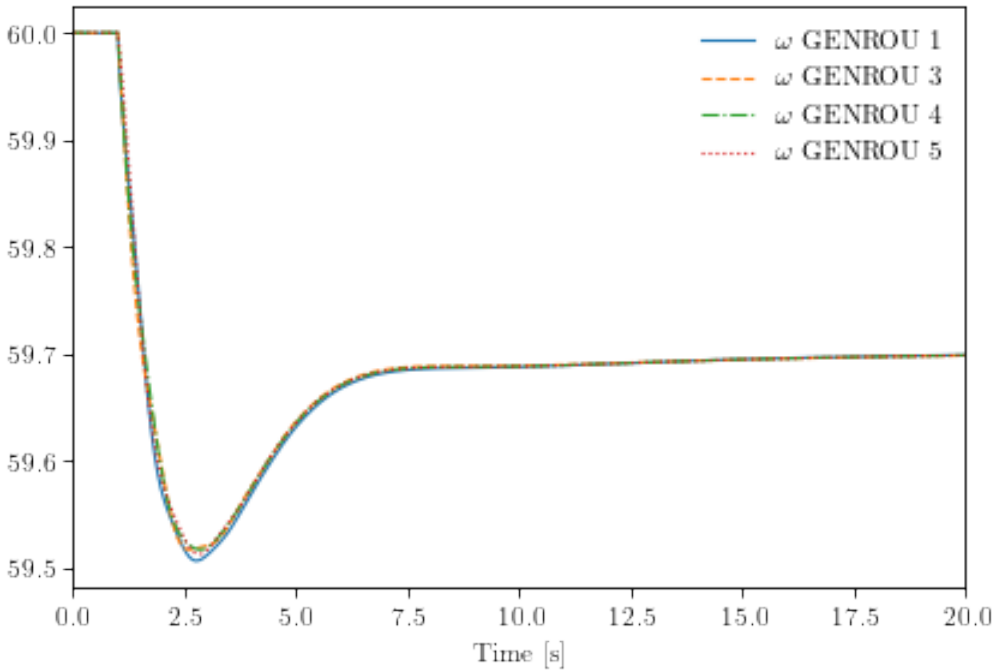
```
Simulation completed in 2.9748 seconds.
Outputs to "ieee14_out.lst" and "ieee14_out.npz".
Outputs written in 0.0421 seconds.
```

```
True
```

```
# Show the frequency response of online generators

# Refer to `plot` documentation by using `help(ss.TDS.plt.plot)` and `help(ss.
↪TDS.plt.plot_data)`
ss.TDS.load_plotter()

ss.TDS.plt.plot(ss.GENROU.omega,
                a=(0, 2, 3, 4),
                ytimes=60,
                )
```



```
(<Figure size 480x320 with 1 Axes>, <AxesSubplot:xlabel='Time [s] '>)
```

2.9.2 Adjusting Load to Compensate for the Generation Loss

Check the power of the lost generator by inspecting the power flow inputs:

```
ss.PV.as_df()
```

	idx	u	name	Sn	Vn	bus	busr	p0	q0	pmax	pmin	qmax	\
uid													
0	2	0.0	2	100.0	69.0	2	None	0.40	0.15	0.5	0.1	0.15	
1	3	0.0	3	100.0	69.0	3	None	0.40	0.15	0.5	0.1	0.15	
2	4	0.0	4	100.0	138.0	6	None	0.30	0.10	0.5	0.1	0.10	
3	5	0.0	5	100.0	69.0	8	None	0.35	0.10	0.5	0.1	0.10	
	qmin	v0	vmax	vmin	ra	xs							
uid													
0	-0.40	1.03	1.4	0.6	0.0	0.13							
1	-0.10	1.01	1.4	0.6	0.0	0.13							
2	-0.06	1.03	1.4	0.6	0.0	0.12							
3	-0.06	1.03	1.4	0.6	0.0	0.12							

The tripped GENROU_2 correspond to the first PV (GENROU_1 corresponds to Slack). Thus, the lost active power is 0.40 pu.

Let's compensate for that by shedding 0.4 pu of active power load at $t=2.0$ s.

By checking the equation documentation of PQ (using `print(ss.PQ.doc())`), we can tell that the imposed active power for time-domain simulation is from `Ppf`, because we used the constant power model with `p2p`

= 1.

Algebraic Equations

Name	Type	RHS of Equation "0 = g(x, y)"
a	ExtAlgeb	u * (dae_t <= 0) * (p0 * vcmp_zi + Rlb * vcmp_zl * v**2 + Rub * vcmp_zu * v**2) + u * (dae_t > 0) * (p2p * Ppf + p2i * Ipeq * v + p2z * Req * v**2)
v	ExtAlgeb	u * (dae_t <= 0) * (q0 * vcmp_zi + Xlb * vcmp_zl * v**2 + Xub * vcmp_zu * v**2) + u * (dae_t > 0) * (q2q * Qpf + q2i * Ipeq * v + q2z * Xeq * v**2)

Ppf may be different from p0 specified in the data file.

```
# active power from power flow solution - make a copy
```

```
Ppf = np.array(ss.PQ.Ppf.v)
```

```
Ppf
```

```
array([0.217, 0.5 , 0.478, 0.076, 0.15 , 0.295, 0.09 , 0.035, 0.061,  
       0.135, 0.2  ])
```

Reload the system and add the generator trip.

```
ss = andes.load(ieee14_raw, addfile=ieee14_dyr, setup=False)

ss.add("Toggle", dict(model='SynGen', dev="GENROU_2", t=1.0))
ss.setup()
ss.Toggle.u.v[[0, 1]] = 0

ss.PQ.config.p2p = 1
ss.PQ.config.q2q = 1
ss.PQ.config.p2z = 0
ss.PQ.config.q2z = 0
ss.PQ.pq2z = 0

ss.PFlow.run()
```

```
Working directory: "/home/hacui/repos/andes/examples"
> Loaded config from file "/home/hacui/.andes/andes.rc"
> Reloaded generated Python code of module "pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/ieee14/ieee14.raw"...
IEEE 14 BUS TEST CASE
03/06/14 CONTO          100.0 1962 W
Input file parsed in 0.0047 seconds.
Parsing additional file "/home/hacui/repos/andes/andes/cases/ieee14/ieee14.dyr
↪"...
Addfile parsed in 0.1101 seconds.
IEEEEST <IEEEEST_1> added BusFreq <BusFreq_1> linked to bus <3.0>
```

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```

ST2CUT <ST2CUT_2> added BusFreq <BusFreq_2> linked to bus <1.0>
ST2CUT <ST2CUT_3> added BusFreq <BusFreq_3> linked to bus <2.0>
System internal structure set up in 0.0547 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0040 seconds.
0: |F(x)| = 0.5605182134
1: |F(x)| = 0.006202200332
2: |F(x)| = 5.819382824e-06
3: |F(x)| = 6.96508129e-12
Converged in 4 iterations in 0.0065 seconds.
Initialization for dynamics completed in 0.0547 seconds.
Initialization was successful.
Report saved to "ieee14_out.txt" in 0.0028 seconds.

```

True

But let's run to 2 seconds.

```

ss.TDS.config.tf = 2.0
ss.TDS.config.criteria = 0  # temporarily turn off stability criteria based
    ↳ on angle separation

ss.TDS.run()

```

```

-> Time Domain Simulation Summary:
Sparse Solver: KLU
Simulation time: 0.0-2.0 s.
Fixed step size: h=33.33 ms. Shrink if not converged.

```

0%| | 0/100 [00:00<?, ?%/s]

<Toggle Toggle_3>: SynGen.GENROU_2 status changed to 0 at t=1.0 sec.

```

Simulation completed in 0.2567 seconds.
Outputs to "ieee14_out.lst" and "ieee14_out.npz".
Outputs written in 0.0043 seconds.

```

True

all `Ppf` before shedding

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```
ss.PQ.Ppf.v
```

```
array([0.217, 0.5 , 0.478, 0.076, 0.15 , 0.295, 0.09 , 0.035, 0.061,
       0.135, 0.2  ])
```

And then apply the load shedding on buses 2, 3, 4, 5, 6, 9.

```
shed_buses = [2, 3, 4, 5, 6, 9]
```

```
# find the `idx` of the loads on these buses
```

```
pq_shed_idx = ss.PQ.find_idx(keys='bus', values=shed_buses)
pq_shed_idx
```

```
['PQ_1', 'PQ_2', 'PQ_3', 'PQ_4', 'PQ_5', 'PQ_6']
```

```
# get `Ppf` on these buses before shedding
```

```
pq_p = ss.PQ.get(src='Ppf', idx=pq_shed_idx, attr='v')
pq_p
```

```
array([0.217, 0.5 , 0.478, 0.076, 0.15 , 0.295])
```

```
pq_p_new = pq_p - 0.4 / len(shed_buses)
```

```
ss.PQ.set(src='Ppf', idx=pq_shed_idx, attr='v', value=pq_p_new)
```

```
True
```

```
# double check
```

```
ss.PQ.Ppf.v
```

```
array([0.15033333, 0.43333333, 0.41133333, 0.00933333, 0.08333333,
       0.22833333, 0.09 , 0.035 , 0.061 , 0.135 ,
       0.2  ])
```

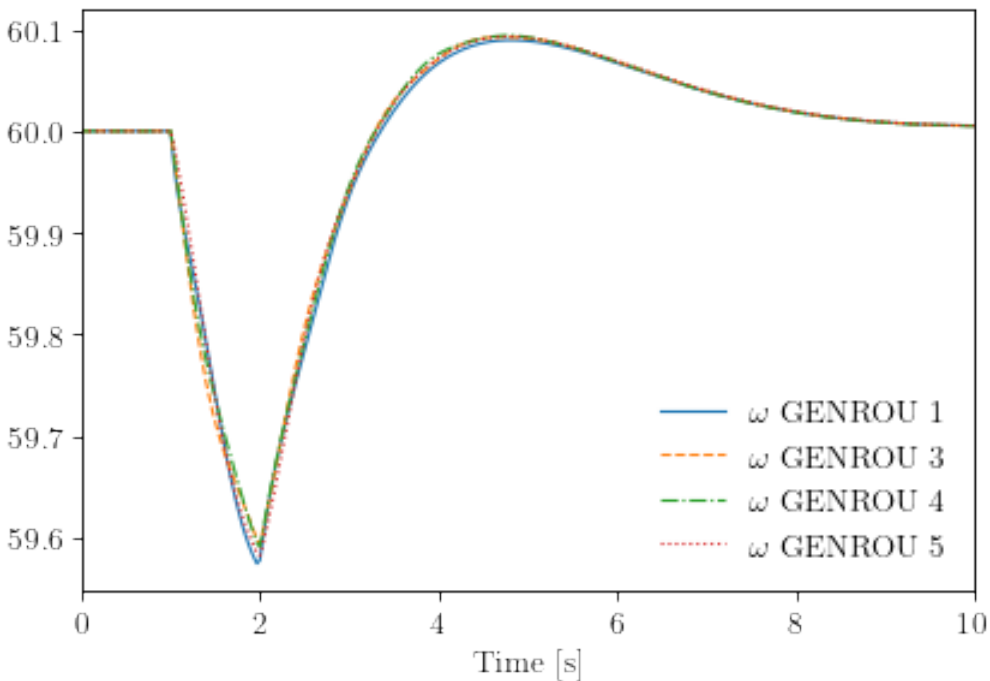
```
ss.TDS.config.tf = 10
```

```
ss.TDS.run()
```

```
ss.TDS.plt.plot(ss.GENROU.omega,
               a=(0, 2, 3, 4),
               ytimes=60,
               )
```

```
0%|          | 0/100 [00:00<?, ?%/s]
```

Simulation completed in 1.2884 seconds.
 Outputs to "ieee14_out.lst" and "ieee14_out.npz".
 Outputs written in 0.0211 seconds.



(<Figure size 480x320 with 1 Axes>, <AxesSubplot:xlabel='Time [s] '>)

```
!andes misc -C
```

"/home/hacui/repos/andes/examples/ieee14_out.txt" removed.
 "/home/hacui/repos/andes/examples/ieee14_out.lst" removed.
 "/home/hacui/repos/andes/examples/ieee14_out.npz" removed.

The result shows the generator speed (frequency) returns to 60 Hz after load shedding.

2.10 Profile in Notebook

2.10.1 Profiling with Python CProfiler

Before getting started, this example requires the config flag `PFlow.init_tds` to be 0, which is the default value.

```
import andes
from andes.utils.paths import get_case

case_path = get_case("kundur/kundur_full.xlsx")
```

Passing `profile=True`, `no_output = True` to run will enable the profiler and have the results printed.

```
ss = andes.run(
    case_path, profile=True, routine="tds", no_output=True, default_
    ↪config=True
)
```

```
Working directory: "/home/hacui/repos/andes/examples"
> Loaded generated Python code in "/home/hacui/.andes/pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/kundur/kundur_full.
↪xlsx"...
Input file parsed in 0.3536 seconds.
System internal structure set up in 0.0412 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0051 seconds.
0: |F(x)| = 14.9282832
1: |F(x)| = 3.608627841
2: |F(x)| = 0.1701107882
3: |F(x)| = 0.002038626956
4: |F(x)| = 3.745103977e-07
Converged in 5 iterations in 0.0045 seconds.
Initialization for dynamics completed in 0.0368 seconds.
Initialization was successful.
```

```
0%|          | 0/100 [00:00<?, ?%/s]
```

```
<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.
```

```
Simulation to t=20.00 sec completed in 0.9577 seconds.
```

```
2126948 function calls (2100484 primitive calls) in 1.634 seconds

Ordered by: cumulative time
List reduced from 5556 to 40 due to restriction <40>

ncalls  tottime  percall  cumtime  percall  filename:lineno(function)
↪1      0.006    0.006    1.065    1.065    /home/hacui/repos/andes/andes/
↪routines/tds.py:326(run)
↪603    0.001    0.000    0.891    0.001    /home/hacui/repos/andes/andes/
↪routines/tds.py:521(itm_step)
↪603    0.051    0.000    0.890    0.001    /home/hacui/repos/andes/andes/
↪routines/daeint.py:27(step)
```

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2025	0.006	0.000	0.703	0.000	/home/hacui/repos/andes/andes/
→ routines/tds.py:820 (fg_update)					
10176	0.060	0.000	0.646	0.000	/home/hacui/repos/andes/andes/
→ system.py:1672 (call_models)					
1	0.000	0.000	0.558	0.558	/home/hacui/repos/andes/andes/
→ main.py:275 (load)					
1040/207	0.003	0.000	0.423	0.002	<frozen importlib._bootstrap>
→ :1022 (_find_and_load)					
960/129	0.002	0.000	0.420	0.003	<frozen importlib._bootstrap>
→ :987 (_find_and_load_unlocked)					
847/34	0.001	0.000	0.419	0.012	<frozen importlib._bootstrap_
→ external>:877 (exec_module)					
905/66	0.002	0.000	0.419	0.006	{built-in method builtins.exec}
1246/34	0.001	0.000	0.418	0.012	<frozen importlib._bootstrap>
→ :233 (_call_with_frames_removed)					
925/130	0.002	0.000	0.415	0.003	<frozen importlib._bootstrap>
→ :664 (_load_unlocked)					
2030	0.001	0.000	0.367	0.000	/home/hacui/repos/andes/andes/
→ system.py:1047 (g_update)					
1	0.000	0.000	0.355	0.355	/home/hacui/repos/andes/andes/
→ io/___init___py:115 (parse)					
1	0.000	0.000	0.353	0.353	/home/hacui/repos/andes/andes/
→ io/xlsx.py:88 (read)					
20279	0.082	0.000	0.349	0.000	/home/hacui/repos/andes/andes/
→ core/model/model.py:963 (g_update)					
35	0.000	0.000	0.270	0.008	/home/hacui/repos/andes/andes/
→ utils/lazyimport.py:61 (__maybe_import__)					
34	0.000	0.000	0.214	0.006	/home/hacui/repos/andes/andes/
→ utils/lazyimport.py:73 (__getattr__)					
1	0.000	0.000	0.213	0.213	/home/hacui/mambaforge/envs/a/
→ lib/python3.10/site-packages/pandas/___init___py:1 (<module>)					
1	0.000	0.000	0.169	0.169	/home/hacui/mambaforge/envs/a/
→ lib/python3.10/site-packages/pandas/core/api.py:1 (<module>)					
1	0.000	0.000	0.161	0.161	/home/hacui/repos/andes/andes/
→ system.py:93 (__init__)					
109/107	0.000	0.000	0.138	0.001	/home/hacui/mambaforge/envs/a/
→ lib/python3.10/importlib/___init___py:108 (import_module)					
109/107	0.000	0.000	0.138	0.001	<frozen importlib._bootstrap>
→ :1038 (_gcd_import)					
1	0.000	0.000	0.122	0.122	/home/hacui/mambaforge/envs/a/
→ lib/python3.10/site-packages/pandas/io/excel/_base.py:460 (read_excel)					
254/196	0.000	0.000	0.108	0.001	{built-in method builtins.__
→ import__}					
2030	0.001	0.000	0.101	0.000	/home/hacui/repos/andes/andes/
→ system.py:1033 (f_update)					
1	0.000	0.000	0.100	0.100	/home/hacui/repos/andes/andes/
→ system.py:1800 (import_models)					
79/52	0.000	0.000	0.097	0.002	<frozen importlib._bootstrap_
→ external>:1182 (exec_module)					
79/52	0.082	0.001	0.097	0.002	{built-in method _imp.exec_
→ dynamic}					
1636/1630	0.009	0.000	0.097	0.000	{built-in method builtins.__

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```

↪build_class__}
    1      0.000      0.000      0.097      0.097 /home/hacui/mambaforge/envs/a/
↪lib/python3.10/site-packages/pandas/io/excel/_base.py:1520(__init__)
    1      0.000      0.000      0.094      0.094 /home/hacui/mambaforge/envs/a/
↪lib/python3.10/site-packages/pandas/io/excel/_openpyxl.py:534(__init__)
   20279      0.039      0.000      0.086      0.000 /home/hacui/repos/andes/andes/
↪core/model/model.py:935(f_update)
   20230      0.002      0.000      0.084      0.000 /home/hacui/repos/andes/andes/
↪system.py:989(l_update_eq)
    4      0.000      0.000      0.083      0.021 /home/hacui/mambaforge/envs/a/
↪lib/python3.10/site-packages/pandas/compat/_optional.py:81(import_optional_
↪dependency)
  1864/802      0.002      0.000      0.082      0.000 <frozen importlib._bootstrap>
↪:1053(_handle_fromlist)
    1      0.000      0.000      0.080      0.080 /home/hacui/mambaforge/envs/a/
↪lib/python3.10/site-packages/openpyxl/_init__.py:1(<module>)
   2025      0.076      0.000      0.076      0.000 /home/hacui/.andes/pycode/
↪GENROU.py:20(g_update)
    1      0.000      0.000      0.069      0.069 /home/hacui/mambaforge/envs/a/
↪lib/python3.10/site-packages/pandas/core/arrays/_init__.py:1(<module>)
   20279      0.011      0.000      0.068      0.000 /home/hacui/repos/andes/andes/
↪core/model/model.py:712(l_check_eq)

```

-> Single process finished in 1.7222 seconds.

2.10.2 Profiling with `line_profiler`.

`line_profiler` provides line-based profiling results for functions.

Install with `pip install line_profiler` and restart the notebook.

```

import andes
from andes.utils.paths import get_case

case_path = get_case("kundur/kundur_full.xlsx")

```

Profile power flow

Pass the function name to profile to the magic `%lprun`, followed by a call to the function itself or an upper-level function.

Results will be shown in a popup window.

```

%load_ext line_profiler

%lprun -f andes.routines.pflow.PFlow.run andes.run(case_path, no_output=True,
↪default_config=True)

```

```

Working directory: "/home/hacui/repos/andes/examples"
> Reloaded generated Python code of module "pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/kundur/kundur_full.
→xlsx"...
Input file parsed in 0.0498 seconds.
System internal structure set up in 0.0402 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0050 seconds.
0: |F(x)| = 14.9282832
1: |F(x)| = 3.608627841
2: |F(x)| = 0.1701107882
3: |F(x)| = 0.002038626956
4: |F(x)| = 3.745103977e-07
Converged in 5 iterations in 0.0041 seconds.

```

```

-> Single process finished in 0.2605 seconds.

```

```

Timer unit: 1e-09 s

```

```

Total time: 0.0114298 s

```

```

File: /home/hacui/repos/andes/andes/routines/pflow.py

```

```

Function: run at line 211

```

Line #	Hits	Time	Per Hit	% Time	Line Contents
211					def run(self, **kwargs):
212					"""
213					Solve the power flow.
→using the selected method.					
214					
215					Returns
216					-----
217					bool
218					convergence.
→status					
219					"""
220					
221	1	1363.0	1363.0	0.0	system = self.system
222	1	581.0	581.0	0.0	if self.config.check_
→conn == 1:					
223	1	1378597.0	1e+06	12.1	self.system.
→connectivity()					
224					
225	1	250450.0	250450.0	2.2	self.summary()

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```

226          1      5393416.0      5e+06      47.2      self.init()
227
228          1          401.0      401.0      0.0      if system.dae.m == 0:
229                                  logger.error(
↪ "Loaded case contains no power flow element.")
230                                  system.exit_code_
↪ = 1
231                                  return False
232
233          1          762.0      762.0      0.0      method = self.config.
↪ method.lower()
234
235          1          4629.0      4629.0      0.0      t0, _ = elapsed()
236
237                                  # ----- Call_
↪ solution methods -----
238          1          251.0      251.0      0.0      if method == 'nr':
239          1      4163484.0      4e+06      36.4          self.nr_solve()
240                                  elif method == 'nk':
241                                  self.newton_
↪ krylov()
242
243          1          5711.0      5711.0      0.0      t1, s1 = elapsed(t0)
244          1          311.0      311.0      0.0      self.exec_time = t1 -
↪ t0
245
246          1          260.0      260.0      0.0      if not self.
↪ converged:
247                                  if abs(self.mis[-
↪ 1] - self.mis[-2]) < self.config.tol:
248                                  max_idx = np.
↪ argmax(np.abs(system.dae.xy))
249                                  name =_
↪ system.dae.xy_name[max_idx]
250                                  logger.error(
↪ 'Mismatch is not correctable possibly due to large load-generation_
↪ imbalance.')
251                                  logger.error(
↪ 'Largest mismatch on equation associated with <%s>', name)
252                                  else:
253                                  logger.error(
↪ 'Power flow failed after %d iterations for "%s".', self.niter + 1, system.
↪ files.case)
254
255                                  else:
256          1      222407.0 222407.0      1.9      logger.info(
↪ 'Converged in %d iterations in %s.', self.niter + 1, s1)
257
258                                  # make a copy of_
↪ power flow solutions
259          1          3146.0      3146.0      0.0      self.x_sol =_
↪ system.dae.x.copy()

```

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```

260          1          862.0    862.0    0.0          self.y_sol =_
↪system.dae.y.copy()
261
262          1          441.0    441.0    0.0          if self.config.
↪init_tds:
263                                     system.TDS.
↪init()
264          1          330.0    330.0    0.0          if self.config.
↪report:
265          1          1803.0   1803.0    0.0          system.PFlow.
↪report()
266
267          1          491.0    491.0    0.0          system.exit_code = 0_
↪if self.converged else 1
268          1          110.0    110.0    0.0          return self.converged

```

Alternatively, do

```

ss = andes.load(case_path, no_output=True, default_config=True)

%lprun -f ss.PFlow.run ss.PFlow.run()

```

```

Working directory: "/home/hacui/repos/andes/examples"
> Reloaded generated Python code of module "pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/kundur/kundur_full.
↪xlsx"...
Input file parsed in 0.0293 seconds.
System internal structure set up in 0.0231 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0043 seconds.
0: |F(x)| = 14.9282832
1: |F(x)| = 3.608627841
2: |F(x)| = 0.1701107882
3: |F(x)| = 0.002038626956
4: |F(x)| = 3.745103977e-07
Converged in 5 iterations in 0.0040 seconds.

```

```

Timer unit: 1e-09 s

Total time: 0.0109119 s
File: /home/hacui/repos/andes/andes/routines/pflow.py
Function: run at line 211

```

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Line #	Hits	Time	Per Hit	% Time	Line Contents
=====					
211					def run(self, **kwargs):
212					"""
213					Solve the power flow.
→using the selected method.					
214					
215					Returns
216					-----
217					bool
218					convergence.
→status					
219					"""
220					
221	1	972.0	972.0	0.0	system = self.system
222	1	511.0	511.0	0.0	if self.config.check_
→conn == 1:					
223	1	1557962.0	2e+06	14.3	self.system.
→connectivity()					
224					
225	1	253977.0	253977.0	2.3	self.summary()
226	1	4784035.0	5e+06	43.8	self.init()
227					
228	1	451.0	451.0	0.0	if system.dae.m == 0:
229					logger.error(
→"Loaded case contains no power flow element.")					
230					system.exit_code.
→= 1					
231					return False
232					
233	1	842.0	842.0	0.0	method = self.config.
→method.lower()					
234					
235	1	4840.0	4840.0	0.0	t0, _ = elapsed()
236					
237					# ----- Call.
→solution methods -----					
238	1	211.0	211.0	0.0	if method == 'nr':
239	1	4053092.0	4e+06	37.1	self.nr_solve()
240					elif method == 'nk':
241					self.newton_
→krylov()					
242					
243	1	5711.0	5711.0	0.1	t1, s1 = elapsed(t0)
244	1	200.0	200.0	0.0	self.exec_time = t1 -
→ t0					
245					
246	1	241.0	241.0	0.0	if not self.
→converged:					
247					if abs(self.mis[-
→1] - self.mis[-2]) < self.config.tol:					
248					max_idx = np.

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```

→argmax(np.abs(system.dae.xy))
    249                                     name =_
→system.dae.xy_name[max_idx]
    250                                     logger.error(
→'Mismatch is not correctable possibly due to large load-generation_
→imbalance.')
```

251					logger.error(
→'Largest mismatch on equation associated with <%s>', name)					
252					else:
253					logger.error(
→'Power flow failed after %d iterations for "%s".', self.niter + 1, system.					
→files.case)					
254					
255					else:
256	1	241955.0	241955.0	2.2	logger.info(
→'Converged in %d iterations in %s.', self.niter + 1, s1)					
257					
258					# make a copy of_
→power flow solutions					
259	1	3116.0	3116.0	0.0	self.x_sol =_
→system.dae.x.copy()					
260	1	701.0	701.0	0.0	self.y_sol =_
→system.dae.y.copy()					
261					
262	1	562.0	562.0	0.0	if self.config.
→init_tds:					system.TDS.
263					
→init()					
264	1	241.0	241.0	0.0	if self.config.
→report:					
265	1	1753.0	1753.0	0.0	system.PFlow.
→report()					
266					
267	1	441.0	441.0	0.0	system.exit_code = 0_
→if self.converged else 1					
268	1	110.0	110.0	0.0	return self.converged

To dig into the Newton Raphson iteration steps, profile each step instead with:

```

ss = andes.load(case_path, no_output=True, default_config=True)
%lprun -f ss.PFlow.nr_step ss.PFlow.run()
```

```

Working directory: "/home/hacui/repos/andes/examples"
> Reloaded generated Python code of module "pycode".
Parsing input file "/home/hacui/repos/andes/andes/cases/kundur/kundur_full.
→xlsx"...
Input file parsed in 0.0299 seconds.
System internal structure set up in 0.0242 seconds.
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
```

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Each island has a slack bus correctly defined and enabled.

```
-> Power flow calculation
      Numba: Off
      Sparse solver: KLU
      Solution method: NR method
Power flow initialized in 0.0045 seconds.
0: |F(x)| = 14.9282832
1: |F(x)| = 3.608627841
2: |F(x)| = 0.1701107882
3: |F(x)| = 0.002038626956
4: |F(x)| = 3.745103977e-07
Converged in 5 iterations in 0.0040 seconds.
```

Timer unit: 1e-09 s

Total time: 0.00289216 s

File: /home/hacui/repos/andes/andes/routines/pflow.py

Function: nr_step at line 104

Line #	Hits	Time	Per Hit	% Time	Line Contents
104					def nr_step(self):
105					"""
106					Solve a single_
↪iteration step using the Newton-Raphson method.					
107					
108					Returns
109					-----
110					float
111					maximum absolute_
↪mismatch					
112					"""
113					
114	5	2064.0	412.8	0.1	system = self.system
115					
116					# ----- Build_
↪numerical DAE-----					
117	5	1288374.0	257674.8	44.5	self.fg_update()
118					
119					# ----- update_
↪the Jacobian on conditions -----					
120	5	2365.0	473.0	0.1	if self.config.
↪method != 'dishonest' or (self.niter < self.config.n_factorize):					
121	5	1263947.0	252789.4	43.7	system.j_
↪update(self.models)					
122	5	4048.0	809.6	0.1	self.solver.
↪worker.new_A = True					
123					
124					# ----- prepare_
↪and solve linear equations -----					

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```

125          5      12294.0   2458.8      0.4      self.res[:system.dae.
↪n] = -system.dae.f[:]
126          5      9229.0    1845.8      0.3      self.res[system.dae.
↪n:] = -system.dae.g[:]
127
128         10      15200.0   1520.0      0.5      self.A =_
↪sparse([[system.dae.fx, system.dae.gx],
129          5      1994.0     398.8      0.1      _
↪[system.dae.fy, system.dae.gy]])
130
131          5      1422.0     284.4      0.0      if not self.config.
↪linsolve:
132          5      95764.0  19152.8      3.3      self.inc = self.
↪solver.solve(self.A, self.res)
133      else:
134      self.inc = self.
↪solver.linsolve(self.A, self.res)
135
136          5      15670.0   3134.0      0.5      system.dae.x += np.
↪ravel(self.inc[:system.dae.n])
137          5      11501.0   2300.2      0.4      system.dae.y += np.
↪ravel(self.inc[system.dae.n:])
138
139      # find out variables_
↪associated with maximum mismatches
140          5      591.0      118.2      0.0      fmax = 0
141          5      1232.0     246.4      0.0      if system.dae.n > 0:
142      fmax_idx = np.
↪argmax(np.abs(system.dae.f))
143      fmax = system.
↪dae.f[fmax_idx]
144      logger.debug(
↪"Max. diff mismatch %.10g on %s", fmax, system.dae.x_name[fmax_idx])
145
146          5      28063.0   5612.6      1.0      gmax_idx = np.
↪argmax(np.abs(system.dae.g))
147          5      2987.0     597.4      0.1      gmax = system.dae.
↪g[gmax_idx]
148          5      87689.0  17537.8      3.0      logger.debug("Max._
↪algeb mismatch %.10g on %s", gmax, system.dae.y_name[gmax_idx])
149
150          5      6012.0     1202.4      0.2      mis = max(abs(fmax), _
↪abs(gmax))
151          5      41141.0   8228.2      1.4      system.vars_to_
↪models()
152
153          5      570.0      114.0      0.0      return mis

```


Profile time-domain simulation

```
xy = ss.TDS.init()
```

Initialization for dynamics completed in 0.0209 seconds.
Initialization was successful.

```
%lprun -f ss.TDS.itm_step ss.TDS.run()
```

-> Time Domain Simulation Summary:
Sparse Solver: KLU
Simulation time: 0.0-20.0 s.
Fixed step size: h=33.33 ms. Shrink if not converged.

```
0%|          | 0/100 [00:00<?, ?%/s]
```

<Toggle 1>: Line.Line_8 status changed to 0 at t=2.0 sec.

Simulation to t=20.00 sec completed in 0.9426 seconds.

Timer unit: 1e-09 s

Total time: 0.882568 s

File: /home/hacui/repos/andes/andes/routines/tds.py

Function: itm_step at line 521

Line #	Hits	Time	Per Hit	% Time	Line Contents
521					def itm_step(self):
522					"""
523					Integrate for the
→step					size of ``self.h`` using implicit trapezoid method.
524					
525					Returns
526					-----
527					bool
528					Convergence
→status					in ``self.converged``.
529					
530					"""
531	602	882567523.0	1e+06	100.0	return self.method.
→step					(self)

2.10.3 Cleanup

```
!andes misc -C
```

```
No output file found in the working directory.
```

2.11 MATPOWER Interface

See also the API reference for `andes.interop.matpower`.

```
import andes

from andes.interop.matpower import (start_instance,
                                     to_matpower, from_matpower)
```

2.11.1 Create an Octave/MATLAB instance

```
m = start_instance()
```

2.11.2 Convert to MATPOWER

```
ss = andes.system.example() # load an ieee14 example case

mpc = to_matpower(m, 'mpc', ss)
```

Test if the power flow of `mpc` can be solved

```
m.eval("runpf(mpc) ")
```

```
warning: error caught while executing handle class delete method:
'osqp_mex' undefined near line 40 column 13
OSQP Error!
```

```
MATPOWER Version 7.1, 08-Oct-2020 -- AC Power Flow (Newton)
```

```
Newton's method power flow (power balance, polar) converged in 3 iterations.
```

```
Converged in 0.01 seconds
```

```
=====
|      System Summary
```

```
↪ |
```

```
=====
How many?              How much?              P (MW)              Q (MVar)
```

```
-----
```

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Buses	14	Total Gen Capacity	400.0	-112.0 to 150.0
Generators	5	On-line Capacity	400.0	-112.0 to 150.0
Committed Gens	5	Generation (actual)	226.4	49.8
Loads	11	Load	223.7	95.4
Fixed	11	Fixed	223.7	95.4
Dispatchable	0	Dispatchable	-0.0 of -0.0	-0.0
Shunts	2	Shunt (inj)	-0.0	35.3
Branches	20	Losses ($I^2 * Z$)	2.73	13.52
Transformers	20	Branch Charging (inj)	-	23.8
Inter-ties	0	Total Inter-tie Flow	0.0	0.0
Areas	1			

	Minimum	Maximum
Voltage Magnitude	1.010 p.u. @ bus 3	1.030 p.u. @ bus 2
Voltage Angle	-9.48 deg @ bus 14	0.00 deg @ bus 1
P Losses ($I^2 * R$)	-	0.50 MW @ line 1-2
Q Losses ($I^2 * X$)	-	2.11 MVar @ line 8-7

| Bus Data

↪ |

Bus #	Voltage Mag (pu)	Voltage Ang (deg)	Generation P (MW)	Generation Q (MVar)	Load P (MW)	Load Q (MVar)
1	1.030	0.000*	81.43	-21.62	-	-
2	1.030	-1.764	40.00	30.44	21.70	12.70
3	1.010	-3.537	40.00	12.60	50.00	25.00
4	1.011	-4.410	-	-	47.80	10.00
5	1.017	-3.843	-	-	7.60	1.60
6	1.030	-6.453	30.00	20.99	15.00	7.50
7	1.022	-4.885	-	-	-	-
8	1.030	-1.540	35.00	7.40	-	-
9	1.022	-7.246	-	-	29.50	16.60
10	1.016	-7.415	-	-	9.00	5.80
11	1.019	-7.080	-	-	3.50	1.80
12	1.017	-7.473	-	-	6.10	1.60
13	1.014	-7.721	-	-	13.50	5.80
14	1.016	-9.481	-	-	20.00	7.00
Total:			226.43	49.80	223.70	95.40

| Branch Data

↪ |

Brnch #	From Bus	To Bus	From Bus Injection P (MW)	From Bus Injection Q (MVar)	To Bus Injection P (MW)	To Bus Injection Q (MVar)	Loss ($I^2 * Z$) P (MW)	Loss ($I^2 * Z$) Q (MVar)
↪ (MVar)								
↪ -								

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1	1	2	50.10	-18.36	-49.60	14.29	0.503	1.53
2	1	5	31.33	-3.26	-30.83	0.17	0.500	2.06
3	2	3	17.79	4.11	-17.63	-8.00	0.158	0.67
4	2	4	28.02	0.46	-27.58	-2.69	0.433	1.31
5	2	5	22.09	-1.13	-21.83	-1.70	0.262	0.80
6	3	4	7.63	-4.40	-7.58	3.21	0.047	0.12
7	4	5	-25.97	-5.70	26.07	5.99	0.092	0.29
8	6	11	6.91	2.37	-6.86	-2.27	0.048	0.10
9	6	12	7.93	1.32	-7.86	-1.17	0.075	0.16
10	6	13	19.15	2.76	-18.92	-2.31	0.234	0.46
11	7	9	39.12	1.46	-39.12	0.15	0.000	1.61
12	9	10	5.67	5.40	-5.65	-5.35	0.019	0.05
13	9	14	13.17	-3.85	-12.94	4.34	0.229	0.49
14	10	11	-3.35	-0.45	3.36	0.47	0.009	0.02
15	12	13	1.76	-0.43	-1.75	0.44	0.007	0.01
16	13	14	7.17	-3.93	-7.06	4.16	0.111	0.23
17	4	7	4.12	-3.76	-4.12	3.83	-0.000	0.06
18	4	9	9.22	-1.06	-9.22	1.53	0.000	0.47
19	6	5	-18.99	7.03	18.99	-6.06	0.000	0.97
20	8	7	35.00	7.40	-35.00	-5.29	0.000	2.11
							-----	-----
							Total:	2.727 13.52

```
mpc_sol = m.pull("mpc") # retrieve the solution
```

One can also save the case to a MATPOWER .m file from Octave/MATLAB. Comment in and run the following code:

```
# m.eval("savecase('case14_andes.m', mpc)")
```

2.11.3 Convert from MATPOWER

```
system = from_matpower(m, 'mpc')
```

`m.pull()` won't work if one has run OPF in Octave/MATLAB because Oct2Py does not support custom class objects created by MATPOWER.

`from_matpower()` will read the individual fields to construct an `mpc` dict internally before creating a `system`.

2.11.4 Add dynamic data

One can create an Excel file with dynamic data only and use the `xlsx` parser to load data into system:

```
from andes.io import xlsx

xlsx.read(system, andes.get_case('ieee14/ieee14_dyn_only.xlsx'))
```

```
<andes.system.System at 0x7f8684043520>
```

```
system.setup()

system.PFlow.run()

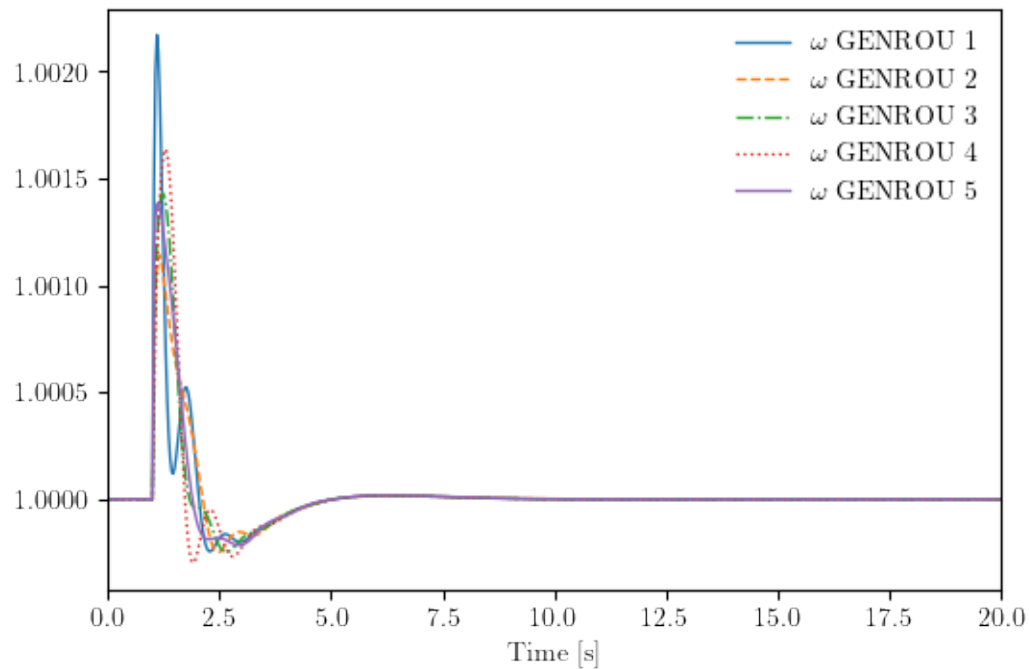
system.TDS.run()
```

```
0%|          | 0/100 [00:00<?, ?%/s]
```

```
<Fault 1>: Applying fault on Bus (idx=7) at t=1.0 sec.
<Fault 1>: Clearing fault on Bus (idx=7) at t=1.03333 sec.
```

```
True
```

```
system.TDS.plt.plot(system.GENROU.omega)
```



```
(<Figure size 600x400 with 1 Axes>, <AxesSubplot:xlabel='Time [s]')>
```

Since the data in `ieee14_dyn_only.xlsx` is stripped from `ieee14/ieee14_fault.xlsx`, the

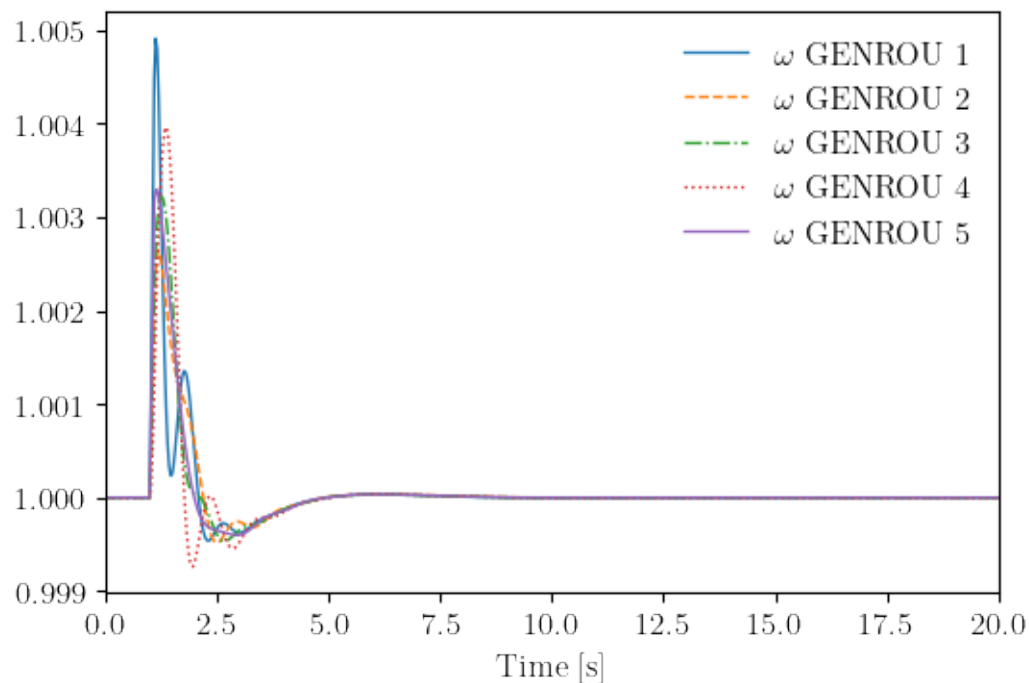
above results is identical to the simulation of the latter case:

```
ss = andes.run(andes.get_case("ieee14/ieee14_fault.xlsx"),
               routine='tds', verbose=30,
               no_output=True, default_config=True)
```

```
0%|          | 0/100 [00:00<?, ?%/s]
```

```
<Fault 1>: Applying fault on Bus (idx=9) at t=1.0 sec.
<Fault 1>: Clearing fault on Bus (idx=9) at t=1.1 sec.
-> Single process finished in 0.7220 seconds.
```

```
ss.TDS.plt.plot(ss.GENROU.omega)
```



```
(<Figure size 600x400 with 1 Axes>, <AxesSubplot:xlabel='Time [s] '>)
```

2.12 pandapower Interface

This example (1) shows how to convert an ANDES system (*ssa*) to a pandapower network (*ssp*), (2) benchmarks the powerflow results, (3) shows how to alter *ssa* active power setpoints according to *ssp* results.

The following clarifications you might need to know:

1. This interface tracks static power flow model in ANDES: Bus, Line, PQ, Shunt, PV, and Slack. The dynamic model in ANDES is not tracked, including but not limited to TurbineGov, SynGen, and Exciter.

2. The interface converts the `Slack` in ANDES to `gen` in pandapower rather than `ext_gen`.
3. **MUST NOT** verify power flow after initializing TDS in ANDES. ANDES does not allow running PFlow for systems with initialized TDS as it will break variable addressing.
4. If you want to track dynamic model outputs in ANDES and feedback into pandapower, you might need to manually transfer the results from ANDES to pandapower.

This interface is mainly developed by [Jinning Wang](#).

```
import andes

from andes.interop.pandapower import to_pandapower, \
    make_link_table, runopp_map, add_gencost

andes.config_logger(20)

import pandapower as pp
import numpy as np
import pandas as pd

from math import pi
```

2.12.1 Load case

Here we use the same ANDES system `ss0` to do the pandapower conversion, which leaves the `ssa` untouched.

This will be useful if you need to modify the `ssa` parametes or setpoints.

```
ssa = andes.load(andes.get_case('ieee14/ieee14_ieeet1.xlsx'),
                setup=False,
                no_output=True,
                default_config=True)
ssa.Toggle.u.v = [0, 0]
ssa.setup()

ss0 = andes.load(andes.get_case('ieee14/ieee14_ieeet1.xlsx'),
                setup=False,
                no_output=True,
                default_config=True)
ss0.Toggle.u.v = [0, 0]
ss0.setup()
```

```
Working directory: "/Users/jinningwang/Documents/work/andes/docs/source/
→examples"
> Loaded generated Python code in "/Users/jinningwang/.andes/pycode".
Generated code for <PQ> is stale.
Numerical code generation (rapid incremental mode) started...
```

```
Generating code for 1 models on 8 processes.
```

```
Saved generated pycode to "/Users/jinningwang/.andes/pycode"
> Reloaded generated Python code of module "pycode".
Generated numerical code for 1 models in 0.1328 seconds.
Parsing input file "/Users/jinningwang/Documents/work/andes/andes/cases/
→ieee14/ieee14_ieee11.xlsx"...
Input file parsed in 0.0441 seconds.
System internal structure set up in 0.0236 seconds.
Working directory: "/Users/jinningwang/Documents/work/andes/docs/source/
→examples"
> Reloaded generated Python code of module "pycode".
Generated code for <PQ> is stale.
Numerical code generation (rapid incremental mode) started...
```

```
Generating code for 1 models on 8 processes.
```

```
Saved generated pycode to "/Users/jinningwang/.andes/pycode"
> Reloaded generated Python code of module "pycode".
Generated numerical code for 1 models in 0.2553 seconds.
Parsing input file "/Users/jinningwang/Documents/work/andes/andes/cases/
→ieee14/ieee14_ieee11.xlsx"...
Input file parsed in 0.0367 seconds.
System internal structure set up in 0.0227 seconds.
```

```
True
```

2.12.2 Convert to pandapower net

Convert ADNES system ssa to pandapower net ssp.

```
ssp = to_pandapower(ss0)
```

```
-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0029 seconds.
0: |F(x)| = 0.5605182134
1: |F(x)| = 0.006202200332
2: |F(x)| = 5.819382825e-06
3: |F(x)| = 6.957087684e-12
Converged in 4 iterations in 0.0038 seconds.
Power flow results are consistent. Conversion is successful.
```

Add generator cost data.


```

gen_cost = np.array([
    [2, 0, 0, 3, 0.0430293, 20, 0],
    [2, 0, 0, 3, 0.25, 20, 0],
    [2, 0, 0, 3, 0.01, 40, 0],
    [2, 0, 0, 3, 0.01, 40, 0],
    [2, 0, 0, 3, 0.01, 40, 0]
])

add_gencost(ssp, gen_cost)

```

```
True
```

Inspect the pandapower net ssp.

```
ssp
```

This pandapower network includes the following parameter tables:

- bus (14 elements)
- load (11 elements)
- gen (5 elements)
- shunt (2 elements)
- line (16 elements)
- trafo (4 elements)
- poly_cost (5 elements)

and the following results tables:

- res_bus (14 elements)
- res_line (16 elements)
- res_trafo (4 elements)
- res_load (11 elements)
- res_shunt (2 elements)
- res_gen (5 elements)

2.12.3 Comapre Power Flow Results

Run power flow of ssa.

```
ssa.PFlow.run()
```

```

-> System connectivity check results:
    No islanded bus detected.
    System is interconnected.
    Each island has a slack bus correctly defined and enabled.

-> Power flow calculation
    Numba: Off
    Sparse solver: KLU
    Solution method: NR method
Power flow initialized in 0.0039 seconds.
0: |F(x)| = 0.5605182134

```

(continues on next page)

(continued from previous page)

```

1: |F(x)| = 0.006202200332
2: |F(x)| = 5.819382825e-06
3: |F(x)| = 6.957087684e-12
Converged in 4 iterations in 0.0045 seconds.

```

```
True
```

```

# ssa
ssa_res_gen = pd.DataFrame(columns=['name', 'p_mw', 'q_mvar', 'va_degree',
→ 'vm_pu'])
ssa_res_gen['name'] = ssa.PV.as_df()['name']
ssa_res_gen['p_mw'] = ssa.PV.p.v * ssa.config.mva
ssa_res_gen['q_mvar'] = ssa.PV.q.v * ssa.config.mva
ssa_res_gen['va_degree'] = ssa.PV.a.v * 180 / pi
ssa_res_gen['vm_pu'] = ssa.PV.v.v
ssa_res_slack = pd.DataFrame([[ssa.Slack.name.v[0], ssa.Slack.p.v[0] * ssa.
→ config.mva,
                                ssa.Slack.q.v[0] * ssa.config.mva, ssa.Slack.a.
→ v[0] * 180 / pi,
                                ssa.Slack.v.v[0]]],
                             columns=ssa_res_gen.columns,
                             )
ssa_res_gen = pd.concat([ssa_res_gen, ssa_res_slack]).reset_index(drop=True)

# ssp
pp.runpp(ssp)
ssp_res_gen = pd.concat([ssp.gen['name'], ssp.res_gen], axis=1)

res_gen_concat = pd.concat([ssa_res_gen, ssp_res_gen], axis=1)

# ssa
ssa_pf_bus = ssa.Bus.as_df()[["name"]].copy()
ssa_pf_bus['v_andes'] = ssa.Bus.v.v
ssa_pf_bus['a_andes'] = ssa.Bus.a.v * 180 / pi

# ssp
ssp_pf_bus = ssa.Bus.as_df()[["name"]].copy()
ssp_pf_bus['v_pp'] = ssp.res_bus['vm_pu']
ssp_pf_bus['a_pp'] = ssp.res_bus['va_degree']

pf_bus_concat = pd.concat([ssa_pf_bus, ssp_pf_bus], axis=1)

```

Generation

In the table below, the left half are ANDES results, and the right half are from pandapower

```
res_gen_concat.round(4)
```

	name	p_mw	q_mvar	va_degree	vm_pu	name	p_mw	q_mvar	va_degree
→ \									
0	2	40.0000	30.4361	-1.7641	1.03	2	40.0000	30.4361	-1.7641
1	3	40.0000	12.5971	-3.5371	1.01	3	40.0000	12.5971	-3.5371
2	4	30.0000	20.9866	-6.4527	1.03	4	30.0000	20.9866	-6.4527
3	5	35.0000	7.3964	-1.5400	1.03	5	35.0000	7.3964	-1.5400
4	1	81.4272	-21.6171	0.0000	1.03	1	81.4272	-21.6171	0.0000
	vm_pu								
0	1.03								
1	1.01								
2	1.03								
3	1.03								
4	1.03								

Bus voltage and angle

Likewise, the left half are ANDES results, and the right half are from pandapower

```
pf_bus_concat.round(4)
```

	name	v_andes	a_andes	name	v_pp	a_pp
uid						
0	BUS1	1.0300	0.0000	BUS1	1.0300	0.0000
1	BUS2	1.0300	-1.7641	BUS2	1.0300	-1.7641
2	BUS3	1.0100	-3.5371	BUS3	1.0100	-3.5371
3	BUS4	1.0114	-4.4098	BUS4	1.0114	-4.4098
4	BUS5	1.0173	-3.8430	BUS5	1.0173	-3.8430
5	BUS6	1.0300	-6.4527	BUS6	1.0300	-6.4527
6	BUS7	1.0225	-4.8852	BUS7	1.0225	-4.8852
7	BUS8	1.0300	-1.5400	BUS8	1.0300	-1.5400
8	BUS9	1.0218	-7.2459	BUS9	1.0218	-7.2459
9	BUS10	1.0155	-7.4155	BUS10	1.0155	-7.4155
10	BUS11	1.0191	-7.0797	BUS11	1.0191	-7.0797
11	BUS12	1.0174	-7.4730	BUS12	1.0174	-7.4730
12	BUS13	1.0145	-7.7208	BUS13	1.0145	-7.7208
13	BUS14	1.0163	-9.4811	BUS14	1.0163	-9.4811

2.12.4 Generator dispatch based on OPF from pandapower

Prepare the link table.

```
# Assign the StaticGen with OPF, in this case, all the SynGen are GENROU
link_table = make_link_table(ssa)
```

```
link_table
```

	stg_name	stg_u	stg_idx	bus_idx	dg_idx	rg_idx	rexc_idx	syg_idx	exc_idx	\
0		1	1.0	1	1	NaN	NaN	NaN	GENROU_1	ESST3A_2
1		2	1.0	2	2	NaN	NaN	NaN	GENROU_2	EXST1_1
2		3	1.0	3	3	NaN	NaN	NaN	GENROU_3	ESST3A_3
3		4	1.0	4	6	NaN	NaN	NaN	GENROU_4	ESST3A_4
4		5	1.0	5	8	NaN	NaN	NaN	GENROU_5	1

	gov_idx	bus_name	gammap	gammaq
0	TGOV1_1	BUS1	1.0	1.0
1	TGOV1_2	BUS2	1.0	1.0
2	TGOV1_3	BUS3	1.0	1.0
3	TGOV1_4	BUS6	1.0	1.0
4	TGOV1_5	BUS8	1.0	1.0

Note: some Jupyter notebooks may not support inline plots. You can use the following command to enable it.

```
import matplotlib
%matplotlib inline
```

```
import matplotlib
%matplotlib inline
```

Run the TDS in ADNES to 2s.

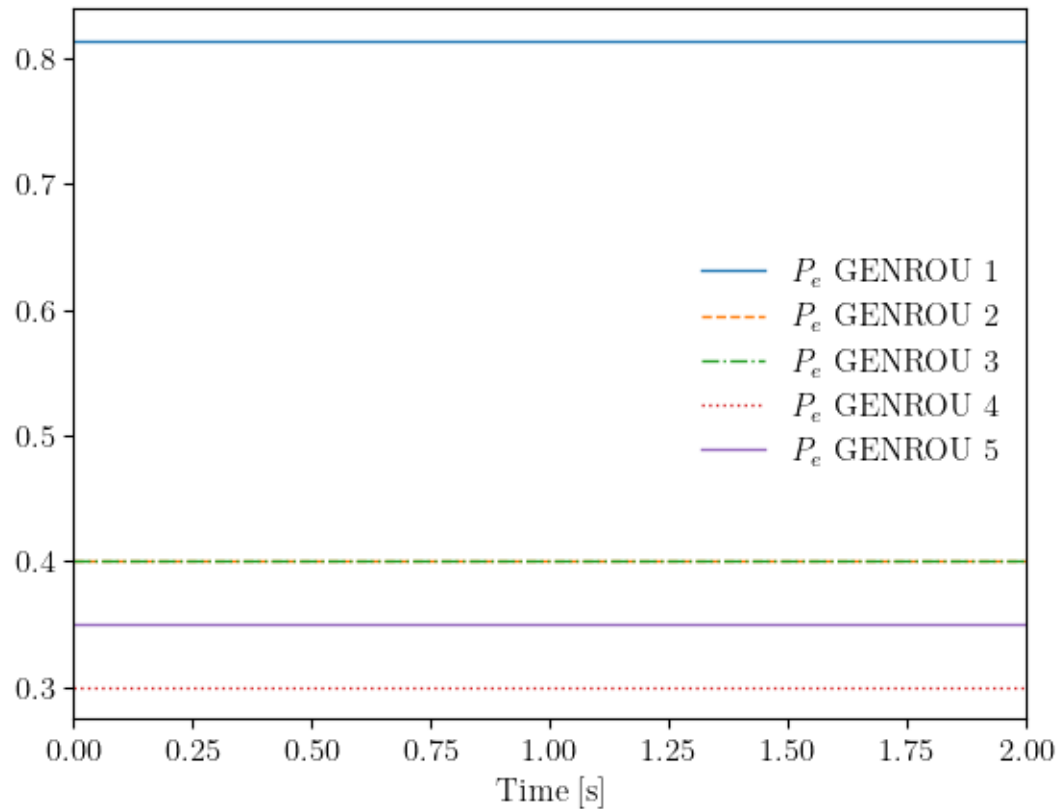
```
ssa.TDS.config.tf = 2
ssa.TDS.run()

ssa.TDS.plt.plot(ssa.GENROU.Pe)
```

```
-> Time Domain Simulation Summary:
Sparse Solver: KLU
Simulation time: 0.0-2 s.
Fixed step size: h=33.33 ms. Shrink if not converged.
Initialization for dynamics completed in 0.1282 seconds.
Initialization was successful.
```

```
0%|          | 0/100 [00:00<?, ?%/s]
```

```
Simulation to t=2.00 sec completed in 0.0623 seconds.
```



(<Figure size 640x480 with 1 Axes>, <AxesSubplot:xlabel='Time [s] '>)

Get the OPF results from pandapower. The `ssp_res` has been converted to p.u..

```
ssp_res = runopp_map(ssp, link_table)
ssp_res
```

ACOPF is solved.

stg_idx	p	q	vm_pu	bus_idx	controllable	dg_idx	rg_idx	\
0	2	0.5	0.129107	1.096903	2	True	NaN	NaN
1	3	0.41275	0.149997	1.082551	3	True	NaN	NaN
2	4	0.34426	0.099998	1.086084	6	True	NaN	NaN
3	5	0.495878	0.085204	1.099996	8	True	NaN	NaN
4	1	0.5	-0.079016	1.100000	1	True	NaN	NaN

	syg_idx	gov_idx	exc_idx
0	GENROU_2	TGOV1_2	EXST1_1
1	GENROU_3	TGOV1_3	ESST3A_3
2	GENROU_4	TGOV1_4	ESST3A_4
3	GENROU_5	TGOV1_5	1
4	GENROU_1	TGOV1_1	ESST3A_2

Now dispatch the results into `ssa`, where the active power setpoints are updated to `TurbinGov.pref0`.

```
ssa_gov_idx = list(ssp_res['gov_idx'][~ssp_res['gov_idx'].isna()])
ssa.TurbineGov.set(src='pref0', idx=ssa_gov_idx, attr='v', value=ssp_res['p
→'] [~ssp_res['gov_idx'].isna()])
ssa.TurbineGov.get(src='pref0', idx=ssa_gov_idx, attr='v')
```

```
array([0.49999998, 0.41274963, 0.34426    , 0.49587786, 0.50000031])
```

Now run the TDS to 50s.

```
ssa.TDS.config.tf = 50
ssa.TDS.run()
```

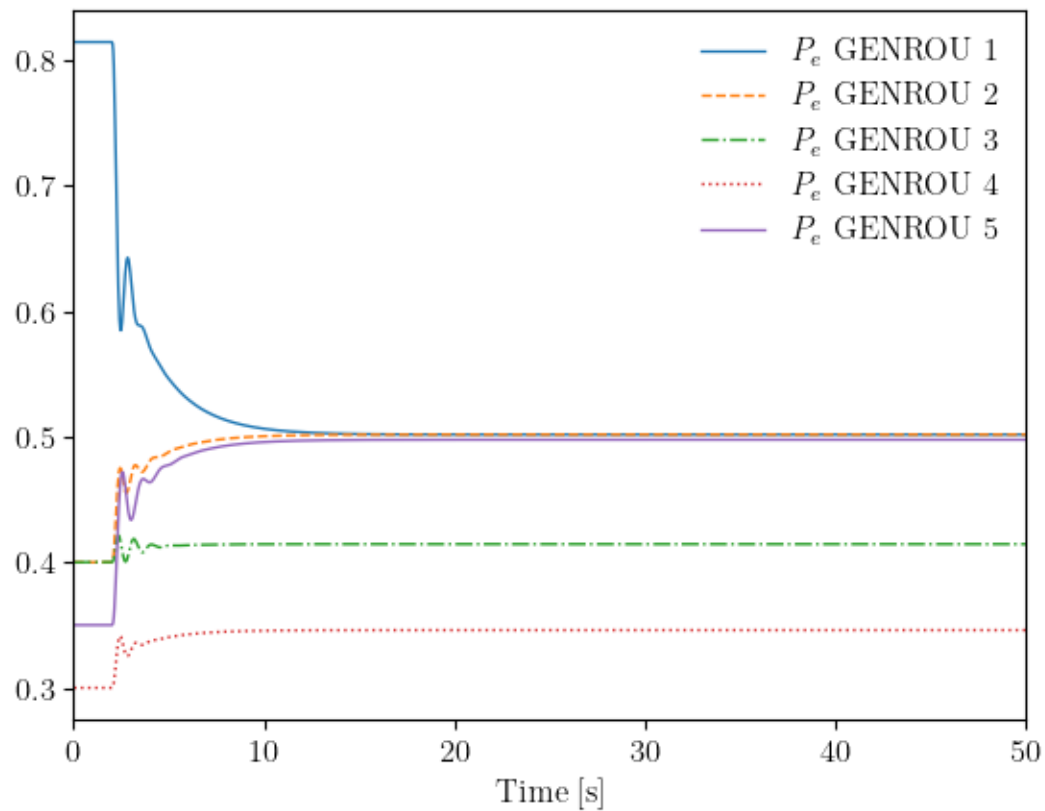
```
0%|          | 0/100 [00:00<?, ?%/s]
```

```
Simulation to t=50.00 sec completed in 1.9001 seconds.
```

```
True
```

We can see the outputs of GENROU are rearranged by the OPF results.

```
ssa.TDS.plt.plot(ssa.GENROU.Pe)
```



```
(<Figure size 640x480 with 1 Axes>, <AxesSubplot:xlabel='Time [s] '>)
```

2.13 pypowsybl Interface

"PowSyBI (Power System Blocks) is an open source framework written in Java, dedicated to electrical grid modelling and simulation, licensed under the Mozilla Public License version 2.0. It is part of LF Energy, an open source foundation focused on the power systems sector, hosted within The Linux Foundation."

pypowsybl is the Python interface to PowSybl. For more information, please visit:

<https://www.powsybl.org/pages/overview/>

ANDES provides a simple interface to pypowsybl. The main goal is to leverage pypowsybl for drawing single-line diagrams and area diagrams for systems loaded in ANDES.

2.13.1 Imports

```
import andes
import pypowsybl as pp

from andes.interop.pypowsybl import to_pypowsybl
```

```
ss = andes.load(andes.get_case("ieee14/ieee14_linetrip.xlsx"))
```

2.13.2 Conversion

Convert to a pypowsybl network:

```
n = to_pypowsybl(ss)
```

Run power flow in pypowsybl:

```
results = pp.loadflow.run_ac(n)
```

2.13.3 Diagrams

pypowsybl provides two functions to draw diagrams:

- `get_network_area_diagram(VOLTAGE_LEVEL_ID = None, DEPTH = 0)`
- `get_single_line_diagram(CONTAINER_ID)`

These function names are self explanatory. To draw the diagram for the whole network, do

```
n.get_network_area_diagram()
```

```
<pypowsybl.network.Svg at 0x7f1f905b33d0>
```

To draw the SLD for bus 6, do

```
n.get_single_line_diagram("VL6")
```

```
<pypowsybl.network.Svg at 0x7f1e879e2760>
```

where VL6 is the voltage level container created for Bus 6. Voltage level container is named as VL + bus idx.

To find out how to work with pypowsybl, visit its documentation at <https://pypowsybl.readthedocs.io>

DEVELOPMENT

This chapter contains advanced topics on modeling and simulation and how they are implemented in ANDES. It aims to provide an in-depth explanation of how the ANDES framework is set up for symbolic modeling and numerical simulation. It also provides an example for interested users to implement customized DAE models.

3.1 System

3.1.1 Overview

System is the top-level class for organizing power system models and orchestrating calculations. The full API reference of System is found at [*andes.system.System*](#).

Dynamic Imports

System dynamically imports groups, models, and routines at creation. To add new models, groups or routines, edit the corresponding file by adding entries following examples.

```
andes.system.System.import_models(self)
```

Import and instantiate models as System member attributes.

Models defined in `models/__init__.py` will be instantiated *sequentially* as attributes with the same name as the class name. In addition, all models will be stored in dictionary `System.models` with model names as keys and the corresponding instances as values.

Examples

`system.Bus` stores the *Bus* object, and `system.GENCLS` stores the classical generator object,

`system.models['Bus']` points the same instance as `system.Bus`.

```
andes.system.System.import_groups(self)
```

Import all groups classes defined in `models/group.py`.

Groups will be stored as instances with the name as class names. All groups will be stored to dictionary `System.groups`.

`andes.system.System.import_routines (self)`

Import routines as defined in `routines/__init__.py`.

Routines will be stored as instances with the name as class names. All routines will be stored to dictionary `System.routines`.

Examples

`System.PFlow` is the power flow routine instance, and `System.TDS` and `System.EIG` are time-domain analysis and eigenvalue analysis routines, respectively.

Code Generation

Under the hood, all models whose equations are provided in strings need be processed to generate executable functions for simulations. We call this process "code generation". Code generation utilizes SymPy, a symbolic toolbox, and can take up to one minute.

Code generation is automatically triggered upon the first ANDES run or whenever model changes are detected. Code generation only needs to run once unless the generated code is removed or model edits are detected. The generated code is then stored and reused for speed up.

The generated Python code is called `pycode`. It is a Python package (folder) with each module (a `.py` file) storing the executable Python code and metadata for numerical simulation. The default path to store `pycode` is `HOME_DIR/.andes`, where `HOME_DIR` is one's [home directory](#).

Note: Code generation has been done if one has executed `andes`, `andes selftest`, or `andes prepare`.

Warning: For developers: when models are modified (such as adding new models or changing equation strings), code generation needs to be executed again for consistency. ANDES can automatically detect changes, and it can be manually triggered from command line using `andes prepare -i`.

`andes.system.System.prepare (self, quick=False, incremental=False, models=None, nomp=False, ncpu=1)`

Generate numerical functions from symbolically defined models.

All procedures in this function must be independent of test case.

Parameters

quick

[bool, optional] True to skip pretty-print generation to reduce code generation time.

incremental

[bool, optional] True to generate only for modified models, incrementally.

models

[list, OrderedDict, None] List or OrderedDict of models to prepare

nomp

[bool] True to disable multiprocessing

Warning: Generated lambda functions will be serialized to file, but pretty prints (SymPy objects) can only exist in the System instance on which prepare is called.

Notes

Option `incremental` compares the md5 checksum of all var and service strings, and only regenerate for updated models.

Examples

If one needs to print out LaTeX-formatted equations in a Jupyter Notebook, one need to generate such equations with

```
import andes
sys = andes.prepare()
```

Alternatively, one can explicitly create a System and generate the code

```
import andes
sys = andes.System()
sys.prepare()
```

`andes.system.System.undill(self, autogen_stale=True)`

Reload generated function functions, from either the `$HOME/.andes/pycode` folder.

If no change is made to models, future calls to `prepare()` can be replaced with `undill()` for acceleration.

Parameters**autogen_stale: bool**

True to automatically call code generation if stale code is detected. Regardless of this option, codegen is trigger if importing existing code fails.

3.1.2 DAE Storage

`System.dae` is an instance of the numerical DAE class.

`andes.variables.dae.DAE` (*system*)

Class for storing numerical values of the DAE system, including variables, equations and first order derivatives (Jacobian matrices).

Variable values and equation values are stored as `numpy.ndarray`, while Jacobians are stored as `kvxopt.spmatrix`. The defined arrays and descriptions are as follows:

DAE Array	Description
<code>x</code>	Array for state variable values
<code>y</code>	Array for algebraic variable values
<code>z</code>	Array for 0/1 limiter states (if enabled)
<code>f</code>	Array for differential equation derivatives
<code>Tf</code>	Left-hand side time constant array for <code>f</code>
<code>g</code>	Array for algebraic equation mismatches

The defined scalar member attributes to store array sizes are

Scalar	Description
<code>m</code>	The number of algebraic variables/equations
<code>n</code>	The number of algebraic variables/equations
<code>o</code>	The number of limiter state flags

The derivatives of f and g with respect to x and y are stored in four `kvxopt.spmatrix` sparse matrices: **fx**, **fy**, **gx**, and **gy**, where the first letter is the equation name, and the second letter is the variable name.

Notes

DAE in ANDES is defined in the form of

$$\begin{aligned}T\dot{x} &= f(x, y) \\ 0 &= g(x, y)\end{aligned}$$

DAE does not keep track of the association of variable and address. Only a variable instance keeps track of its addresses.

3.1.3 Model and DAE Values

ANDES uses a decentralized architecture between models and DAE value arrays. In this architecture, variables are initialized and equations are evaluated inside each model. Then, `System` provides methods for collecting initial values and equation values into DAE, as well as copying solved values to each model.

The collection of values from models needs to follow protocols to avoid conflicts. Details are given in the subsection `Variables`.

```
andes.system.System.vars_to_dae(self, model)
```

Copy variables values from models to `System.dae`.

This function clears `DAE.x` and `DAE.y` and collects values from models.

```
andes.system.System.vars_to_models(self)
```

Copy variable values from `System.dae` to models.

```
andes.system.System._e_to_dae(self, eq_name: str | Tuple = ('f', 'g'))
```

Helper function for collecting equation values into `System.dae.f` and `System.dae.g`.

Parameters

`eq_name`

['x' or 'y' or tuple] Equation type name

Matrix Sparsity Patterns

The largest overhead in building and solving nonlinear equations is the building of Jacobian matrices. This is especially relevant when we use the implicit integration approach which algebraized the differential equations. Given the unique data structure of power system models, the sparse matrices for Jacobians are built **incrementally**, model after model.

There are two common approaches to incrementally build a sparse matrix. The first one is to use simple in-place add on sparse matrices, such as doing

```
self.fx += spmatrix(v, i, j, (n, n), 'd')
```

Although the implementation is simple, it involves creating and discarding temporary objects on the right hand side and, even worse, changing the sparse pattern of `self.fx`.

The second approach is to store the rows, columns and values in an array-like object and construct the Jacobians at the end. This approach is very efficient but has one caveat: it does not allow accessing the sparse matrix while building.

ANDES uses a pre-allocation approach to avoid the change of sparse patterns by filling values into a known the sparse matrix pattern matrix. `System` collects the indices of rows and columns for each Jacobian matrix. Before in-place additions, ANDES builds a temporary zero-filled `spmatrix`, to which the actual Jacobian values are written later. Since these in-place add operations are only modifying existing values, it does not change the pattern and thus avoids memory copying. In addition, updating sparse matrices can be done with the exact same code as the first approach.

Still, this approach creates and discards temporary objects. It is however feasible to write a C function which takes three array-likes and modify the sparse matrices in place. This is feature to be developed, and our prototype shows a promising acceleration up to 50%.

`andes.system.System.store_sparse_pattern(self, models: OrderedDict)`

Collect and store the sparsity pattern of Jacobian matrices.

This is a runtime function specific to cases.

Notes

For gy matrix, always make sure the diagonal is reserved. It is a safeguard if the modeling user omitted the diagonal term in the equations.

3.1.4 Calling Model Methods

System is an orchestrator for calling shared methods of models. These API methods are defined for initialization, equation update, Jacobian update, and discrete flags update.

The following methods take an argument *models*, which should be an *OrderedDict* of models with names as keys and instances as values.

`andes.system.System.init(self, models: OrderedDict, routine: str)`

Initialize the variables for each of the specified models.

For each model, the initialization procedure is:

- Get values for all *ExtService*.
- Call the model *init()* method, which initializes internal variables.
- Copy variables to DAE and then back to the model.

`andes.system.System.e_clear(self, models: OrderedDict)`

Clear equation arrays in DAE and model variables.

This step must be called before calling *f_update* or *g_update* to flush existing values.

`andes.system.System.l_update_var(self, models: OrderedDict, niter=0, err=None)`

Update variable-based limiter discrete states by calling *l_update_var* of models.

This function is must be called before any equation evaluation.

`andes.system.System.f_update(self, models: OrderedDict)`

Call the differential equation update method for models in sequence.

Notes

Updated equation values remain in models and have not been collected into DAE at the end of this step.

`andes.system.System.l_update_eq(self, models: OrderedDict, init=False, niter=0)`

Update equation-dependent limiter discrete components by calling `l_check_eq` of models. Force set equations after evaluating equations.

This function is must be called after differential equation updates.

`andes.system.System.g_update(self, models: OrderedDict)`

Call the algebraic equation update method for models in sequence.

Notes

Like `f_update`, updated values have not collected into DAE at the end of the step.

`andes.system.System.j_update(self, models: OrderedDict, info=None)`

Call the Jacobian update method for models in sequence.

The procedure is - Restore the sparsity pattern with `andes.variables.dae.DAE.restore_sparse()` - For each sparse matrix in (fx, fy, gx, gy), evaluate the Jacobian function calls and add values.

Notes

Updated Jacobians are immediately reflected in the DAE sparse matrices (fx, fy, gx, gy).

3.1.5 Configuration

System, models and routines have a member attribute `config` for model-specific or routine-specific configurations. System manages all configs, including saving to a config file and loading back.

`andes.system.System.save_config(self, file_path=None, overwrite=False)`

Save all system, model, and routine configurations to an rc-formatted file.

Parameters

file_path

[str, optional] path to the configuration file default to `~/andes/andes.rc`.

overwrite

[bool, optional] If file exists, True to overwrite without confirmation. Otherwise prompt for confirmation.

Warning: Saved config is loaded back and populated *at system instance creation time*. Configs from the config file takes precedence over default config values.

Warning: It is important to note that configs from files is passed to *model constructors* during instantiation. If one needs to modify config for a run, it needs to be done before instantiating `System`, or before running `andes` from command line. Directly modifying `Model.config` may not take effect or have side effect as for the current implementation.

3.2 Group

A group is a collection of similar functional models with common variables and parameters. It is mandatory to enforce the common variables and parameters when develop new models. The common variables and parameters are typically the interface when connecting different group models.

For example, the Group *RenGen* has variables *Pe* and *Qe*, which are active power output and reactive power output. Such common variables can be retrieved by other models, such as one in the Group *RenExciter* for further calculation.

In such a way, the same variable interface is realized so that all model in the same group could carry out similar function.

*GroupBase()*Base class for groups.

3.2.1 andes.models.group.GroupBase

```
class andes.models.group.GroupBase
```

```
    Base class for groups.
```

```
    __init__()
```


Methods

<code>add(idx, model)</code>	Register an idx from model_name to the group
<code>add_model(name, instance)</code>	Add a Model instance to group.
<code>doc([export])</code>	Return the documentation of the group in a string.
<code>doc_all([export])</code>	Return documentation of the group and its models.
<code>find_idx(keys, values[, allow_none, default])</code>	Find indices of devices that satisfy the given <i>key=value</i> condition.
<code>get(src, idx[, attr, allow_none, default])</code>	Based on the indexer, get the <i>attr</i> field of the <i>src</i> parameter or variable.
<code>get_field(src, idx, field)</code>	Helper function for retrieving an attribute of a member variable shared by models in this group.
<code>get_next_idx([idx, model_name])</code>	Get a no-conflict idx for a new device.
<code>idx2model(idx[, allow_none])</code>	Find model name for the given idx.
<code>idx2uid(idx)</code>	Convert idx to the 0-indexed unique index.
<code>set(src, idx, attr, value)</code>	Set the value of an attribute of a group property.
<code>set_backref(name, from_idx, to_idx)</code>	Set idxes to <code>BackRef</code> , and set them to models.

GroupBase.add

`GroupBase.add(idx, model)`

Register an idx from model_name to the group

Parameters

idx: `Union[str, float, int]`

Register an element to a model

model: `Model`

instance of the model

Returns

GroupBase.add_model

`GroupBase.add_model(name: str, instance)`

Add a Model instance to group.

Parameters

name

[str] Model name

instance

[Model] Model instance

Returns

None

GroupBase.doc

GroupBase.**doc** (*export='plain'*)

Return the documentation of the group in a string.

GroupBase.doc_all

GroupBase.**doc_all** (*export='plain'*)

Return documentation of the group and its models.

Parameters

export

[*'plain'* or *'rest'*] Export format, plain-text or RestructuredText

Returns

str

GroupBase.find_idx

GroupBase.**find_idx** (*keys, values, allow_none=False, default=None*)

Find indices of devices that satisfy the given *key=value* condition.

This method iterates over all models in this group.

GroupBase.get

GroupBase.**get** (*src: str, idx, attr: str = 'v', allow_none=False, default=0.0*)

Based on the indexer, get the *attr* field of the *src* parameter or variable.

Parameters

src

[*str*] param or var name

idx

[array-like] device idx

attr

The attribute of the param or var to retrieve

allow_none

[*bool*] True to allow None values in the indexer

default

[*float*] If *allow_none* is true, the default value to use for None indexer.

Returns

The requested param or variable attribute. If *idx* is a list, return a list of values.

If *idx* is a single element, return a single value.

GroupBase.get_field

GroupBase.get_field(*src: str, idx, field: str*)

Helper function for retrieving an attribute of a member variable shared by models in this group.

Returns

list

A list with the length equal to `len(idx)`.

GroupBase.get_next_idx

GroupBase.get_next_idx(*idx=None, model_name=None*)

Get a no-conflict idx for a new device. Use the provided *idx* if no conflict. Generate a new one otherwise.

Parameters

idx

[str or None] Proposed idx. If None, assign a new one.

model_name

[str or None] Model name. If not, prepend the group name.

Returns

str

New device name.

GroupBase.idx2model

GroupBase.idx2model(*idx, allow_none=False*)

Find model name for the given idx.

Parameters

idx

[float, int, str, array-like] idx or idx-es of devices.

allow_none

[bool] If True, return *None* at the positions where idx is not found.

Returns

If *idx* is a list, return a list of model instances.
If *idx* is a single element, return a model instance.

GroupBase.idx2uid

GroupBase.**idx2uid** (*idx*)

Convert *idx* to the 0-indexed unique index.

Parameters

idx

[array-like, numbers, or str] *idx* of devices

Returns

list

A list containing the unique indices of the devices

GroupBase.set

GroupBase.**set** (*src*: *str*, *idx*, *attr*, *value*)

Set the value of an attribute of a group property. Performs `self.<src>.<attr>[idx] = value`.

The user needs to ensure that the property is shared by all models in this group.

Parameters

src

[str] Name of property.

idx

[str, int, float, array-like] Indices of devices.

attr

[str, optional, default='v'] The internal attribute of the property to get. v for values, a for address, and e for equation value.

value

[array-like] New values to be set

Returns

bool

True when successful.

GroupBase.set_backref

`GroupBase.set_backref(name, from_idx, to_idx)`

Set idxes to BackRef, and set them to models.

Attributes

<code>class_name</code>	
<code>n</code>	Total number of devices.

GroupBase.class_name

property `GroupBase.class_name`

GroupBase.n

property `GroupBase.n`

Total number of devices.

3.3 Models

This section introduces the modeling of power system devices. The terminology "model" is used to describe the mathematical representation of a *type* of device, such as synchronous generators or turbine governors. The terminology "device" is used to describe a particular instance of a model, for example, a specific generator.

To define a model in ANDES, two classes, `ModelData` and `Model` need to be utilized. Class `ModelData` is used for defining parameters that will be provided from input files. It provides API for adding data from devices and managing the data. Class `Model` is used for defining other non-input parameters, service variables, and DAE variables. It provides API for converting symbolic equations, storing Jacobian patterns, and updating equations.

The following classes are related to models:

<code>ModelData(*args[, three_params])</code>	Class for holding parameter data for a model.
<code>Model([system, config])</code>	Base class for power system DAE models.
<code>ModelCache()</code>	Class for caching the return value of callback functions.
<code>ModelCall()</code>	Class for storing generated function calls, Jacobian calls, and arguments.

3.3.1 andes.core.model.ModelData

class `andes.core.model.ModelData` (*args, three_params=True, **kwargs)

Class for holding parameter data for a model.

This class is designed to hold the parameter data separately from model equations. Models should inherit this class to define the parameters from input files.

Inherit this class to create the specific class for holding input parameters for a new model. The recommended name for the derived class is the model name with `Data`. For example, data for *GENROU* should be named *GENROUData*.

Parameters should be defined in the `__init__` function of the derived class.

Refer to `andes.core.param` for available parameter types.

Notes

Three default parameters are pre-defined in `ModelData` and will be inherited by all models. They are

- `idx`, unique device idx of type `andes.core.param.DataParam`
- `u`, connection status of type `andes.core.param.NumParam`
- `name`, (device name of type `andes.core.param.DataParam`)

In rare cases one does not want to define these three parameters, one can pass `three_params=True` to the constructor of `ModelData`.

Examples

If we want to build a class `PQData` (for static PQ load) with three parameters, *Vn*, *p0* and *q0*, we can use the following

```
from andes.core.model import ModelData, Model
from andes.core.param import IdxParam, NumParam

class PQData(ModelData):
    super().__init__()
    self.Vn = NumParam(default=110,
                        info="AC voltage rating",
                        unit='kV', non_zero=True,
                        tex_name=r'V_n')
    self.p0 = NumParam(default=0,
                        info='active power load in system base',
                        tex_name=r'p_0', unit='p.u.')
    self.q0 = NumParam(default=0,
                        info='reactive power load in system base',
                        tex_name=r'q_0', unit='p.u.')
```

In this example, all the three parameters are defined as `andes.core.param.NumParam`. In the full `PQData` class, other types of parameters also exist. For example, to store the idx of *owner*, `PQData` uses

```
self.owner = IdxParam(model='Owner', info="owner idx")
```

Attributes

cache

A cache instance for different views of the internal data.

flags

[dict] Flags to control the routine and functions that get called. If the model is using user-defined numerical calls, set `f_num`, `g_num` and `j_num` properly.

`__init__` (*args, three_params=True, **kwargs)

Methods

<code>add(**kwargs)</code>	Add a device (an instance) to this model.
<code>as_df([vin])</code>	Export all parameters as a <i>pandas.DataFrame</i> object.
<code>as_df_local()</code>	Export local variable values and services to a DataFrame.
<code>as_dict([vin])</code>	Export all parameters as a dict.
<code>find_idx(keys, values[, allow_none, default])</code>	Find <i>idx</i> of devices whose values match the given pattern.
<code>find_param(prop)</code>	Find params with the given property and return in an OrderedDict.
<code>update_from_df(df[, vin])</code>	Update parameter values from a DataFrame.

ModelData.add

`ModelData.add` (**kwargs)

Add a device (an instance) to this model.

Parameters

kwargs

model parameters are collected into the kwargs dictionary

Warning: This function is not intended to be used directly. Use the `add` method from `System` so that the index can be registered correctly.

ModelData.as_df

`ModelData.as_df (vin=False)`

Export all parameters as a *pandas.DataFrame* object. This function utilizes *as_dict* for preparing data.

Returns

DataFrame

A dataframe containing all model data. An *uid* column is added.

vin

[bool] If True, export all parameters from original input (*vin*).

ModelData.as_df_local

`ModelData.as_df_local ()`

Export local variable values and services to a DataFrame.

ModelData.as_dict

`ModelData.as_dict (vin=False)`

Export all parameters as a dict.

Returns

dict

a dict with the keys being the *ModelData* parameter names and the values being an array-like of data in the order of adding. An additional *uid* key is added with the value default to `range(n)`.

ModelData.find_idx

`ModelData.find_idx (keys, values, allow_none=False, default=False)`

Find *idx* of devices whose values match the given pattern.

Parameters

keys

[str, array-like, Sized] A string or an array-like of strings containing the names of parameters for the search criteria

values

[array, array of arrays, Sized] Values for the corresponding key to search for. If *keys* is a str, *values* should be an array of elements. If *keys* is a list, *values* should be an array of arrays, each corresponds to the key.

allow_none

[bool, Sized] Allow key, value to be not found. Used by groups.

default

[bool] Default idx to return if not found (missing)

Returns**list**

indices of devices

ModelData.find_param`ModelData.find_param(prop)`

Find params with the given property and return in an OrderedDict.

Parameters**prop**

[str] Property name

Returns**OrderedDict****ModelData.update_from_df**`ModelData.update_from_df(df, vin=False)`

Update parameter values from a DataFrame.

Adding devices are not allowed.

3.3.2 andes.core.model.Model**class** `andes.core.model.Model` (*system=None, config=None*)

Base class for power system DAE models.

After subclassing *ModelData*, subclass *Model* to complete a DAE model. Subclasses of *Model* define DAE variables, services, and other types of parameters, in the constructor `__init__`.

Examples

Take the static PQ as an example, the subclass of *Model*, *PQ*, should look like

```
class PQ(PQData, Model):
    def __init__(self, system, config):
        PQData.__init__(self)
        Model.__init__(self, system, config)
```

Since *PQ* is calling the base class constructors, it is meant to be the final class and not further derived. It inherits from *PQData* and *Model* and must call constructors in the order of *PQData* and *Model*. If the derived class of *Model* needs to be further derived, it should only derive from *Model* and use a name ending with *Base*. See `andes.models.synchronous.genbase.GENBase`.

Next, in `PQ.__init__`, set proper flags to indicate the routines in which the model will be used

```
self.flags.update({'pflow': True})
```

Currently, flags `pflow` and `tds` are supported. Both are *False* by default, meaning the model is neither used in power flow nor in time-domain simulation. **A very common pitfall is forgetting to set the flag.**

Next, the group name can be provided. A group is a collection of models with common parameters and variables. Devices' idx of all models in the same group must be unique. To provide a group name, use

```
self.group = 'StaticLoad'
```

The group name must be an existing class name in `andes.models.group`. The model will be added to the specified group and subject to the variable and parameter policy of the group. If not provided with a group class name, the model will be placed in the *Undefined* group.

Next, additional configuration flags can be added. Configuration flags for models are load-time variables, specifying the behavior of a model. They can be exported to an *andes.rc* file and automatically loaded when creating the *System*. Configuration flags can be used in equation strings, as long as they are numerical values. To add config flags, use

```
self.config.add(OrderedDict((('pq2z', 1), )))
```

It is recommended to use *OrderedDict* instead of *dict*, although the syntax is verbose. Note that booleans should be provided as integers (1 or 0), since *True* or *False* is interpreted as a string when loaded from the *rc* file and will cause an error.

Next, it's time for variables and equations! The *PQ* class does not have internal variables itself. It uses its *bus* parameter to fetch the corresponding *a* and *v* variables of buses. Equation wise, it imposes an active power and a reactive power load equation.

To define external variables from *Bus*, use

```
self.a = ExtAlgeb(model='Bus', src='a',
                  indexer=self.bus, tex_name=r'\theta')
self.v = ExtAlgeb(model='Bus', src='v',
                  indexer=self.bus, tex_name=r'V')
```

Refer to the subsection Variables for more details.

The simplest *PQ* model will impose constant P and Q, coded as

```
self.a.e_str = "u * p"
self.v.e_str = "u * q"
```

where the *e_str* attribute is the equation string attribute. *u* is the connectivity status. Any parameter, config, service or variable can be used in equation strings.

Three additional scalars can be used in equations: - `dae_t` for the current simulation time (can be used if the model has flag *tds*). - `sys_f` for system frequency (from `system.config.freq`). - `sys_mva` for system base mva (from `system.config.mva`).

The above example is overly simplified. Our *PQ* model wants a feature to switch itself to a constant impedance if the voltage is out of the range (*vmin*, *vmax*). To implement this, we need to introduce

a discrete component called *Limiter*, which yields three arrays of binary flags, z_i , z_l , and z_u indicating in-range, below lower-limit, and above upper-limit, respectively.

First, create an attribute *vcmp* as a *Limiter* instance

```
self.vcmp = Limiter(u=self.v, lower=self.vmin, upper=self.vmax,
                    enable=self.config.pq2z)
```

where *self.config.pq2z* is a flag to turn this feature on or off. After this line, we can use *vcmp_zi*, *vcmp_zl*, and *vcmp_zu* in other equation strings.

```
self.a.e_str = "u * (p0 * vcmp_zi + " \
               "p0 * vcmp_zl * (v ** 2 / vmin ** 2) + " \
               "p0 * vcmp_zu * (v ** 2 / vmax ** 2))"

self.v.e_str = "u * (q0 * vcmp_zi + " \
               "q0 * vcmp_zl * (v ** 2 / vmin ** 2) + "\
               "q0 * vcmp_zu * (v ** 2 / vmax ** 2))"
```

Note that *PQ.a.e_str* can use the three variables from *vcmp* even before defining *PQ.vcmp*, as long as *PQ.vcmp* is defined, because *vcmp_zi* is just a string literal in *e_str*.

The two equations above implement a piece-wise power injection equation. It selects the original power demand if within range, and uses the calculated power when out of range.

Finally, to let ANDES pick up the model, the model name needs to be added to *models/__init__.py*. Follow the examples in the *OrderedDict*, where the key is the file name, and the value is the class name.

Attributes

num_params

[OrderedDict] {name: instance} of numerical parameters, including internal and external ones

__init__ (*system=None, config=None*)

Methods

<i>a_reset()</i>	Reset addresses to empty and reset flags.address to False.
<i>alter</i> (src, idx, value)	Alter values of input parameters or constant service.
<i>doc</i> ([max_width, export])	Retrieve model documentation as a string.
<i>e_clear()</i>	Clear equation value arrays associated with all internal variables.
<i>externalize()</i>	Externalize internal data as a snapshot.
<i>f_numeric</i> (**kwargs)	Custom fcall functions.
<i>f_update()</i>	Evaluate differential equations.
<i>g_numeric</i> (**kwargs)	Custom gcall functions.

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Table 1 – continued from previous page

<code>g_update()</code>	Evaluate algebraic equations.
<code>get(src, idx[, attr, allow_none, default])</code>	Get the value of an attribute of a model property.
<code>get_init_order()</code>	Get variable initialization order and send to <i>logger.info</i> .
<code>get_inputs([refresh])</code>	Get an OrderedDict of the inputs to the numerical function calls.
<code>get_md5()</code>	Return the md5 hash of concatenated equation strings.
<code>get_times()</code>	Get event switch_times from <i>TimerParam</i> .
<code>idx2uid(idx)</code>	Convert idx to the 0-indexed unique index.
<code>init(routine)</code>	Numerical initialization of a model.
<code>internalize()</code>	Internalize snapshot data.
<code>j_numeric(**kwargs)</code>	Custom numeric update functions.
<code>j_update()</code>	Update Jacobian elements.
<code>l_check_eq([init, niter])</code>	Call the <code>check_eq</code> method of discrete components to update equation-dependent flags.
<code>l_update_var(dae_t, *args[, niter, err])</code>	Call the <code>check_var</code> method of discrete components to update the internal status flags.
<code>list2array()</code>	Convert all the value attributes <code>v</code> to NumPy arrays.
<code>mock_refresh_inputs()</code>	Use mock data to fill the inputs.
<code>numba_jitify([parallel, cache, nopython])</code>	Convert equation residual calls, Jacobian calls, and variable service calls into JIT compiled functions.
<code>post_init_check()</code>	Post init checking.
<code>precompile()</code>	Trigger numba compilation for this model.
<code>prepare([quick, pycode_path, yapf_pycode])</code>	Symbolic processing and code generation.
<code>refresh_inputs()</code>	This is the helper function to refresh inputs.
<code>refresh_inputs_arg()</code>	Refresh inputs for each function with individual argument list.
<code>register_debug_equation(var_name)</code>	Helper function to register a variable for debugging the initialization.
<code>s_numeric(**kwargs)</code>	Custom service value functions.
<code>s_numeric_var(**kwargs)</code>	Custom variable service value functions.
<code>s_update()</code>	Update service equation values.
<code>s_update_post()</code>	Update post-initialization services.
<code>s_update_var()</code>	Update values of <code>andes.core.service.VarService</code> .
<code>set(src, idx, attr, value)</code>	Set the value of an attribute of a model property.
<code>set_backref(name, from_idx, to_idx)</code>	Helper function for setting idx-es to <code>BackRef</code> .
<code>set_in_use()</code>	Set the <i>in_use</i> attribute.
<code>solve_iter(name, kwargs)</code>	Solve iterative initialization.
<code>solve_iter_single(name, inputs, pos)</code>	Solve iterative initialization for one given device.
<code>store_sparse_pattern()</code>	Store rows and columns of the non-zeros in the Jacobians for building the sparsity pattern.

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Table 1 – continued from previous page

<code>switch_action(dae_t)</code>	Call the switch actions.
<code>v_numeric(**kwargs)</code>	Custom variable initialization function.

Model.a_reset`Model.a_reset()`

Reset addresses to empty and reset flags.address to `False`.

Model.alter`Model.alter(src, idx, value)`

Alter values of input parameters or constant service.

If the method operates on an input parameter, the new data should be in the same base as that in the input file. This function will convert `value` to per unit in the system base whenever necessary.

The values for storing the input data, i.e., the parameter's `vin` field, will be overwritten. As a result, altered values will be reflected in the dumped case file.

Parameters**src**

[str] The parameter name to alter

idx

[str, float, int] The device to alter

value

[float] The desired value

Model.doc`Model.doc(max_width=78, export='plain')`

Retrieve model documentation as a string.

Model.e_clear`Model.e_clear()`

Clear equation value arrays associated with all internal variables.

Model.externalize

`Model.externalize()`

Externalize internal data as a snapshot.

Model.f_numeric

`Model.f_numeric(**kwargs)`

Custom fcall functions. Modify equations directly.

Model.f_update

`Model.f_update()`

Evaluate differential equations.

Notes

In-place equations: added to the corresponding DAE array. Non-in-place equations: in-place set to internal array to overwrite old values (and avoid clearing).

Model.g_numeric

`Model.g_numeric(**kwargs)`

Custom gcall functions. Modify equations directly.

Model.g_update

`Model.g_update()`

Evaluate algebraic equations.

Model.get

`Model.get(src: str, idx, attr: str = 'v', allow_none=False, default=0.0)`

Get the value of an attribute of a model property.

The return value is `self.<src>.<attr>[idx]`

Parameters

src

[str] Name of the model property

idx

[str, int, float, array-like] Indices of the devices

attr

[str, optional, default='v'] The attribute of the property to get. v for values, a for address, and e for equation value.

allow_none

[bool] True to allow None values in the indexer

default

[float] If *allow_none* is true, the default value to use for None indexer.

Returns**array-like**

`self.<src>.<attr>[idx]`

Model.get_init_order

`Model.get_init_order()`

Get variable initialization order and send to *logger.info*.

Model.get_inputs

`Model.get_inputs(refresh=False)`

Get an OrderedDict of the inputs to the numerical function calls.

Parameters**refresh**

[bool] Refresh the values in the dictionary. This is only used when the memory addresses of arrays change. After initialization, all array assignments are in place. To avoid overhead, refresh should not be used after initialization.

Returns**OrderedDict**

The input name and value array pairs in an OrderedDict

Notes

dae.t is now a `numpy.ndarray` which has stable memory. There is no need to refresh *dat_t* in this version.

Model.get_md5

`Model.get_md5()`

Return the md5 hash of concatenated equation strings.

Model.get_times

`Model.get_times()`

Get event switch_times from *TimerParam*.

Returns

list

A list containing all switching times defined in TimerParams

Model.idx2uid

`Model.idx2uid(idx)`

Convert idx to the 0-indexed unique index.

Parameters

idx

[array-like, numbers, or str] idx of devices

Returns

list

A list containing the unique indices of the devices

Model.init

`Model.init(routine)`

Numerical initialization of a model.

Initialization sequence: 1. Sequential initialization based on the order of definition 2. Use Newton-Krylov method for iterative initialization 3. Custom init

Model.internalize

`Model.internalize()`

Internalize snapshot data.

Model.j_numeric

`Model.j_numeric (**kwargs)`

Custom numeric update functions.

This function should append indices to `_ifx`, `_jfx`, and append anonymous functions to `_vfx`. It is only called once by `store_sparse_pattern`.

Model.j_update

`Model.j_update ()`

Update Jacobian elements.

Values are stored to `Model.triplets[jname]`, where `jname` is a jacobian name.

Returns

None

Model.l_check_eq

`Model.l_check_eq (init=False, niter=0, **kwargs)`

Call the `check_eq` method of discrete components to update equation-dependent flags.

This function should be called after equation updates. AntiWindup limiters use it to append pegged states to the `x_set` list.

Returns

None

Model.l_update_var

`Model.l_update_var (dae_t, *args, niter=None, err=None, **kwargs)`

Call the `check_var` method of discrete components to update the internal status flags.

The function is variable-dependent and should be called before updating equations.

Returns

None

Model.list2array

`Model.list2array()`

Convert all the value attributes v to NumPy arrays.

Value attribute arrays should remain in the same address afterwards. Namely, all assignments to value array should be operated in place (e.g., with [:]).

Model.mock_refresh_inputs

`Model.mock_refresh_inputs()`

Use mock data to fill the inputs.

This function is used to generate input data of the desired type to trigger JIT compilation.

Model.numba_jitify

`Model.numba_jitify (parallel=False, cache=True, nopython=True)`

Convert equation residual calls, Jacobian calls, and variable service calls into JIT compiled functions.

This function can be enabled by setting `System.config.numba = 1`.

Model.post_init_check

`Model.post_init_check()`

Post init checking. Warns if values of *InitChecker* are not True.

Model.precompile

`Model.precompile()`

Trigger numba compilation for this model.

This function requires the system to be setup, i.e., memory allocated for storage.

Model.prepare

`Model.prepare (quick=False, pycode_path=None, yapf_pycode=False)`

Symbolic processing and code generation.

Model.refresh_inputs

`Model.refresh_inputs()`

This is the helper function to refresh inputs.

The functions collects object references into `OrderedDict self._input` and `self._input_z`.

Returns

None

Model.refresh_inputs_arg

`Model.refresh_inputs_arg()`

Refresh inputs for each function with individual argument list.

Model.register_debug_equation

`Model.register_debug_equation(var_name)`

Helper function to register a variable for debugging the initialization.

This function needs to be called before calling `TDS.init()`, and logging level needs to be set to `DEBUG`.

Model.s_numeric

`Model.s_numeric(**kwargs)`

Custom service value functions. Modify `Service.v` directly.

Model.s_numeric_var

`Model.s_numeric_var(**kwargs)`

Custom variable service value functions. Modify `VarService.v` directly.

This custom numerical function is evaluated at each step/iteration before equation update.

Model.s_update

`Model.s_update()`

Update service equation values.

This function is only evaluated at initialization. Service values are updated sequentially. The `v` attribute of services will be assigned at a new memory address.

Model.s_update_post

`Model.s_update_post()`

Update post-initialization services.

Model.s_update_var

`Model.s_update_var()`

Update values of `andes.core.service.VarService`.

Model.set

`Model.set(src, idx, attr, value)`

Set the value of an attribute of a model property.

Performs `self.<src>.<attr>[idx] = value`. This method will not modify the input values from the case file that have not been converted to the system base. As a result, changes applied by this method will not affect the dumped case file.

To alter parameters and reflect it in the case file, use `alter()` instead.

Parameters

src

[str] Name of the model property

idx

[str, int, float, array-like] Indices of the devices

attr

[str, optional, default='v'] The internal attribute of the property to get. `v` for values, `a` for address, and `e` for equation value.

value

[array-like] New values to be set

Returns

bool

True when successful.

Model.set_backref

`Model.set_backref(name, from_idx, to_idx)`

Helper function for setting `idx`-es to `BackRef`.

Model.set_in_use

`Model.set_in_use()`

Set the *in_use* attribute. Called at the end of `System.collect_ref`.

This function is overloaded by models with *BackRef* to disable calls when no model is referencing. Models with no back references will have internal variable addresses assigned but external addresses being empty.

For internal equations that have external variables, the row indices will be non-zeros, while the col indices will be empty, which causes an error when updating Jacobians.

Setting *self.in_use* to False when *len(back_ref_instance.v) == 0* avoids this error. See COI.

Model.solve_iter

`Model.solve_iter(name, kwargs)`

Solve iterative initialization.

Model.solve_iter_single

`Model.solve_iter_single(name, inputs, pos)`

Solve iterative initialization for one given device.

Model.store_sparse_pattern

`Model.store_sparse_pattern()`

Store rows and columns of the non-zeros in the Jacobians for building the sparsity pattern.

This function converts the internal 0-indexed equation/variable address to the numerical addresses for the loaded system.

Calling sequence: For each Jacobian name, *fx*, *fy*, *gx* and *gy*, store by a) generated constant and variable Jacobians c) user-provided constant and variable Jacobians, d) user-provided block constant and variable Jacobians

Notes

If *self.n == 0*, skipping this function will avoid appending empty lists/arrays and non-empty values, which, as a combination, is not accepted by *kvxopt.spmatrix*.

Model.switch_action

`Model.switch_action(dae_t)`

Call the switch actions.

Parameters

dae_t

[float] Current simulation time

Returns

None

Warning: Timer exported from blocks are supposed to work but have not been tested.

Model.v_numeric

`Model.v_numeric(**kwargs)`

Custom variable initialization function.

Attributes

<i>class_name</i>	Return the class name
-------------------	-----------------------

Model.class_name

property `Model.class_name`

Return the class name

3.3.3 andes.core.model.ModelCache

class `andes.core.model.ModelCache`

Class for caching the return value of callback functions.

Check `ModelCache.__dict__.keys()` for fields.

`__init__()`

Methods

<code>add_callback(name, callback)</code>	Add a cache attribute and a callback function for updating the attribute.
<code>refresh([name])</code>	Refresh the cached values

ModelCache.add_callback

`ModelCache.add_callback` (*name*: *str*, *callback*)

Add a cache attribute and a callback function for updating the attribute.

Parameters

name

[str] name of the cached function return value

callback

[callable] callback function for updating the cached attribute

ModelCache.refresh

`ModelCache.refresh` (*name*=None)

Refresh the cached values

Parameters

name

[str, list, optional] name or list of cached to refresh, by default None for refreshing all

3.3.4 andes.core.model.ModelCall

class `andes.core.model.ModelCall`

Class for storing generated function calls, Jacobian calls, and arguments.

`__init__()`

Methods

```
append_ijv(j_full_name, ii, jj, vv)
```

```
clear_ijv()
```

```
zip_ijv(j_full_name)
```

Return a zipped iterator for the rows, cols and vals for the specified matrix name.

ModelCall.append_ijv

```
ModelCall.append_ijv(j_full_name, ii, jj, vv)
```

ModelCall.clear_ijv

```
ModelCall.clear_ijv()
```

ModelCall.zip_ijv

```
ModelCall.zip_ijv(j_full_name)
```

Return a zipped iterator for the rows, cols and vals for the specified matrix name.

3.3.5 Cache

ModelData uses a lightweight class `andes.core.model.ModelCache` for caching its data as a dictionary or a pandas *DataFrame*. Four attributes are defined in *ModelData.cache*:

- *dict*: all data in a dictionary with the parameter names as keys and *v* values as arrays.
- *dict_in*: the same as *dict* except that the values are from *v_in*, the original input.
- *df*: all data in a pandas *DataFrame*.
- *df_in*: the same as *df* except that the values are from *v_in*.

Other attributes can be added by registering with `cache.add_callback`.

```
andes.core.model.ModelCache.add_callback(self, name: str, callback)
```

Add a cache attribute and a callback function for updating the attribute.

Parameters

name

[str] name of the cached function return value

callback

[callable] callback function for updating the cached attribute

3.3.6 Define Voltage Ratings

If a model is connected to an AC Bus or a DC Node, namely, if `bus`, `bus1`, `node` or `node1` exists as parameter, it must provide the corresponding parameter, `Vn`, `Vn1`, `Vdcn` or `Vdcn1`, for rated voltages.

Controllers not connected to Bus or Node will have its rated voltages omitted and thus $V_b = V_n = 1$, unless one uses `andes.core.param.ExtParam` to retrieve the bus/node values.

As a rule of thumb, controllers not directly connected to the network shall use system-base per unit for voltage and current parameters. Controllers (such as a turbine governor) may inherit rated power from controlled models and thus power parameters will be converted consistently.

Define a DAE Model

`class andes.core.model.Model (system=None, config=None)`

Base class for power system DAE models.

After subclassing `ModelData`, subclass `Model` to complete a DAE model. Subclasses of `Model` define DAE variables, services, and other types of parameters, in the constructor `__init__`.

Examples

Take the static PQ as an example, the subclass of `Model`, `PQ`, should look like

```
class PQ(PQData, Model):
    def __init__(self, system, config):
        PQData.__init__(self)
        Model.__init__(self, system, config)
```

Since `PQ` is calling the base class constructors, it is meant to be the final class and not further derived. It inherits from `PQData` and `Model` and must call constructors in the order of `PQData` and `Model`. If the derived class of `Model` needs to be further derived, it should only derive from `Model` and use a name ending with `Base`. See `andes.models.synchronous.genbase.GENBase`.

Next, in `PQ.__init__`, set proper flags to indicate the routines in which the model will be used

```
self.flags.update({'pflow': True})
```

Currently, flags `pflow` and `tds` are supported. Both are `False` by default, meaning the model is neither used in power flow nor in time-domain simulation. **A very common pitfall is forgetting to set the flag.**

Next, the group name can be provided. A group is a collection of models with common parameters and variables. Devices' idx of all models in the same group must be unique. To provide a group name, use

```
self.group = 'StaticLoad'
```

The group name must be an existing class name in `andes.models.group`. The model will be added to the specified group and subject to the variable and parameter policy of the group. If not provided with a group class name, the model will be placed in the `Undefined` group.

Next, additional configuration flags can be added. Configuration flags for models are load-time variables, specifying the behavior of a model. They can be exported to an *andes.rc* file and automatically loaded when creating the *System*. Configuration flags can be used in equation strings, as long as they are numerical values. To add config flags, use

```
self.config.add(OrderedDict((( 'pq2z', 1), )))
```

It is recommended to use *OrderedDict* instead of *dict*, although the syntax is verbose. Note that booleans should be provided as integers (1 or 0), since *True* or *False* is interpreted as a string when loaded from the *rc* file and will cause an error.

Next, it's time for variables and equations! The *PQ* class does not have internal variables itself. It uses its *bus* parameter to fetch the corresponding *a* and *v* variables of buses. Equation wise, it imposes an active power and a reactive power load equation.

To define external variables from *Bus*, use

```
self.a = ExtAlgeb(model='Bus', src='a',
                  indexer=self.bus, tex_name=r'\theta')
self.v = ExtAlgeb(model='Bus', src='v',
                  indexer=self.bus, tex_name=r'V')
```

Refer to the subsection Variables for more details.

The simplest *PQ* model will impose constant P and Q, coded as

```
self.a.e_str = "u * p"
self.v.e_str = "u * q"
```

where the *e_str* attribute is the equation string attribute. *u* is the connectivity status. Any parameter, config, service or variable can be used in equation strings.

Three additional scalars can be used in equations: - *dae_t* for the current simulation time (can be used if the model has flag *tds*). - *sys_f* for system frequency (from *system.config.freq*). - *sys_mva* for system base mva (from *system.config.mva*).

The above example is overly simplified. Our *PQ* model wants a feature to switch itself to a constant impedance if the voltage is out of the range (*vmin*, *vmax*). To implement this, we need to introduce a discrete component called *Limiter*, which yields three arrays of binary flags, *zi*, *zl*, and *zu* indicating in-range, below lower-limit, and above upper-limit, respectively.

First, create an attribute *vcmp* as a *Limiter* instance

```
self.vcmp = Limiter(u=self.v, lower=self.vmin, upper=self.vmax,
                   enable=self.config.pq2z)
```

where *self.config.pq2z* is a flag to turn this feature on or off. After this line, we can use *vcmp_zi*, *vcmp_zl*, and *vcmp_zu* in other equation strings.

```
self.a.e_str = "u * (p0 * vcmp_zi + " \
               "p0 * vcmp_zl * (v ** 2 / vmin ** 2) + " \
               "p0 * vcmp_zu * (v ** 2 / vmax ** 2))"
```

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```
self.v.e_str = "u * (q0 * vcmp_zi + " \
               "q0 * vcmp_zl * (v ** 2 / vmin ** 2) + "\
               "q0 * vcmp_zu * (v ** 2 / vmax ** 2)) "
```

Note that *PQ.a.e_str* can use the three variables from *vcmp* even before defining *PQ.vcmp*, as long as *PQ.vcmp* is defined, because *vcmp_zi* is just a string literal in *e_str*.

The two equations above implement a piece-wise power injection equation. It selects the original power demand if within range, and uses the calculated power when out of range.

Finally, to let ANDES pick up the model, the model name needs to be added to *models/__init__.py*. Follow the examples in the *OrderedDict*, where the key is the file name, and the value is the class name.

Attributes

num_params

[OrderedDict] {name: instance} of numerical parameters, including internal and external ones

Dynamicity Under the Hood

The magic for automatic creation of variables are all hidden in `andes.core.model.Model.__setattr__()`, and the code is incredible simple. It sets the name, `tex_name`, and owner model of the attribute instance and, more importantly, does the book keeping. In particular, when the attribute is a `andes.core.block.Block` subclass, `__setattr__` captures the exported instances, recursively, and prepends the block name to exported ones. All these convenience owe to the dynamic feature of Python.

During the code generation phase, the symbols are created by checking the book-keeping attributes, such as *states*, *algebs*, and attributes in *Model.cache*.

In the numerical evaluation phase, *Model* provides a method, `andes.core.model.get_inputs()`, to collect the variable value arrays in a dictionary, which can be effortlessly passed as arguments to numerical functions.

3.3.7 Commonly Used Attributes in Models

The following *Model* attributes are commonly used for debugging. If the attribute is an *OrderedDict*, the keys are attribute names in str, and corresponding values are the instances.

- *params* and *params_ext*, two *OrderedDict* for internal (both numerical and non-numerical) and external parameters, respectively.
- *num_params* for numerical parameters, both internal and external.
- *states* and *algebs*, two *OrderedDict* for state variables and algebraic variables, respectively.
- *states_ext* and *algebs_ext*, two *OrderedDict* for external states and algebraics.
- *discrete*, an *OrderedDict* for discrete components.

- `blocks`, an *OrderedDict* for blocks.
- `services`, an *OrderedDict* for services with `v_str`.
- `services_ext`, an *OrderedDict* for externally retrieved services.

3.3.8 Attributes in *Model.cache*

Attributes in *Model.cache* are additional book-keeping structures for variables, parameters and services. The following attributes are defined.

- `all_vars`: all the variables.
- `all_vars_names`, a list of all variable names.
- `all_params`, all parameters.
- `all_params_names`, a list of all parameter names.
- `algebs_and_ext`, an *OrderedDict* of internal and external algebraic variables.
- `states_and_ext`, an *OrderedDict* of internal and external differential variables.
- `services_and_ext`, an *OrderedDict* of internal and external service variables.
- `vars_int`, an *OrderedDict* of all internal variables, states and then algebs.
- `vars_ext`, an *OrderedDict* of all external variables, states and then algebs.

Equation Generation

`Model.syms`, an instance of `SymProcessor`, handles the symbolic to numeric generation when called. The equation generation is a multi-step process with symbol preparation, equation generation, Jacobian generation, initializer generation, and pretty print generation.

class `andes.core.SymProcessor` (*parent*)

A helper class for symbolic processing and code generation.

Parameters

parent

[Model] The *Model* instance to process

Attributes

xy

[sympy.Matrix] variables pretty print in the order of State, ExtState, Algeb, ExtAlgeb

f

[sympy.Matrix] differential equations pretty print

g

[sympy.Matrix] algebraic equations pretty print

df

[sympy.SparseMatrix] df /d (xy) pretty print

dg

[sympy.SparseMatrix] dg /d (xy) pretty print

inputs_dict

[OrderedDict] All possible symbols in equations, including variables, parameters, discrete flags, and config flags. It has the same variables as what `get_inputs()` returns.

vars_dict

[OrderedDict] variable-only symbols, which are useful when getting the Jacobian matrices.

generate_equations()

Generate equations.

The pretty-print equations in matrices can be accessed in `self.f_matrix` and `self.g_matrix`.

generate_init()

Generate initialization equations.

generate_jacobians (*diag_eps=1e-08*)

Generate Jacobians and store to corresponding triplets.

The internal indices of equations and variables are stored, alongside the lambda functions.

For example, `dg/dy` is a sparse matrix whose elements are (`row`, `col`, `val`), where `row` and `col` are the internal indices, and `val` is the numerical lambda function. They will be stored to

`row -> self.calls._igy col -> self.calls._jgy val -> self.calls._vgy`

generate_symbols()

Generate symbols for symbolic equation generations.

This function should run before other generate equations.

Attributes**inputs_dict**

[OrderedDict] name-symbol pair of all parameters, variables and configs

vars_dict

[OrderedDict] name-symbol pair of all variables, in the order of (`states_and_ext` + `algebs_and_ext`)

Next, function `generate_equation` converts each DAE equation set to one numerical function calls and store it in `Model.calls`. The attributes for differential equation set and algebraic equation set are `f` and `g`. Differently, service variables will be generated one by one and store in an `OrderedDict` in `Model.calls.s`.

Jacobian Storage

3.3.9 Abstract Jacobian Storage

Using the `.jacobian` method on `sympy.Matrix`, the symbolic Jacobians can be easily obtained. The complexity lies in the storage of the Jacobian elements. Observed that the Jacobian equation generation happens before any system is loaded, thus only the variable indices in the variable array is available. For each non-zero item in each Jacobian matrix, ANDES stores the equation index, variable index, and the Jacobian value (either a constant number or a callable function returning an array).

Note that, again, a non-zero entry in a Jacobian matrix can be either a constant or an expression. For efficiency, constant numbers and lambdified callables are stored separately. Constant numbers, therefore, can be loaded into the sparse matrix pattern when a particular system is given.

Warning: Data structure for the Jacobian storage has changed. Pending documentation update. Please check `andes.core.common.JacTriplet` class for more details.

The triplets, the equation (row) index, variable (column) index, and values (constant numbers or callable) are stored in `Model` attributes with the name of `_{i, j, v}{Jacobian Name}{c or None}`, where `{i, j, v}` is a single character for row, column or value, `{Jacobian Name}` is a two-character Jacobian name chosen from `fx`, `fy`, `gx`, and `gy`, and `{c or None}` is either character `c` or no character, indicating whether it corresponds to the constants or non-constants in the Jacobian.

For example, the triplets for the constants in Jacobian `gy` are stored in `_igyc`, `_jgyc`, and `_vgyc`.

In terms of the non-constant entries in Jacobians, the callable functions are stored in the corresponding `_v{Jacobian Name}` array. Note the differences between, for example, `_vgy` and `_vgyc`: `_vgy` is a list of callables, while `_vgyc` is a list of constant numbers.

3.3.10 Concrete Jacobian Storage

When a specific system is loaded and the addresses are assigned to variables, the abstract Jacobian triplets, more specifically, the rows and columns, are replaced with the array of addresses. The new addresses and values will be stored in `Model` attributes with the names `{i, j, v}{Jacobian Name}{c or None}`. Note that there is no underscore for the concrete Jacobian triplets.

For example, if model `PV` has a list of variables `[p, q, a, v]`. The equation associated with `p` is $-u * p_0$, and the equation associated with `q` is $u * (v_0 - v)$. Therefore, the derivative of equation $v_0 - v$ over `v` is $-u$. Note that `u` is unknown at generation time, thus the value is NOT a constant and should go to `vgy`.

The values in `_igy`, `_jgy` and `_vgy` contains, respectively, 1, 3, and a lambda function which returns $-u$.

When a specific system is loaded, for example, a 5-bus system, the addresses for the `q` and `v` are `[11, 13, 15, and [5, 7, 9]`. `PV.igy` and `PV.jgy` will thus query the corresponding address list based on `PV._igy` and `PV._jgy` and store `[11, 13, 15, and [5, 7, 9]`.

Initialization

Value providers such as services and DAE variables need to be initialized. Services are initialized before any DAE variable. Both Services and DAE Variables are initialized *sequentially* in the order of declaration.

Each Service, in addition to the standard `v_str` for symbolic initialization, provides a `v_numeric` hook for specifying a custom function for initialization. Custom initialization functions for DAE variables, are lumped in a single function in `Model.v_numeric`.

ANDES has an *experimental* Newton-Krylov method based iterative initialization. All DAE variables with `v_iter` will be initialized using the iterative approach

Additional Numerical Equations

Addition numerical equations are allowed to complete the "hybrid symbolic-numeric" framework. Numerical function calls are useful when the model DAE is non-standard or hard to be generalized. Since the symbolic-to-numeric generation is an additional layer on top of the numerical simulation, it is fundamentally the same as user-provided numerical function calls.

ANDES provides the following hook functions in each `Model` subclass for custom numerical functions:

- `v_numeric`: custom initialization function
- `s_numeric`: custom service value function
- `g_numeric`: custom algebraic equations; update the `e` of the corresponding variable.
- `f_numeric`: custom differential equations; update the `e` of the corresponding variable.
- `j_numeric`: custom Jacobian equations; the function should append to `_i`, `_j` and `_v` structures.

For most models, numerical function calls are unnecessary and not recommended as it increases code complexity. However, when the data structure or the DAE are difficult to generalize in the symbolic framework, the numerical equations can be used.

For interested readers, see the COI symbolic implementation which calculated the center-of-inertia speed of generators. The COI could have been implemented numerically with for loops instead of `NumReduce`, `NumRepeat` and external variables.

3.4 Atomic Types

ANDES contains three types of atom classes for building DAE models. These types are parameter, variable and service.

3.4.1 Value Provider

Before addressing specific atom classes, the terminology *v-provider*, and *e-provider* are discussed. A value provider class (or *v-provider* for short) references any class with a member attribute named *v*, which should be a list or a 1-dimensional array of values. For example, all parameter classes are v-providers, since a parameter class should provide values for that parameter.

Note: In fact, all types of atom classes are v-providers, meaning that an instance of an atom class must contain values.

The values in the *v* attribute of a particular instance are values that will substitute the instance for computation. If in a model, one has a parameter

```
self.v0 = NumParam()
self.b = NumParam()

# where self.v0.v = np.array([1., 1.05, 1.1]
# and self.b.v = np.array([10., 10., 10.]
```

Later, this parameter is used in an equation, such as

```
self.v = ExtAlgeb(model='Bus', src='v',
                  indexer=self.bus,
                  e_str='v0 **2 * b')
```

While computing $v0 ** 2 * b$, *v0* and *b* will be substituted with the values in *self.v0.v* and *self.b.v*.

Sharing this interface *v* allows interoperability among parameters and variables and services. In the above example, if one defines *v0* as a *ConstService* instance, such as

```
self.v0 = ConstService(v_str='1.0')
```

Calculations will still work without modification.

3.4.2 Equation Provider

Similarly, an equation provider class (or *e-provider*) references any class with a member attribute named *e*, which should be a 1-dimensional array of values. The values in the *e* array are the results from the equation and will be summed to the numerical DAE at the addresses specified by the attribute *a*.

Note: Currently, only variables are *e-provider* types.

If a model has an external variable that links to *Bus.v* (voltage), such as

```
self.v = ExtAlgeb(model='Bus', src='v',
                  indexer=self.bus,
                  e_str='v0 **2 * b')
```


The addresses of the corresponding voltage variables will be retrieved into *self.v.a*, and the equation evaluation results will be stored in *self.v.e*

3.5 Parameters

3.5.1 Background

Parameter is a type of building atom for DAE models. Most parameters are read directly from an input file and passed to equation, and other parameters can be calculated from existing parameters.

The base class for parameters in ANDES is *BaseParam*, which defines interfaces for adding values and checking the number of values. *BaseParam* has its values stored in a plain list, the member attribute *v*. Subclasses such as *NumParam* stores values using a NumPy ndarray.

An overview of supported parameters is given below.

<i>BaseParam</i> ([default, name, tex_name, info, ...])	The base parameter class.
<i>DataParam</i> ([default, name, tex_name, info, ...])	An alias of the <i>BaseParam</i> class.
<i>IdxParam</i> ([default, name, tex_name, info, ...])	An alias of <i>BaseParam</i> with an additional storage of the owner model name
<i>NumParam</i> (default, name, tex_name, info, ...)	A computational numerical parameter.
<i>ExtParam</i> (model, src[, indexer, vtype, ...])	A parameter whose values are retrieved from an external model or group.
<i>TimerParam</i> ([callback, default, name, ...])	A parameter whose values are event occurrence times during the simulation.

andes.core.param.BaseParam

```
class andes.core.param.BaseParam (default: float | str | int | None = None, name: str | None =
None, tex_name: str | None = None, info: str | None =
None, unit: str | None = None, mandatory: bool = False,
export: bool = True, iconvert: Callable | None = None,
oconvert: Callable | None = None)
```

The base parameter class.

This class provides the basic data structure and interfaces for all types of parameters. Parameters are from input files and in general constant once initialized.

Subclasses should overload the *n()* method for the total count of elements in the value array.

Parameters

default

[str or float, optional] The default value of this parameter if None is provided

name

[str, optional] Parameter name. If not provided, it will be automatically set to the attribute name defined in the owner model.

tex_name

[str, optional] LaTeX-formatted parameter name. If not provided, *tex_name* will be assigned the same as *name*.

info

[str, optional] Descriptive information of parameter

mandatory

[bool] True if this parameter is mandatory

export

[bool] True if the parameter will be exported when dumping data into files. True for most parameters. False for `BackRef`.

Other Parameters**iconvert**

[Callable] Converter to be applied to input data when a device is being added.

oconvert

[callable] Converter to be applied to internal data when outputting.

Warning: The most distinct feature of `BaseParam`, `DataParam` and `IdxParam` is that values are stored in a list without conversion to array. `BaseParam`, `DataParam` or `IdxParam` are **not allowed** in equations.

Attributes**v**

[list] A list holding all the values. The `BaseParam` class does not convert the `v` attribute into NumPy arrays.

property

[dict] A dict containing the truth values of the model properties.

__init__ (default: *float* | *str* | *int* | *None* = *None*, *name*: *str* | *None* = *None*, *tex_name*: *str* | *None* = *None*, *info*: *str* | *None* = *None*, *unit*: *str* | *None* = *None*, *mandatory*: *bool* = *False*, *export*: *bool* = *True*, *iconvert*: *Callable* | *None* = *None*, *oconvert*: *Callable* | *None* = *None*)

Methods

<code>add([value])</code>	Add a new parameter value (from a new device of the owner model) to the <code>v</code> list.
<code>get_names()</code>	Return <code>self.name</code> in a list.
<code>get_property(property_name)</code>	Check the boolean value of the given property.
<code>set(pos, attr, value)</code>	Set attributes of the BaseParam class to new values at the given positions.
<code>set_all(attr, value)</code>	Set attributes of the BaseParam class to new values for all positions.

BaseParam.add

`BaseParam.add (value=None)`

Add a new parameter value (from a new device of the owner model) to the `v` list.

Parameters

value

[str or float, optional] Parameter value of the new element. If None, the default will be used.

Notes

If the value is `math.nan`, it will set to None.

BaseParam.get_names

`BaseParam.get_names ()`

Return `self.name` in a list.

This is a helper function to provide the same API as blocks or discrete components.

Returns

list

A list only containing the name of the parameter

BaseParam.get_property

BaseParam.**get_property** (*property_name: str*)

Check the boolean value of the given property. If the property does not exist in the dictionary, False will be returned.

Parameters

property_name
[str] Property name

Returns

The truth value of the property.

BaseParam.set

BaseParam.**set** (*pos, attr, value*)

Set attributes of the BaseParam class to new values at the given positions.

Parameters

pos
[int, list of integers] Positions in arrays where the values should be set

attr
['v', 'vin'] Name of the attribute to be set

value
[str, float or list of above] New values

BaseParam.set_all

BaseParam.**set_all** (*attr, value*)

Set attributes of the BaseParam class to new values for all positions.

Parameters

attr
['v', 'vin'] Name of the attribute to be set

value
[list of str, float or int] New values

Attributes

<code>class_name</code>	Return the class name.
<code>n</code>	Return the count of elements in the value array.

BaseParam.class_name

property BaseParam.class_name

Return the class name.

BaseParam.n

property BaseParam.n

Return the count of elements in the value array.

andes.core.param.DataParam

```
class andes.core.param.DataParam (default: float | str | int | None = None, name: str | None =
None, tex_name: str | None = None, info: str | None =
None, unit: str | None = None, mandatory: bool = False,
export: bool = True, iconvert: Callable | None = None,
oconvert: Callable | None = None)
```

An alias of the *BaseParam* class.

This class is used for string parameters or non-computational numerical parameters. This class does not provide a *to_array* method. All input values will be stored in *v* as a list.

See also:

[*andes.core.param.BaseParam*](#)

Base parameter class

```
__init__ (default: float | str | int | None = None, name: str | None = None, tex_name: str | None =
None, info: str | None = None, unit: str | None = None, mandatory: bool = False, export:
bool = True, iconvert: Callable | None = None, oconvert: Callable | None = None)
```

Methods

<code>add([value])</code>	Add a new parameter value (from a new device of the owner model) to the <code>v</code> list.
<code>get_names()</code>	Return <code>self.name</code> in a list.
<code>get_property(property_name)</code>	Check the boolean value of the given property.
<code>set(pos, attr, value)</code>	Set attributes of the BaseParam class to new values at the given positions.
<code>set_all(attr, value)</code>	Set attributes of the BaseParam class to new values for all positions.

DataParam.add

`DataParam.add (value=None)`

Add a new parameter value (from a new device of the owner model) to the `v` list.

Parameters

value

[str or float, optional] Parameter value of the new element. If `None`, the default will be used.

Notes

If the value is `math.nan`, it will set to `None`.

DataParam.get_names

`DataParam.get_names ()`

Return `self.name` in a list.

This is a helper function to provide the same API as blocks or discrete components.

Returns

list

A list only containing the name of the parameter

DataParam.get_property

DataParam.**get_property** (*property_name: str*)

Check the boolean value of the given property. If the property does not exist in the dictionary, False will be returned.

Parameters

property_name
[str] Property name

Returns

The truth value of the property.

DataParam.set

DataParam.**set** (*pos, attr, value*)

Set attributes of the BaseParam class to new values at the given positions.

Parameters

pos
[int, list of integers] Positions in arrays where the values should be set

attr
['v', 'vin'] Name of the attribute to be set

value
[str, float or list of above] New values

DataParam.set_all

DataParam.**set_all** (*attr, value*)

Set attributes of the BaseParam class to new values for all positions.

Parameters

attr
['v', 'vin'] Name of the attribute to be set

value
[list of str, float or int] New values

Attributes

<code>class_name</code>	Return the class name.
<code>n</code>	Return the count of elements in the value array.

`DataParam.class_name`

property `DataParam.class_name`

Return the class name.

`DataParam.n`

property `DataParam.n`

Return the count of elements in the value array.

`andes.core.param.IdxParam`

```
class andes.core.param.IdxParam (default: float | str | int | None = None, name: str | None =  
None, tex_name: str | None = None, info: str | None = None,  
unit: str | None = None, mandatory: bool = False, unique:  
bool = False, export: bool = True, model: str | None = None,  
iconvert: Callable | None = None, oconvert: Callable | None  
= None)
```

An alias of *BaseParam* with an additional storage of the owner model name

This class is intended for storing *idx* into other models. It can be used in the future for data consistency check.

Notes

This will be useful when, for example, one connects two TGs to one SynGen.

Examples

A PQ model connected to Bus model will have the following code

```
class PQModel (...):  
    def __init__(...):  
        ...  
        self.bus = IdxParam(model='Bus')
```


`__init__` (default: *float* | *str* | *int* | *None* = *None*, name: *str* | *None* = *None*, tex_name: *str* | *None* = *None*, info: *str* | *None* = *None*, unit: *str* | *None* = *None*, mandatory: *bool* = *False*, unique: *bool* = *False*, export: *bool* = *True*, model: *str* | *None* = *None*, iconvert: *Callable* | *None* = *None*, oconvert: *Callable* | *None* = *None*)

Methods

<code>add([value])</code>	Add a new parameter value (from a new device of the owner model) to the <code>v</code> list.
<code>get_names()</code>	Return <code>self.name</code> in a list.
<code>get_property(property_name)</code>	Check the boolean value of the given property.
<code>set(pos, attr, value)</code>	Set attributes of the BaseParam class to new values at the given positions.
<code>set_all(attr, value)</code>	Set attributes of the BaseParam class to new values for all positions.

IdxParam.add

`IdxParam.add` (*value=None*)

Add a new parameter value (from a new device of the owner model) to the `v` list.

Parameters

value

[*str* or *float*, optional] Parameter value of the new element. If *None*, the default will be used.

Notes

If the value is `math.nan`, it will set to *None*.

IdxParam.get_names

`IdxParam.get_names` ()

Return `self.name` in a list.

This is a helper function to provide the same API as blocks or discrete components.

Returns

list

A list only containing the name of the parameter

IdxParam.get_property

`IdxParam.get_property` (*property_name*: *str*)

Check the boolean value of the given property. If the property does not exist in the dictionary, `False` will be returned.

Parameters

property_name
[*str*] Property name

Returns

The truth value of the property.

IdxParam.set

`IdxParam.set` (*pos*, *attr*, *value*)

Set attributes of the `BaseParam` class to new values at the given positions.

Parameters

pos
[*int*, list of integers] Positions in arrays where the values should be set

attr
['v', 'vin'] Name of the attribute to be set

value
[*str*, float or list of above] New values

IdxParam.set_all

`IdxParam.set_all` (*attr*, *value*)

Set attributes of the `BaseParam` class to new values for all positions.

Parameters

attr
['v', 'vin'] Name of the attribute to be set

value
[list of *str*, float or *int*] New values

Attributes

<code>class_name</code>	Return the class name.
<code>n</code>	Return the count of elements in the value array.

`IdxParam.class_name`

property `IdxParam.class_name`

Return the class name.

`IdxParam.n`

property `IdxParam.n`

Return the count of elements in the value array.

`andes.core.param.NumParam`

```
class andes.core.param.NumParam (default: float | str | ~typing.Callable | None = None, name:
    str | None = None, tex_name: str | None = None, info: str |
    None = None, unit: str | None = None, vrange: ~typing.List |
    ~typing.Tuple | None = None, vtype: ~typing.Type | None =
    <class 'float'>, iconvert: ~typing.Callable | None = None,
    oconvert: ~typing.Callable | None = None, non_zero: bool =
    False, non_positive: bool = False, non_negative: bool =
    False, mandatory: bool = False, power: bool = False,
    ipower: bool = False, voltage: bool = False, current: bool =
    False, z: bool = False, y: bool = False, r: bool = False, g:
    bool = False, dc_voltage: bool = False, dc_current: bool =
    False, export: bool = True)
```

A computational numerical parameter.

Parameters defined using this class will have their `v` field converted to a NumPy array after adding.

The original input values will be copied to `vin`, and the system-base per-unit conversion coefficients (through multiplication) will be stored in `pu_coeff`.

Parameters

default

[str or float, optional] The default value of this parameter if no value is provided

name

[str, optional] Name of this parameter. If not provided, `name` will be set to the attribute name of the owner model.

tex_name

[str, optional] LaTeX-formatted parameter name. If not provided, *tex_name* will be assigned the same as *name*.

info

[str, optional] A description of this parameter

mandatory

[bool] True if this parameter is mandatory

unit

[str, optional] Unit of the parameter

vrange

[list, tuple, optional] Typical value range

vtype

[type, optional] Type of the *v* field. The default is `float`.

Other Parameters**Sn**

[str] Name of the parameter for the device base power.

Vn

[str] Name of the parameter for the device base voltage.

non_zero

[bool] True if this parameter must be non-zero. *non_zero* can be combined with *non_positive* or *non_negative*.

non_positive

[bool] True if this parameter must be non-positive.

non_negative

[bool] True if this parameter must be non-negative.

mandatory

[bool] True if this parameter must not be None.

power

[bool] True if this parameter is a power per-unit quantity under the device base.

iconvert

[callable] Callable to convert input data from excel or others to the internal *v* field.

oconvert

[callable] Callable to convert input data from internal type to a serializable type.

ipower

[bool] True if this parameter is an inverse-power per-unit quantity under the device base.

voltage

[bool] True if the parameter is a voltage pu quantity under the device base.

current

[bool] True if the parameter is a current pu quantity under the device base.

z

[bool] True if the parameter is an AC impedance pu quantity under the device base.

y

[bool] True if the parameter is an AC admittance pu quantity under the device base.

r

[bool] True if the parameter is a DC resistance pu quantity under the device base.

g

[bool] True if the parameter is a DC conductance pu quantity under the device base.

dc_current

[bool] True if the parameter is a DC current pu quantity under device base.

dc_voltage

[bool] True if the parameter is a DC voltage pu quantity under device base.

__init__ (default: float | str | ~typing.Callable | None = None, name: str | None = None, tex_name: str | None = None, info: str | None = None, unit: str | None = None, vrange: ~typing.List | ~typing.Tuple | None = None, vtype: ~typing.Type | None = <class 'float'>, iconvert: ~typing.Callable | None = None, oconvert: ~typing.Callable | None = None, non_zero: bool = False, non_positive: bool = False, non_negative: bool = False, mandatory: bool = False, power: bool = False, ipower: bool = False, voltage: bool = False, current: bool = False, z: bool = False, y: bool = False, r: bool = False, g: bool = False, dc_voltage: bool = False, dc_current: bool = False, export: bool = True)

Methods

<code>add([value])</code>	Add a value to the parameter value list.
<code>get_names()</code>	Return <code>self.name</code> in a list.
<code>get_property(property_name)</code>	Check the boolean value of the given property.
<code>restore()</code>	Restore parameter to the original input by copying <code>self.vin</code> to <code>self.v</code> .
<code>set(pos, attr, value)</code>	Set attributes of the BaseParam class to new values at the given positions.
<code>set_all(attr, value)</code>	Set attributes of the BaseParam class to new values for all positions.
<code>set_pu_coeff(coeff)</code>	Store p.u.
<code>to_array()</code>	Converts field <code>v</code> to the NumPy array type.

NumParam.add

`NumParam.add (value=None)`

Add a value to the parameter value list.

In addition to `BaseParam.add`, this method checks for non-zero property and reset to default if is zero.

See also:

`BaseParam.add`

the add method of `BaseParam`

NumParam.get_names

`NumParam.get_names ()`

Return `self.name` in a list.

This is a helper function to provide the same API as blocks or discrete components.

Returns

list

A list only containing the name of the parameter

NumParam.get_property

`NumParam.get_property (property_name: str)`

Check the boolean value of the given property. If the property does not exist in the dictionary, `False` will be returned.

Parameters

property_name

[str] Property name

Returns

The truth value of the property.

NumParam.restore

`NumParam.restore()`

Restore parameter to the original input by copying `self.vin` to `self.v`.

`pu_coeff` will not be overwritten.

NumParam.set

`NumParam.set(pos, attr, value)`

Set attributes of the BaseParam class to new values at the given positions.

Parameters

pos

[int, list of integers] Positions in arrays where the values should be set

attr

['v', 'vin'] Name of the attribute to be set

value

[str, float or list of above] New values

NumParam.set_all

`NumParam.set_all(attr, value)`

Set attributes of the BaseParam class to new values for all positions.

Parameters

attr

['v', 'vin'] Name of the attribute to be set

value

[list of str, float or int] New values

NumParam.set_pu_coeff

`NumParam.set_pu_coeff(coeff)`

Store p.u. conversion coefficient into `self.pu_coeff` and calculate the system-base per unit with `self.v = self.vin * self.pu_coeff`.

This function must be called after `self.to_array`.

Parameters

coeff

[np.ndarray] An array with the pu conversion coefficients

NumParam.to_array

`NumParam.to_array()`

Converts field `v` to the NumPy array type. to enable array-based calculation.

Must be called after adding all elements. Store a copy of original input values to field `vin`. Set `pu_coeff` to all ones.

Warning: After this call, *add* will not be allowed to avoid unexpected issues.

Attributes

<code>class_name</code>	Return the class name.
<code>n</code>	Return the count of elements in the value array.

NumParam.class_name

property `NumParam.class_name`

Return the class name.

NumParam.n

property `NumParam.n`

Return the count of elements in the value array.

andes.core.param.ExtParam

```
class andes.core.param.ExtParam (model: str, src: str, indexer=None, vtype=<class 'float'>, allow_none=False, default=0.0, **kwargs)
```

A parameter whose values are retrieved from an external model or group.

Parameters

model

[str] Name of the model or group providing the original parameter

src

[str] The source parameter name

indexer

[BaseParam] A parameter defined in the model defining this ExtParam instance. *indexer.v* should contain indices into *model.src.v*. If is None, the source parameter values will be fully copied. If *model* is a group name, the indexer cannot be None.

vtype

[type, optional, default to float] Type of each element to be retrieved. Can be `str` if the `ExtParam` is used to access an `IdxParam`.

Attributes**parent_model**

[Model] The parent model providing the original parameter.

__init__ (*model: str, src: str, indexer=None, vtype=<class 'float'>, allow_none=False, default=0.0, **kwargs*)

Methods

<code>add([value])</code>	ExtParam has an empty <i>add</i> method.
<code>get_names()</code>	Return <code>self.name</code> in a list.
<code>get_property(property_name)</code>	Check the boolean value of the given property.
<code>link_external(ext_model)</code>	Update parameter values provided by external models.
<code>restore()</code>	ExtParam has an empty <i>restore</i> method
<code>set(pos, attr, value)</code>	Set attributes of the BaseParam class to new values at the given positions.
<code>set_all(attr, value)</code>	Set attributes of the BaseParam class to new values for all positions.
<code>set_pu_coeff(coeff)</code>	Store p.u.
<code>to_array()</code>	Convert to array when <code>d_type</code> is not <code>str</code>

ExtParam.add

`ExtParam.add(value=None)`

ExtParam has an empty *add* method.

ExtParam.get_names

`ExtParam.get_names()`

Return `self.name` in a list.

This is a helper function to provide the same API as blocks or discrete components.

Returns**list**

A list only containing the name of the parameter

ExtParam.get_property

ExtParam.**get_property** (*property_name: str*)

Check the boolean value of the given property. If the property does not exist in the dictionary, False will be returned.

Parameters

property_name
[str] Property name

Returns

The truth value of the property.

ExtParam.link_external

ExtParam.**link_external** (*ext_model*)

Update parameter values provided by external models. This needs to be called before pu conversion.

Parameters

ext_model
[Model, Group] Instance of the parent model or group, provided by the System calling this method.

ExtParam.restore

ExtParam.**restore** ()

ExtParam has an empty *restore* method

ExtParam.set

ExtParam.**set** (*pos, attr, value*)

Set attributes of the BaseParam class to new values at the given positions.

Parameters

pos
[int, list of integers] Positions in arrays where the values should be set

attr
['v', 'vin'] Name of the attribute to be set

value
[str, float or list of above] New values

ExtParam.set_all

ExtParam.**set_all** (*attr*, *value*)

Set attributes of the BaseParam class to new values for all positions.

Parameters

attr

['v', 'vin'] Name of the attribute to be set

value

[list of str, float or int] New values

ExtParam.set_pu_coeff

ExtParam.**set_pu_coeff** (*coeff*)

Store p.u. conversion coefficient into `self.pu_coeff` and calculate the system-base per unit with `self.v = self.vin * self.pu_coeff`.

This function must be called after `self.to_array`.

Parameters

coeff

[np.ndarray] An array with the pu conversion coefficients

ExtParam.to_array

ExtParam.**to_array** ()

Convert to array when `d_type` is not str

Attributes

<i>class_name</i>	Return the class name.
<i>n</i>	Return the count of elements in the value array.

ExtParam.class_name

property ExtParam.**class_name**

Return the class name.

ExtParam.n

property ExtParam.n

Return the count of elements in the value array.

andes.core.param.TimerParam

```
class andes.core.param.TimerParam (callback: Callable | None = None, default: float | str |  
                                     Callable | None = None, name: str | None = None,  
                                     tex_name: str | None = None, info: str | None = None,  
                                     unit: str | None = None, non_zero: bool = False,  
                                     mandatory: bool = False, export: bool = True)
```

A parameter whose values are event occurrence times during the simulation.

The constructor takes an additional Callable *self.callback* for the action of the event. *TimerParam* has a default value of -1, meaning deactivated.

Examples

A connectivity status toggle class *Toggle* takes a parameter *t* for the toggle time. Inside *Toggle.__init__*, one would have

```
self.t = TimerParam()
```

The *Toggle* class also needs to define a method for toggling the connectivity status

```
def _u_switch(self, is_time: np.ndarray):  
    action = False  
    for i in range(self.n):  
        if is_time[i] and (self.u.v[i] == 1):  
            instance = self.system.__dict__[self.model.v[i]]  
            # get the original status and flip the value  
            u0 = instance.get(src='u', attr='v', idx=self.dev.v[i])  
            instance.set(src='u',  
                        attr='v',  
                        idx=self.dev.v[i],  
                        value=1-u0)  
            action = True  
    return action
```

Finally, in *Toggle.__init__*, assign the function as the callback for *self.t*

```
self.t.callback = self._u_switch
```

```
__init__ (callback: Callable | None = None, default: float | str | Callable | None = None, name: str |  
          None = None, tex_name: str | None = None, info: str | None = None, unit: str | None =  
          None, non_zero: bool = False, mandatory: bool = False, export: bool = True)
```

Methods

<code>add([value])</code>	Add a value to the parameter value list.
<code>get_names()</code>	Return <code>self.name</code> in a list.
<code>get_property(property_name)</code>	Check the boolean value of the given property.
<code>is_time(dae_t)</code>	Element-wise check if the DAE time is the same as the parameter value.
<code>restore()</code>	Restore parameter to the original input by copying <code>self.vin</code> to <code>self.v</code> .
<code>set(pos, attr, value)</code>	Set attributes of the BaseParam class to new values at the given positions.
<code>set_all(attr, value)</code>	Set attributes of the BaseParam class to new values for all positions.
<code>set_pu_coeff(coeff)</code>	Store p.u.
<code>to_array()</code>	Converts field <code>v</code> to the NumPy array type.

TimerParam.add

`TimerParam.add (value=None)`

Add a value to the parameter value list.

In addition to `BaseParam.add`, this method checks for non-zero property and reset to default if is zero.

See also:

`BaseParam.add`

the add method of `BaseParam`

TimerParam.get_names

`TimerParam.get_names ()`

Return `self.name` in a list.

This is a helper function to provide the same API as blocks or discrete components.

Returns

list

A list only containing the name of the parameter

TimerParam.get_property

TimerParam.**get_property** (*property_name: str*)

Check the boolean value of the given property. If the property does not exist in the dictionary, False will be returned.

Parameters

property_name
[str] Property name

Returns

The truth value of the property.

TimerParam.is_time

TimerParam.**is_time** (*dae_t*)

Element-wise check if the DAE time is the same as the parameter value. The current implementation uses *np.equal*.

Parameters

dae_t
[float] Current simulation time

Returns

np.ndarray
The array containing the truth value of if the DAE time is close to the parameter value.

Notes

The previous implementation with *np.isclose* with default *rtol=1e-5* mistakes the immediate pre- and post-event time as in-event when simulation time is greater than 10.

TimerParam.restore

TimerParam.**restore** ()

Restore parameter to the original input by copying *self.vin* to *self.v*.

pu_coeff will not be overwritten.

TimerParam.set

TimerParam.**set** (*pos*, *attr*, *value*)

Set attributes of the BaseParam class to new values at the given positions.

Parameters

pos

[int, list of integers] Positions in arrays where the values should be set

attr

['v', 'vin'] Name of the attribute to be set

value

[str, float or list of above] New values

TimerParam.set_all

TimerParam.**set_all** (*attr*, *value*)

Set attributes of the BaseParam class to new values for all positions.

Parameters

attr

['v', 'vin'] Name of the attribute to be set

value

[list of str, float or int] New values

TimerParam.set_pu_coeff

TimerParam.**set_pu_coeff** (*coeff*)

Store p.u. conversion coefficient into `self.pu_coeff` and calculate the system-base per unit with `self.v = self.vin * self.pu_coeff`.

This function must be called after `self.to_array`.

Parameters

coeff

[np.ndarray] An array with the pu conversion coefficients

TimerParam.to_array

TimerParam.to_array()

Converts field `v` to the NumPy array type. to enable array-based calculation.

Must be called after adding all elements. Store a copy of original input values to field `vin`. Set `pu_coeff` to all ones.

Warning: After this call, *add* will not be allowed to avoid unexpected issues.

Attributes

<code>class_name</code>	Return the class name.
<code>n</code>	Return the count of elements in the value array.

TimerParam.class_name

property TimerParam.class_name

Return the class name.

TimerParam.n

property TimerParam.n

Return the count of elements in the value array.

3.6 Variables

DAE Variables, or variables for short, are unknowns to be solved using numerical or analytical methods. A variable stores values, equation values, and addresses in the DAE array. The base class for variables is *BaseVar*. In this subsection, *BaseVar* is used to represent any subclass of *VarBase* list in the table below.

<code>BaseVar</code> ([name, tex_name, info, unit, v_str, ...])	Base variable class.
<code>ExtVar</code> (model, src[, indexer, allow_none, ...])	Algebraic variable that links to an external model.
<code>State</code> ([name, tex_name, info, unit, v_str, ...])	Differential variable class, an alias of the <i>BaseVar</i> .
<code>Algeb</code> ([name, tex_name, info, unit, v_str, ...])	Algebraic variable class, an alias of <i>andes.core.var.BaseVar</i> .
<code>ExtState</code> (model, src[, indexer, allow_none, ...])	External state variable type.
<code>ExtAlgeb</code> (model, src[, indexer, allow_none, ...])	External algebraic variable type.
<code>AliasState</code> (var, **kwargs)	Alias state variable.
<code>AliasAlgeb</code> (var, **kwargs)	Alias algebraic variable.

3.6.1 andes.core.var.BaseVar

```
class andes.core.var.BaseVar (name: str | None = None, tex_name: str | None = None, info: str |
                             None = None, unit: str | None = None, v_str: str | float | None =
                             None, v_iter: str | None = None, e_str: str | None = None,
                             discrete: Discrete | None = None, v_setter: bool | None = False,
                             e_setter: bool | None = False, v_str_add: bool | None = False,
                             addressable: bool | None = True, export: bool | None = True,
                             diag_eps: float | None = 0.0, deps: List | None = None, is_output:
                             bool | None = False)
```

Base variable class.

Derived classes *State* and *Algeb* should be used to build model variables.

Parameters

info

[str, optional] Descriptive information

unit

[str, optional] Unit

tex_name

[str] LaTeX-formatted variable symbol. If is None, the value of *name* will be used.

discrete

[Discrete] Discrete component on which this variable depends. ANDES will call *check_var()* of the discrete component before initializing this variable.

name

[str, optional] Variable name. One should typically assigning the name directly because it will be automatically assigned by the model. The value of *name* will be the symbol name to be used in expressions.

Attributes

a

[array-like] variable address

v

[array-like] local-storage of the variable value

e

[array-like] local-storage of the corresponding equation value

e_str

[str] the string/symbolic representation of the equation

v_str

[str] explicit initialization equation

v_str_add

[bool] True if the value of *v_str* will be added to the variable. Useful when other models access this variable and set part of the initial value

v_iter

[str] implicit iterative equation in the form of $0 = v_iter$

__init__ (*name: str | None = None, tex_name: str | None = None, info: str | None = None, unit: str | None = None, v_str: str | float | None = None, v_iter: str | None = None, e_str: str | None = None, discrete: Discrete | None = None, v_setter: bool | None = False, e_setter: bool | None = False, v_str_add: bool | None = False, addressable: bool | None = True, export: bool | None = True, diag_eps: float | None = 0.0, deps: List | None = None, is_output: bool | None = False*)

Methods

get_names()

reset()

Reset the internal numpy arrays and flags.

set_address(addr[, contiguous])

Set the address of internal variables.

set_arrays(dae[, inplace, alloc])

Set the equation and values arrays.

BaseVar.get_names

`BaseVar.get_names()`

BaseVar.reset

`BaseVar.reset()`

Reset the internal numpy arrays and flags.

BaseVar.set_address

`BaseVar.set_address(addr: ndarray, contiguous=False)`

Set the address of internal variables.

Parameters

addr

[np.ndarray] The assigned address for this variable

contiguous

[bool, optional] If the addresses are contiguous

BaseVar.set_arrays

`BaseVar.set_arrays (dae, inplace=True, alloc=True)`

Set the equation and values arrays.

Parameters

dae

[DAE] Reference to System.dae

Attributes

class_name

BaseVar.class_name

property `BaseVar.class_name`

3.6.2 andes.core.var.ExtVar

```
class andes.core.var.ExtVar (model: str, src: str, indexer: List | ndarray | BaseParam |
    BaseService | None = None, allow_none: bool | None = False,
    name: str | None = None, tex_name: str | None = None, ename: str
    | None = None, tex_ename: str | None = None, info: str | None =
    None, unit: str | None = None, v_str: str | float | None = None,
    v_iter: str | None = None, e_str: str | None = None, v_setter: bool |
    None = False, e_setter: bool | None = False, addressable: bool |
    None = True, export: bool | None = True, diag_eps: float | None =
    0.0, is_input: bool | None = False)
```

Algebraic variable that links to an external model.

This class is used to retrieve the addresses of a variable defined in an external model. An equation can be defined for the `ExtVar`. The evaluated value for the equation will be stored in the `ExtVar.e` attribute and added to the equations corresponding to the external variables.

Parameters

model

[str] Name of the source model

src

[str] Source variable name

indexer

[BaseParam, BaseService] A parameter of the hosting model, used as indices into

the source model and variable. If is None, the source variable address will be fully copied.

allow_none

[bool, optional, default=False] True to allow None in indexer

e_str

[string, optional, default=None] Equation string, the evaluated value of which will be added to the source residual equation

Attributes

parent_model

[Model] The parent model providing the original parameter.

uid

[array-like] An array containing the absolute indices into the parent_instance values.

e_code

[str] Equation code string; copied from the parent instance.

v_code

[str] Variable code string; copied from the parent instance.

__init__ (*model: str, src: str, indexer: List | ndarray | BaseParam | BaseService | None = None, allow_none: bool | None = False, name: str | None = None, tex_name: str | None = None, ename: str | None = None, tex_ename: str | None = None, info: str | None = None, unit: str | None = None, v_str: str | float | None = None, v_iter: str | None = None, e_str: str | None = None, v_setter: bool | None = False, e_setter: bool | None = False, addressable: bool | None = True, export: bool | None = True, diag_eps: float | None = 0.0, is_input: bool | None = False*)

Methods

get_names()

link_external(ext_model)

Update variable addresses provided by external models

reset()

Reset the internal numpy arrays and flags.

set_address(addr[, contiguous])

Assigns address for equation RHS.

set_arrays(dae[, inplace, alloc])

Access `dae.h` or `dae.i` for the RHS of external variables when `e_str` exists..

ExtVar.get_names

`ExtVar.get_names()`

ExtVar.link_external

`ExtVar.link_external(ext_model)`

Update variable addresses provided by external models

This method sets attributes including *parent_model*, *parent_instance*, *uid*, *a*, *n*, *e_code* and *v_code*. It initializes the *e* and *v* to zero.

Parameters

ext_model

[Model] Instance of the parent model

Returns

None

Warning: *link_external* does not check if the ExtVar type is the same as the original variable to reduce performance overhead. It will be a silent error (a dimension too small error from *dae.build_pattern*) if a model uses *ExtAlgeb* to access a *State*, or vice versa.

ExtVar.reset

`ExtVar.reset()`

Reset the internal numpy arrays and flags.

ExtVar.set_address

`ExtVar.set_address(addr, contiguous=False)`

Assigns address for equation RHS.

ExtVar.set_arrays

`ExtVar.set_arrays(dae, inplace=True, alloc=True)`

Access `dae.h` or `dae.i` for the RHS of external variables when `e_str` exists..

Attributes

```
class_name
```

ExtVar.class_name

property ExtVar.class_name

3.6.3 andes.core.var.State

```
class andes.core.var.State (name: str | None = None, tex_name: str | None = None, info: str |
    None = None, unit: str | None = None, v_str: str | float | None =
    None, v_iter: str | None = None, e_str: str | None = None, discrete:
    Discrete | None = None, t_const: BaseParam | DummyValue |
    BaseService | None = None, check_init: bool | None = True,
    v_setter: bool | None = False, e_setter: bool | None = False,
    addressable: bool | None = True, export: bool | None = True,
    diag_eps: float | None = 0.0, deps: List | None = None)
```

Differential variable class, an alias of the *BaseVar*.

Parameters

t_const

[BaseParam, DummyValue] Left-hand time constant for the differential equation. They will be collected to array `dae.Tf`. Time constants will not be used when evaluating the right-hand side specified in `e_str` but will be applied to the left-hand side.

check_init

[bool] True to check if the equation right-hand-side is zero initially. Disabling the checking can be used for integrators when the initial input may not be zero.

Examples

To implement the swing equation

$$M\dot{\omega} = \tau_m - \tau_e - D(\omega - 1)$$

Do the following in the `__init__()` of a model class:

```
self.omega = State(e_str = 'tm - te - D * (omega - 1)',
    t_const = self.M,
    ...
)
```

Note that `self.M`, the inertia parameter is given through `t_const` and is not part of `e_str`.

Attributes

`e_code`

[str] Equation code string, equals string literal `f`

`v_code`

[str] Variable code string, equals string literal `x`

`__init__` (*name*: str | None = None, *tex_name*: str | None = None, *info*: str | None = None, *unit*: str | None = None, *v_str*: str | float | None = None, *v_iter*: str | None = None, *e_str*: str | None = None, *discrete*: Discrete | None = None, *t_const*: BaseParam | DummyValue | BaseService | None = None, *check_init*: bool | None = True, *v_setter*: bool | None = False, *e_setter*: bool | None = False, *addressable*: bool | None = True, *export*: bool | None = True, *diag_eps*: float | None = 0.0, *deps*: List | None = None)

Methods

`get_names()`

`reset()`

Reset the internal numpy arrays and flags.

`set_address(addr[, contiguous])`

Set the address of internal variables.

`set_arrays(dae[, inplace, alloc])`

Set the equation and values arrays.

`State.get_names`

`State.get_names()`

`State.reset`

`State.reset()`

Reset the internal numpy arrays and flags.

`State.set_address`

`State.set_address(addr: ndarray, contiguous=False)`

Set the address of internal variables.

Parameters

`addr`

[np.ndarray] The assigned address for this variable

`contiguous`

[bool, optional] If the addresses are contiguous

State.set_arrays

`State.set_arrays(dae, inplace=True, alloc=True)`

Set the equation and values arrays.

Parameters

dae

[DAE] Reference to System.dae

Attributes

class_name

e_code

v_code

State.class_name

property `State.class_name`

State.e_code

`State.e_code = 'f'`

State.v_code

`State.v_code = 'x'`

3.6.4 andes.core.var.Algeb

```
class andes.core.var.Algeb(name: str | None = None, tex_name: str | None = None, info: str |  
                          None = None, unit: str | None = None, v_str: str | float | None =  
                          None, v_iter: str | None = None, e_str: str | None = None, discrete:  
                          Discrete | None = None, v_setter: bool | None = False, e_setter: bool  
                          | None = False, v_str_add: bool | None = False, addressable: bool |  
                          None = True, export: bool | None = True, diag_eps: float | None =  
                          0.0, deps: List | None = None, is_output: bool | None = False)
```

Algebraic variable class, an alias of `andes.core.var.BaseVar`.

Note that residual equations corresponding to algebraic variables are given in an implicit form.

Examples

When an algebraic variable y and the equation $y = x + z$ shall be defined, use

```
e_str = 'x + z - y'
```

because it expresses the equation $x + z - y = 0$. It is a common mistake to use `e_str = 'x + z'`, which will result in a singular Jacobian matrix because $d(x + z) / d(y)$ is zero.

Attributes

e_code

[str] Equation code string, equals string literal `g`

v_code

[str] Variable code string, equals string literal `y`

```
__init__ (name: str | None = None, tex_name: str | None = None, info: str | None = None, unit: str | None = None, v_str: str | float | None = None, v_iter: str | None = None, e_str: str | None = None, discrete: Discrete | None = None, v_setter: bool | None = False, e_setter: bool | None = False, v_str_add: bool | None = False, addressable: bool | None = True, export: bool | None = True, diag_eps: float | None = 0.0, deps: List | None = None, is_output: bool | None = False)
```

Methods

```
get_names()
```

```
reset()
```

Reset the internal numpy arrays and flags.

```
set_address(addr[, contiguous])
```

Set the address of internal variables.

```
set_arrays(dae[, inplace, alloc])
```

Set the equation and values arrays.

Algeb.get_names

```
Algeb.get_names()
```

Algeb.reset

```
Algeb.reset()
```

Reset the internal numpy arrays and flags.

Algeb.set_address

Algeb.**set_address** (*addr: ndarray, contiguous=False*)

Set the address of internal variables.

Parameters

addr

[np.ndarray] The assigned address for this variable

contiguous

[bool, optional] If the addresses are contiguous

Algeb.set_arrays

Algeb.**set_arrays** (*dae, inplace=True, alloc=True*)

Set the equation and values arrays.

Parameters

dae

[DAE] Reference to System.dae

Attributes

<i>class_name</i>
<i>e_code</i>
<i>v_code</i>

Algeb.class_name

property Algeb.**class_name**

Algeb.e_code

Algeb.**e_code** = 'g'

Algeb.v_code

```
Algeb.v_code = 'y'
```

3.6.5 andes.core.var.ExtState

```
class andes.core.var.ExtState(model: str, src: str, indexer: List | ndarray | BaseParam |
                             BaseService | None = None, allow_none: bool | None = False,
                             name: str | None = None, tex_name: str | None = None, ename:
                             str | None = None, tex_ename: str | None = None, info: str |
                             None = None, unit: str | None = None, v_str: str | float | None =
                             None, v_iter: str | None = None, e_str: str | None = None,
                             v_setter: bool | None = False, e_setter: bool | None = False,
                             addressable: bool | None = True, export: bool | None = True,
                             diag_eps: float | None = 0.0, is_input: bool | None = False)
```

External state variable type.

Warning: ExtState is not allowed to set `t_const`, as it may conflict with the source State variable.

Only in rare cases should one set `e_str` for ExtState. The `t_const` of the source State variable is used.

```
__init__(model: str, src: str, indexer: List | ndarray | BaseParam | BaseService | None = None,
          allow_none: bool | None = False, name: str | None = None, tex_name: str | None = None,
          ename: str | None = None, tex_ename: str | None = None, info: str | None = None, unit: str
          | None = None, v_str: str | float | None = None, v_iter: str | None = None, e_str: str | None
          = None, v_setter: bool | None = False, e_setter: bool | None = False, addressable: bool |
          None = True, export: bool | None = True, diag_eps: float | None = 0.0, is_input: bool |
          None = False)
```

Methods

<code>get_names()</code>	
<code>link_external(ext_model)</code>	Update variable addresses provided by external models
<code>reset()</code>	Reset the internal numpy arrays and flags.
<code>set_address(addr[, contiguous])</code>	Assigns address for equation RHS.
<code>set_arrays(dae[, inplace, alloc])</code>	Access <code>dae.h</code> or <code>dae.i</code> for the RHS of external variables when <code>e_str</code> exists..

ExtState.get_names

`ExtState.get_names()`

ExtState.link_external

`ExtState.link_external(ext_model)`

Update variable addresses provided by external models

This method sets attributes including *parent_model*, *parent_instance*, *uid*, *a*, *n*, *e_code* and *v_code*. It initializes the *e* and *v* to zero.

Parameters

ext_model

[Model] Instance of the parent model

Returns

None

Warning: *link_external* does not check if the ExtVar type is the same as the original variable to reduce performance overhead. It will be a silent error (a dimension too small error from *dae.build_pattern*) if a model uses *ExtAlgeb* to access a *State*, or vice versa.

ExtState.reset

`ExtState.reset()`

Reset the internal numpy arrays and flags.

ExtState.set_address

`ExtState.set_address(addr, contiguous=False)`

Assigns address for equation RHS.

ExtState.set_arrays

`ExtState.set_arrays(dae, inplace=True, alloc=True)`

Access `dae.h` or `dae.i` for the RHS of external variables when `e_str` exists..

Attributes

<i>class_name</i>
<i>e_code</i>
<i>r_code</i>
<i>t_const</i>
<i>v_code</i>

ExtState.class_name

property ExtState.class_name

ExtState.e_code

ExtState.e_code = 'f'

ExtState.r_code

ExtState.r_code = 'h'

ExtState.t_const

ExtState.t_const = None

ExtState.v_code

ExtState.v_code = 'x'

3.6.6 andes.core.var.ExtAlgeb

```
class andes.core.var.ExtAlgeb (model: str, src: str, indexer: List | ndarray | BaseParam |
    BaseService | None = None, allow_none: bool | None = False,
    name: str | None = None, tex_name: str | None = None, ename:
    str | None = None, tex_ename: str | None = None, info: str |
    None = None, unit: str | None = None, v_str: str | float | None =
    None, v_iter: str | None = None, e_str: str | None = None,
    v_setter: bool | None = False, e_setter: bool | None = False,
    addressable: bool | None = True, export: bool | None = True,
    diag_eps: float | None = 0.0, is_input: bool | None = False)
```

External algebraic variable type.

```
__init__ (model: str, src: str, indexer: List | ndarray | BaseParam | BaseService | None = None,
    allow_none: bool | None = False, name: str | None = None, tex_name: str | None = None,
    ename: str | None = None, tex_ename: str | None = None, info: str | None = None, unit: str
    | None = None, v_str: str | float | None = None, v_iter: str | None = None, e_str: str | None
    = None, v_setter: bool | None = False, e_setter: bool | None = False, addressable: bool |
    None = True, export: bool | None = True, diag_eps: float | None = 0.0, is_input: bool |
    None = False)
```

Methods

<code>get_names()</code>	
<code>link_external(ext_model)</code>	Update variable addresses provided by external models
<code>reset()</code>	Reset the internal numpy arrays and flags.
<code>set_address(addr[, contiguous])</code>	Assigns address for equation RHS.
<code>set_arrays(dae[, inplace, alloc])</code>	Access <code>dae.h</code> or <code>dae.i</code> for the RHS of external variables when <code>e_str</code> exists..

ExtAlgeb.get_names

`ExtAlgeb.get_names()`

ExtAlgeb.link_external

`ExtAlgeb.link_external(ext_model)`

Update variable addresses provided by external models

This method sets attributes including *parent_model*, *parent_instance*, *uid*, *a*, *n*, *e_code* and *v_code*. It initializes the *e* and *v* to zero.

Parameters

ext_model

[Model] Instance of the parent model

Returns

None

Warning: *link_external* does not check if the ExtVar type is the same as the original variable to reduce performance overhead. It will be a silent error (a dimension too small error from *dae.build_pattern*) if a model uses *ExtAlgeb* to access a *State*, or vice versa.

ExtAlgeb.reset

`ExtAlgeb.reset()`

Reset the internal numpy arrays and flags.

ExtAlgeb.set_address

`ExtAlgeb.set_address(addr, contiguous=False)`

Assigns address for equation RHS.

ExtAlgeb.set_arrays

`ExtAlgeb.set_arrays(dae, inplace=True, alloc=True)`

Access `dae.h` or `dae.i` for the RHS of external variables when `e_str` exists..

Attributes

<code>class_name</code>
<code>e_code</code>
<code>r_code</code>
<code>v_code</code>

ExtAlgeb.class_name

property ExtAlgeb.class_name

ExtAlgeb.e_code

ExtAlgeb.e_code = 'g'

ExtAlgeb.r_code

ExtAlgeb.r_code = 'i'

ExtAlgeb.v_code

ExtAlgeb.v_code = 'y'

3.6.7 andes.core.var.AliasState

class andes.core.var.AliasState (var, **kwargs)

Alias state variable.

Refer to the docs of AliasAlgeb.

__init__ (var, **kwargs)

Methods

<code>get_names()</code>	
<code>link_external(ext_model)</code>	Update variable addresses provided by external models
<code>reset()</code>	Reset the internal numpy arrays and flags.
<code>set_address(addr[, contiguous])</code>	Assigns address for equation RHS.
<code>set_arrays(dae[, inplace, alloc])</code>	Access <code>dae.h</code> or <code>dae.i</code> for the RHS of external variables when <code>e_str</code> exists..

AliasState.get_names

`AliasState.get_names()`

AliasState.link_external

`AliasState.link_external(ext_model)`

Update variable addresses provided by external models

This method sets attributes including *parent_model*, *parent_instance*, *uid*, *a*, *n*, *e_code* and *v_code*. It initializes the *e* and *v* to zero.

Parameters

ext_model

[Model] Instance of the parent model

Returns

None

Warning: *link_external* does not check if the *ExtVar* type is the same as the original variable to reduce performance overhead. It will be a silent error (a dimension too small error from *dae.build_pattern*) if a model uses *ExtAlgeb* to access a *State*, or vice versa.

AliasState.reset

`AliasState.reset()`

Reset the internal numpy arrays and flags.

AliasState.set_address

`AliasState.set_address(addr, contiguous=False)`

Assigns address for equation RHS.

AliasState.set_arrays

`AliasState.set_arrays(dae, inplace=True, alloc=True)`

Access `dae.h` or `dae.i` for the RHS of external variables when `e_str` exists..

Attributes

<code>class_name</code>
<code>e_code</code>
<code>r_code</code>
<code>t_const</code>
<code>v_code</code>

AliasState.class_name

property `AliasState.class_name`

AliasState.e_code

`AliasState.e_code = 'f'`

AliasState.r_code

`AliasState.r_code = 'h'`

AliasState.t_const

```
AliasState.t_const = None
```

AliasState.v_code

```
AliasState.v_code = 'x'
```

3.6.8 andes.core.var.AliasAlgeb

```
class andes.core.var.AliasAlgeb (var, **kwargs)
```

Alias algebraic variable. Essentially ExtAlgeb that links to a model's own variable.

AliasAlgeb is useful when the final output of a model is from a block, but the model must provide the final output in a pre-defined name. Using AliasAlgeb, A model can avoid adding an additional variable with a dummy equations.

Like ExtVar, labels of AliasAlgeb will not be saved in the final output. When plotting from file, one need to look up the original variable name.

```
__init__ (var, **kwargs)
```

Methods

<code>get_names()</code>	
<code>link_external(ext_model)</code>	Update variable addresses provided by external models
<code>reset()</code>	Reset the internal numpy arrays and flags.
<code>set_address(addr[, contiguous])</code>	Assigns address for equation RHS.
<code>set_arrays(dae[, inplace, alloc])</code>	Access <code>dae.h</code> or <code>dae.i</code> for the RHS of external variables when <code>e_str</code> exists..

AliasAlgeb.get_names

```
AliasAlgeb.get_names ()
```

AliasAlgeb.link_external

AliasAlgeb.**link_external** (*ext_model*)

Update variable addresses provided by external models

This method sets attributes including *parent_model*, *parent_instance*, *uid*, *a*, *n*, *e_code* and *v_code*. It initializes the *e* and *v* to zero.

Parameters

ext_model

[Model] Instance of the parent model

Returns

None

Warning: *link_external* does not check if the ExtVar type is the same as the original variable to reduce performance overhead. It will be a silent error (a dimension too small error from *dae.build_pattern*) if a model uses *ExtAlgeb* to access a *State*, or vice versa.

AliasAlgeb.reset

AliasAlgeb.**reset** ()

Reset the internal numpy arrays and flags.

AliasAlgeb.set_address

AliasAlgeb.**set_address** (*addr*, *contiguous=False*)

Assigns address for equation RHS.

AliasAlgeb.set_arrays

AliasAlgeb.**set_arrays** (*dae*, *inplace=True*, *alloc=True*)

Access *dae.h* or *dae.i* for the RHS of external variables when *e_str* exists..

Attributes

<code>class_name</code>
<code>e_code</code>
<code>r_code</code>
<code>v_code</code>

AliasAlgeb.class_name

property AliasAlgeb.class_name

AliasAlgeb.e_code

AliasAlgeb.e_code = 'g'

AliasAlgeb.r_code

AliasAlgeb.r_code = 'i'

AliasAlgeb.v_code

AliasAlgeb.v_code = 'y'

Note that equations associated with state variables are in the form of $\mathbf{M}\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}, \mathbf{y})$, where \mathbf{x} are the differential variables, \mathbf{y} are the algebraic variables, and \mathbf{M} is the mass matrix, and \mathbf{f} are the right-hand side of differential equations. Equations associated with algebraic variables take the form of $0 = \mathbf{g}$, where \mathbf{g} are the equation right-hand side

BaseVar has two types: the differential variable type *State* and the algebraic variable type *Algeb*. State variables are described by differential equations, whereas algebraic variables are described by algebraic equations. State variables can only change continuously, while algebraic variables can be discontinuous.

Based on the model the variable is defined, variables can be internal or external. Most variables are internal and only appear in equations in the same model. Some models have "public" variables that can be accessed by other models. For example, a *Bus* defines *v* for the voltage magnitude. Each device attached to a particular bus needs to access the value and impose the reactive power injection. It can be done with *ExtAlgeb* or *ExtState*, which links with an existing variable from a model or a group.

3.6.9 Variable, Equation and Address

Subclasses of *BaseVar* are value providers and equation providers. Each *BaseVar* has member attributes *v* and *e* for variable values and equation values, respectively. The initial value of *v* is set by the initialization routine, and the initial value of *e* is set to zero. In the process of power flow calculation or time domain simulation, *v* is not directly modifiable by models but rather updated after solving non-linear equations. *e* is updated by the models and summed up before solving equations.

Each *BaseVar* also stores addresses of this variable, for all devices, in its member attribute *a*. The addresses are 0-based indices into the numerical DAE array, *f* or *g*, based on the variable type.

For example, *Bus* has `self.a = Algeb()` as the voltage phase angle variable. For a 5-bus system, `Bus.a.a` stores the addresses of the *a* variable for all the five *Bus* devices. Conventionally, `Bus.a.a` will be assigned `np.array([0, 1, 2, 3, 4])`.

3.6.10 Value and Equation Strings

The most important feature of the symbolic framework is allowing to define equations using strings. There are three types of strings for a variable, stored in the following member attributes, respectively:

- *v_str*: equation string for **explicit** initialization in the form of $v = v_str(x, y)$.
- *v_iter*: equation string for **implicit** initialization in the form of $v_iter(x, y) = 0$
- *e_str*: equation string for (full or part of) the differential or algebraic equation.

The difference between *v_str* and *v_iter* should be clearly noted. *v_str* evaluates directly into the initial value, while all *v_iter* equations are solved numerically using the Newton-Krylov iterative method.

3.6.11 Values Between DAE and Models

ANDES adopts a decentralized architecture which provides each model a copy of variable values before equation evaluation. This architecture allows to parallelize the equation evaluation (in theory, or in practice if one works round the Python GIL). However, this architecture requires a coherent protocol for updating the DAE arrays and the *BaseVar* arrays. More specifically, how the variable and equations values from model *VarBase* should be summed up or forcefully set at the DAE arrays needs to be defined.

The protocol is relevant when a model defines subclasses of *BaseVar* that are supposed to be "public". Other models share this variable with *ExtAlgeb* or *ExtState*.

By default, all *v* and *e* at the same address are summed up. This is the most common case, such as a *Bus* connected by multiple devices: power injections from devices should be summed up.

In addition, *BaseVar* provides two flags, *v_setter* and *e_setter*, for cases when one *VarBase* needs to overwrite the variable or equation values.

3.6.12 Flags for Value Overwriting

BaseVar have special flags for handling value initialization and equation values. This is only relevant for public or external variables. The *v_setter* is used to indicate whether a particular *BaseVar* instance sets the initial value. The *e_setter* flag indicates whether the equation associated with a *BaseVar* sets the equation value.

The *v_setter* flag is checked when collecting data from models to the numerical DAE array. If *v_setter* is *False*, variable values of the same address will be added. If one of the variable or external variable has *v_setter* is *True*, it will, at the end, set the values in the DAE array to its value. Only one *BaseVar* of the same address is allowed to have *v_setter* == *True*.

3.6.13 A *v_setter* Example

A Bus is allowed to default the initial voltage magnitude to 1 and the voltage phase angle to 0. If a PV device is connected to a Bus device, the PV should be allowed to override the voltage initial value with the voltage set point.

In *Bus.__init__()*, one has

```
self.v = Algeb(v_str='1')
```

In *PV.__init__*, one can use

```
self.v0 = Param()
self.bus = IdxParam(model='Bus')

self.v = ExtAlgeb(src='v',
                  model='Bus',
                  indexer=self.bus,
                  v_str='v0',
                  v_setter=True)
```

where an *ExtAlgeb* is defined to access *Bus.v* using indexer *self.bus*. The *v_str* line sets the initial value to *v0*. In the variable initialization phase for *PV*, *PV.v.v* is set to *v0*.

During the value collection into *DAE.y* by the *System* class, *PV.v*, as a final *v_setter*, will overwrite the voltage magnitude for Bus devices with the indices provided in *PV.bus*.

3.7 Services

Services are helper variables outside the DAE variable list. Services are most often used for storing intermediate constants but can be used for special operations to work around restrictions in the symbolic framework. Services are value providers, meaning each service has an attribute *v* for storing service values. The base class of services is `:py:mod`BaseService``, and the supported services are listed as follows.

<code>BaseService</code> ([name, tex_name, unit, info, vtype])	Base class for Service.
<code>OperationService</code> ([name, tex_name, info])	Base class for a type of Service which performs specific operations.

3.7.1 andes.core.service.BaseService

class `andes.core.service.BaseService` (*name: str = None, tex_name: str = None, unit: str = None, info: str = None, vtype: Type = None*)

Base class for Service.

Service is a v-provider type for holding internal and temporary values. Subclasses need to implement `v` as a member attribute or using a property decorator.

Parameters

name

[str] Instance name

Attributes

owner

[Model] The hosting/owner model instance

__init__ (*name: str = None, tex_name: str = None, unit: str = None, info: str = None, vtype: Type = None*)

Methods

<code>assign_memory</code> (n)	Assign memory for <code>self.v</code> and set the array to zero.
<code>get_names</code> ()	Return <i>name</i> in a list

BaseService.assign_memory

`BaseService.assign_memory` (*n*)

Assign memory for `self.v` and set the array to zero.

Parameters

n

[int] Number of elements of the value array. Provided by caller (`Model.list2array`).

BaseService.get_names`BaseService.get_names()`Return *name* in a list**Returns****list**

A list only containing the name of the service variable

Attributes

<code>class_name</code>	Return the class name
<code>n</code>	Return the count of values in <code>self.v</code> .

BaseService.class_name**property** `BaseService.class_name`

Return the class name

BaseService.n**property** `BaseService.n`Return the count of values in `self.v`.Needs to be overloaded if `v` of subclasses is not a 1-dimensional array.**Returns****int**

The count of elements in this variable

3.7.2 andes.core.service.OperationService**class** `andes.core.service.OperationService` (*name=None, tex_name=None, info=None*)Base class for a type of Service which performs specific operations. `OperationService` may not use the *assign_memory* from *BaseService*, because it can have a different size.

This class cannot be used by itself.

See also:**NumReduce**

Service for Reducing linearly stored 2-D services into 1-D

NumRepeat

Service for repeating 1-D NumParam/ v-array following a

sub-pattern**IdxRepeat**

Service for repeating 1-D IdxParam/ v-list following a

sub-pattern

__init__ (*name=None, tex_name=None, info=None*)

Methods

<code>assign_memory(n)</code>	Assign memory for <code>self.v</code> and set the array to zero.
<code>get_names()</code>	Return <i>name</i> in a list

OperationService.assign_memory

`OperationService.assign_memory(n)`

Assign memory for `self.v` and set the array to zero.

Parameters

n

[int] Number of elements of the value array. Provided by caller (Model.list2array).

OperationService.get_names

`OperationService.get_names()`

Return *name* in a list

Returns

list

A list only containing the name of the service variable

Attributes

<code>class_name</code>	Return the class name
<code>n</code>	Return the count of values in <code>self.v</code> .
<code>v</code>	Return values stored in <code>self.v</code> .

OperationService.class_name

property OperationService.class_name

Return the class name

OperationService.n

property OperationService.n

Return the count of values in `self.v`.

Needs to be overloaded if `v` of subclasses is not a 1-dimensional array.

Returns

int

The count of elements in this variable

OperationService.v

property OperationService.v

Return values stored in `self._v`. May be overloaded by subclasses.

Class	Description
ConstService	Internal service for constant values.
VarService	Variable service updated at each iteration before equations.
ExtService	External service for retrieving values from value providers.
PostInitService	Constant service evaluated after TDS initialization
NumReduce	The service type for reducing linear 2-D arrays into 1-D arrays
NumRepeat	The service type for repeating a 1-D array to linear 2-D arrays
IdxRepeat	The service type for repeating a 1-D list to linear 2-D list
EventFlag	Service type for flagging changes in inputs as an event
VarHold	Hold input value when a hold signal is active
ExtendedEvent	Extend an event signal for a given period of time
DataSelect	Select optional str data if provided or use the fallback
NumSelect	Select optional numerical data if provided
DeviceFinder	Finds or creates devices linked to the given devices
BackRef	Collects idx-es for the backward references
RefFlatten	Converts BackRef list of lists into a 1-D list
InitChecker	Checks initial values against typical values
FlagValue	Flags values that equals the given value
Replace	Replace values that returns True for the given lambda func

3.7.3 Internal Constants

The most commonly used service is *ConstService*. It is used to store an array of constants, whose value is evaluated from a provided symbolic string. They are only evaluated once in the model initialization phase, ahead of variable initialization. *ConstService* comes handy when one wants to calculate intermediate constants from parameters.

For example, a turbine governor has a *NumParam* *R* for the droop. *ConstService* allows to calculate the inverse of the droop, the gain, and use it in equations. The snippet from a turbine governor's `__init__()` may look like

```
self.R = NumParam()
self.G = ConstService(v_str='u/R')
```

where *u* is the online status parameter. The model can thus use *G* in subsequent variable or equation strings.

```
class andes.core.service.ConstService (v_str: str | None = None, v_numeric: Callable |
                                     None = None, vtype: type | None = None, name: str
                                     | None = None, tex_name: str | None = None, info:
                                     str | None = None, unit: str | None = None)
```

A type of Service that stays constant once initialized.

ConstService are usually constants calculated from parameters. They are only evaluated once in the initialization phase before variables are initialized. Therefore, uninitialized variables must not be used in *v_str*.

ConstService are evaluated *in sequence* after getting external variables and parameters and before initializing internal variables.

Parameters

name

[str] Name of the ConstService

v_str

[str] An equation string to calculate the variable value.

v_numeric

[Callable, optional] A callable which returns the value of the ConstService

v_type: type, optional, default to float

Type of element in the value array in float or complex

Attributes

v

[array-like or a scalar] ConstService value

```
class andes.core.service.VarService (v_str: str | None = None, v_numeric: Callable | None
                                     = None, vtype: type | None = None, name: str | None
                                     = None, tex_name: str | None = None, info: str | None
                                     = None, unit: str | None = None, sequential: bool |
                                     None = True)
```

Variable service that gets updated in each step/iteration before computing the residual equations. As a results, variable values from the k-th step are used to compute a `VarService` that will be used to compute the residual for the (k+1)-th step.

This class is useful when one has non-differentiable algebraic equations, which make use of *abs()*, *re* and *im*. Instead of creating *Algeb*, one can put the equation in *VarService*, which will be updated before solving algebraic equations.

Parameters

sequential

[bool, optional, default to True] True if this `VarService` depends on previously defined `VarService` and should be evaluated in sequence. False if this `VarService` only uses known variables.

Warning: *VarService* is not solved with other algebraic equations, meaning that there is one step "delay" between the algebraic variables and *VarService*. Use an algebraic variable whenever possible.

Examples

In ESST3A model, the voltage and current sensors ($v_d + jv_q$), ($I_d + jI_q$) estimate the sensed VE using equation

$$VE = |K_{PC} * (v_d + 1jv_q) + 1j(K_I + K_{PC} * X_L) * (I_d + 1jI_q)|$$

One can use *VarService* to implement this equation

```
self.VE = VarService(
    tex_name='V_E', info='VE', v_str='Abs(KPC*(vd + 1j*vq) + 1j*(KI +
    KPC*XL)*(Id + 1j*Iq))', )
```

```
class andes.core.service.PostInitService(v_str: str | None = None, v_numeric: Callable |
None = None, vtype: type | None = None,
name: str | None = None, tex_name: str | None
= None, info: str | None = None, unit: str |
None = None)
```

Constant service that gets stored once after init.

This service is useful when one need to store initialization values stored in variables.

Examples

In ESST3A model, the v_f variable is initialized followed by other variables. One can store the initial v_f into v_{f0} so that equation $v_f - v_{f0} = 0$ will hold.

```
self.vref0 = PostInitService(info='Initial reference voltage input',
                             tex_name='V_{ref0}', v_str='vref', )
```

Since all *ConstService* are evaluated before equation evaluation, without using *PostInitService*, one will need to create lots of *ConstService* to store values in the initialization path towards v_{f0} , in order to correctly initialize v_f .

3.7.4 External Constants

Service constants whose value is retrieved from an external model or group. Using *ExtService* is similar to using external variables. The values of *ExtService* will be retrieved once during the initialization phase before *ConstService* evaluation.

For example, a synchronous generator needs to retrieve the p and q values from static generators for initialization. *ExtService* is used for this purpose. In the `__init__()` of a synchronous generator model, one can define the following to retrieve *StaticGen.p* as p_0 :

```
self.p0 = ExtService(src='p',
                     model='StaticGen',
                     indexer=self.gen,
                     tex_name='P_0')
```

```
class andes.core.service.ExtService (model: str, src: str, indexer: BaseParam | BaseService,
                                     attr: str = 'v', allow_none: bool = False, default=0,
                                     name: str = None, tex_name: str = None, vtype=None,
                                     info: str = None)
```

Service constants whose value is from an external model or group.

Parameters

src

[str] Variable or parameter name in the source model or group

model

[str] A model name or a group name

indexer

[IdxParam or BaseParam] An "Indexer" instance whose `v` field contains the `idx` of devices in the model or group.

Examples

A synchronous generator needs to retrieve the `p` and `q` values from static generators for initialization. `ExtService` is used for this purpose.

In a synchronous generator, one can define the following to retrieve `StaticGen.p` as `p0`:

```
class GENCLSMModel(Model):
    def __init__(...):
        ...
        self.p0 = ExtService(src='p',
                             model='StaticGen',
                             indexer=self.gen,
                             tex_name='P_0')
```

3.7.5 Shape Manipulators

This section is for advanced model developer.

All generated equations operate on 1-dimensional arrays and can use algebraic calculations only. In some cases, one model would use *BackRef* to retrieve 2-dimensional indices and will use such indices to retrieve variable addresses. The retrieved addresses usually has a different length of the referencing model and cannot be used directly for calculation. Shape manipulator services can be used in such case.

NumReduce is a helper Service type which reduces a linearly stored 2-D ExtParam into 1-D Service. *NumRepeat* is a helper Service type which repeats a 1-D value into linearly stored 2-D value based on the shape from a *BackRef*.

class `andes.core.service.BackRef` (***kwargs*)

A special type of reference collector.

BackRef is used for collecting device indices of other models referencing the parent model of the *BackRef*. The *v`field* will be a list of lists, each containing the *idx* of other models referencing each device of the parent model.

BackRef can be passed as indexer for params and vars, or shape for *NumReduce* and *NumRepeat*. See examples for illustration.

See also:

andes.core.service.NumReduce

A more complete example using *BackRef* to build the COI model

Examples

A Bus device has an *IdxParam* of *area*, storing the *idx* of area to which the bus device belongs. In `Bus.__init__()`, one has

```
self.area = IdxParam(model='Area')
```

Suppose *Bus* has the following data

idx	area	Vn
1	1	110
2	2	220
3	1	345
4	1	500

The Area model wants to collect the indices of Bus devices which points to the corresponding Area device. In `Area.__init__`, one defines

```
self.Bus = BackRef()
```

where the member attribute name *Bus* needs to match exactly model name that *Area* wants to collect *idx* for. Similarly, one can define `self.ACTopology = BackRef()` to collect devices in the *ACTopology* group that references Area.

The collection of *idx* happens in `andes.system.System._collect_ref_param()`. It has to be noted that the specific *Area* entry must exist to collect model idx-dx referencing it. For example, if *Area* has the following data

```
idx 1
```

Then, only Bus 1, 3, and 4 will be collected into `self.Bus.v`, namely, `self.Bus.v == [[1, 3, 4]]`.

If *Area* has data

```
idx 1 2
```

Then, `self.Bus.v` will end up with `[[1, 3, 4], [2]]`.

```
class andes.core.service.NumReduce(u, ref: BackRef, fun: Callable, name=None,
                                   tex_name=None, info=None, cache=True)
```

A helper Service type which reduces a linearly stored 2-D ExtParam into 1-D Service.

NumReduce works with ExtParam whose *v* field is a list of lists. A reduce function which takes an array-like and returns a scalar need to be supplied. NumReduce calls the reduce function on each of the lists and return all the scalars in an array.

Parameters

u

[ExtParam] Input ExtParam whose *v* contains linearly stored 2-dimensional values

ref

[BackRef] The BackRef whose 2-dimensional shapes are used for indexing

fun

[Callable] The callable for converting a 1-D array-like to a scalar

Examples

Suppose one wants to calculate the mean value of the V_n in one Area. In the `Area` class, one defines

```
class AreaModel(...):
    def __init__(...):
        ...
        # backward reference from `Bus`
        self.Bus = BackRef()

        # collect the  $V_n$  in an 1-D array
        self.Vn = ExtParam(model='Bus',
                           src='Vn',
                           indexer=self.Bus)

        self.Vn_mean = NumReduce(u=self.Vn,
                                fun=np.mean,
                                ref=self.Bus)
```

Suppose we define two areas, 1 and 2, the Bus data looks like

idx	area	V_n
1	1	110
2	2	220
3	1	345
4	1	500

Then, `self.Bus.v` is a list of two lists `[[1, 3, 4], [2]]`. `self.Vn.v` will be retrieved and linearly stored as `[110, 345, 500, 220]`. Based on the shape from `self.Bus`, `numpy.mean()` will be called on `[110, 345, 500]` and `[220]` respectively. Thus, `self.Vn_mean.v` will become `[318.33, 220]`.

```
class andes.core.service.NumRepeat (u, ref, **kwargs)
```

A helper Service type which repeats a v-provider's value based on the shape from a BackRef

Examples

NumRepeat was originally designed for computing the inertia-weighted average rotor speed (center of inertia speed). COI speed is computed with

$$\omega_{COI} = \frac{\sum M_i * \omega_i}{\sum M_i}$$

The numerator can be calculated with a mix of BackRef, ExtParam and ExtState. The denominator needs to be calculated with NumReduce and Service Repeat. That is, use NumReduce to calculate the sum, and use NumRepeat to repeat the summed value for each device.

In the COI class, one would have

```
class COIModel(...):
    def __init__(...):
        ...
        self.SynGen = BackRef()
        self.SynGenIdx = RefFlatten(ref=self.SynGen)
        self.M = ExtParam(model='SynGen',
                           src='M',
                           indexer=self.SynGenIdx)

        self.wgen = ExtState(model='SynGen',
                              src='omega',
                              indexer=self.SynGenIdx)

        self.Mt = NumReduce(u=self.M,
                             fun=np.sum,
                             ref=self.SynGen)

        self.Mtr = NumRepeat(u=self.Mt,
                              ref=self.SynGen)

        self.pidx = IdxRepeat(u=self.idx, ref=self.SynGen)
```

Finally, one would define the center of inertia speed as

```
self.wcoi = Algeb(v_str='1', e_str='-wcoi')

self.wcoi_sub = ExtAlgeb(model='COI',
                          src='wcoi',
                          e_str='M * wgen / Mtr',
                          v_str='M / Mtr',
                          indexer=self.pidx,
                          )
```

It is very worth noting that the implementation uses a trick to separate the average weighted sum into n sub-equations, each calculating the $(M_i * \omega_i) / (\sum M_i)$. Since all the variables are preserved in the sub-equation, the derivatives can be calculated correctly.

```
class andes.core.service.IdxRepeat(u, ref, **kwargs)
```

Helper class to repeat IdxParam.

This class has the same functionality as `andes.core.service.NumRepeat` but only operates on `IdxParam`, `DataParam` or `NumParam`.

class `andes.core.service.RefFlatten` (*ref*, ***kwargs*)

A service type for flattening `andes.core.service.BackRef` into a 1-D list.

Examples

This class is used when one wants to pass *BackRef* values as indexer.

`andes.models.coi.COI` collects referencing `andes.models.group.SynGen` with

```
self.SynGen = BackRef(info='SynGen idx lists', export=False)
```

After collecting *BackRefs*, `self.SynGen.v` will become a two-level list of indices, where the first level correspond to each COI and the second level correspond to generators of the COI.

Convert `self.SynGen` into 1-d as `self.SynGenIdx`, which can be passed as indexer for retrieving other parameters and variables

```
self.SynGenIdx = RefFlatten(ref=self.SynGen)

self.M = ExtParam(model='SynGen', src='M',
                  indexer=self.SynGenIdx, export=False,
                  )
```

3.7.6 Value Manipulation

class `andes.core.service.Replace` (*old_val*, *flt*, *new_val*, *name=None*, *tex_name=None*, *info=None*, *cache=True*)

Replace parameters with new values if the function returns True

class `andes.core.service.ParamCalc` (*param1*, *param2*, *func*, *name=None*, *tex_name=None*, *info=None*, *cache=True*)

Parameter calculation service.

Useful to create parameters calculated instantly from existing ones.

3.7.7 Idx and References

class `andes.core.service.DeviceFinder` (*u*, *link*, *idx_name: str*, *default_model: str*, *auto_find: bool | None = True*, *auto_add: bool | None = True*, *name: str | None = None*, *tex_name: str | None = None*, *info: str | None = None*)

Service for finding `idx` of devices which are linked to the given devices.

The `auto_find` parameter controls if the device `idx` should be automatically looked up. The `auto_add` parameter controls if the device will be automatically added. The two parameters are not exclusive. One can skip finding the device but automatically adding it.

If `auto_find` is `True` and the `idx` is `None`, `DeviceFinder` will look up for the device. If not found and `auto_add` is `True`, `DevFinder` will then automatically add the devices. The `idx` of the devices that are found or added will be stored to the `DeviceFinder` instance, so that *DeviceFinder* can be used like any *IdxParam*.

Adding new devices are called at the beginning of `andes.system.System.setup()`.

Examples

The IEEEEST stabilizer takes an optional parameter `busf` of the type *IdxParam* for specifying the connected bus frequency measurement device, which is needed for mode 6. To avoid reimplementing *BusFreq* within IEEEEST, one can do

```
self.busfreq = DeviceFinder(self.busf,
                             link=self.buss, idx_name='bus',
                             default_model='BusFreq')
```

where `self.busf` is for the optional parameter for the `idx` of bus frequency estimation devices (e.g., *BusFreq*), `self.buss` is for the `idx` of buses that `self.busf` devices should measure, and `idx_name` is the name of the *BusFreq* parameter through which the indices of measured buses are given.

For each `None` or invalid values in `self.busf`, a *BusFreq* device will be created with its `bus` set to the corresponding value in `self.buss`. That is, `BusFreq[idx_name].v = [link]`.

At the end, the *DeviceFinder* instance will contain the list of *BusFreq* that are are connected to `self.buss`, respectively.

In the case of any valid value in `self.busf`, that is, the value is an existing *BusFreq* device, *DeviceFinder* will return it as is without checking if the *BusFreq* device actually measures the bus specified by `self.buss`. It allows to use the measurement at a different location, but the user have to perform the data consistency check.

class `andes.core.service.BackRef` (***kwargs*)

A special type of reference collector.

BackRef is used for collecting device indices of other models referencing the parent model of the *BackRef*. The *v* field will be a list of lists, each containing the *idx* of other models referencing each device of the parent model.

BackRef can be passed as indexer for params and vars, or shape for *NumReduce* and *NumRepeat*. See examples for illustration.

See also:

`andes.core.service.NumReduce`

A more complete example using *BackRef* to build the COI model

Examples

A Bus device has an *IdxParam* of *area*, storing the *idx* of area to which the bus device belongs. In `Bus.__init__()`, one has

```
self.area = IdxParam(model='Area')
```

Suppose *Bus* has the following data

idx	area	Vn
1	1	110
2	2	220
3	1	345
4	1	500

The Area model wants to collect the indices of Bus devices which points to the corresponding Area device. In `Area.__init__`, one defines

```
self.Bus = BackRef()
```

where the member attribute name *Bus* needs to match exactly model name that *Area* wants to collect *idx* for. Similarly, one can define `self.ACTopology = BackRef()` to collect devices in the *ACTopology* group that references Area.

The collection of *idx* happens in `andes.system.System._collect_ref_param()`. It has to be noted that the specific *Area* entry must exist to collect model idx-dx referencing it. For example, if *Area* has the following data

```
idx 1
```

Then, only Bus 1, 3, and 4 will be collected into `self.Bus.v`, namely, `self.Bus.v == [[1, 3, 4]]`.

If *Area* has data

```
idx 1 2
```

Then, `self.Bus.v` will end up with `[[1, 3, 4], [2]]`.

class `andes.core.service.RefFlatten` (*ref*, ****kwargs**)

A service type for flattening `andes.core.service.BackRef` into a 1-D list.

Examples

This class is used when one wants to pass *BackRef* values as indexer.

`andes.models.coi.COI` collects referencing `andes.models.group.SynGen` with

```
self.SynGen = BackRef(info='SynGen idx lists', export=False)
```

After collecting *BackRefs*, `self.SynGen.v` will become a two-level list of indices, where the first level correspond to each COI and the second level correspond to generators of the COI.

Convert `self.SynGen` into 1-d as `self.SynGenIdx`, which can be passed as indexer for retrieving other parameters and variables

```
self.SynGenIdx = RefFlatten(ref=self.SynGen)

self.M = ExtParam(model='SynGen', src='M',
                  indexer=self.SynGenIdx, export=False,
                  )
```

3.7.8 Events

```
class andes.core.service.EventFlag(u, vtype: type | None = None, name: str | None = None,
                                   tex_name=None, info=None)
```

Service to flag events when the input value changes. The typical input is a *v-provider* with binary values.

Implemented by providing `self.check(**kwargs)` as *v_numeric*. `EventFlag.v` stores the values of the input variable in the most recent iteration/step.

After the evaluation of `self.check()`, `self.v` will be updated.

```
class andes.core.service.ExtendedEvent(u, t_ext: int | float | BaseParam | BaseService =
                                       0.0, trig: str = 'rise', enable=True, v_disabled=0,
                                       extend_only=False, vtype: type | None = None,
                                       name: str | None = None, tex_name=None,
                                       info=None)
```

Service for indicating an event for an extended, predefined period of time following the event disappearance.

The triggering of an event, whether the rise or fall edge, is specified through *trig*. For example, if *trig* = *rise*, the change of the input from 0 to 1 will be considered as an input, whereas the subsequent change back to 0 will be considered as the event end.

`ExtendedEvent.v` stores the flags whether the extended time has completed. Outputs will become 1 once the event starts and return to 0 when the extended time ends.

Parameters

u

[v-provider] Triggering signal where the values are 0 or 1.

trig

[str in ("rise", "fall")] Triggering edge for the beginning of an event. *rise* by default.

enable

[bool or v-provider] If disabled, the output will be *v_disabled*

extend_only

[bool] Only output during the extended period, not the event period.

Warning: The performance of this class needs to be optimized.

```
class andes.core.service.VarHold (u, hold, vtype=None, name=None, tex_name=None,  
                                info=None)
```

Service for holding the input when the hold signal is on.

Parameters**hold**

[v-provider, binary] Hold signal array with length equal to the input. For elements that are 1, the corresponding inputs are held until the hold signal returns to 0.

3.7.9 Flags

```
class andes.core.service.FlagCondition (u, func, flag=1, name=None, tex_name=None,  
                                       info=None, cache=True)
```

Class for flagging values based on a condition function.

By default, values whose condition function output equal that equal to True/1 will be flagged as 1. 0 otherwise.

Parameters**u**

Input parameter

func

A condition function that returns True or False.

flag

[1 by default, only 0 or 1 is accepted.] The flag for the inputs whose condition output is True.

Warning: This class is not ready.

FlagCondition can only be applied to *BaseParam* with *cache=True*. Applying to *Service* will fail unless *cache* is False (at a performance cost).

```
class andes.core.service.FlagGreaterThan (u, value=0.0, flag=1, equal=False,  
                                           name=None, tex_name=None, info=None,  
                                           cache=True)
```

Service for flagging parameters $>$ or \geq the given value element-wise.

Parameters that satisfy the comparison ($u >$ or \geq value) will be flagged as *flag* (1 by default).

```
class andes.core.service.FlagLessThan (u, value=0.0, flag=1, equal=False, name=None,
                                       tex_name=None, info=None, cache=True)
```

Service for flagging parameters $<$ or \leq the given value element-wise.

Parameters that satisfy the comparison ($u <$ or \leq value) will be flagged as *flag* (1 by default).

```
class andes.core.service.FlagValue (u, value, flag=0, name=None, tex_name=None,
                                    info=None, cache=True)
```

Class for flagging values that equal to the given value.

By default, values that equal to *value* will be flagged as 0. Non-matching values will be flagged as 1.

Parameters

u

Input parameter

value

Value to flag. Can be None, string, or a number.

flag

[0 by default, only 0 or 1 is accepted.] The flag for the matched ones

Warning: *FlagNotNone* can only be applied to *BaseParam* with *cache=True*. Applying to *Service* will fail unless *cache* is False (at a performance cost).

3.7.10 Data Select

```
class andes.core.service.DataSelect (optional, fallback, name: str | None = None, tex_name:
                                     str | None = None, info: str | None = None)
```

Class for selecting values for optional DataParam or NumParam.

This service is a v-provider that uses optional DataParam when available. Otherwise, use the fallback value.

DataParam will be tested for *None*, and NumParam will be tested with `np.isnan()`.

Notes

An use case of DataSelect is remote bus. One can do

```
self.buss = DataSelect(option=self.busr, fallback=self.bus)
```

Then, pass `self.buss` instead of `self.bus` as indexer to retrieve voltages.

Another use case is to allow an optional turbine rating. One can do

```
self.Tn = NumParam(default=None)
self.Sg = ExtParam(...)
self.Sn = DataSelect(Tn, Sg)
```

```
class andes.core.service.NumSelect (optional, fallback, name: str | None = None, tex_name:
                                str | None = None, info: str | None = None, ignore_cond:
                                ~typing.Callable | None = functools.partial(<ufunc
                                'equal'>, 0))
```

Class for selecting values for optional NumParam.

NumSelect works with internal and external parameters.

Any values equal to `np.nan` will always be ignored. If one needs to ignore values based on additional conditions, pass it through `ignore_cond`. For example, to ignore zero values, use `ignore_cond = partial(np.equal, 0)`.

Examples

One use case is to allow an optional turbine rating. One can do

```
self.Tn = NumParam(default=None) self.Sg = ExtParam(...) self.Sn =
DataSelect(Tn, Sg)
```

3.7.11 Miscellaneous

```
class andes.core.service.InitChecker (u, lower=None, upper=None, equal=None,
                                not_equal=None, enable=True, error_out=False,
                                **kwargs)
```

Class for checking init values against known typical values.

Instances will be stored in `Model.services_post` and `Model.services_ichack`, which will be checked in `Model.post_init_check()` after initialization.

Parameters

u

v-provider to be checked

lower

[float, BaseParam, BaseVar, BaseService] lower bound

upper

[float, BaseParam, BaseVar, BaseService] upper bound

equal

[float, BaseParam, BaseVar, BaseService] values that the value from *v_str* should equal

not_equal

[float, BaseParam, BaseVar, BaseService] values that should not equal

enable

[bool] True to enable checking

Examples

Let's say generator excitation voltages are known to be in the range of 1.6 - 3.0 per unit. One can add the following instance to *GENBase*

```
self._vfc = InitChecker(u=self.vf,
                        info='vf range',
                        lower=1.8,
                        upper=3.0,
                        )
```

lower and *upper* can also take v-providers instead of float values.

One can also pass float values from Config to make it adjustable as in our implementation of *GENBase*.
_vfc.

```
class andes.core.service.ApplyFunc (u, func, name=None, tex_name=None, info=None,
                                     cache=True)
```

Class for applying a numerical function on a parameter..

Parameters

u

Input parameter

func

A condition function that returns True or False.

Warning: This class is not ready.

```
class andes.core.service.CurrentSign (bus, bus1, bus2, name=None, tex_name=None,
                                       info=None)
```

Service for computing the sign of the current flowing through a series device.

With a given line connecting *bus1* and *bus2*, one can compute the current flow using $(v1 \cdot \exp(1j \cdot a1) - v2 \cdot \exp(1j \cdot a2)) / (r + jx)$ whose value is the outflow on *bus1*.

CurrentSign can be used to compute the sign to be multiplied depending on the observing bus. For each value in *bus*, the sign will be +1 if it appears in *bus1* or -1 otherwise.

```
bus1          bus2
*----->>-----*
bus (+)       bus (-)
```

```
class andes.core.service.RandomService (func=<built-in method rand of
                                         numpy.random.mtrand.RandomState object>,
                                         **kwargs)
```

A service type for generating random numbers.

Parameters

name

[str] Name

func

[Callable] A callable for generating the random variable.

Warning: The value will be randomized every time it is accessed. Do not use it if the value needs to be stable for each simulation step.

```
class andes.core.service.SwBlock (*, init, ns, blocks, ext_sel=None, name=None,
                                   tex_name=None, info=None)
```

Service type for switched shunt blocks.

3.8 Discrete

3.8.1 Background

The discrete component library contains a special type of block for modeling the discontinuity in power system devices. Such continuities can be device-level physical constraints or algorithmic limits imposed on controllers.

The base class for discrete components is `andes.core.discrete.Discrete`.

```
Discrete([name, tex_name, info, no_warn, ...])    Base discrete class.
```

andes.core.discrete.Discrete

```
class andes.core.discrete.Discrete (name=None, tex_name=None, info=None,  
no_warn=False, min_iter=2, err_tol=0.01)
```

Base discrete class.

Discrete classes export flag arrays (usually boolean) .

```
__init__ (name=None, tex_name=None, info=None, no_warn=False, min_iter=2, err_tol=0.01)
```

Methods

<code>check_eq(**kwargs)</code>	This function is called in <code>l_check_eq</code> after updating equations.
<code>check_iter_err([niter, err])</code>	Check if the minimum iteration or maximum error is reached so that this discrete block should be enabled.
<code>check_var(*args, **kwargs)</code>	This function is called in <code>l_update_var</code> before evaluating equations.
<code>get_names()</code>	Available symbols from this class
<code>get_tex_names()</code>	Return <code>tex_names</code> of exported flags.
<code>get_values()</code>	
<code>list2array(n)</code>	Allocate memory for the discrete flags specified in <code>self.export_flags</code> .
<code>warn_init_limit()</code>	Warn if associated variables are initialized at limits.

Discrete.check_eq

`Discrete.check_eq (**kwargs)`

This function is called in `l_check_eq` after updating equations.

It updates internal flags, set differential equations, and record pegged variables.

Discrete.check_iter_err

`Discrete.check_iter_err (niter=None, err=None)`

Check if the minimum iteration or maximum error is reached so that this discrete block should be enabled.

Only when both *niter* and *err* are given, (*niter* < *min_iter*) , and (*err* > *err_tol*) it will return False.

This logic will start checking the discrete states if called from an external solver that does not feed *niter* or *err* at each step.

Returns**bool**

True if it should be enabled, False otherwise

Discrete.check_var`Discrete.check_var(*args, **kwargs)`This function is called in `l_update_var` before evaluating equations.

It should update internal flags only.

Parameters**adjust_upper**

[bool] True to adjust the upper limit to the value of the variable. Supported by limiters.

adjust_lower

[bool] True to adjust the lower limit to the value of the variable. Supported by limiters.

Discrete.get_names`Discrete.get_names()`

Available symbols from this class

Returns**Discrete.get_tex_names**`Discrete.get_tex_names()`Return `tex_names` of exported flags.

TODO: Fix the bug described in the warning below.

Returns**list**A list of `tex_names` for all exported flags.

Warning: If underscore `_` appears in both flag `tex_name` and `self.tex_name` (for example, when this discrete is within a block), the exported `tex_name` will become invalid for SymPy. Variable name substitution will fail.

Discrete.get_values

`Discrete.get_values()`

Discrete.list2array

`Discrete.list2array(n)`

Allocate memory for the discrete flags specified in *self.export_flags*.

Parameters

n

[int] Number of elements in the array. Provided by the calling function.

Discrete.warn_init_limit

`Discrete.warn_init_limit()`

Warn if associated variables are initialized at limits.

Attributes

`class_name`

Discrete.class_name

property `Discrete.class_name`

The uniqueness of discrete components is the way it works. Discrete components take inputs, criteria, and exports a set of flags with the component-defined meanings. These exported flags can be used in algebraic or differential equations to build piece-wise equations.

For example, *Limiter* takes a v-provider as input, two v-providers as the upper and the lower bound. It exports three flags: *zi* (within bound), *zl* (below lower bound), and *zu* (above upper bound). See the code example in `models/pv.py` for an example voltage-based PQ-to-Z conversion.

It is important to note when the flags are updated. Discrete subclasses can use three methods to check and update the value and equations. Among these methods, *check_var* is called *before* equation evaluation, but *check_eq* and *set_eq* are called *after* equation update. In the current implementation, *check_var* updates flags for variable-based discrete components (such as *Limiter*). *check_eq* updates flags for equation-involved discrete components (such as *AntiWindup*). *set_var* is currently only used by *AntiWindup* to store the pegged states.

ANDES includes the following types of discrete components.

3.8.2 Limiters

```
class andes.core.discrete.Limiter (u, lower, upper, enable=True, name: str = None,  
                                tex_name: str = None, info: str = None, min_iter: int = 2,  
                                err_tol: float = 0.01, allow_adjust: bool = True,  
                                no_lower=False, no_upper=False, sign_lower=1,  
                                sign_upper=1, equal=True, no_warn=False, zu=0.0,  
                                zl=0.0, zi=1.0)
```

Base limiter class.

This class compares values and sets limit values. Exported flags are *zi*, *zl* and *zu*.

Parameters

u

[BaseVar] Input Variable instance

lower

[BaseParam] Parameter instance for the lower limit

upper

[BaseParam] Parameter instance for the upper limit

no_lower

[bool] True to only use the upper limit

no_upper

[bool] True to only use the lower limit

sign_lower: 1 or -1

Sign to be multiplied to the lower limit

sign_upper: bool

Sign to be multiplied to the upper limit

equal

[bool] True to include equal signs in comparison (\geq or \leq).

no_warn

[bool] Disable initial limit warnings

zu

[0 or 1] Default value for *zu* if not enabled

zl

[0 or 1] Default value for *zl* if not enabled

zi

[0 or 1] Default value for *zi* if not enabled

Notes

If not enabled, the default flags are $z_u = z_l = 0, z_i = 1$.

Attributes

zl

[array-like] Flags of elements violating the lower limit; A array of zeros and/or ones.

zi

[array-like] Flags for within the limits

zu

[array-like] Flags for violating the upper limit

```
class andes.core.discrete.SortedLimiter (u, lower, upper, n_select: int = 5, name=None,  
                                         tex_name=None, enable=True,  
                                         abs_violation=True, min_iter: int = 2, err_tol:  
                                         float = 0.01, allow_adjust: bool = True, zu=0.0,  
                                         zl=0.0, zi=1.0, ql=0.0, qu=0.0)
```

A limiter that sorts inputs based on the absolute or relative amount of limit violations.

Parameters

n_select

[int] the number of violations to be flagged, for each of over-limit and under-limit cases. If $n_select == 1$, at most one over-limit and one under-limit inputs will be flagged. If n_select is zero, heuristics will be used.

abs_violation

[bool] True to use the absolute violation. False if the relative violation $abs(violation/limit)$ is used for sorting. Since most variables are in per unit, absolute violation is recommended.

```
class andes.core.discrete.HardLimiter (u, lower, upper, enable=True, name: str = None,  
                                         tex_name: str = None, info: str = None, min_iter:  
                                         int = 2, err_tol: float = 0.01, allow_adjust: bool =  
                                         True, no_lower=False, no_upper=False,  
                                         sign_lower=1, sign_upper=1, equal=True,  
                                         no_warn=False, zu=0.0, zl=0.0, zi=1.0)
```

Hard limiter for algebraic or differential variable. This class is an alias of *Limiter*.

```
class andes.core.discrete.RateLimiter (u, lower, upper, enable=True, no_lower=False,  
                                         no_upper=False, lower_cond=1, upper_cond=1,  
                                         name=None, tex_name=None, info=None)
```

Rate limiter for a differential variable.

RateLimiter does not export any variable. It directly modifies the differential equation value.

Warning: RateLimiter cannot be applied to a state variable that already undergoes an AntiWindup limiter. Use *AntiWindupRate* for a rate-limited anti-windup limiter.

Notes

RateLimiter inherits from Discrete to avoid internal naming conflicts with *Limiter*.

```
class andes.core.discrete.AntiWindup (u, lower, upper, enable=True, no_warn=False,
                                       no_lower=False, no_upper=False, sign_lower=1,
                                       sign_upper=1, name=None, tex_name=None,
                                       info=None, state=None, allow_adjust: bool = True)
```

Anti-windup limiter.

Anti-windup limiter prevents the wind-up effect of a differential variable. The derivative of the differential variable is reset if it continues to increase in the same direction after exceeding the limits. During the derivative return, the limiter will be inactive

```
if x > xmax and x dot > 0: x = xmax and x dot = 0
if x < xmin and x dot < 0: x = xmin and x dot = 0
```

This class takes one more optional parameter for specifying the equation.

Parameters

state

[State, ExtState] A State (or ExtState) whose equation value will be checked and, when condition satisfies, will be reset by the anti-windup-limiter.

```
class andes.core.discrete.AntiWindupRate (u, lower, upper, rate_lower, rate_upper,
                                           no_lower=False, no_upper=False,
                                           rate_no_lower=False, rate_no_upper=False,
                                           rate_lower_cond=None,
                                           rate_upper_cond=None, enable=True,
                                           name=None, tex_name=None, info=None,
                                           allow_adjust: bool = True)
```

Anti-windup limiter with rate limits

3.8.3 Comparers

```
class andes.core.discrete.LessThan (u, bound, equal=False, enable=True, name=None,
                                       tex_name=None, info: str = None, cache: bool = False,
                                       z0=0, z1=1)
```

Less than (<) comparison function that tests if $u < \text{bound}$.

Exports two flags: z1 and z0. For elements satisfying the less-than condition, the corresponding $z1 = 1$. z0 is the element-wise negation of z1.

Notes

The default $z0$ and $z1$, if not enabled, can be set through the constructor. By default, the model will not adjust the limit.

class `andes.core.discrete.Selector` (*args, fun, tex_name=None, info=None)

Selection between two variables using the provided reduce function.

The reduce function should take the given number of arguments. An example function is `np.maximum.reduce` which can be used to select the maximum.

Names are in $s0$, $s1$.

Warning: A potential bug when more than two inputs are provided, and values in different inputs are equal. Only two inputs are allowed.

Deprecated since version 1.5.9: Use of this class for comparison-based output is discouraged. Instead, use *LessThan* and *Limiter* to construct pieewise equations.

See the new implementation of `HVGate` and `LVGate`.

See also:

`numpy.ufunc.reduce`

NumPy reduce function

Notes

A common pitfall is the 0-based indexing in the Selector flags. Note that exported flags start from 0. Namely, $s0$ corresponds to the first variable provided for the Selector constructor.

Examples

Example 1: select the largest value between $v0$ and $v1$ and put it into $vmax$.

After the definitions of $v0$ and $v1$, define the algebraic variable $vmax$ for the largest value, and a selector vs

```
self.vmax = Algeb(v_str='maximum(v0, v1)',
                  tex_name='v_{max}',
                  e_str='vs_s0 * v0 + vs_s1 * v1 - vmax')

self.vs = Selector(self.v0, self.v1, fun=np.maximum.reduce)
```

The initial value of $vmax$ is calculated by `maximum(v0, v1)`, which is the element-wise maximum in SymPy and will be generated into `np.maximum(v0, v1)`. The equation of $vmax$ is to select the values based on vs_{s0} and vs_{s1} .

```
class andes.core.discrete.Switcher (u, options: list | Tuple, info: str = None, name: str =  
None, tex_name: str = None, cache=True)
```

Switcher based on an input parameter.

The switch class takes one v-provider, compares the input with each value in the option list, and exports one flag array for each option. The flags are 0-indexed.

Exported flags are named with `_s0`, `_s1`, ..., with a total number of `len(options)`. See the examples section.

Notes

Switches needs to be distinguished from Selector.

Switcher is for generating flags indicating option selection based on an input parameter. Selector is for generating flags at run time based on variable values and a selection function.

Examples

The IEEEEST model takes an input for selecting the signal. Options are 1 through 6. One can construct

```
self.IC = NumParam(info='input code 1-6') # input code
self.SW = Switcher(u=self.IC, options=[0, 1, 2, 3, 4, 5, 6])
```

If the IC values from the data file ends up being

```
self.IC.v = np.array([1, 2, 2, 4, 6])
```

Then, the exported flag arrays will be

```
{'IC_s0': np.array([0, 0, 0, 0, 0]),
 'IC_s1': np.array([1, 0, 0, 0, 0]),
 'IC_s2': np.array([0, 1, 1, 0, 0]),
 'IC_s3': np.array([0, 0, 0, 0, 0]),
 'IC_s4': np.array([0, 0, 0, 1, 0]),
 'IC_s5': np.array([0, 0, 0, 0, 0]),
 'IC_s6': np.array([0, 0, 0, 0, 1])
}
```

where `IC_s0` is used for padding so that following flags align with the options.

3.8.4 Deadband

```
class andes.core.discrete.DeadBand (u, center, lower, upper, enable=True, equal=False,  
zu=0.0, zl=0.0, zi=0.0, name=None, tex_name=None,  
info=None)
```

The basic deadband type.

Parameters

- u**
[NumParam] The pre-deadband input variable
- center**
[NumParam] Neutral value of the output
- lower**
[NumParam] Lower bound
- upper**
[NumParam] Upper bound
- enable**
[bool] Enabled if True; Disabled and works as a pass-through if False.

Notes

Input changes within a deadband will incur no output changes. This component computes and exports three flags.

Three flags computed from the current input:

- **zl**: True if the input is below the lower threshold
- **zi**: True if the input is within the deadband
- **zu**: True if is above the lower threshold

Initial condition:

All three flags are initialized to zero. All flags are updated during *check_var* when enabled. If the deadband component is not enabled, all of them will remain zero.

Examples

Exported deadband flags need to be used in the algebraic equation corresponding to the post-deadband variable. Assume the pre-deadband input variable is *var_in* and the post-deadband variable is *var_out*. First, define a deadband instance *db* in the model using

```
self.db = DeadBand(u=self.var_in, center=self.dbc,
                  lower=self.dbl, upper=self.dbu)
```

To implement a no-memory deadband whose output returns to center when the input is within the band, the equation for *var* can be written as

```
var_out.e_str = 'var_in * (1 - db_zi) + \
                (dbc * db_zi) - var_out'
```

class andes.core.discrete.**DeadBandRT** (*u, center, lower, upper, enable=True*)

Deadband with flags for directions of return.

Parameters

- u**
[NumParam] The pre-deadband input variable
- center**
[NumParam] Neutral value of the output
- lower**
[NumParam] Lower bound
- upper**
[NumParam] Upper bound
- enable**
[bool] Enabled if True; Disabled and works as a pass-through if False.

Notes

Input changes within a deadband will incur no output changes. This component computes and exports five flags. The additional two flags on top of *DeadBand* indicate the direction of return:

- zur: True if the input is/has been within the deadband and was returned from the upper threshold
- zlr: True if the input is/has been within the deadband and was returned from the lower threshold

Initial condition:

All five flags are initialized to zero. All flags are updated during *check_var* when enabled. If the deadband component is not enabled, all of them will remain zero.

Examples

To implement a deadband whose output is pegged at the nearest deadband bounds, the equation for *var* can be provided as

```
var_out.e_str = 'var_in * (1 - db_zi) + \
                db_l * db_zlr + \
                db_u * db_zur - var_out'
```

3.8.5 Others

class andes.core.discrete.**Average** (*u*, mode='step', delay=0, name=None, tex_name=None, info=None)

Compute the average value of a BaseVar over a period of time or a number of simulation steps.

Average is based on the memory implemented in the Delay class. The same modes as in Delay are supported.

The output of the Average class is named <INSTANCE_NAME>_v, where <INSTANCE_NAME> is the instance name of Average.

```
class andes.core.discrete.Delay (u, mode='step', delay=0, name=None, tex_name=None,  
                                info=None)
```

The delay class.

Delay allows to impose a predefined and fixed "delay" (in either steps or seconds) for an input variable. The amount of delay must be a scalar and has to be given when instantiating the Delay class when defining the model.

Delay implements an internal memorize to store past variable values.

The default delay mode is *step* but can be set to *time*. In the *time* mode, the value at the `current time - delay` will be interpolated based on the two nearest times and values.

Delay can be applied to a state or an algebraic variable. The exported variable is named `<INSTANCE_NAME>_v`, where `<INSTANCE_NAME>` is the name of the Delay instance.

```
class andes.core.discrete.Derivative (u, name=None, tex_name=None, info=None)
```

Compute the derivative of a variable using numerical differentiation.

Derivative is based on the storage implemented in the Delay class. The delay is set to 1 step so that the current and the previous step are used.

A simple first order derivative is computed using $u(t) - u(t-1) / tstep$, where `tstep` is the current step size.

Derivative is intended to be used for algebraic variables because of discontinuity. It can be applied to a state variable, but one should instead implement the right-hand side equation of the state variable in an algebraic equation to obtain the accurate derivative.

Alternatively, the washout filter (`andes.core.block.Washout`) can be used to implement a numerically stable derivative.

The output of the Derivative class is named `<INSTANCE_NAME>_v` just like Delay.

```
class andes.core.discrete.Sampling (u, interval=1.0, offset=0.0, name=None,  
                                tex_name=None, info=None)
```

Sample and hold

Sample an input variable periodically at the given time interval and hold the value until the next sample time.

For example, this class can be used to implement a 4-second sampling of the AGC signal.

The output of *Sampling* is named `<INSTANCE_NAME>_v`, where `<INSTANCE_NAME>` is the Sampling instance name.

```
class andes.core.discrete.ShuntAdjust (*, v, lower, upper, bsw, gsw, dt, u, enable=True,  
                                min_iter=2, err_tol=0.01, name=None,  
                                tex_name=None, info=None, no_warn=False)
```

Class for adjusting switchable shunts.

Parameters

v

[BaseVar] Voltage measurement

lower	[BaseParam] Lower voltage bound
upper	[BaseParam] Upper voltage bound
bsw	[SwBlock] SwBlock instance for susceptance
gsw	[SwBlock] SwBlock instance for conductance
dt	[NumParam] Delay time
u	[NumParam] Connection status
min_iter	[int] Minimum iteration number to enable shunt switching
err_tol	[float] Minimum iteration tolerance to enable switching

3.9 Blocks

3.9.1 Background

The block library contains commonly used blocks (such as transfer functions and nonlinear functions). Variables and equations are pre-defined for blocks to be used as "lego pieces" for scripting DAE models. The base class for blocks is `andes.core.block.Block`.

The supported blocks include `Lag`, `LeadLag`, `Washout`, `LeadLagLimit`, `PIController`. In addition, the base class for piece-wise nonlinear functions, `Piecewise` is provided. `Piecewise` is used for implementing the quadratic saturation function `MagneticQuadSat` and exponential saturation function `MagneticExpSat`.

All variables in a block must be defined as attributes in the constructor, just like variable definition in models. The difference is that the variables are "exported" from a block to the capturing model. All exported variables need to be placed in a dictionary, `self.vars` at the end of the block constructor.

Blocks can be nested as advanced usage. See the following API documentation for more details.

```
class andes.core.block.Block (name: str | None = None, tex_name: str | None = None, info: str | None = None, namespace: str = 'local')
```

Base class for control blocks.

Blocks are meant to be instantiated as Model attributes to provide pre-defined equation sets. Subclasses must overload the `__init__` method to take custom inputs. Subclasses of `Block` must overload the `define` method to provide initialization and equation strings. Exported variables, services and blocks must be constructed into a dictionary `self.vars` at the end of the constructor.

Blocks can be nested. A block can have blocks but itself as attributes and therefore reuse equations. When a block has sub-blocks, the outer block must be constructed with a ``name``.

Nested block works in the following way: the parent block modifies the sub-block's `name` attribute by prepending the parent block's name at the construction phase. The parent block then exports the sub-block as a whole. When the parent Model class picks up the block, it will recursively import the variables in the block and the sub-blocks correctly. See the example section for details.

Parameters

name

[str, optional] Block name

tex_name

[str, optional] Block LaTeX name

info

[str, optional] Block description.

namespace

[str, local or parent] Namespace of the exported elements. If 'local', the block name will be prepended by the parent. If 'parent', the original element name will be used when exporting.

Warning: It is a good practice to avoid more than one level of nesting, to avoid multi-underscore variable names.

Examples

Example for two-level nested blocks. Suppose we have the following hierarchy

SomeModel instance M contains an instance of LeadLag block named A, which contains a Lag instance named B. Both A and B exports two variables `x` and `y`.

In the code for SomeModel, the following code is used to instantiate LeadLag

```
class SomeModel:
    def __init__(...):
        ... self.A = LeadLag(name='A',
                               u=self.foo1, T1=self.foo2, T2=self.foo3)
```

To use Lag in the LeadLag code, the following lines are found in the constructor of LeadLag

```
class LeadLag:
    def __init__(name, ...):
        ... self.B = Lag(u=self.y, K=self.K, T=self.T)

        # register `self.B` with the name `A`
        self.vars = {..., 'B': self.B}
```


When instantiating any block instance, its `__setattr__` function assigns names to exported variables and blocks. For the `LeadLag` instance with the name `A`, its member attribute `B` is assigned the name `A_B` by convention. That is, `A_B` will be set to `B.name`.

When `A` is picked up by `SomeModel.__setattr__`, `B` is captured from `A`'s exports with the name `A_B`. Recursively, `B`'s variables are exported. Recall that `B.name` is now `A_B`, following the naming rule (parent block's name + variable name), `B`'s internal variables become `A_B_x` and `A_B_y`.

Again, the `LeadLag` instance name (`A.name` in this example) must be given when instantiating in `SomeModel`'s constructor to ensure correct name propagation. If there is more than one level of nesting, other than the terminal-level block, all names of the parent blocks must be provided at instantiation.

In such a way, `B.define()` needs no modification since the naming rule is the same. For example, `B`'s internal `y` is always `{self.name}_y`, although the nested `B` has gotten a new name `A_B`.

define()

Function for setting the initialization and equation strings for internal variables. This method must be implemented by subclasses.

The equations should be written with the "final" variable names. Let's say the block instance is named `blk` (kept at `self.name` of the block), and an internal variable `v` is defined. The internal variable will be captured as `blk_v` by the parent model. Therefore, all equations should use `{self.name}_v` to represent variable `v`, where `{self.name}` is the name of the block at run time.

On the other hand, the names of externally provided parameters or variables are obtained by directly accessing the `name` attribute. For example, if `self.T` is a parameter provided through the block constructor, `{self.T.name}` should be used in the equation.

See also:

PIController.define

Equations for the PI Controller block

Examples

An internal variable `v` has a trivial equation $T = v$, where `T` is a parameter provided to the block constructor.

In the model, one has

```
class SomeModel():
    def __init__(...):
        self.input = Algeb()
        self.T = Param()

        self.blk = ExampleBlock(u=self.input, T=self.T)
```

In the `ExampleBlock` function, the internal variable is defined in the constructor as

```
class ExampleBlock():
    def __init__(...):
        self.v = Algeb()
        self.vars = {'v', self.v}
```

In the define, the equation is provided as

```
def define(self):
    self.v.v_str = '{self.T.name}'
    self.v.e_str = '{self.T.name} - {self.name}_v'
```

In the parent model, `v` from the block will be captured as `blk_v`, and the equation will evaluate into

```
self.blk_v.v_str = 'T'
self.blk_v.e_str = 'T - blk_v'
```

3.9.2 Transfer Functions

The following transfer function blocks have been implemented. They can be imported to build new models.

Linear

```
class andes.core.block.Gain(u, K, name=None, tex_name=None, info=None)
```

Gain block.



Exports an algebraic output `y`.

```
define()
```

Implemented equation and the initial condition are

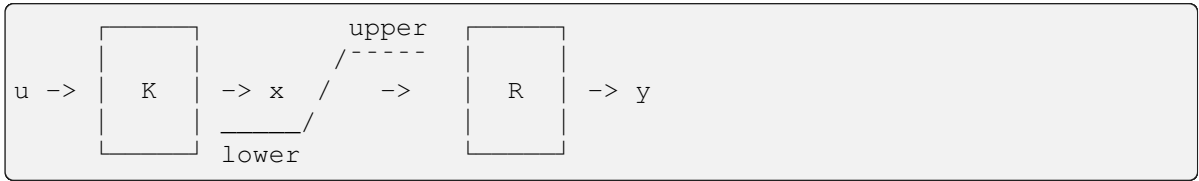
$$y = Ku$$

$$y^{(0)} = Ku^{(0)}$$

```
class andes.core.block.GainLimiter(u, K, R, lower, upper, no_lower=False,
                                   no_upper=False, sign_lower=1, sign_upper=1,
                                   name=None, tex_name=None, info=None)
```

Gain followed by a limiter and another gain.

Exports the limited output `y`, unlimited output `x`, and HardLimiter `lim`.



Parameters

u

[str, BaseVar] Input variable, or an equation string for constructing an anonymous variable

K

[str, BaseParam, BaseService] Initial gain for u before limiter

R

[str, BaseParam, BaseService] Post limiter gain

define()

TODO: write docstring

```
class andes.core.block.Piecewise (u, points: List | Tuple, funs: List | Tuple, name=None,
                                tex_name=None, info=None)
```

Piecewise block. Outputs an algebraic variable y .

This block takes a list of N points, $[x_0, x_1, \dots, x_{n-1}]$ to define $N+1$ ranges, namely $(-\infty, x_0)$, (x_0, x_1) , ..., $(x_{n-1}, +\infty)$. and a list of $N+1$ function strings $[fun_0, \dots, fun_n]$.

Inputs that fall within each range applies the corresponding function. The first range $(-\infty, x_0)$ applies fun_0 , and the last range $(x_{n-1}, +\infty)$ applies the last function fun_n .

The function returns zero if no condition is met.

Parameters

points

[list, tuple] A list of piecewise points. Need to be provided in the constructor function.

funs

[list, tuple] A list of strings for the piecewise functions. Need to be provided in the overloaded *define* function.

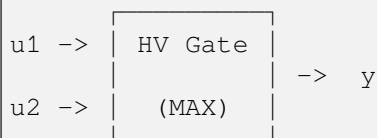
define()

Build the equation string for the piecewise equations.

`self.funs` needs to be provided with the function strings corresponding to each range.

```
class andes.core.block.HVGate (u1, u2, name=None, tex_name=None, info=None)
```

High Value Gate. Outputs the maximum of two inputs.



```
class andes.core.block.LVGate(u1, u2, name=None, tex_name=None, info=None)
```

Low Value Gate. Outputs the minimum of the two inputs.



```
class andes.core.block.DeadBand1(u, center, lower, upper, gain=1.0, enable=True,
                                name=None, tex_name=None, info=None,
                                namespace='local')
```

Deadband type 1 (linear, non-step).

Parameters

center

Default value when within the deadband. If the input is an error signal, center should be set to zero.

gain

Gain multiplied to DeadBand discrete block's output.

Notes

Block diagram



First Order

```
class andes.core.block.Integrator(u, T, K, y0, check_init=True, name=None,
                                tex_name=None, info=None)
```

Integrator block.



Exports a differential variable y .

The initial output needs to be specified through $y0$.

define ()

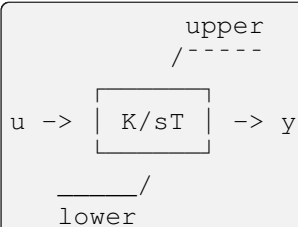
Implemented equation and the initial condition are

$$\dot{y} = Ku$$

$$y^{(0)} = 0$$

class andes.core.block.**IntegratorAntiWindup** ($u, T, K, y0, lower, upper, name=None, tex_name=None, info=None, no_warn=False$)

Integrator block with anti-windup limiter.



Exports a differential variable y and an AntiWindup lim . The initial output must be specified through $y0$.

define ()

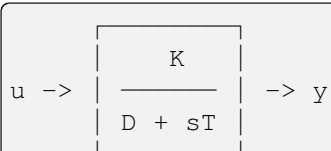
Implemented equation and the initial condition are

$$\dot{y} = Ku$$

$$y^{(0)} = 0$$

class andes.core.block.**Lag** ($u, T, K, D=1, name=None, tex_name=None, info=None$)

Lag (low pass filter) transfer function.



Exports one state variable y as the output.

Parameters

K

Gain

T

Time constant

D

Constant

u

Input variable

define()

Notes

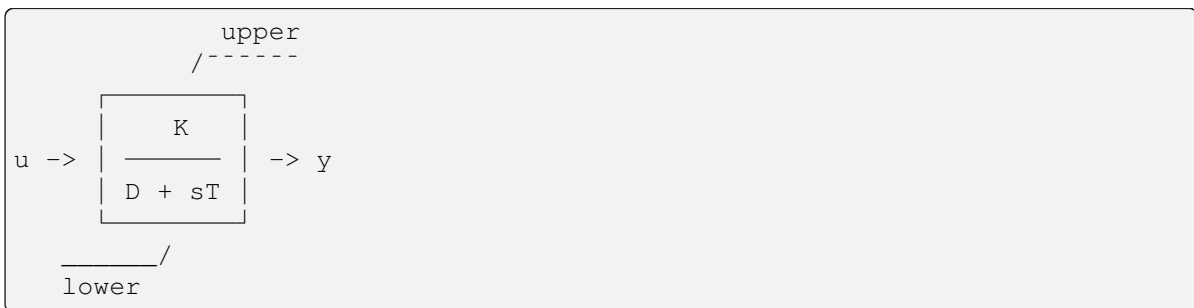
Equations and initial values are

$$T\dot{y} = (Ku - Dy)$$

$$y^{(0)} = Ku/D$$

```
class andes.core.block.LagAntiWindup (u, T, K, lower, upper, D=1, name=None,
                                     tex_name=None, info=None)
```

Lag (low pass filter) transfer function block with an anti-windup limiter.

Exports one state variable y as the output and one AntiWindup instance lim .

Parameters

K

Gain

T

Time constant

D

Constant

u

Input variable

define()

Notes

Equations and initial values are

$$T\dot{y} = (Ku - Dy)$$

$$y^{(0)} = Ku/D$$

```
class andes.core.block.LagFreeze(u, T, K, freeze, D=1, name=None, tex_name=None,
                                info=None)
```

Lag with an input to freeze the state.

During the period when the freeze signal is 1, the LagFreeze output will be frozen.

```
define ()
```

Notes

Equations and initial values are

$$T\dot{y} = (1 - freeze) * (Ku - y)$$

$$y^{(0)} = Ku$$

```
class andes.core.block.LagAWFreeze(u, T, K, lower, upper, freeze, D=1, name=None,
                                   tex_name=None, info=None)
```

Lag with anti-windup limiter and state freeze.

Note that the output y is a state variable.

```
define ()
```

Notes

Equations and initial values are

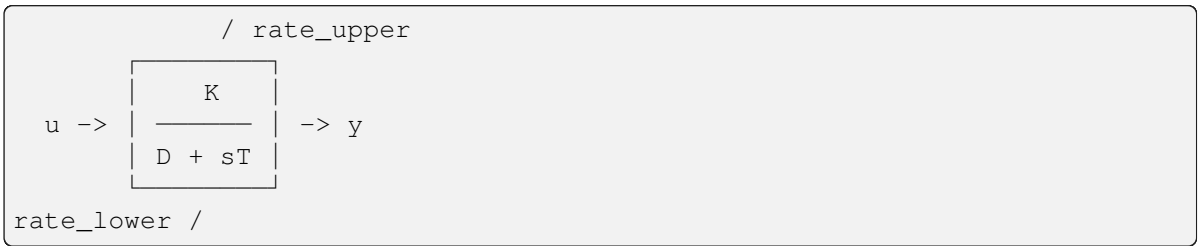
$$T\dot{y} = (1 - freeze)(Ku - y)$$

$$y^{(0)} = Ku$$

y undergoes an anti-windup limiter.

```
class andes.core.block.LagRate(u, T, K, rate_lower, rate_upper, D=1, rate_no_lower=False,
                               rate_no_upper=False, rate_lower_cond=None,
                               rate_upper_cond=None, name=None, tex_name=None,
                               info=None)
```

Lag (low pass filter) transfer function block with a rate limiter.



Exports one state variable y as the output and one AntiWindupRate instance lim .

Parameters

- K**
Gain
- T**
Time constant
- D**
Constant
- u**
Input variable

define ()

Notes

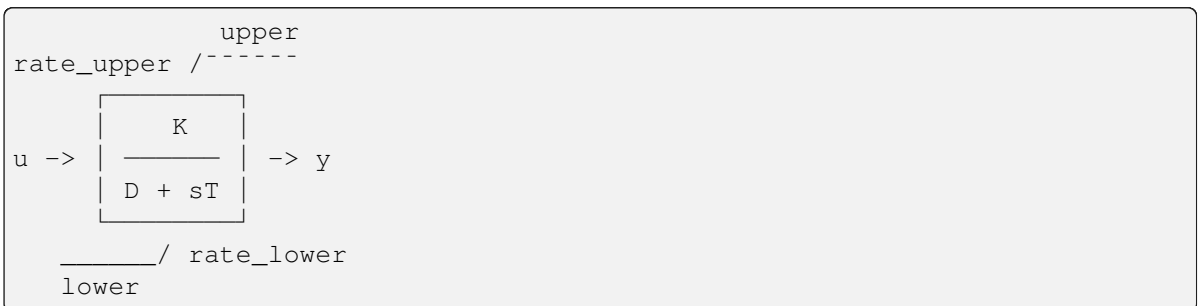
Equations and initial values are

$$T\dot{y} = (Ku - y)$$

$$y^{(0)} = Ku$$

```
class andes.core.block.LagAntiWindupRate(u, T, K, lower, upper, rate_lower, rate_upper,
                                         D=1, no_lower=False, no_upper=False,
                                         rate_no_lower=False, rate_no_upper=False,
                                         rate_lower_cond=None,
                                         rate_upper_cond=None, name=None,
                                         tex_name=None, info=None)
```

Lag (low pass filter) transfer function block with a rate limiter and an anti-windup limiter.



Exports one state variable y as the output and one AntiWindupRate instance lim .

Parameters

K	Gain
T	Time constant
D	Constant
u	Input variable

define()

Notes

Equations and initial values are

$$T\dot{y} = (Ku - Dy)$$

$$y^{(0)} = Ku/D$$

class andes.core.block.**Washout** ($u, T, K, name=None, tex_name=None, info=None$)

Washout filter (high pass) block.

$$u \rightarrow \left[\frac{sK}{1 + sT} \right] \rightarrow y$$

Exports state x (symbol x') and output algebraic variable y .

define()

Notes

Equations and initial values:

$$T\dot{x}' = (u - x')$$

$$Ty = K(u - x')$$

$$x'^{(0)} = u$$

$$y^{(0)} = 0$$

```
class andes.core.block.WashoutOrLag (u, T, K, name=None, zero_out=True,  
                                     tex_name=None, info=None)
```

Washout with the capability to convert to Lag when $K = 0$.

Can be enabled with *zero_out*. Need to provide *name* to construct.

Exports state x (symbol x'), output algebraic variable y , and a LessThan block LT .

Parameters

zero_out

[bool, optional] If True, sT will become 1, and the washout will become a low-pass filter. If False, functions as a regular Washout.

```
define ()
```

Notes

Equations and initial values:

$$\begin{aligned}Tx' &= (u - x') \\Ty &= z_0 K(u - x') + z_1 Tx \\x^{(0)} &= u \\y^{(0)} &= 0\end{aligned}$$

where z_0 is a flag array for the greater-than-zero elements, and z_1 is that for the less-than or equal-to zero elements.

```
class andes.core.block.LeadLag (u, T1, T2, K=1, zero_out=True, name=None,  
                                tex_name=None, info=None)
```

Lead-Lag transfer function block in series implementation.

$$u \rightarrow \left[K \frac{1 + sT1}{1 + sT2} \right] \rightarrow y$$

Exports two variables: internal state x and output algebraic variable y .

Parameters

T1

[BaseParam] Time constant 1

T2

[BaseParam] Time constant 2

zero_out

[bool] True to allow zeroing out lead-lag as a pass through (when $T1=T2=0$)

Notes

To allow zeroing out lead-lag as a pure gain, set `zero_out` to *True*.

define()

Notes

Implemented equations and initial values

$$\begin{aligned}
 T_2 \dot{x}' &= (u - x') \\
 T_2 y &= K T_1 (u - x') + K T_2 x' + E_2, \text{ where} \\
 E_2 &= \begin{cases} (y - K x') & \text{if } T_1 = T_2 = 0 \& \text{zero_out} = \text{True} \\ 0 & \text{otherwise} \end{cases} \\
 x'^{(0)} &= u \\
 y^{(0)} &= K u
 \end{aligned}$$

class `andes.core.block.LeadLagLimit` (*u, T1, T2, lower, upper, name=None, tex_name=None, info=None*)

Lead-Lag transfer function block with hard limiter (series implementation).

$$u \rightarrow \left[\begin{array}{c} 1 + sT_1 \\ 1 + sT_2 \end{array} \right] \rightarrow \frac{\text{ynl}}{\text{lower}} \xrightarrow{\text{upper}} y$$

Exports four variables: state *x*, output before hard limiter *ynl*, output *y*, and AntiWindup *lim*.

define()

Notes

Implemented control block equations (without limiter) and initial values

$$\begin{aligned}
 T_2 \dot{x}' &= (u - x') \\
 T_2 y &= T_1 (u - x') + T_2 x' \\
 x'^{(0)} &= y^{(0)} = u
 \end{aligned}$$

Second Order

class andes.core.block.Lag2ndOrd (*u, K, T1, T2, name=None, tex_name=None, info=None*)

Second order lag transfer function (low-pass filter).



Exports one two state variables (x, y), where y is the output.

Parameters

u

Input

K

Gain

T1

First order time constant

T2

Second order time constant

define ()

Notes

Implemented equations and initial values are

$$T_2 \dot{x} = Ku - y - T_1 x$$

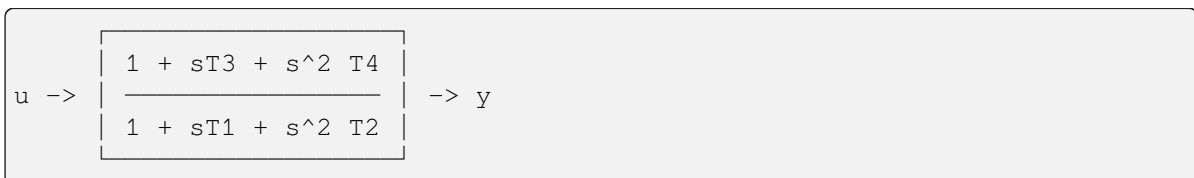
$$\dot{y} = x$$

$$x^{(0)} = 0$$

$$y^{(0)} = Ku$$

class andes.core.block.LeadLag2ndOrd (*u, T1, T2, T3, T4, zero_out=False, name=None, tex_name=None, info=None*)

Second-order lead-lag transfer function block.



Exports two internal states ($x1$ and $x2$) and output algebraic variable y .

The current implementation allows any or all parameters to be zero. Four LessThan blocks are used to check if the parameter values are all zero. If yes, $y = u$ will be imposed in the algebraic equation.

```
define()
```

Notes

Implemented equations and initial values are

$$\begin{aligned}
 T_2 \dot{x}_1 &= u - x_2 - T_1 x_1 \\
 \dot{x}_2 &= x_1 \\
 T_2 y &= T_2 x_2 + T_2 T_3 x_1 + T_4 (u - x_2 - T_1 x_1) + E_2, \text{ where} \\
 E_2 &= \begin{cases} (y - x_2) & \text{if } T_1 = T_2 = T_3 = T_4 = 0 \& \text{zero_out} = \text{True} \\ 0 & \text{otherwise} \end{cases} \\
 x_1^{(0)} &= 0 \\
 x_2^{(0)} = y^{(0)} &= u
 \end{aligned}$$

PI Controllers

```
class andes.core.block.PIController(u, kp, ki, ref=0.0, x0=0.0, name=None,
                                     tex_name=None, info=None)
```

Proportional Integral Controller.

The controller takes an error signal as the input. It takes an optional *ref* signal, which will be subtracted from the input.

Parameters

u

[BaseVar] The input variable instance

kp

[BaseParam] The proportional gain parameter instance

ki

[[type]] The integral gain parameter instance

```
define()
```

Define equations for the PI Controller.

Notes

One state variable *xi* and one algebraic variable *y* are added.

Equations implemented are

$$\begin{aligned}
 \dot{x}_i &= k_i * (u - ref) \\
 y &= x_i + k_p * (u - ref)
 \end{aligned}$$

```
class andes.core.block.PIAWHardLimit (u, kp, ki, aw_lower, aw_upper, lower, upper,  
                                     no_lower=False, no_upper=False, ref=0.0, x0=0.0,  
                                     name=None, tex_name=None, info=None)
```

PI controller with anti-windup limiter on the integrator and hard limit on the output.

Limits `lower` and `upper` are on the final output, and `aw_lower` `aw_upper` are on the integrator.

```
define ()
```

Define equations for the PI Controller.

Notes

One state variable `xi` and one algebraic variable `y` are added.

Equations implemented are

$$\begin{aligned}\dot{x}_i &= k_i * (u - ref) \\ y &= x_i + k_p * (u - ref)\end{aligned}$$

```
class andes.core.block.PITrackAW (u, kp, ki, ks, lower, upper, no_lower=False,  
                                  no_upper=False, ref=0.0, x0=0.0, name=None,  
                                  tex_name=None, info=None)
```

PI with tracking anti-windup limiter

```
define ()
```

Function for setting the initialization and equation strings for internal variables. This method must be implemented by subclasses.

The equations should be written with the "final" variable names. Let's say the block instance is named `blk` (kept at `self.name` of the block), and an internal variable `v` is defined. The internal variable will be captured as `blk_v` by the parent model. Therefore, all equations should use `{self.name}_v` to represent variable `v`, where `{self.name}` is the name of the block at run time.

On the other hand, the names of externally provided parameters or variables are obtained by directly accessing the `name` attribute. For example, if `self.T` is a parameter provided through the block constructor, `{self.T.name}` should be used in the equation.

See also:

PIController.define

Equations for the PI Controller block

Examples

An internal variable v has a trivial equation $T = v$, where T is a parameter provided to the block constructor.

In the model, one has

```
class SomeModel():
    def __init__(...):
        self.input = Algeb()
        self.T = Param()

        self.blk = ExampleBlock(u=self.input, T=self.T)
```

In the ExampleBlock function, the internal variable is defined in the constructor as

```
class ExampleBlock():
    def __init__(...):
        self.v = Algeb()
        self.vars = {'v', self.v}
```

In the define, the equation is provided as

```
def define(self):
    self.v.v_str = '{self.T.name}'
    self.v.e_str = '{self.T.name} - {self.name}_v'
```

In the parent model, v from the block will be captured as blk_v , and the equation will evaluate into

```
self.blk_v.v_str = 'T'
self.blk_v.e_str = 'T - blk_v'
```

```
class andes.core.block.PIFreeze(u, kp, ki, freeze, ref=0.0, x0=0.0, name=None,
                                tex_name=None, info=None)
```

PI controller with state freeze.

Freezes state when the corresponding *freeze* == 1.

Notes

Tested in *experimental.TestPITrackAW.PIFreeze*.

define()

Notes

One state variable x_i and one algebraic variable y are added.

Equations implemented are

$$\begin{aligned}\dot{x}_i &= k_i * (u - ref) \\ y &= (1 - freeze) * (x_i + k_p * (u - ref)) + freeze * y\end{aligned}$$

```
class andes.core.block.PITrackAWFreeze (u, kp, ki, ks, lower, upper, freeze, no_lower=False,
                                         no_upper=False, ref=0.0, x0=0.0, name=None,
                                         tex_name=None, info=None)
```

PI controller with tracking anti-windup limiter and state freeze.

define()

Function for setting the initialization and equation strings for internal variables. This method must be implemented by subclasses.

The equations should be written with the "final" variable names. Let's say the block instance is named *blk* (kept at `self.name` of the block), and an internal variable *v* is defined. The internal variable will be captured as `blk_v` by the parent model. Therefore, all equations should use `{self.name}_v` to represent variable *v*, where `{self.name}` is the name of the block at run time.

On the other hand, the names of externally provided parameters or variables are obtained by directly accessing the `name` attribute. For example, if `self.T` is a parameter provided through the block constructor, `{self.T.name}` should be used in the equation.

See also:

PIController.define

Equations for the PI Controller block

Examples

An internal variable *v* has a trivial equation $T = v$, where *T* is a parameter provided to the block constructor.

In the model, one has

```
class SomeModel():
    def __init__(...):
        self.input = Algeb()
        self.T = Param()

        self.blk = ExampleBlock(u=self.input, T=self.T)
```

In the `ExampleBlock` function, the internal variable is defined in the constructor as


```
class ExampleBlock():
    def __init__(...):
        self.v = Algeb()
        self.vars = {'v', self.v}
```

In the define, the equation is provided as

```
def define(self):
    self.v.v_str = '{self.T.name}'
    self.v.e_str = '{self.T.name} - {self.name}_v'
```

In the parent model, v from the block will be captured as blk_v, and the equation will evaluate into

```
self.blk_v.v_str = 'T'
self.blk_v.e_str = 'T - blk_v'
```

```
class andes.core.block.PIDController(u, kp, ki, kd, Td, name, ref=0.0, x0=0.0,
                                     tex_name=None, info=None)
```

Proportional Integral Derivative Controller.

$$u \rightarrow \left[kp + \frac{ki}{s} + \frac{skd}{1 + sTd} \right] \rightarrow y$$

The controller takes an error signal as the input. It takes an optional `ref` signal, which will be subtracted from the input.

The name is suggested to be specified the same as the instance name.

This block assembles a `PIDController` and a `Washout`.

Parameters

u

[BaseVar] The input variable instance

kp

[BaseParam] The proportional gain parameter instance

ki

[BaseParam] The integral gain parameter instance

kd

[BaseParam] The derivative gain parameter instance

Td

[BaseParam] The derivative time constant parameter instance

define()

Define equations for the PID Controller.

Notes

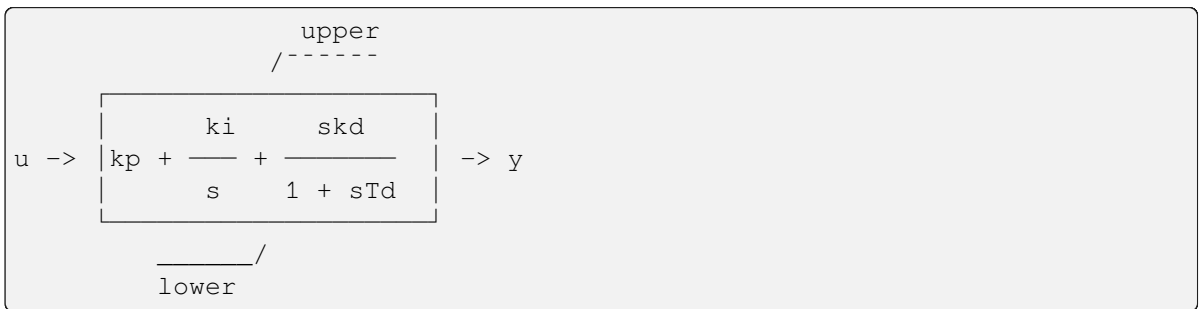
One `PIController` `PIC`, one `Washout` `xd`, and one algebraic variable `y` are added.

Equations implemented are

$$\begin{aligned} \dot{x}_i &= k_i * (u - ref) \\ xd &= Washout(u - ref)y \\ &= x_i + k_p * (u - ref) + xd \end{aligned}$$

```
class andes.core.block.PIDAWHardLimit (u, kp, ki, kd, Td, aw_lower, aw_upper, lower,
upper, name, no_lower=False, no_upper=False,
ref=0.0, x0=0.0, tex_name=None, info=None)
```

PID controller with anti-windup limiter on the integrator and hard limit on the output.



The controller takes an error signal as the input.

Limits `lower` and `upper` are on the final output, and `aw_lower` `aw_upper` are on the integrator.

The name is suggested to be specified the same as the instance name.

Parameters

u

[BaseVar] The input variable instance

kp

[BaseParam] The proportional gain parameter instance

ki

[BaseParam] The integral gain parameter instance

kd

[BaseParam] The derivative gain parameter instance

Td

[BaseParam] The derivative time constant parameter instance

define()

Define equations for the PI Controller.

Notes

One state variable x_i and one algebraic variable y are added.

Equations implemented are

$$\begin{aligned} \dot{x}_i &= k_i * (u - ref) \\ y &= x_i + k_p * (u - ref) \end{aligned}$$

```
class andes.core.block.PIDTrackAW(u, kp, ki, kd, Td, ks, lower, upper, no_lower=False,  
                                no_upper=False, ref=0.0, x0=0.0, name=None,  
                                tex_name=None, info=None)
```

PID with tracking anti-windup limiter

define()

Function for setting the initialization and equation strings for internal variables. This method must be implemented by subclasses.

The equations should be written with the "final" variable names. Let's say the block instance is named *blk* (kept at `self.name` of the block), and an internal variable *v* is defined. The internal variable will be captured as `blk_v` by the parent model. Therefore, all equations should use `{self.name}_v` to represent variable *v*, where `{self.name}` is the name of the block at run time.

On the other hand, the names of externally provided parameters or variables are obtained by directly accessing the `name` attribute. For example, if `self.T` is a parameter provided through the block constructor, `{self.T.name}` should be used in the equation.

See also:

PIController.define

Equations for the PI Controller block

Examples

An internal variable *v* has a trivial equation $T = v$, where *T* is a parameter provided to the block constructor.

In the model, one has

```
class SomeModel():  
    def __init__(...)  
        self.input = Algeb()  
        self.T = Param()  
  
        self.blk = ExampleBlock(u=self.input, T=self.T)
```

In the `ExampleBlock` function, the internal variable is defined in the constructor as

```
class ExampleBlock():
    def __init__(...):
        self.v = Algeb()
        self.vars = {'v', self.v}
```

In the define, the equation is provided as

```
def define(self):
    self.v.v_str = '{self.T.name}'
    self.v.e_str = '{self.T.name} - {self.name}_v'
```

In the parent model, v from the block will be captured as blk_v, and the equation will evaluate into

```
self.blk_v.v_str = 'T'
self.blk_v.e_str = 'T - blk_v'
```

3.9.3 Saturation

```
class andes.models.exciter.ExcExpSat (E1, SE1, E2, SE2, name=None, tex_name=None,
                                     info=None)
```

Exponential exciter saturation block to calculate A and B from E1, SE1, E2 and SE2. Input parameters will be corrected and the user will be warned. To disable saturation, set either E1 or E2 to 0.

Parameters

E1

[BaseParam] First point of excitation field voltage

SE1: BaseParam

Coefficient corresponding to E1

E2

[BaseParam] Second point of excitation field voltage

SE2: BaseParam

Coefficient corresponding to E2

```
define()
```

Notes

The implementation solves for coefficients A and B which satisfy

$$E_1 S_{E1} = A e^{E_1 \times B} E_2 S_{E2} = A e^{E_2 \times B}$$

The solutions are given by

$$E_1 S_{E1} e^{\frac{E_1 \log \left(\frac{E_2 S_{E2}}{E_1 S_{E1}} \right)}{E_1 - E_2}} - \frac{\log \left(\frac{E_2 S_{E2}}{E_1 S_{E1}} \right)}{E_1 - E_2}$$

3.9.4 Naming Convention

We loosely follow a naming convention when using modeling blocks. An instance of a modeling block is named with a two-letter acronym, followed by a number or a meaningful but short variable name. The acronym and the name are spelled in one word without underscore, as the output of the block already contains `_y`.

For example, two washout filters can be names `WO1` and `WO2`. In another case, a first-order lag function for voltage sensing can be called `LGv`, or even `LG` if there is only one Lag instance in the model.

Naming conventions are not strictly enforced. Expressiveness and concision are encouraged.

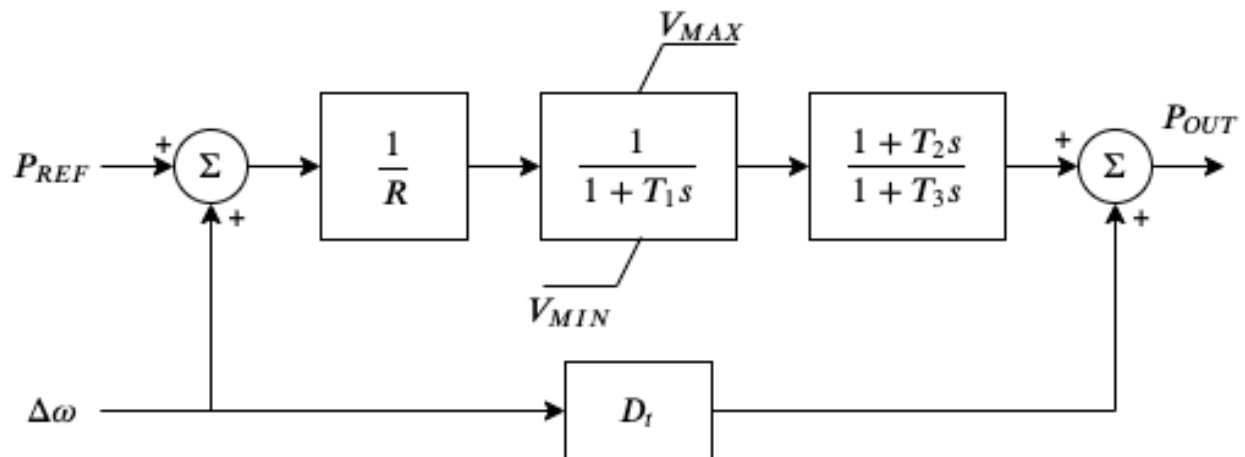
3.10 Examples

We show two examples to demonstrate modeling from equations and modeling from control block diagrams.

- The `TGOV1` example shows code snippet for equation-based modeling and, as well as code for block-based modeling.
- The `IEEEEST` example walks through the source code and explains the complete setup, including optional parameters, input selection, and manual per-unit conversion.

3.10.1 TGOV1

The *TGOV1* turbine governor model is shown as a practical example using the library.



This model is composed of a lead-lag transfer function and a first-order lag transfer function with an anti-windup limiter, which are sufficiently complex for demonstration. The corresponding differential equations

and algebraic equations are given below.

$$\begin{bmatrix} \dot{x}_{LG} \\ \dot{x}_{LL} \end{bmatrix} = \begin{bmatrix} z_{i,lim}^{LG} (P_d - x_{LG}) / T_1 \\ (x_{LG} - x_{LL}) / T_3 \end{bmatrix}$$

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} (1 - \omega) - \omega_d \\ R \times \tau_{m0} - P_{ref} \\ (P_{ref} + \omega_d) / R - P_d \\ D_t \omega_d + y_{LL} - P_{OUT} \\ \frac{T_2}{T_3} (x_{LG} - x_{LL}) + x_{LL} - y_{LL} \\ u (P_{OUT} - \tau_{m0}) \end{bmatrix}$$

where LG and LL denote the lag block and the lead-lag block, \dot{x}_{LG} and \dot{x}_{LL} are the internal states, y_{LL} is the lead-lag output, ω the generator speed, ω_d the generator under-speed, P_d the droop output, τ_{m0} the steady-state torque input, and P_{OUT} the turbine output that will be summed at the generator.

The code to describe the above model using equations is given below. The complete code can be found in class `TGOV1ModelAlt` in `andes/models/governor.py`.

```
def __init__(self, system, config):
    # 1. Declare parameters from case file inputs.
    self.R = NumParam(info='Turbine governor droop',
                      non_zero=True, ipower=True)
    # Other parameters are omitted.

    # 2. Declare external variables from generators.
    self.omega = ExtState(src='omega',
                          model='SynGen',
                          indexer=self.syn,
                          info='Generator speed')
    self.tm = ExtAlgeb(src='tm',
                      model='SynGen',
                      indexer=self.syn,
                      e_str='u*(pout-tm0)',
                      info='Generator torque input')

    # 3. Declare initial values from generators.
    self.tm0 = ExtService(src='tm',
                          model='SynGen',
                          indexer=self.syn,
                          info='Initial torque input')

    # 4. Declare variables and equations.
    self.pref = Algeb(info='Reference power input',
                     v_str='tm0*R',
                     e_str='tm0*R-pref')
    self.wd = Algeb(info='Generator under speed',
                    e_str='(1-omega)-wd')
    self.pd = Algeb(info='Droop output',
                    v_str='tm0',
                    e_str='(wd+pref)/R-pd')
    self.LG_x = State(info='State in the lag TF',
                      v_str='pd',
```

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```

        e_str='LG_lim_zi*(pd-LG_x)/T1')
self.LG_lim = AntiWindup(u=self.LG_x,
                        lower=self.VMIN,
                        upper=self.VMAX)
self.LL_x = State(info='State in the lead-lag TF',
                 v_str='LG_x',
                 e_str='(LG_x-LL_x)/T3')
self.LL_y = Algeb(info='Lead-lag Output',
                 v_str='LG_x',
                 e_str='T2/T3*(LG_x-LL_x)+LL_x-LL_y')
self.pout = Algeb(info='Turbine output power',
                 v_str='tm0',
                 e_str='(LL_y+Dt*wd)-pout')

```

Another implementation of *TGOV1* makes extensive use of the modeling blocks. The resulting code is more readable as follows.

```

def __init__(self, system, config):
    TGBase.__init__(self, system, config)

    self.gain = ConstService(v_str='u/R')

    self.pref = Algeb(info='Reference power input',
                     tex_name='P_{ref}',
                     v_str='tm0 * R',
                     e_str='tm0 * R - pref',
                     )

    self.wd = Algeb(info='Generator under speed',
                   unit='p.u.',
                   tex_name=r'\omega_{dev}',
                   v_str='0',
                   e_str='(wref - omega) - wd',
                   )

    self.pd = Algeb(info='Pref plus under speed times gain',
                   unit='p.u.',
                   tex_name="P_d",
                   v_str='u * tm0',
                   e_str='u*(wd + pref + paux) * gain - pd')

    self.LAG = LagAntiWindup(u=self.pd,
                             K=1,
                             T=self.T1,
                             lower=self.VMIN,
                             upper=self.VMAX,
                             )

    self.LL = LeadLag(u=self.LAG_y,
                     T1=self.T2,
                     T2=self.T3,
                     )

```

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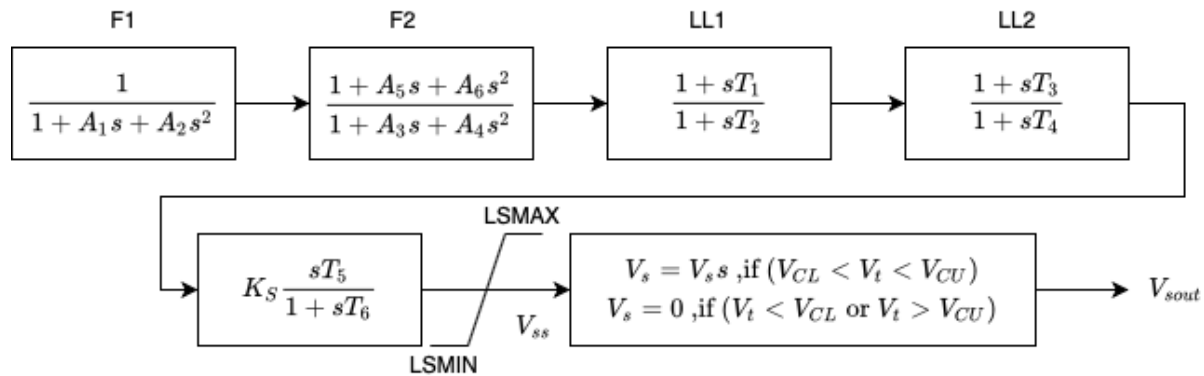
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```
self.pout.e_str = '(LL_y + Dt * wd) - pout'
```

The complete code can be found in class `TGOV1Model` in `andes/models/governor.py`.

3.10.2 IEEEEST

In this example, we will explain step-by-step how *IEEEEST* is programmed. The block diagram of IEEEEST is given as follows. We recommend you to open up the source code in `andes/models/pss.py` and then continue reading.



First of all, modeling components are imported at the beginning.

Next, `PSSBaseData` is defined to hold parameters shared by all PSSs. `PSSBaseData` inherits from `ModelData` and calls the base constructor. There is only one field `avr` defined for the linked exciter idx.

Then, `IEEEESTData` defines the input parameters for IEEEEST. Use `IdxParam` for fields that store idx-es of devices that IEEEEST devices link to. Use `NumParam` for numerical parameters.

PSSBase

`PSSBase` is defined for the common (external) parameters, services and variables shared by all PSSs. The class and constructor signatures are

```
class PSSBase(Model):
    def __init__(self, system, config):
        super().__init__(system, config)
```

`PSSBase` inherits from `Model` and calls the base constructor. Note that the call to `Model`'s constructor takes two positional arguments, `system` and `config` of types `System` and `ModelConfig`. Next, the group is specified, and the model flags are set.

Note: It is important to set the TDS flag to register the model. If not set, data for the model will be successfully loaded, but the variables in the model will not receive any address, and the model equations will be skipped.

There is a similar flag `self.flags.pflow` for models to participate in power flow calculations. Most dynamic models, however, are initialized after power flow.

```
self.group = 'PSS'
self.flags.tds = True
```

Next, `Replace` is used to replace input parameters that satisfy a lambda function with new values.

```
self.VCUr = Replace(self.VCU, lambda x: np.equal(x, 0.0), 999)
self.VCLr = Replace(self.VCL, lambda x: np.equal(x, 0.0), -999)
```

The value replacement happens when `VCUr` and `VCLr` is first accessed. `Replace` is executed in the model initialization phase (at the end of services update).

Next, the indices of connected generators, buses, and bus frequency measurements are retrieved. Synchronous generator `idx` is retrieved with

```
self.syn = ExtParam(model='Exciter', src='syn', indexer=self.avr,
    ↳export=False,
                        info='Retrieved generator idx', vtype=str)
```

Using the retrieved `self.syn`, it retrieves the buses to which the generators are connected.

```
self.bus = ExtParam(model='SynGen', src='bus', indexer=self.syn, export=False,
    info='Retrieved bus idx', vtype=str, default=None,
    )
```

PSS models support an optional remote bus specified through parameter `busr`. When `busr` is `None`, the generator-connected bus should be used. The following code uses `DataSelect` to select `busr` if available but falls back to `bus` otherwise.

```
self.buss = DataSelect(self.busr, self.bus, info='selected bus (bus or busr)')
```

Each PSS links to a bus frequency measurement device. If the input data does not specify one or the specified one does not exist, `DeviceFinder` can find the correct measurement device for the bus where frequency measurements should be taken.

```
self.busfreq = DeviceFinder(self.busf, link=self.buss, idx_name='bus')
```

where `busf` is the optional frequency measurement device `idx`, `buss` is the bus `idx` for which measurement device needs to be found or created.

Next, external parameters, variables and services are retrieved. Note that the PSS output `vsout` is pre-allocated but the equation string is left to specific models.

IEEEESTModel

IEEEESTModel inherits from PSSBase and adds specific model components. After calling PSSBase's constructor, IEEEESTModel adds config entries to allow specifying the model for frequency measurement, because there may be multiple frequency measurement models in the future.

```
self.config.add(OrderedDict([('freq_model', 'BusFreq')]))
self.config.add_extra('_help', {'freq_model': 'default freq. measurement model
↪'})
self.config.add_extra('_alt', {'freq_model': ('BusFreq',)})
```

We set the chosen measurement model to busf so that DeviceFinder knows which model to use if it needs to create new devices.

```
self.busf.model = self.config.freq_model
```

Next, because bus voltage is an algebraic variable, we use Derivative to calculate the finite difference to approximate its derivative.

```
self.dv = Derivative(self.v, tex_name='dV/dt', info='Finite difference of bus_
↪voltage')
```

Then, we retrieve the coefficient to convert power from machine base to system base using ConstService, given by S_b / S_n . This is needed for input mode 3, electric power in machine base.

```
self.SnSb = ExtService(model='SynGen', src='M', indexer=self.syn, attr='pu_
↪coeff',
                        info='Machine base to sys base factor for power',
                        tex_name='(Sb/Sn)')
```

Note that the ExtService access the `pu_coeff` field of the `M` variables of synchronous generators. Since `M` is a machine-base power quantity, `M.pu_coeff` stores the multiplication coefficient to convert each of them from machine bases to the system base, which is S_b / S_n .

The input mode is parsed into boolean flags using Switcher:

```
self.SW = Switcher(u=self.MODE,
                   options=[0, 1, 2, 3, 4, 5, 6],
                   )
```

where the input `u` is the `MODE` parameter, and `options` is a list of accepted values. Switcher boolean arrays `s0, s1, ..., sN`, where $N = \text{len}(\text{options}) - 1$. We added 0 to `options` for padding so that `SW_s1` corresponds to `MODE 1`. It improves the readability of the code as we will see next.

The input signal `sig` is an algebraic variable given by

```
self.sig = Algeb(tex_name='S_{ig}',
                 info='Input signal',
                 )

self.sig.v_str = 'SW_s1*(omega-1) + SW_s2*0 + SW_s3*(tm0/SnSb) + ' \
                 'SW_s4*(tm-tm0) + SW_s5*v + SW_s6*0'
```

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```
self.sig.e_str = 'SW_s1*(omega-1) + SW_s2*(f-1) + SW_s3*(te/SnSb) + ' \
                'SW_s4*(tm-tm0) + SW_s5*v + SW_s6*dv_v - sig'
```

The `v_str` and `e_str` are separated from the constructor to improve readability. They construct piece-wise functions to select the correct initial values and equations based on mode. For any variables in `v_str`, they must be defined before `sig` so that they will be initialized ahead of `sig`. Clearly, `omega`, `tm`, and `v` are defined in `PSSBase` and thus come before `sig`.

The following comes the most effective part: modeling using transfer function blocks. We utilized several blocks to describe the model from the diagram. Note that the output of a block is always the block name followed by `_y`. For example, the input of `F2` is the output of `F1`, given by `F1_y`.

```
self.F1 = Lag2ndOrd(u=self.sig, K=1, T1=self.A1, T2=self.A2)

self.F2 = LeadLag2ndOrd(u=self.F1_y, T1=self.A3, T2=self.A4,
                       T3=self.A5, T4=self.A6, zero_out=True)

self.LL1 = LeadLag(u=self.F2_y, T1=self.T1, T2=self.T2, zero_out=True)

self.LL2 = LeadLag(u=self.LL1_y, T1=self.T3, T2=self.T4, zero_out=True)

self.Vks = Gain(u=self.LL2_y, K=self.KS)

self.WO = WashoutOrLag(u=self.Vks_y, T=self.T6, K=self.T5, name='WO',
                      zero_out=True) # WO_y == Vss

self.VLIM = Limiter(u=self.WO_y, lower=self.LSMIN, upper=self.LSMAX,
                    info='Vss limiter')

self.Vss = Algeb(tex_name='V_{ss}', info='Voltage output before output limiter
→',
                 e_str='VLIM_zi * WO_y + VLIM_zu * LSMAX + VLIM_zl * LSMIN -
→Vss')

self.OLIM = Limiter(u=self.v, lower=self.VCLr, upper=self.VCUr,
                    info='output limiter')

self.vsout.e_str = 'OLIM_zi * Vss - vsout'
```

In the end, the output equation is assigned to `vsout.e_str`. It completes the equations of the IEEEEST model.

Finalize

Assemble IEEEESTData and IEEEESTModel into IEEEEST:

```
class IEEEEST(IEEEESTData, IEEEESTModel):
    def __init__(self, system, config):
        IEEEESTData.__init__(self)
        IEEEESTModel.__init__(self, system, config)
```

Locate and edit the file `andes/models/__init__.py`. The variable `file_classes` is a list of tuples that stores the source file and class names in strings. In each tuple, the first element is the `.py` file name in the `models` folder, and the second element is a list of class names to be imported from that file.

Find the line with `pss`, then add `IEEEEST` to the corresponding list of model names. The line will look like

```
file_classes = list([
    ...
    ('pss', ['IEEEEST', 'ST2CUT']),
    ...
])
```

Note in the above that the string `'IEEEEST'` is used. The line above is valid as long as `from andes.models.pss import IEEEEST` is valid. If the source file name does not exist in any line of `file_classes`, one may add it after all prerequisite models. For example, the `pss` line should be added after `exciters` (and `generators`, of course).

Finally, locate `andes/models/group.py`, check if the class `PSS` exist. It needs to match the group name of `IEEEEST`. If not, create one by inheriting from `GroupBase`:

```
class PSS(GroupBase):
    """Power system stabilizer group."""

    def __init__(self):
        super().__init__()
        self.common_vars.extend(('vsout',))
```

where we added `vsout` to the `common_vars` list. All models in the `PSS` group must have a variable named `vsout`, which is defined in `PSSBase`.

This completes the `IEEEEST` model. When developing new models, use `andes prepare` to generate numerical code and start debugging.

RELEASE NOTES

The APIs before v3.0.0 are in beta and may change without prior notice.

4.1 v1.9 Notes

4.1.1 v1.3.1 (2024-02-04)

This is a hotfix to pass `pip check` for KVOPT version.

4.1.2 v1.9.0 (2024-02-01)

- Initially, `dae.t` is set to `-1.0` during power flow calculation. TDS initialization will set `dae.t = 0.0`.
- Rewritten the islanding detection algorithm.
- In `system.py`, import `importlib.util` to workaround unexported `util` module in Python 3.10.

4.2 v1.8 Notes

4.2.1 v1.8.10 (2023-08-10)

- An internal change to the `xlsx` parser option. Previously, the index column was set to 0, which assumes the existence of `uid` as the header. Manually input sheets without `uid` will fail. This version unsets the index column when using `pandas` to parse the `xlsx` file.
- `Jumper` is included for connectivity check.
- Add curly brackets for LaTeX symbols from sub-blocks. Nested symbols with subscripts and superscripts now display properly.

4.2.2 v1.8.9 (2023-06-22)

- Fix *Model.alter()* for parameters that are time constants for differential equations. Altered time constants are now properly updated in `dae.Tf` and will be correctly reflected in simulation results.
- Fix a bug in connectivity check.
- Support numba for Python 3.11.

4.2.3 v1.8.8 (2023-04-24)

- Repository transferred to *github.com/curent/andes*.
- Fix for frequency-dependent load model `FLoad` by not exporting the external *bus* parameter.

4.2.4 v1.8.7 (2023-03-10)

- Added IEEE 39-bus test case with dynamics in the ANDES `xlsx` format. Contributed by @jinningwang.
- In *interop.pandapower*, the `_verify_pf` function will not be called if TDS has been initialized. This prevents the breaking of variable addresses.

4.2.5 v1.8.6 (2023-02-13)

- Minor fix in *timeseries.py* for backward compatibility with Python 3.6.

4.2.6 v1.8.5 (2022-12-22)

- Fixed an issue to properly handle turning off a `Jumper`.
- New interface to GridCal by @JosepFanals. GridCal installation required.
- Bug fixes in WTARA1.

4.2.7 v1.8.4 (2022-11-23)

- Fixed a bug in time stepping where step sizes were not properly reduced when the solver failed to converge.

4.2.8 v1.8.3 (2022-11-15)

- Support Python 3.11. The average performance gain is a few percent.
- Made `numba` an optional dependency because it does not yet support Python 3.11.
- Fixes a bug in the time stepping logic that causes resumed simulations to overwrite the result of the previous final step.

4.2.9 v1.8.2 (2022-10-30)

This is a minor release to support SymPy 1.11.x.

Internally, `ModelData` contains a new member field `index_bases` to record the variables by which other variables are indexed. Most variables, by default, are indexed by `idx`. Some models (such as COI) whose device can link to multiple other devices can have multiple index bases.

Index bases are currently placeholders and have not been used in the current version.

4.2.10 v1.8.1 (2022-09-24)

- New turbine governor model *HYGOV4*. Thanks to Zaid Mahmood for the contribution.
- Bug fixes to saving data to `xlsx` file.

4.2.11 v1.8.0 (2022-08-30)

- Internal change: drop the support for reloading generated code from `calls.pkl`. All generated code are serialized into Python files and reloaded as a `pycode` module.
- Fix an issue where cases in multiprocessing fail to serialize due to not being able to find `pycode`. `pycode` is now properly imported by the main process.
- When one needs to serialize a `System` object, such as during multiprocessing, one needs to manually import `pycode`. This can be done by calling `andes.system.import_pycode()`.
- Internal change: serializing with `dill` is not set to recursive by default.

4.3 v1.7 Notes

4.3.1 v1.7.8 (2022-08-24)

- Support marking tests as extra so that they are not run by default. The function names for extra tests should contain `extra_test`. To run all tests, use `andes st -e` or `andes selftest --extra`.
- Add the `new_A` flag for sparse solvers to trigger actions. Currently, only the `spsolve` solver will need to rebuild and refactorize the sparse matrix.

4.3.2 v1.7.7 (2022-08-02)

- Implemented a chattering detection and stop algorithm by increasing the step size when chattering is detected.
- `TimeSeries.get_data()` works for systems with `Output`.
- Allow freezing states associated with anti-windup limiters after a certain number of iterations to prevent chattering.

Models:

- New exciter models: `ESDC1A`, `EXAC2`.
- New grid-forming inverter models: `REGF1`, `REGF2`, `REGF3`.
- For `IEEEG1`, normalize `K1` through `K8` if they do not sum up to 1.0

4.3.3 v1.7.6 (2022-07-11)

- In eigenvalue analysis, added parameter sweeping and scatter plot for root loci. See revised Example 4.
- Documentation improvements.

4.3.4 v1.7.5 (2022-07-05)

- Added *Fortescue* model to support symmetric component calculation. The model allows interfacing a positive-sequence bus with three buses representing three phases. See the model description for details.
- Added *PLL2* for the Synchronously-rotating Reference Frame (SRF)-based PLL.
- *REGCP1* works identically to *REGCA1* when the *pll* parameter is empty and works with a PLL.
- *REECA1* is updated to work with *vd* of the converter. If using the *REGCA1* model, $vd = v$.
- Reverted a change in *Line* parameter that caused SMIB case to crash.

4.3.5 v1.7.4 (2022-07-01)

- Renamed model *Toggler* to *Toggle*.
- New model: *ESAC5A*. (Contributed by Ahmad Ali).
- Added documentation for creating disturbances.
- Updated documentation for modeling blocks.

4.3.6 v1.7.3 (2022-06-25)

Bug fix:

- Fix *Ipcmd* initialization equation of *REGCAI*.

Improved the interface to pandapower:

- Improved `to_pandapower` performance using vectorized conversion.
- Enhanced `make_link_table` to include group `RenGen`.

4.3.7 v1.7.2 (2022-06-07)

- Improved documentation and examples.

4.3.8 v1.7.1 (2022-05-31)

This release contains minor fixes to the documentation.

Other changes:

- In `PVD1`, Enable *pmx* limiting by default.
- In `ST2CUT`, fix the type of `busr2` and `busr` to `IdxParam`.

4.3.9 v1.7.0 (2022-05-22)

Allow incrementally offloading simulation data from memory to the output file:

- `[TDS].limit_store` is a boolean value to enable the limit for in-memory time-series storage. If set to 1, data will be offloaded to the `npz` file every `[TDS].max_store` steps. Offloaded data will then be erased from memory.
- If you need to interact with the time-series data in memory, you need to keep `[TDS].limit_store` to 0.

Allow specifying models, variables, and/or devices to output:

- See [Output](#). The *model* field is mandatory. Leaving *varname* or *dev* blank indicates the selection of all applicable elements. For example, specifying *model* and *varname* without *dev* means that the variable for all devices will be exported.
- Plot tool works with in-memory time-series data specified by `Output`.

Simulation output control:

- Allow controlling the save frequency for output data in `[TDS].save_every`. The default value is 1, which means that every step will be saved. Setting it to 4, for example, will save data every four steps. This setting applies to the in-memory storage and the output data file.
- Setting `save_every = 0` will immediately discard all data after each simulation step.

- Added the option `[TDS].save_mode` to change the automatic simulation data dumping to manual. Accepted values are `auto` and `manual`. This option shall only be adjusted to `manual` when one is manually stepping the simulation and wants to avoid writing to the output file when the simulation reaches `TDS.config.tf`. One will need to call `TDS.save_output()` when the full simulation concludes to avoid losing unsaved data.

Other changes:

- Fix the initialization of offline synchronous generators.
- Allow styles to be set for plots using the argument `style`. To generate figures for IEEE publications, use `style=ieee` (require package `scienceplots`).
- Moved the writing of the `lst` file to the first step of simulation.
- `andes misc -C` will not remove `_out.csv` file as it is considered data for post-processing just like exported figures.

4.4 v1.6 Notes

4.4.1 v1.6.6 (2022-04-30)

- Rename `[System] call_stats` to `[System] save_stats` for clarity. If turned on, one can retrieve statistics of function calls in `TDS.call_stats`.
- Store routine execution time to routine member `execution_time`.
- Fix PSS/E parsing issues with *GAST*.
- Fix issues and update default parameters for *REGCV1* and *REGCV2*.
- Allow adjusting limits for state variables during initialization. Like for algebraic variables, the default setting automatically adjusts the upper limit but not the lower one.

4.4.2 v1.6.5 (2022-04-19)

- Added a TDS stop criteria based on rotor angle separation with reference to Power System Analysis Toolbox.
- Fix a bug for snapshot save and load. It now supports writing to and reading from `io.BytesIO()`.

4.4.3 v1.6.4 (2022-04-17)

Breaking change:

- PV model no longer has `p` as a variable in the DAE. `p` copies the value of `p0`. This change affects the addresses of variables.
- Changed `models.file_classes` to a list to improve the control over the class initialization sequence in the same package.

Operator splitting for internal algebraic variables:

- `VarService` can be evaluated model-internal algebraic variables outside the DAE system. This approach is known as operator splitting and is commonly used in other simulation tools.
- Operator splitting reduces the size of the DAE system but introduces a one-iteration lag between the internal algebraic variables and others in the DAE system.
- `VarService` shall be avoided for singular functions (non-continuous) and shall not be adopted to circumvent initializing algebraic equations.
- `VarService` takes an argument `sequential`, which is `True` by default. Non-sequential `VarService` shall not depend on other `VarService` calculated at the same step as they will be evaluated simultaneously.
- `andes.interop.pandapower.to_pandapower()` set all generators as controllable by default. Generators in converted the pandapower case are named using the `idx` of `StaticGen`.
- Bug fixes in `interop.pandapower.make_link_table()`.

Other changes:

- Added a new service type `andes.core.service.SubsService` for temporary symbols that will be substituted at code generation time.
- `TDS.plt.plot()` now accepts a list of variable objects. For example, `ss.TDS.plt.plot([ss.GENROU.omega, ss.GENROU.delta], a=[0, 1])` will plot the rotor speed and angles of the 0-th and the 1-st generator.
- Added *REGCPI* model for generic converters with PLL support.
- Fixed PSS/E parser for *HYGOV*.

4.4.4 v1.6.3 (2022-04-06)

- Adjustments in the Pandapower interface. Added `make_GSF()` for the generation shift factor matrix.
- Reduced import overhead for the command-line tool.

4.4.5 v1.6.2 (2022-03-27)

Interoperability:

- Added interoperability modules for MATPOWER (through Oct2Py), pandapower and pypowsybl.
- Added Examples and API reference for the interoperability module.
- Improved the setup script to support extra dependencies. The following extras groups are supported: `dev` and `interop`. See [Extra support package](#) for more information.
- Added tests for power flow calculation against MATPOWER.

Others:

- Added a shorthand command `andes.system.example()` to return a disposable system. It can be useful for quick prototyping.
- Improved the formatting and navigation of Model references.
- Models store the base values for per-unit conversion in `Model.bases`.

4.4.6 v1.6.1 (2022-03-13)

- Revamped documentation with a much improved "Getting started" section.

4.4.7 v1.6.0 (2022-03-11)

- Migrated documentation to the pydata template.
- Added compatibility with SymPy 1.9 and 1.10.

4.5 v1.5 Notes

4.5.1 v1.5.12 (2022-03-05)

- Improved PSS/E parsers for WTDTA1 model to follow PSS/E parameter definition.
- Included the Jupyter notebook examples in the documentation.
- Tweaks to the plot utility.

4.5.2 v1.5.11 (2022-02-23)

- Reduced the tolerance for tiny variable increments to be treated as zero.
- Fixed PSS/E parsers for renewable models.
- Minor renewable model fixes.

4.5.3 v1.5.10 (2022-02-01)

- Fixed one equation in *REGC_A*.

4.5.4 v1.5.9 (2022-01-31)

- Added PLL1, a simple PLL model.
- Renamed REGCVSG to REGCV1 and REGCVSG2 to REGCV2.
- Added an alias list for model names. See `models/__init__.py`.
- Multiprocessing now executes on all CPUs that are physical, instead of logical. A new package `psutil` needs to be installed.
- Use of `Selector` is deprecated.

4.5.5 v1.5.8 (2021-12-21)

- Full initialization debug message will be printed only when `-v 10` and `run --init` are both used.
- Improved warning of out-of-limit initialization. Variables initialized at limits will be shown only at the debug level.
- Initialization improvements for models REGCA1 and REECA1.
- Added model HYGOV.
- Changed the default `vout` of offline exciters to zeros. All `vout` equations need to be multiplied by `ue`.

4.5.6 v1.5.7 (2021-12-11)

This minor release highlights the improved debugging of initialization.

Highly verbose initialization output can be enabled when the verbose level is 10 or less. For example,

```
andes -v 10 run test.xlsx -r tds --init
```

will set the verbose level to 10 and run `test.xlsx` in the current folder, proceed to time-domain simulation but only initialize the models. Outputs will be printed to the shell where the command is executed.

To save the output to a file, use the following in a UNIX shell:

```
andes -v 10 run test.xlsx -r tds --init > info.txt 2>&1
```

where the first `>` pipes the output to a file named `info.txt`, and `2>&1` appends stderr (2) to stdout (1).

The other main improvement is allowing automatic limit adjustment during initialization. Due to parameter errors, some variables will be initialized to values outside the given limits. Most commercial software does not attempt to fix the parameter but rather adjust the limit in run time.

The same approach is followed in ANDES by automatically adjusting the upper limit, if exceeded, to variable initial values. The lower limit, however, is kept unadjusted by default.

Discrete components now take an argument named `allow_adjust` so that the model developer can specify if its limits can be adjusted or must be kept as is. Each model is allowed to specify three config flags to customize runtime behaviors: `allow_adjust`, `adjust_lower`, and `adjust_upper`. By default, `allow_adjust=True`, `adjust_upper=True`, and `adjust_lower=False`. One can modify the config file to enable or disable the limit adjustments for specific models.

Other fixes include:

- Bug fixes for GAST parameter AT.
- Bug fixes for IEEEET3, GAST, ESAC1A and ESST1A when device is off to avoid matrix singularity.

4.5.7 v1.5.6 (2021-11-25)

- Allow specifying config options through command-line arguments `--config-option`.
- Added a voltage and frequency playback model PLBVFU1.
- Bug fixes to an SEXS equation.

4.5.8 v1.5.5 (2021-11-13)

- Added a *Timeseries* model for reading timeseries data from `xlsx`.
- Converted several models into Python packages.
- Bug fixes to TGOV1 equations (#226)

4.5.9 v1.5.4 (2021-11-02)

- Fixed a bug in generated `select` functions that omitted the coefficients of `__ones`.

4.5.10 v1.5.3 (2021-10-31)

- Reversed special arguments for the generated `select` function.
- Stabilized the argument list of `pycode`. If the `pycode` is identical to existing ones, the existing file will not be overwritten. As a result, compiled code is fully cached.
- Partially separated time-domain integration method into `daeint.py`.

4.5.11 v1.5.2 (2021-10-27)

- Removed `CVXOPT` dependency.
- Removed `__zeros` and `__ones` as they are no longer needed.
- Added `andes prep -c` to precompile the generated code.
- Added utility functions for saving and loading system snapshots. See `andes/utis/snapshot.py`.
- Compiled `numba` code is always cached.
- Bug fixes.

4.5.12 v1.5.1 (2021-10-23)

- Restored compatibility with SymPy 1.6.
- Added a group for voltage compensators.
- New models: `IEEEVC` and `GAST`.

4.5.13 v1.5.0 (2021-10-13)

- Support `numba` just-in-time compilation of all equation and Jacobian calls.

This option accelerates simulations by up to 30%. The acceleration is visible in medium-scale systems with multiple models. Such systems involve heavy function calls but a rather moderate load for linear equation solvers. The speed up is less significant in large-scale systems where solving equations is the major time consumer.

`Numba` is required and can be installed with `pip install numba` or `conda install numba`.

To turn on `numba` for ANDES, in the ANDES configuration under `[System]`, set `numba = 1` and `numba_cache = 1`.

The just-in-time compilation will compile the code upon the first execution based on the input types. When compilation is triggered, ANDES may appear frozen due to the compilation lag. The option `numba_cache = 1` will cache compiled machine code, so that the lag only occurs once until the next `andes prep`.

- Allow `BackRef` to populate to models through `Group`.

When model `A` stores an `IdxParam` pointing to a group, if `BackRef` with the name `A` are declared in both the group and the model, both `BackRef` will retrieve the backward references from model `A`.

- Allow `BaseVar` to accept partial initializations.

If `BaseVar.v_str_add = True`, the value of `v_str` will be added in place to variable value. An example is that voltage compensator sets part of the input voltage, and exciter reads the bus voltage. Exciter has `v.v_str_add = True` so that when compensators exist, the input voltage will be bus voltage (`vbus`) plus (`Eterm - vbus`). If no compensator exists, exciter will use bus voltages and function as expected.

- Added reserved variable names `__ones` and `__zeros` for ones and zeros with length equal to the device number.

`__ones` and `__zeros` are useful for vectorizing `choicelist` in `Piecewise` functions.

4.6 v1.4 Notes

4.6.1 v1.4.4 (2021-10-05)

- Bug fixes for refreshing generated code.

4.6.2 v1.4.3 (2021-09-25)

This release features parallel processing that cuts the time for `andes prepare` by more than half.

- `andes prepare` supports multiprocessing and uses it by default.
- Added aliases `andes st` and `andes prep` for `andes selftest` and `andes prepare`.
- `andes.config_logger` supports setting new `stream_level` and `file_level`.

New exciter models are contributed by Jinning Wang.

- Added AC8B, IEEEET3 and ESAC1A.

Other changes include disallowing numba's `nopython` mode.

4.6.3 v1.4.2 (2021-09-12)

- Bug fixes
- Dropped support for `cvxoptklu`.

4.6.4 v1.4.1 (2021-09-12)

- Bug fixes.
- Overhaul of the `prepare` and `undill` methods.
- `andes prepare` can be called for specific models through `-m`, which takes one or many model names as arguments.

4.6.5 v1.4.0 (2021-09-08)

This release highlights the distributed energy resource protection model.

- Added DGPRCT1 model to provide DG models with voltage- and frequency-based protection following IEEE 1547-2018.
- REECA1E supports frequency droop on power.
- Throws TypeError if type mismatches when using ExtAlgeb and ExtState.

4.7 v1.3 Notes

4.7.1 v1.3.12 (2021-08-22)

Plot enhancements:

- `plot()` takes an argument `mark` for masking y-axis data based on the `left` and `right` range parameters.
- `TDS.plt` provides a `panoview` method for plotting an panoramic view for selected variables and devices of a model.

Models:

- Added WIP EV models and protection models.

Test case: - Added CURENT EI test system. - Added a number of IEEE 14 bus test systems for specific models.

4.7.2 v1.3.11 (2021-07-27)

- Added REECA1E model with inertia emulation.
- Fixed an issue where the `vtype` of services was ignored.
- Changed default DPI for plotting to 100.

4.7.3 v1.3.10 (2021-06-08)

- Bug fixes for controllers when generators are off.

4.7.4 v1.3.9 (2021-06-02)

- Bug fixes in exciters when generators are offline.
- Added *safe_div* function for initialization equations.

4.7.5 v1.3.8 (2021-06-02)

- Added REGCVSG model for voltage-source controlled renewables.
- Turbine governors are now aware of the generator connection status.

4.7.6 v1.3.7 (2021-05-03)

- Allow manually specifying variables needing initialization preceding a variable. Specify a list of variable names through `BaseVar.deps`.

4.7.7 v1.3.6 (2021-04-23)

- Patched ESD1 model. Converted *distributed.py* into a package.
- Bug fixes.

4.7.8 v1.3.5 (2021-03-20)

- Fixed a bug in connectivity check when bus 0 is islanded.
- Updated notebook examples.
- Updated tutorials.

4.7.9 v1.3.4 (2021-03-13)

- Fixed a bug for the generated renewable energy code.

4.7.10 v1.3.2 (2021-03-08)

- Relaxed the version requirements for NumPy and SymPy.

4.7.11 v1.3.1 (2021-03-07)

- Writes all generated Python code to `~/ .andes/pycode` by default.
- Uses generated Python code by default instead of `calls.pkl`.
- Works with NumPy 1.20; works on Apple Silicon (use *miniforge*) to install native Python and NumPy for Apple Silicon.
- Generalized model initialization: automatically determines the initialization sequence and solve equations iteratively when necessary.
- In *System.config*, *save_pycode* and *use_pycode* are now deprecated.

4.7.12 v1.3.0 (2021-02-20)

- Allow *State* variable set *check_init=False* to skip initialization test. One use case is for integrators with non-zero inputs (such as state-of-charge integration).
- Solves power flow for systems with multiple areas, each with one Slack generator.
- Added *Jumper* for connecting two buses with zero impedance.
- *REGCA1* and synchronous generators can take power ratio parameters *gammap* and *gammaq*.
- New models: *IEESGO* and *IEEEET1*, *EXAC4*.
- Refactored exciters, turbine governors, and renewable models into modules.

4.8 v1.2 Notes

4.8.1 v1.2.9 (2021-01-16)

- Added system connectivity check for islanded buses.
- Depend on *openpyxl* for reading excel files since *xlrd* dropped support for any format but *xlsx* since v2.0.0.

4.8.2 v1.2.7 (2020-12-08)

- Time-domain integration now evaluates anti-windup limiter before algebraic residuals. It assures that algebraic residuals are calculated with the new state values if pegged at limits.
- Fixed the conditions for Iq ramping in REGC; removed *Iqmax* and *Iqmin*.
- Added a new plot function `plotn` to allow multiple subplots in one figure.
- `TDS.config.g_scale` is now now used as a factor for scaling algebraic equations for better convergence. Setting it to 1.0 functions the same as before.

4.8.3 v1.2.6 (2020-12-01)

- Added *TGOVIN* model which sums *pref* and *paux* after the 1/droop block.
- Added *ZIP* and *FLoad* for dynamic analysis. Need to be initialized after power flow.
- Added *DAETimeSeries.get_data()* method.
- Added IEEE 14-bus test cases with solar PV (*ieee14_solar.xlsx*) and Generic Type 3 wind (*ieee14_wt3.xlsx*).

4.8.4 v1.2.5 (2020-11-19)

- Added *Summary* model to allow arbitrary information for a test case. Works in *xlsx* and *json* formats.
- PV reactive power limit works. Automatically determines the number of PVs to convert if *npv2pq=0*.
- Limiter and AntiWindup limiter can use *sign_upper=-1* and *sign_lower=-1* to negate the provided limits.
- Improved error messages for inconsistent data.
- *DAETimeSeries* functions refactored.

4.8.5 v1.2.4 (2020-11-13)

- Added switched shunt class *ShuntSw*.
- *BaseParam* takes *inconvert* and *oconvert* for converting parameter elements from and to files.

4.8.6 v1.2.3 (2020-11-02)

- Support variable *sys_mva* (system base mva) in equation strings.
- Default support for KVOPT through *pip* installation.

4.8.7 v1.2.2 (2020-11-01)

New Models:

- PVD1 model, WECC distributed PV model. Supports multiple PVD1 devices on the same bus.
- Added *ACEc* model, ACE calculation with continuous freq.

Changes and fixes:

- Renamed *TDS._itm_step* to *TDS.itm_step* as a public API.
- Allow variable *sys_f* (system frequency) in equation strings.
- Fixed ACE equation. measurement.
- Support *kvopt* as a drop-in replacement for *cvxopt* to bring KLU to Windows (and other platforms).

- Added `kvxopt` as a dependency for PyPI installation.

4.8.8 v1.2.1 (2020-10-11)

- Renamed `models.non_jit` to `models.file_classes`.
- Removed `models/jit.py` as models have to be loaded and instantiated anyway before undill.
- Skip generating empty equation calls.

4.8.9 v1.2.0 (2020-10-10)

This version contains major refactor for speed improvement.

- Refactored Jacobian calls generation so that for each model, one call is generated for each Jacobian type.
- Refactored Service equation generation so that the exact arguments are passed.

Also contains an experimental Python code dump function.

- Controlled in `System.config`, one can turn on `save_pycode` to dump equation and Jacobian calls to `~/ .andes/pycode`. Requires one call to `andes prepare`.
- The Python code dump can be reformatted with `yapf` through the config option `yapf_pycode`. Requires separate installation.
- The dumped Python code can be used for subsequent simulations through the config option `use_pycode`.

4.9 v1.1 Notes

4.9.1 v1.1.5 (2020-10-08)

- Allow plotting to existing axes with the same plot API.
- Added TGOV1DB model (TGOV1 with an input dead-band).
- Added an experimental numba support.
- Patched *LazyImport* for a snappier command-line interface.
- `andes selftest -q` now skips code generation.

4.9.2 v1.1.4 (2020-09-22)

- Support *BackRef* for groups.
- Added CLI `--pool` to use `multiprocess.Pool` for multiple cases. When combined with `--shell`, `--pool` returns System Objects in the list system.
- Fixed bugs and improved manual.

4.9.3 v1.1.3 (2020-09-05)

- Improved documentation.
- Minor bug fixes.

4.9.4 v1.1.2 (2020-09-03)

- Patched time-domain for continuing simulation.

4.9.5 v1.1.1 (2020-09-02)

- Added back quasi-real-time speed control through `--qrt` and `--kqrt KQRT`.
- Patched the time-domain routine for the final step.

4.9.6 v1.1.0 (2020-09-01)

- Defaulted *BaseVar.diag_eps* to *System.Config.diag_eps*.
- Added option *TDS.config.g_scale* to allow for scaling the algebraic mismatch with step size.
- Added induction motor models *Motor3* and *Motor5* (PSAT models).
- Allow a PFlow-TDS model to skip TDS initialization by setting *ModelFlags.tds_init* to False.
- Added Motor models *Motor3* and *Motor5*.
- Imported *get_case* and *list_cases* to the root package level.
- Added test cases (Kundur's system) with wind.

Added Generic Type 3 wind turbine component models:

- Drive-train models *WTDTA1* (dual-mass model) and *WTDS* (single-mass model).
- Aerodynamic model *WTARA1*.
- Pitch controller model *WTPTA1*.
- Torque (a.k.a. Pref) model *WTTQA1*.

4.10 v1.0 Notes

4.10.1 v1.0.8 (2020-07-29)

New features and models:

- Added renewable energy models *REECA1* and *REPCA1*.
- Added service *EventFlag* which automatically calls events if its input changes.
- Added service *ExtendedEvent* which flags an extended event for a given time.
- Added service *ApplyFunc* to apply a numeric function. For the most cases where one would need *ApplyFunc*, consider using *ConstService* first.
- Allow *selftest -q* for quick selftest by skipping codegen.
- Improved time stepping logic and convergence tests.
- Updated examples.

Default behavior changes include:

- `andes prepare` now takes three mutually exclusive arguments, *full*, *quick* and *incremental*. The command-line now defaults to the quick mode. `andes.prepare()` still uses the full mode.
- `Model.s_update` now evaluates the generated and the user-provided calls in sequence for each service in order.
- Renamed model *REGCAU1* to *REGCA1*.

4.10.2 v1.0.7 (2020-07-18)

- Use in-place assignment when updating Jacobian values in Triplets.
- Patched a major but simple bug where the Jacobian refactorization flag is set to the wrong place.
- New models: PMU, REGCAU1 (tests pending).
- New blocks: DeadBand1, PIFreeze, PITrackAW, PITrackAWFreeze (tests pending), and LagFreeze (tests pending).
- *andes plot* supports dashed horizontal and vertical lines through *hline1*, *hline2*, *vline1* and *vline2*.
- Discrete: renamed *DeadBand* to *DeadBandRT* (deadband with return).
- Service: renamed *FlagNotNone* to *FlagValue* with an option to flip the flags.
- Other tweaks.

4.10.3 v1.0.6 (2020-07-08)

- Patched step size adjustment algorithm.
- Added Area Control Error (ACE) model.

4.10.4 v1.0.5 (2020-07-02)

- Minor bug fixes for service initialization.
- Added a wrapper to call `TDS.fg_update` to allow passing variables from caller.
- Added pre-event time to the `switch_times`.

4.10.5 v1.0.4 (2020-06-26)

- Implemented compressed NumPy format (npz) for time-domain simulation output data file.
- Implemented optional attribute *vtype* for specifying data type for Service.
- Patched COI speed initialization.
- Patched PSS/E parser for two-winding transformer winding and impedance modes.

4.10.6 v1.0.3 (2020-06-02)

- Patches *PQ* model equations where the "or" logic "l" is ignored in equation strings. To adjust PQ load in time domain simulation, refer to the note in *pq.py*.
- Allow *Model.alter* to update service values.

4.10.7 v1.0.2 (2020-06-01)

- Patches the conda-forge script to use SymPy < 1.6. After SymPy version 1.5.1, comparison operations cannot be sympified. Pip installations are not affected.

4.10.8 v1.0.1 (2020-05-27)

- Generate one lambda function for each of f and g, instead of generating one for each single f/g equation. Requires to run *andes prepare* after updating.

4.10.9 v1.0.0 (2020-05-25)

This release is going to be tagged as v0.9.5 and later tagged as v1.0.0.

- Added verification results using IEEE 14-bus, NPCC, and WECC systems under folder *examples*.
- Patches GENROU and EXDC2 models.
- Updated test cases for WECC, NPCC IEEE 14-bus.
- Documentation improvements.
- Various tweaks.

4.11 Pre-v1.0.0

4.11.1 v0.9.4 (2020-05-20)

- Added exciter models EXST1, ESST3A, ESDC2A, SEXS, and IEEEEX1, turbine governor model IEEEG1 (dual-machine support), and stabilizer model ST2CUT.
- Added blocks HVGate and LVGate with a work-around for sympy.maximum/ minimum.
- Added services *PostInitService* (for storing initialized values), and *VarService* (variable services that get updated) after limiters and before equations).
- Added service *InitChecker* for checking initialization values against typical values. Warnings will be issued when out of bound or equality/ inequality conditions are not met.
- Allow internal variables to be associated with a discrete component which will be updated before initialization (through *BaseVar.discrete*).
- Allow turbine governors to specify an optional *Tn* (turbine rating). If not provided, turbine rating will fall back to *Sn* (generator rating).
- Renamed *OptionalSelect* to *DataSelect*; Added *NumSelect*, the array-based version of *DataSelect*.
- Allow to regenerate code for updated models through `andes prepare -qi`.
- Various patches to allow zeroing out time constants in transfer functions.

4.11.2 v0.9.3 (2020-05-05)

This version contains bug fixes and performance tweaks.

- Fixed an *AntiWindup* issue that causes variables to stuck at limits.
- Allow `TDS.run()` to resume from a stopped simulation and run to the new end time in `TDS.config.tf`.
- Improved TDS data dump speed by not constructing `DataFrame` by default.
- Added tests for *kundur_full.xlsx* and *kundur_aw.xlsx* to ensure results are the same as known values.

- Other bug fixes.

4.11.3 v0.9.1 (2020-05-02)

This version accelerates computations by about 35%.

- Models with flag `collate=False`, which is the new default, will slice DAE arrays for all internal vars to reduce copying back and forth.
- The change above greatly reduced computation time. For `kundur_ieeest.xlsx`, simulation time is down from 2.50 sec to 1.64 sec.
- The side-effects include a change in variable ordering in output `lst` file. It also eliminated the feasibility of evaluating model equations in parallel, which has not been implemented and does not seem promising in Python.
- Separated symbolic processor and documentation generator from `Model` into `SymProcessor` and `Documenter` classes.
- `andes prepare` now shows progress in the console.
- Store exit code in `System.exit_code` and returns to system when called from CLI.
- Refactored the solver interface.
- Patched `Config.check` for routines.
- SciPy Newton-Krylov power flow solver is no longer supported.
- Patched a bug in v0.9.0 related to `dae.Tf`.

4.11.4 v0.8.8 (2020-04-28)

This update contains a quick but significant fix to boost the simulation speed by avoiding calls to empty user-defined numerical calls.

- In `Model.flags` and `Block.flags`, added `f_num`, `g_num` and `j_num` to indicate if user-defined numerical calls exist.
- In `Model.f_update`, `Model.g_update` and `Model.j_update`, check the above flags to avoid unnecessary calls to empty numeric functions.
- For the `kundur_ieeest.xlsx` case, simulation time was reduced from 3.5s to 2.7s.

4.11.5 v0.8.7 (2020-04-28)

- Changed *RefParam* to a service type called *BackRef*.
- Added *DeviceFinder*, a service type to find device idx when not provided. *DeviceFinder* will also automatically add devices if not found.
- Added *OptionalSelect*, a service type to select optional parameters if provided and select fallback ones otherwise.
- Added discrete types *Derivative*, *Delay*, and *Average*,
- Implemented full IEEEEST stabilizer.
- Implemented COI for generator speed and angle measurement.

4.11.6 v0.8.6 (2020-04-21)

This release contains important documentation fixes and two new blocks.

- Fixed documentations in *andes doc* to address a misplacement of symbols and equations.
- Converted all blocks to the division-free formulation (with *dae.zf* renamed to *dae.Tf*).
- Fixed equation errors in the block documentation.
- Implemented two new blocks: *Lag2ndOrd* and *LeadLag2ndOrd*.
- Added a prototype for IEEEEST stabilizer with some fixes needed.

4.11.7 v0.8.5 (2020-04-17)

- Converted the differential equations to the form of $T \dot{x} = f(x, y)$, where T is supplied to `t_const` of `State/ExtState`.
- Added the support for Config fields in documentation (in *andes doc* and on *readthedocs*).
- Added Config consistency checking.
- Converted *Model.idx* from a list to *DataParam*.
- Renamed the API of routines (summary, init, run, report).
- Automatically generated indices now start at 1 (i.e., "GENCLS_1" is the first GENCLS device).
- Added test cases for WECC system. The model with classical generators is verified against TSAT.
- Minor features: *andes -v l* for debug output with levels and line numbers.

4.11.8 v0.8.4 (2020-04-07)

- Added support for JSON case files. Convert existing case file to JSON with `--convert json`.
- Added support for PSS/E dyr files, loadable with `-addfile ADDFILE`.
- Added `andes plot --xargs` for searching variable name and plotting. See example 6.
- Various bug fixes: Fault power injection fix;

4.11.9 v0.8.3 (2020-03-25)

- Improved storage for Jacobian triplets (see `andes.core.triplet.JacTriplet`).
- On-the-fly parameter alteration for power flow calculations (`Model.alter method`).
- Exported frequently used functions to the root package (`andes.config_logger`, `andes.run`, `andes.prepare` and `andes.load`).
- Return a list of System objects when multiprocessing in an interactive environment.
- Exported classes to *andes.core*.
- Various bug fixes and documentation improvements.

4.11.10 v0.8.0 (2020-02-12)

- First release of the hybrid symbolic-numeric framework in ANDES.
- A new framework is used to describe DAE models, generate equation documentation, and generate code for numerical simulation.
- Models are written in the new framework. Supported models include GENCLS, GENROU, EXDC2, TGOV1, TG2
- PSS/E raw parser, MATPOWER parser, and ANDES xlsx parser.
- Newton-Raphson power flow, trapezoidal rule for numerical integration, and full eigenvalue analysis.

4.11.11 v0.6.9 (2020-02-12)

- Version 0.6.9 is the last version for the numeric-only modeling framework.
- This version will not be updated any more. But, models, routines and functions will be ported to the new version.

MODEL REFERENCE

Use the left navigation pane to locate the group and model and view details.

Supported Groups and Models

Group	Models
<i>ACLine</i>	<i>Line</i>
<i>ACShort</i>	<i>Jumper</i>
<i>ACTopology</i>	<i>Bus</i>
<i>Calculation</i>	<i>ACE, ACEc, COI</i>
<i>Collection</i>	<i>Area</i>
<i>DCLink</i>	<i>Ground, R, L, C, RCp, RCs, RLs, RLCs, RLCp</i>
<i>DCTopology</i>	<i>Node</i>
<i>DG</i>	<i>PVD1, ESD1, EV1, EV2</i>
<i>DGProtection</i>	<i>DGPRCT1, DGPRCTExt</i>
<i>DataSet</i>	<i>TimeSeries</i>
<i>DynLoad</i>	<i>ZIP, FLoad</i>
<i>Exciter</i>	<i>EXDC2, IEEEEX1, ESDC1A, ESDC2A, EXST1, ESST3A, SEXS, IEEEET1, EXAC1, EXAC2, EXAC4, ESS</i>
<i>FreqMeasurement</i>	<i>BusFreq, BusROCOF</i>
<i>Information</i>	<i>Summary</i>
<i>Interface</i>	<i>Fortescue</i>
<i>Motor</i>	<i>Motor3, Motor5</i>
<i>OutputSelect</i>	<i>Output</i>
<i>PLL</i>	<i>PLL1, PLL2</i>
<i>PSS</i>	<i>IEEEEST, ST2CUT</i>
<i>PhasorMeasurement</i>	<i>PMU</i>
<i>RenAerodynamics</i>	<i>WTARA1, WTARV1</i>
<i>RenExciter</i>	<i>REECA1, REECA1E, REECA1G</i>
<i>RenGen</i>	<i>REGCA1, REGCP1, REGCV1, REGCV2, REGF1, REGF2, REGF3</i>
<i>RenGovernor</i>	<i>WTDTA1, WTDS</i>
<i>RenPitch</i>	<i>WTPTA1</i>
<i>RenPlant</i>	<i>REPCA1</i>
<i>RenTorque</i>	<i>WTTQA1</i>
<i>StaticACDC</i>	<i>VSCShunt</i>
<i>StaticGen</i>	<i>PV, Slack</i>

Table 1 – continued from previous page

Group	Models
<i>StaticLoad</i>	<i>PQ</i>
<i>StaticShunt</i>	<i>Shunt, ShuntTD, ShuntSw</i>
<i>SynGen</i>	<i>GENCLS, GENROU, PLBVFU1</i>
<i>TimedEvent</i>	<i>Toggle, Fault, Alter</i>
<i>TurbineGov</i>	<i>TG2, TGOV1, TGOV1DB, TGOV1N, TGOV1NDB, IEEEG1, IEESGO, GAST, HYGOV, HYGOVDB, H</i>
<i>VoltComp</i>	<i>IEEEVC</i>

5.1 ACLine

Common Parameters: *u*, *name*, *bus1*, *bus2*, *r*, *x*

Common Variables: *v1*, *v2*, *a1*, *a2*

Available models: *Line*

5.1.1 Line

AC transmission line model.

The model is also used for two-winding transformer. Transformers can set the tap ratio in *tap* and/or phase shift angle *phi*.

To reduce the number of variables, line injections are summed at bus equations and are not stored. Current injections are not computed.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus1		idx of from bus			
bus2		idx of to bus			
Sn	S_n	Power rating	100	<i>MW</i>	non_zero
fn	f	rated frequency	60	<i>Hz</i>	
Vn1	V_{n1}	AC voltage rating	110	<i>kV</i>	non_zero
Vn2	V_{n2}	rated voltage of bus2	110	<i>kV</i>	non_zero
r	r	line resistance	0.000	<i>p.u.</i>	z
x	x	line reactance	0.000	<i>p.u.</i>	non_zero,z
b		shared shunt susceptance	0	<i>p.u.</i>	y
g		shared shunt conductance	0	<i>p.u.</i>	y
b1	b_1	from-side susceptance	0	<i>p.u.</i>	y
g1	g_1	from-side conductance	0	<i>p.u.</i>	y
b2	b_2	to-side susceptance	0	<i>p.u.</i>	y
g2	g_2	to-side conductance	0	<i>p.u.</i>	y
trans		transformer branch flag	0	<i>bool</i>	
tap	t_{ap}	transformer branch tap ratio	1	<i>float</i>	non_negative
phi	ϕ	transformer branch phase shift in rad	0	<i>radian</i>	
rate_a	R_{ATEA}	long-term flow limit (placeholder)	0	<i>MVA</i>	
rate_b	R_{ATEB}	short-term flow limit (placeholder)	0	<i>MVA</i>	
rate_c	R_{ATEC}	emergency flow limit (placeholder)	0	<i>MVA</i>	
owner		owner code			
xcoord		x coordinates			
ycoord		y coordinates			

Variables

Name	Symbol	Type	Description	Unit	Properties
a1	a_1	ExtAlgeb	phase angle of the from bus		
a2	a_2	ExtAlgeb	phase angle of the to bus		
v1	v_1	ExtAlgeb	voltage magnitude of the from bus		
v2	v_2	ExtAlgeb	voltage magnitude of the to bus		

Initialization Equations

Name	Symbol	Type	Initial Value
a1	a_1	ExtAlgeb	
a2	a_2	ExtAlgeb	
v1	v_1	ExtAlgeb	
v2	v_2	ExtAlgeb	

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
a1	a_1	ExtAl- geb	$u \left(-1/t_{ap} v_1 v_2 (-b_{hk} \sin(\phi - a_1 + a_2) + g_{hk} \cos(\phi - a_1 + a_2)) + 1/t_{ap}^2 v_1^2 (g_h + g_{hk}) \right)$
a2	a_2	ExtAl- geb	$u \left(-1/t_{ap} v_1 v_2 (b_{hk} \sin(\phi - a_1 + a_2) + g_{hk} \cos(\phi - a_1 + a_2)) + v_2^2 (g_h + g_{hk}) \right)$
v1	v_1	ExtAl- geb	$u \left(-1/t_{ap} v_1 v_2 (-b_{hk} \cos(\phi - a_1 + a_2) - g_{hk} \sin(\phi - a_1 + a_2)) - 1/t_{ap}^2 v_1^2 (b_h + b_{hk}) \right)$
v2	v_2	ExtAl- geb	$u \left(1/t_{ap} v_1 v_2 (b_{hk} \cos(\phi - a_1 + a_2) - g_{hk} \sin(\phi - a_1 + a_2)) - v_2^2 (b_h + b_{hk}) \right)$

Services

Name	Symbol	Equation	Type
gh	g_h	$0.5g + g_1$	ConstService
bh	b_h	$0.5b + b_1$	ConstService
gk	g_k	$0.5g + g_2$	ConstService
bk	b_k	$0.5b + b_2$	ConstService
yh	y_h	$u(ib_h + g_h)$	ConstService
yk	y_k	$u(ib_k + g_k)$	ConstService
yhk	y_{hk}	$\frac{u}{r+i(x+1.0 \cdot 10^{-8})+1.0 \cdot 10^{-8}}$	ConstService
ghk	g_{hk}	$\text{re}(y_{hk})$	ConstService
bhk	b_{hk}	$\text{im}(y_{hk})$	ConstService
itap	$1/t_{ap}$	$\frac{1}{t_{ap}}$	ConstService
itap2	$1/t_{ap}^2$	$\frac{1}{t_{ap}^2}$	ConstService

Config Fields in [Line]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.2 ACShort

Common Parameters: u, name, bus1, bus2

Common Variables: v1, v2, a1, a2

Available models: *Jumper*

5.2.1 Jumper

Jumper is a device to short two buses (merging two buses into one).

Jumper can connect two buses satisfying one of the following conditions:

- neither bus is voltage-controlled
- either bus is voltage-controlled
- both buses are voltage-controlled, and the voltages are the same.

If the buses are controlled in different voltages, power flow will not solve (as the power flow through the jumper will be infinite).

In the solutions, the p and q are flowing out of bus1 and flowing into bus2.

Setting a Jumper's connectivity status u to zero will disconnect the two buses. In the case of a system split, one will need to call `System.connectivity()` immediately following the split to detect islands.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus1		idx of from bus			
bus2		idx of to bus			

Variables

Name	Symbol	Type	Description	Unit	Properties
p	P	Algeb	active power (1 to 2)		
q	Q	Algeb	active power (1 to 2)		
a1	a_1	ExtAlgeb	phase angle of the from bus		
a2	a_2	ExtAlgeb	phase angle of the to bus		
v1	v_1	ExtAlgeb	voltage magnitude of the from bus		
v2	v_2	ExtAlgeb	voltage magnitude of the to bus		

Initialization Equations

Name	Symbol	Type	Initial Value
p	P	Algeb	
q	Q	Algeb	
a1	a_1	ExtAlgeb	
a2	a_2	ExtAlgeb	
v1	v_1	ExtAlgeb	
v2	v_2	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation " $0 = g(x, y)$ "
p	P	Algeb	$P(1 - u) + u(a_1 - a_2)$
q	Q	Algeb	$P(1 - u) + u(v_1 - v_2)$
a1	a_1	ExtAlgeb	P
a2	a_2	ExtAlgeb	$-P$
v1	v_1	ExtAlgeb	Q
v2	v_2	ExtAlgeb	$-Q$

Config Fields in [Jumper]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.3 ACTopology

Common Parameters: u, name

Common Variables: a, v

Available models: *Bus*

5.3.1 Bus

AC Bus model.

Power balance equation have the form of $\text{load} - \text{injection} = 0$. Namely, load is positively summed, while injections are negative.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
Vn	V_n	AC voltage rating	110	<i>kV</i>	non_zero
vmax	V_{max}	Voltage upper limit	1.100	<i>p.u.</i>	
vmin	V_{min}	Voltage lower limit	0.900	<i>p.u.</i>	
v0	V_0	initial voltage magnitude	1	<i>p.u.</i>	non_zero
a0	θ_0	initial voltage phase angle	0	<i>rad</i>	
xcoord		x coordinate (longitude)	0		
ycoord		y coordinate (latitude)	0		
area		Area code			
zone		Zone code			
owner		Owner code			

Variables

Name	Symbol	Type	Description	Unit	Properties
a	θ	Algeb	voltage angle	<i>rad</i>	v_str
v	V	Algeb	voltage magnitude	<i>p.u.</i>	v_str

Initialization Equations

Name	Symbol	Type	Initial Value
a	θ	Algeb	$\theta_0 \cdot (1 - z_{flat}) + 1.0 \cdot 10^{-8} z_{flat}$
v	V	Algeb	$V_0 \cdot (1 - z_{flat}) + z_{flat}$

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
a	θ	Algeb	0
v	V	Algeb	0

Config Fields in [Bus]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
flat_start	z_{flat}	0	flat start for voltages	(0, 1)

5.4 Calculation

Group of classes that calculates based on other models.

Common Parameters: u, name

Available models: *ACE*, *ACEc*, *COI*

5.4.1 ACE

Area Control Error model.

Discrete frequency sampling. System base frequency from `system.config.freq` is used.

Frequency sampling period (in seconds) can be specified in `ACE.config.interval`. The sampling start time (in seconds) can be specified in `ACE.config.offset`.

Note: area idx is automatically retrieved from *bus*.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		bus idx for freq. measurement			mandatory
bias	β	bias parameter	1	<i>MW/0.1Hz</i>	power
busf		Optional BusFreq device idx			
area			0		

Variables

Name	Symbol	Type	Description	Unit	Properties
ace	ace	Algeb	area control error	<i>p.u. (MW)</i>	
f	f	ExtAlgeb	Bus frequency	<i>p.u. (Hz)</i>	

Initialization Equations

Name	Symbol	Type	Initial Value
ace	ace	Algeb	
f	f	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
ace	ace	Algeb	$10 \cdot 1 / S_{b,sys} \beta f_{sys} (v^{f_s} - 1) - ace$
f	f	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
imva	$1/S_{b,sys}$	$\frac{1}{S_{b,sys}}$	ConstService

Discretes

Name	Symbol	Type	Info
fs	f_s	Sampling	Sampled freq.

Config Fields in [ACE]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
freq_model		BusFreq	default freq. measurement model	('BusFreq',)
interval		4	sampling time interval	
offset		0	sampling time offset	

5.4.2 ACEc

Area Control Error model.

Continuous frequency sampling. System base frequency from `system.config.freq` is used.

Note: area idx is automatically retrieved from *bus*.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		bus idx for freq. measurement			mandatory
bias	β	bias parameter	1	<i>MW/0.1Hz</i>	power
busf		Optional BusFreq device idx			
area			0		

Variables

Name	Symbol	Type	Description	Unit	Properties
ace	ace	Algeb	area control error	$p.u. (MW)$	
f	f	ExtAlgeb	Bus frequency	$p.u. (Hz)$	

Initialization Equations

Name	Symbol	Type	Initial Value
ace	ace	Algeb	
f	f	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
ace	ace	Algeb	$10 \cdot 1 / S_{b,sys} \beta f_{sys} (f - 1) - ace$
f	f	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
imva	$1 / S_{b,sys}$	$\frac{1}{S_{b,sys}}$	ConstService

Config Fields in [ACEc]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
freq_model		BusFreq	default freq. measurement model	('BusFreq',)

5.4.3 COI

Center of inertia calculation class.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
M		Linearly stored SynGen.M	0		

Variables

Name	Sym- bol	Type	Description	Unit	Properties
wgen	ω_{gen}	ExtState	Linearly stored SynGen.omega		
agen	δ_{gen}	ExtState	Linearly stored SynGen.delta		
omega	ω_{coi}	Algeb	COI speed		v_str,v_setter
delta	δ_{coi}	Algeb	COI rotor angle		v_str,v_setter
omega_sub	ω_{sub}	ExtAl- geb	COI frequency contribution of each generator		
delta_sub	δ_{sub}	ExtAl- geb	COI angle contribution of each generator		

Initialization Equations

Name	Symbol	Type	Initial Value
wgen	ω_{gen}	ExtState	
agen	δ_{gen}	ExtState	
omega	ω_{coi}	Algeb	$\omega_{gen,0,avg}$
delta	δ_{coi}	Algeb	$\delta_{gen,0,avg}$
omega_sub	ω_{sub}	ExtAlgeb	
delta_sub	δ_{sub}	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
wgen	ω_{gen}	ExtState	0	
agen	δ_{gen}	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
omega	ω_{coi}	Algeb	$-\omega_{coi}$
delta	δ_{coi}	Algeb	$-\delta_{coi}$
omega_sub	ω_{sub}	ExtAlgeb	$M_w \omega_{gen}$
delta_sub	δ_{sub}	ExtAlgeb	$M_w \delta_{gen}$

Services

Name	Symbol	Equation	Type
Mw	M_w	$\frac{M}{M_{tr}}$	ConstService
d0w	$\delta_{gen,0,w}$	$M_w \delta_{gen,0}$	ConstService
a0w	$\omega_{gen,0,w}$	$M_w \omega_{gen,0}$	ConstService

Config Fields in [COI]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.5 Collection

Collection of topology models

Common Parameters: u, name

Available models: [Area](#)

5.5.1 Area

Area model.

Area collects back references from the Bus model and the ACTopology group.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	<i>u</i>	connection status	1	<i>bool</i>	
name		device name			

Config Fields in [Area]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.6 DCLink

Basic DC links

Common Parameters: u, name

Available models: *Ground*, *R*, *L*, *C*, *RCp*, *RCs*, *RLs*, *RLCs*, *RLCp*

5.6.1 Ground

Ground model that sets the voltage of the connected DC node.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	<i>u</i>	connection status	1	<i>bool</i>	
name		device name			
node		Node index			mandatory
voltage	V_0	Ground voltage (typically 0)	0	<i>p.u.</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
Idc	I_{dc}	Algeb	Fictitious current injection from ground		v_str
v	v	ExtAlgeb			

Initialization Equations

Name	Symbol	Type	Initial Value
Idc	I_{dc}	Algeb	0
v	v	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation " $0 = g(x, y)$ "
Idc	I_{dc}	Algeb	$u(-V_0 + v)$
v	v	ExtAlgeb	$-I_{dc}$

Config Fields in [Ground]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.6.2 R

Resistive dc line

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	<i>kV</i>	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	<i>kV</i>	non_zero
Idcn	I_{dcn}	DC current rating	1	<i>kA</i>	non_zero
R		DC line resistance	0.010	<i>p.u.</i>	non_zero,r

Variables

Name	Symbol	Type	Description	Unit	Properties
Idc	I_{dc}	Algeb	Current from node 2 to 1	<i>p.u.</i>	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Initialization Equations

Name	Symbol	Type	Initial Value
Idc	I_{dc}	Algeb	$\frac{u(-v_1+v_2)}{R}$
v1	v_1	ExtAlgeb	
v2	v_2	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Idc	I_{dc}	Algeb	$-I_{dc} + \frac{u(-v_1+v_2)}{R}$
v1	v_1	ExtAlgeb	$-I_{dc}$
v2	v_2	ExtAlgeb	I_{dc}

Config Fields in [R]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.6.3 L

Inductive dc line

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	<i>kV</i>	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	<i>kV</i>	non_zero
Idcn	I_{dcn}	DC current rating	1	<i>kA</i>	non_zero
L		DC line inductance	0.001	<i>p.u.</i>	non_zero,r

Variables

Name	Symbol	Type	Description	Unit	Properties
IL	I_L	State	Inductance current	<i>p.u.</i>	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Initialization Equations

Name	Symbol	Type	Initial Value
IL	I_L	State	0
v1	v_1	ExtAlgeb	
v2	v_2	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
IL	I_L	State	$-u (v_1 - v_2)$	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v1	v_1	ExtAlgeb	$-I_L$
v2	v_2	ExtAlgeb	I_L

Config Fields in [L]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.6.4 C

Capacitive dc branch

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	<i>kV</i>	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	<i>kV</i>	non_zero
Idcn	I_{dcn}	DC current rating	1	<i>kA</i>	non_zero
C		DC capacitance	0.001	<i>p.u.</i>	non_zero,g

Variables

Name	Symbol	Type	Description	Unit	Properties
vC	v_C	State	Capacitor current	<i>p.u.</i>	v_str
Idc	I_{dc}	Algeb	Current from node 2 to 1	<i>p.u.</i>	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Initialization Equations

Name	Symbol	Type	Initial Value
vC	v_C	State	0
Idc	I_{dc}	Algeb	0
v1	v_1	ExtAlgeb	
v2	v_2	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
vC	v_C	State	$-I_{dc}u$	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Idc	I_{dc}	Algeb	$I_{dc}(1 - u) + u(-v_1 + v_2 + v_C)$
v1	v_1	ExtAlgeb	$-I_{dc}$
v2	v_2	ExtAlgeb	I_{dc}

Config Fields in [C]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.6.5 RCp

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	<i>kV</i>	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	<i>kV</i>	non_zero
Idcn	I_{dcn}	DC current rating	1	<i>kA</i>	non_zero
R	R	DC line resistance	0.010	<i>p.u.</i>	non_zero,r
C	C	DC capacitance	0.001	<i>p.u.</i>	non_zero,g

Variables

Name	Symbol	Type	Description	Unit	Properties
vC	v_C	State	Capacitor current	<i>p.u.</i>	v_str
Idc	I_{dc}	Algeb	Current from node 2 to 1	<i>p.u.</i>	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Initialization Equations

Name	Symbol	Type	Initial Value
vC	v_C	State	$v_1 - v_2$
Idc	I_{dc}	Algeb	$\frac{-v_1 + v_2}{R}$
v1	v_1	ExtAlgeb	
v2	v_2	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
vC	v_C	State	$-u \left(I_{dc} - \frac{v_C}{R} \right)$	C

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Idc	I_{dc}	Algeb	$I_{dc} (1 - u) + u (-v_1 + v_2 + v_C)$
v1	v_1	ExtAlgeb	$-I_{dc}$
v2	v_2	ExtAlgeb	I_{dc}

Config Fields in [RCp]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.6.6 RCs

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	<i>kV</i>	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	<i>kV</i>	non_zero
Idcn	I_{dcn}	DC current rating	1	<i>kA</i>	non_zero
R	R	DC line resistance	0.010	<i>p.u.</i>	non_zero,r
C	C	DC capacitance	0.001	<i>p.u.</i>	non_zero,g

Variables

Name	Symbol	Type	Description	Unit	Properties
vC	v_C	State	Capacitor current	<i>p.u.</i>	v_str
Idc	I_{dc}	Algeb	Current from node 2 to 1	<i>p.u.</i>	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Initialization Equations

Name	Symbol	Type	Initial Value
vC	v_C	State	$v_1 - v_2$
Idc	I_{dc}	Algeb	$\frac{-v_1 + v_2}{R}$
v1	v_1	ExtAlgeb	
v2	v_2	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
vC	v_C	State	$-I_{dc}u$	C

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Idc	I_{dc}	Algeb	$I_{dc}(1 - u) + u(-I_{dc}R - v_1 + v_2 + v_C)$
v1	v_1	ExtAlgeb	$-I_{dc}$
v2	v_2	ExtAlgeb	I_{dc}

Config Fields in [RCs]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.6.7 RLs

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	<i>kV</i>	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	<i>kV</i>	non_zero
Idcn	I_{dcn}	DC current rating	1	<i>kA</i>	non_zero
R	R	DC line resistance	0.010	<i>p.u.</i>	non_zero,r
L	L	DC line inductance	0.001	<i>p.u.</i>	non_zero,r

Variables

Name	Symbol	Type	Description	Unit	Properties
IL	I_L	State	Inductance current	<i>p.u.</i>	v_str
Idc	I_{dc}	Algeb	Current from node 2 to 1	<i>p.u.</i>	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Initialization Equations

Name	Symbol	Type	Initial Value
IL	I_L	State	$\frac{v_1 - v_2}{R}$
Idc	I_{dc}	Algeb	$-\frac{u(v_1 - v_2)}{R}$
v1	v_1	ExtAlgeb	
v2	v_2	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
IL	I_L	State	$u(-I_L R + v_1 - v_2)$	L

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Idc	I_{dc}	Algeb	$-I_L u - I_{dc}$
v1	v_1	ExtAlgeb	$-I_{dc}$
v2	v_2	ExtAlgeb	I_{dc}

Config Fields in [RLs]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.6.8 RLCs

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	<i>kV</i>	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	<i>kV</i>	non_zero
Idcn	I_{dcn}	DC current rating	1	<i>kA</i>	non_zero
R	R	DC line resistance	0.010	<i>p.u.</i>	non_zero,r
L	L	DC line inductance	0.001	<i>p.u.</i>	non_zero,r
C	C	DC capacitance	0.001	<i>p.u.</i>	non_zero,g

Variables

Name	Symbol	Type	Description	Unit	Properties
IL	I_L	State	Inductance current	<i>p.u.</i>	v_str
vC	v_C	State	Capacitor current	<i>p.u.</i>	v_str
Idc	I_{dc}	Algeb	Current from node 2 to 1	<i>p.u.</i>	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Initialization Equations

Name	Symbol	Type	Initial Value
IL	I_L	State	0
vC	v_C	State	$v_1 - v_2$
Idc	I_{dc}	Algeb	0
v1	v_1	ExtAlgeb	
v2	v_2	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation " $T \dot{x} = f(x, y)$ "	T (LHS)
IL	I_L	State	$u(-I_L R + v_1 - v_2 - v_C)$	L
vC	v_C	State	$I_L u$	C

Algebraic Equations

Name	Symbol	Type	RHS of Equation " $0 = g(x, y)$ "
Idc	I_{dc}	Algeb	$-I_L - I_{dc}$
v1	v_1	ExtAlgeb	$-I_{dc}$
v2	v_2	ExtAlgeb	I_{dc}

Config Fields in [RLCs]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.6.9 RLCp

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	<i>kV</i>	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	<i>kV</i>	non_zero
Idcn	I_{dcn}	DC current rating	1	<i>kA</i>	non_zero
R	R	DC line resistance	0.010	<i>p.u.</i>	non_zero,r
L	L	DC line inductance	0.001	<i>p.u.</i>	non_zero,r
C	C	DC capacitance	0.001	<i>p.u.</i>	non_zero,g

Variables

Name	Symbol	Type	Description	Unit	Properties
IL	I_L	State	Inductance current	<i>p.u.</i>	v_str
vC	v_C	State	Capacitor current	<i>p.u.</i>	v_str
Idc	I_{dc}	Algeb	Current from node 2 to 1	<i>p.u.</i>	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Initialization Equations

Name	Symbol	Type	Initial Value
IL	I_L	State	0
vC	v_C	State	$v_1 - v_2$
Idc	I_{dc}	Algeb	$\frac{-v_1 + v_2}{R}$
v1	v_1	ExtAlgeb	
v2	v_2	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
IL	I_L	State	uv_C	L
vC	v_C	State	$-u \left(-I_L + I_{dc} - \frac{v_C}{R} \right)$	C

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Idc	I_{dc}	Algeb	$I_{dc} (1 - u) + u (-v_1 + v_2 + v_C)$
v1	v_1	ExtAlgeb	$-I_{dc}$
v2	v_2	ExtAlgeb	I_{dc}

Config Fields in [RLCp]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.7 DCTopology

Common Parameters: u, name

Common Variables: v

Available models: *Node*

5.7.1 Node

DC Node model.

A DC Node is like an AC Bus. DC devices need to be connected to Nodes to inject power flow.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
Vdcn	V_{dcn}	DC voltage rating	100	<i>kV</i>	non_zero
Idcn	I_{dcn}	DC current rating	1	<i>kA</i>	non_zero
v0	V_{dc0}	initial voltage magnitude	1	<i>p.u.</i>	
xcoord		x coordinate (longitude)	0		
ycoord		y coordinate (latitude)	0		
area		Area code			
zone		Zone code			
owner		Owner code			

Variables

Name	Symbol	Type	Description	Unit	Properties
v	V_{dc}	Algeb	voltage magnitude	<i>p.u.</i>	v_str

Initialization Equations

Name	Symbol	Type	Initial Value
v	V_{dc}	Algeb	$V_{dc0} \cdot (1 - z_{flat}) + z_{flat}$

Algebraic Equations

Name	Symbol	Type	RHS of Equation " $0 = g(x, y)$ "
v	V_{dc}	Algeb	0

Config Fields in [Node]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
flat_start	z_{flat}	0	flat start for voltages	(0, 1)

5.8 DG

Distributed generation (small-scale).

See *SynGen* for the notes on replacing StaticGen and setting the power ratio parameters.

Common Parameters: *u*, *name*, *bus*, *fn*

Available models: *PVD1*, *ESD1*, *EV1*, *EV2*

5.8.1 PVD1

WECC Distributed PV model.

Device power rating is specified in *Sn*. Output currents are named *Ipout_y* and *Iqout_y*. Output power can be computed as $P_e = I_{pout_y} * v$ and $Q_e = I_{qout_y} * v$.

Frequency tripping response points *ft0*, *ft1*, *ft2*, and *ft3* must be monotonically increasing. Same rule applies to the voltage tripping response points *vt0*, *vt1*, *vt2*, and *vt3*. The program does not check these values, and the user is responsible for the parameter validity.

Frequency and voltage recovery latching is yet to be implemented.

Modifications to the active and reactive power references, typically by an external scheduling program, should write to *pref0.v* and *qref0.v* in place. AGC signals should write to *pext0.v* in place.

Maximum power limit *pmx* can be disabled by editing the configuration file by setting *plim=0*. It cannot be modified in runtime.

Reference: [1] ESIG, WECC Distributed and Small PV Plants Generic Model (PVD1), [Online], Available:

<https://www.esig.energy/wiki-main-page/wecc-distributed-and-small-pv-plants-generic-model-pvd1/>

Parameters

Name	Symbol	Description	Default	Unit	Properties
<i>idx</i>		unique device idx			
<i>u</i>	<i>u</i>	connection status	1	<i>bool</i>	
<i>name</i>		device name			
<i>bus</i>		interface bus id			mandatory
<i>gen</i>		static generator index			mandatory
<i>Sn</i>	<i>Sn</i>	device MVA rating	100	<i>MVA</i>	
<i>fn</i>	<i>fn</i>	nominal frequency	60	<i>Hz</i>	
<i>busf</i>		Optional BusFreq measurement device idx			
<i>xc</i>	<i>xc</i>	coupling reactance	0	<i>p.u.</i>	<i>z</i>
<i>pqflag</i>		P/Q priority for I limit; 0-Q priority, 1-P priority		<i>bool</i>	mandatory
<i>igreg</i>		Remote bus idx for droop response, None for local			
<i>qmx</i>	<i>qmx</i>	Max. reactive power command	0.330	<i>pu</i>	power

continues on

Table 2 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
qmn	q_{mn}	Min. reactive power command	-0.330	<i>pu</i>	power
pmx	p_{mx}	maximum power limit	9999	<i>pu</i>	power
v0	v_0	Lower limit of deadband for Vdroop response	0.800	<i>pu</i>	non_zero
v1	v_1	Upper limit of deadband for Vdroop response	1.100	<i>pu</i>	non_zero
dqdv	dq/dv	Q-V droop characteristics (negative)	-1		non_zero,power
fdbd	f_{dbd}	frequency deviation deadband	-0.017	<i>Hz</i>	non_positive
ddn	D_{dn}	Gain after f deadband	0	<i>pu (MW)/Hz</i>	non_negative,power
ialim	I_{alim}	Apparent power limit	1.300		non_zero,non_negative
vt0	V_{t0}	Voltage tripping response curve point 0	0.880	<i>p.u.</i>	non_zero,non_negative
vt1	V_{t1}	Voltage tripping response curve point 1	0.900	<i>p.u.</i>	non_zero,non_negative
vt2	V_{t2}	Voltage tripping response curve point 2	1.100	<i>p.u.</i>	non_zero,non_negative
vt3	V_{t3}	Voltage tripping response curve point 3	1.200	<i>p.u.</i>	non_zero,non_negative
vrflag	z_{VR}	V-trip is latching (0) or self-resetting (0-1)	0		
ft0	f_{t0}	Frequency tripping response curve point 0	59.500	<i>Hz</i>	non_zero,non_negative
ft1	f_{t1}	Frequency tripping response curve point 1	59.700	<i>Hz</i>	non_zero,non_negative
ft2	f_{t2}	Frequency tripping response curve point 2	60.300	<i>Hz</i>	non_zero,non_negative
ft3	f_{t3}	Frequency tripping response curve point 3	60.500	<i>Hz</i>	non_zero,non_negative
frflag	z_{FR}	f-trip is latching (0) or self-resetting (0-1)	0		
tip	T_{ip}	Inverter active current lag time constant	0.020	<i>s</i>	non_negative
tiq	T_{iq}	Inverter reactive current lag time constant	0.020	<i>s</i>	non_negative
gammap	γ_p	Ratio of PVD1.pref0 w.r.t to that of static PV	1		
gammaq	γ_q	Ratio of PVD1.qref0 w.r.t to that of static PV	1		
recflag	z_{rec}	Enable flag for voltage and frequency recovery limiters	1		

Variables

Name	Symbol	Type	Description	Unit	Properties
Ipout_y	y_{Ipout}	State	State in lag transfer function		v_str
Iqout_y	y_{Iqout}	State	State in lag transfer function		v_str
fHz	f_{Hz}	Algeb	frequency in Hz	Hz	v_str
Ffl	F_{fl}	Algeb	Coeff. for under frequency		v_str
Ffh	F_{fh}	Algeb	Coeff. for over frequency		v_str
Fdev	f_{dev}	Algeb	Frequency deviation	Hz	v_str
DB_y	y_{DB}	Algeb	Deadband type 1 output		v_str
Fvl	F_{vl}	Algeb	Coeff. for under voltage		v_str
Fvh	F_{vh}	Algeb	Coeff. for over voltage		v_str
vp	V_p	Algeb	Sensed positive voltage		v_str
Pext	P_{ext}	Algeb	External power signal (for AGC)		v_str
Pref	P_{ref}	Algeb	Reference power signal (for scheduling setpoint)		v_str
Psum	P_{tot}	Algeb	Sum of P signals		v_str
Qdrp	Q_{drp}	Algeb	External power signal (for AGC)		v_str
Qref	Q_{ref}	Algeb	Reference power signal (for scheduling setpoint)		v_str
Qsum	Q_{tot}	Algeb	Sum of Q signals		v_str
Ipul	$I_{p,ul}$	Algeb	Ipcmd before Ip hard limit		v_str
Iqul	$I_{q,ul}$	Algeb	Iqcmd before Iq hard limit		v_str
Ipmax	I_{pmax}	Algeb	Upper limit of Ip		v_str
Iqmax	I_{qmax}	Algeb	Upper limit of Iq		v_str
Ipcmd_x	x_{Ipcmd}	Algeb	Value before limiter		v_str
Ipcmd_y	y_{Ipcmd}	Algeb	Output after limiter and post gain		v_str
Iqcmd_x	x_{Iqcmd}	Algeb	Value before limiter		v_str
Iqcmd_y	y_{Iqcmd}	Algeb	Output after limiter and post gain		v_str
a	θ	ExtAlgeb	bus (or igreg) phase angle	rad.	
v	V	ExtAlgeb	bus (or igreg) terminal voltage	p.u.	
f	f	ExtAlgeb	Bus frequency	p.u.	

Initialization Equations

Name	Sym- bol	Type	Initial Value
Ipout_	y_{Ipout}	State	$1.0y_{IpCmd}$
Iqout_	y_{Iqout}	State	$1.0y_{IqCmd}$
fHz	f_{Hz}	Al- geb	$f f_n$
Ffl	F_{fl}	Al- geb	$K_{ft01} z_i^{FL1} (f_{Hz} - f_{t0}) + z_u^{FL1}$
Ffh	F_{fh}	Al- geb	$z_i^{FL2} (K_{ft23} (-f_{Hz} + f_{t2}) + 1) + z_l^{FL2}$
Fdev	f_{dev}	Al- geb	$f_n - f_{Hz}$
DB_y	y_{DB}	Al- geb	$D_{dn} \left(f_{dev} z_u^{dbDB} + z_l^{dbDB} (-f_{dbd} + f_{dev}) \right)$
Fvl	F_{vl}	Al- geb	$K_{vt01} z_i^{VL1} (V - V_{t0}) + z_u^{VL1}$
Fvh	F_{vh}	Al- geb	$z_i^{VL2} (K_{vt23} (-V + V_{t2}) + 1) + z_l^{VL2}$
vp	V_p	Al- geb	$V z_i^{VLo} + 0.01 z_l^{VLo}$
Pext	P_{ext}	Al- geb	$P_{ext0} u$
Pref	P_{ref}	Al- geb	$P_{ref0} u$
Psum	P_{tot}	Al- geb	$u (P_{ext} + P_{ref} + y_{DB})$
Qdrp	Q_{drp}	Al- geb	$dq/dv z_i^{VQ2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ2} + q_{mx} u z_l^{VQ1} +$ $u z_i^{VQ1} (dq/dv (-V_{comp} + V_{qu}) + q_{mx})$
Qref	Q_{ref}	Al- geb	$Q_{ref0} u$
Qsum	Q_{tot}	Al- geb	$u \left(Q_{ref0} + dq/dv z_i^{VQ2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ2} + q_{mx} u z_l^{VQ1} + u z_i^{VQ1} (dq/dv (-V_{comp} + V_{qu}) + q_{mx}) \right)$
Ipul	$I_{p,ul}$	Al- geb	$\frac{P_{tot} z_i^{PHL} + p_{mx} z_u^{PHL}}{V_p}$
Iqul	$I_{q,ul}$	Al- geb	$\frac{Q_{tot}}{V_p}$
Ip- max	I_{pmax}	Al- geb	$I_{alim} s_1^{SWPQ} + \sqrt{I_{pmax0}^2 s_0^{SWPQ}}$
Iq- max	I_{qmax}	Al- geb	$I_{alim} s_0^{SWPQ} + \sqrt{I_{qmax0}^2 s_1^{SWPQ}}$
Ipcmd	x_{IpCmd}	Al- geb	$I_{p,ul}$
Ipcmd	y_{IpCmd}	Al- geb	$I_{pmax} z_u^{lim_{IpCmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) +$ $x_{IpCmd} z_i^{lim_{IpCmd}} (F_{fh} F_{fl} F_{vh} F_{vt} z_{rec} - z_{rec} + 1)$
Iqcmd	x_{IqCmd}	Al- geb	$I_{q,ul}$
Iqcmd	y_{IqCmd}	Al- geb	$-I_{qmax} z_l^{lim_{IqCmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) +$ $x_{IqCmd} z_i^{lim_{IqCmd}} (F_{fh} F_{fl} F_{vh} F_{vt} z_{rec} - z_{rec} + 1)$

Differential Equations

Name	Symbol	Type	RHS of Equation " $\dot{T} = f(x, y)$ "	T (LHS)
Ipout_y	y_{Ipout}	State	$1.0y_{Ipcmd} - y_{Ipout}$	T_{ip}
Iqout_y	y_{Iqout}	State	$1.0y_{Iqcmd} - y_{Iqout}$	T_{iq}

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
fHz	f_{Hz}	Al- geb	$f f_n - f_{Hz}$
Ffl	F_{fl}	Al- geb	$-F_{fl} + K_{ft01} z_i^{FL1} (f_{Hz} - f_{t0}) + z_u^{FL1}$
Ffh	F_{fh}	Al- geb	$-F_{fh} + z_i^{FL2} (K_{ft23} (-f_{Hz} + f_{t2}) + 1) + z_l^{FL2}$
Fdev	f_{dev}	Al- geb	$f_n - f_{Hz} - f_{dev}$
DB_y	y_{DB}	Al- geb	$D_{dn} \left(f_{dev} z_u^{db_{DB}} + z_l^{db_{DB}} (-f_{dbd} + f_{dev}) \right) - y_{DB}$
Fvl	F_{vl}	Al- geb	$-F_{vl} + K_{vt01} z_i^{VL1} (V - V_{t0}) + z_u^{VL1}$
Fvh	F_{vh}	Al- geb	$-F_{vh} + z_i^{VL2} (K_{vt23} (-V + V_{t2}) + 1) + z_l^{VL2}$
vp	V_p	Al- geb	$V z_i^{VLo} - V_p + 0.01 z_l^{VLo}$
Pext	P_{ext}	Al- geb	$P_{ext0} u - P_{ext}$
Pref	P_{ref}	Al- geb	$P_{ref0} u - P_{ref}$
Psum	P_{tot}	Al- geb	$-P_{tot} + u (P_{ext} + P_{ref} + y_{DB})$
Qdrp	Q_{drp}	Al- geb	$-Q_{drp} + dq/dv z_i^{VQ2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ2} + q_{mx} u z_l^{VQ1} +$ $u z_i^{VQ1} (dq/dv (-V_{comp} + V_{qu}) + q_{mx})$
Qref	Q_{ref}	Al- geb	$Q_{ref0} u - Q_{ref}$
Qsum	Q_{tot}	Al- geb	$-Q_{tot} + u (Q_{drp} + Q_{ref})$
Ipul	$I_{p,ul}$	Al- geb	$-I_{p,ul} + \frac{P_{tot} z_i^{PHL} + p_{mx} z_u^{PHL}}{V_p}$
Iqul	$I_{q,ul}$	Al- geb	$-I_{q,ul} + \frac{Q_{tot}}{V_p}$
Ip- max	I_{pmax}	Al- geb	$I_{alim} s_1^{SWPQ} - I_{pmax} + \sqrt{I_{pmax}^2 s_0^{SWPQ}}$
Iq- max	I_{qmax}	Al- geb	$I_{alim} s_0^{SWPQ} - I_{qmax} + \sqrt{I_{qmax}^2 s_1^{SWPQ}}$
Ipcmc	x_{Ipcmd}	Al- geb	$I_{p,ul} - x_{Ipcmd}$
Ipcmc	y_{Ipcmd}	Al- geb	$I_{pmax} z_u^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) +$ $x_{Ipcmd} z_i^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) - y_{Ipcmd}$
Iqcmc	x_{Iqcmd}	Al- geb	$I_{q,ul} - x_{Iqcmd}$
Iqcmc	y_{Iqcmd}	Al- geb	$-I_{qmax} z_l^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) +$ $I_{qmax} z_u^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) +$ $x_{Iqcmd} z_i^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) - y_{Iqcmd}$

Services

Name	Sym- bol	Equation	Type
pref0	P_{ref0}	$P_{0s}\gamma_p$	ConstService
qref0	Q_{ref0}	$Q_{0s}\gamma_q$	ConstService
Kft01	K_{ft01}	$\frac{1}{-f_{t0}+f_{t1}}$	ConstService
Kft23	K_{ft23}	$\frac{1}{-f_{t2}+f_{t3}}$	ConstService
Kvt01	K_{vt01}	$\frac{1}{-V_{t0}+V_{t1}}$	ConstService
Kvt23	K_{vt23}	$\frac{1}{-V_{t2}+V_{t3}}$	ConstService
Pext0	P_{ext0}	0	ConstService
Vcomp	V_{comp}	$ Ve^{i\theta} + ix_c(y_{Ipout} + iy_{Iqout}) $	VarService
Vqu	V_{qu}	$v_1 - \frac{Q_{ref0}-q_{mn}}{dq/dv}$	ConstService
Vql	V_{ql}	$v_0 + \frac{-Q_{ref0}+q_{mx}}{dq/dv}$	ConstService
Ipmxsq	I_{pmax}^2	$\text{FixPiecewise}\left(\left(0, I_{alim}^2 - (y_{Iqcmd})^2 \leq 0\right), \left(I_{alim}^2 - (y_{Iqcmd})^2, \text{True}\right)\right)$	VarService
Ip-maxsq0	I_{pmax0}^2	$\text{FixPiecewise}\left(\left(0, I_{alim}^2 - \frac{Q_{ref0}^2 u^2}{V^2} \leq 0\right), \left(I_{alim}^2 - \frac{Q_{ref0}^2 u^2}{V^2}, \text{True}\right)\right)$	ConstService
Iqmaxsq	I_{qmax}^2	$\text{FixPiecewise}\left(\left(0, I_{alim}^2 - (y_{Ipcmd})^2 \leq 0\right), \left(I_{alim}^2 - (y_{Ipcmd})^2, \text{True}\right)\right)$	VarService
Iq-maxsq0	I_{qmax0}^2	$\text{FixPiecewise}\left(\left(0, I_{alim}^2 - \frac{P_{ref0}^2 u^2}{V^2} \leq 0\right), \left(I_{alim}^2 - \frac{P_{ref0}^2 u^2}{V^2}, \text{True}\right)\right)$	ConstService

Discretes

Name	Symbol	Type	Info
SWPQ	SW_{PQ}	Switcher	
FL1	$FL1$	Limiter	Under frequency comparer
FL2	$FL2$	Limiter	Over frequency comparer
DB_db	db_{DB}	DeadBand	
VL1	$VL1$	Limiter	Under voltage comparer
VL2	$VL2$	Limiter	Over voltage comparer
VLo	VLo	Limiter	Voltage lower limit (0.01) flag
PHL	PHL	Limiter	limiter for Psum in [0, pmx]
VQ1	$VQ1$	Limiter	Under voltage comparer for Q droop
VQ2	$VQ2$	Limiter	Over voltage comparer for Q droop
Ipcmd_lim	lim_{Ipcmd}	HardLimiter	
Iqcmd_lim	lim_{Iqcmd}	HardLimiter	

Blocks

Name	Symbol	Type	Info
DB	DB	DeadBand1	frequency deviation deadband with gain
Ipcmd	I^{pcmd}	GainLimiter	Ip with limiter and coeff.
Iqcmd	I^{qcmd}	GainLimiter	Iq with limiter and coeff.
Ipout	$Ipout$	Lag	Output Ip filter
Iqout	$Iqout$	Lag	Output Iq filter

Config Fields in [PVD1]

Option	Sym- bol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
ad- just_upper		1	adjust upper limit	(0, 1)
plim	P_{lim}	1	enable input power limit check bound by [0, pmx]	(0, 1)

5.8.2 ESD1

Distributed energy storage model.

A state-of-charge limit is added to the PVD1 model. This limit is applied to I_{pmax} and I_{pmin} . The state of charge is in state variable SOC , which is an alias of pIG_y .

Reference: [1] Powerworld, Renewable Energy Electrical Control Model REEC_C Available:

https://www.powerworld.com/WebHelp/Content/TransientModels_HTML/Exciter%20REEC_C.htm

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
Sn	S_n	device MVA rating	100	<i>MVA</i>	
fn	f_n	nominal frequency	60	<i>Hz</i>	
busf		Optional BusFreq measurement device idx			
xc	x_c	coupling reactance	0	<i>p.u.</i>	z
pqflag		P/Q priority for I limit; 0-Q priority, 1-P priority		<i>bool</i>	mandatory
igreg		Remote bus idx for droop response, None for local			
qmx	q_{mx}	Max. reactive power command	0.330	<i>pu</i>	power
qmn	q_{mn}	Min. reactive power command	-0.330	<i>pu</i>	power
pmx	p_{mx}	maximum power limit	9999	<i>pu</i>	power
v0	v_0	Lower limit of deadband for Vdroop response	0.800	<i>pu</i>	non_zero
v1	v_1	Upper limit of deadband for Vdroop response	1.100	<i>pu</i>	non_zero
dqdv	dq/dv	Q-V droop characteristics (negative)	-1		non_zero,power
fdbd	f_{dbd}	frequency deviation deadband	-0.017	<i>Hz</i>	non_positive
ddn	D_{dn}	Gain after f deadband	0	<i>pu (MW)/Hz</i>	non_negative,pow
ialim	I_{alim}	Apparent power limit	1.300		non_zero,non_ne
vt0	V_{t0}	Voltage tripping response curve point 0	0.880	<i>p.u.</i>	non_zero,non_ne
vt1	V_{t1}	Voltage tripping response curve point 1	0.900	<i>p.u.</i>	non_zero,non_ne
vt2	V_{t2}	Voltage tripping response curve point 2	1.100	<i>p.u.</i>	non_zero,non_ne
vt3	V_{t3}	Voltage tripping response curve point 3	1.200	<i>p.u.</i>	non_zero,non_ne
vrflag	z_{VR}	V-trip is latching (0) or self-resetting (0-1)	0		
ft0	f_{t0}	Frequency tripping response curve point 0	59.500	<i>Hz</i>	non_zero,non_ne
ft1	f_{t1}	Frequency tripping response curve point 1	59.700	<i>Hz</i>	non_zero,non_ne
ft2	f_{t2}	Frequency tripping response curve point 2	60.300	<i>Hz</i>	non_zero,non_ne
ft3	f_{t3}	Frequency tripping response curve point 3	60.500	<i>Hz</i>	non_zero,non_ne
frflag	z_{FR}	f-trip is latching (0) or self-resetting (0-1)	0		
tip	T_{ip}	Inverter active current lag time constant	0.020	<i>s</i>	non_negative
tiq	T_{iq}	Inverter reactive current lag time constant	0.020	<i>s</i>	non_negative

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Table 3 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
gammap	γ_p	Ratio of PVD1.pref0 w.r.t to that of static PV	1		
gammaq	γ_q	Ratio of PVD1.qref0 w.r.t to that of static PV	1		
recflag	z_{rec}	Enable flag for voltage and frequency recovery limiters	1		
Tf	T_f	Integrator constant for SOC model	1		
SOCmin	SOC_{min}	Minimum required value for SOC in limiter	0		
SOCmax	SOC_{max}	Maximum allowed value for SOC in limiter	1		
SOCinit	SOC_{init}	Initial state of charge	0.500		
En	E_n	Rated energy capacity	100	MWh	
EtaC	Eta_C	Efficiency during charging	1		
EtaD	Eta_D	Efficiency during discharging	1		

Variables

Name	Symbol	Type	Description	Unit	Properties
Ipout_y	y_{Ipout}	State	State in lag transfer function		v_str
Iqout_y	y_{Iqout}	State	State in lag transfer function		v_str
pIG_y	y_{pIG}	State	Integrator output		v_str
SOC	SOC	AliasState	Alias for state of charge		
fHz	f_{Hz}	Algeb	frequency in Hz	Hz	v_str
Ffl	F_{fl}	Algeb	Coeff. for under frequency		v_str
Ffh	F_{fh}	Algeb	Coeff. for over frequency		v_str
Fdev	f_{dev}	Algeb	Frequency deviation	Hz	v_str
DB_y	y_{DB}	Algeb	Deadband type 1 output		v_str
Fvl	F_{vl}	Algeb	Coeff. for under voltage		v_str
Fvh	F_{vh}	Algeb	Coeff. for over voltage		v_str
vp	V_p	Algeb	Sensed positive voltage		v_str
Pext	P_{ext}	Algeb	External power signal (for AGC)		v_str
Pref	P_{ref}	Algeb	Reference power signal (for scheduling setpoint)		v_str
Psum	P_{tot}	Algeb	Sum of P signals		v_str
Qdrp	Q_{drp}	Algeb	External power signal (for AGC)		v_str
Qref	Q_{ref}	Algeb	Reference power signal (for scheduling setpoint)		v_str
Qsum	Q_{tot}	Algeb	Sum of Q signals		v_str
Ipul	$I_{p,ul}$	Algeb	Ipcmd before Ip hard limit		v_str
Iqul	$I_{q,ul}$	Algeb	Iqcmd before Iq hard limit		v_str
Ipmax	I_{pmax}	Algeb	Upper limit of Ip		v_str
Iqmax	I_{qmax}	Algeb	Upper limit of Iq		v_str
Ipcmd_x	x_{Ipcmd}	Algeb	Value before limiter		v_str
Ipcmd_y	y_{Ipcmd}	Algeb	Output after limiter and post gain		v_str
Iqcmd_x	x_{Iqcmd}	Algeb	Value before limiter		v_str
Iqcmd_y	y_{Iqcmd}	Algeb	Output after limiter and post gain		v_str
Ipmin	I_{pmin}	Algeb	Minimum value of Ip		v_str

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Table 4 – continued from previous page

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb	bus (or igr) phase angle	rad.	
v	V	ExtAlgeb	bus (or igr) terminal voltage	p.u.	
f	f	ExtAlgeb	Bus frequency	p.u.	

Initialization Equations

Name	Symbol	Type	Initial Value
Ipout_y	y_{Ipout}	State	$1.0y_{Ipcmd}$
Iqout_y	y_{Iqout}	State	$1.0y_{Iqcmd}$
pIG_y	y_{pIG}	State	SOC_{init}
SOC	SOC	AliasState	
fHz	f_{Hz}	Algeb	$f f_n$
Ffl	F_{fl}	Algeb	$K_{ft01} z_i^{FL1} (f_{Hz} - f_{t0}) + z_u^{FL1}$
Ffh	F_{fh}	Algeb	$z_i^{FL2} (K_{ft23} (-f_{Hz} + f_{t2}) + 1) + z_l^{FL2}$
Fdev	f_{dev}	Algeb	$f_n - f_{Hz}$
DB_y	y_{DB}	Algeb	$D_{dn} (f_{dev} z_u^{db_{DB}} + z_l^{db_{DB}} (-f_{dbd} + f_{dev}))$
Fvl	F_{vl}	Algeb	$K_{vt01} z_i^{VL1} (V - V_{t0}) + z_u^{VL1}$
Fvh	F_{vh}	Algeb	$z_i^{VL2} (K_{vt23} (-V + V_{t2}) + 1) + z_l^{VL2}$
vp	V_p	Algeb	$V z_i^{VLo} + 0.01 z_l^{VLo}$
Pext	P_{ext}	Algeb	$P_{ext0} u$
Pref	P_{ref}	Algeb	$P_{ref0} u$
Psum	P_{tot}	Algeb	$u (P_{ext} + P_{ref} + y_{DB})$
Qdrp	Q_{drp}	Algeb	$dq/dv u z_i^{VQ2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ2} + q_{mx} u z_l^{VQ1} + u z_i^{VQ1} (dq/dv (-V_{comp} + V_{ref}))$
Qref	Q_{ref}	Algeb	$Q_{ref0} u$
Qsum	Q_{tot}	Algeb	$u (Q_{ref0} + dq/dv u z_i^{VQ2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ2} + q_{mx} u z_l^{VQ1} + u z_i^{VQ1} (dq/dv (-V_{comp} + V_{ref})))$
Ipul	$I_{p,ul}$	Algeb	$\frac{P_{tot} z_i^{PHL} + p_{mx} z_u^{PHL}}{V_p}$
Iqul	$I_{q,ul}$	Algeb	$\frac{Q_{tot}}{V_p}$
Ipmax	I_{pmax}	Algeb	$(1 - z_l^{SOClim}) (I_{alim} s_1^{SW_{PQ}} + \sqrt{I_{pmax0}^2 s_0^{SW_{PQ}}})$
Iqmax	I_{qmax}	Algeb	$I_{alim} s_0^{SW_{PQ}} + \sqrt{I_{qmax0}^2 s_1^{SW_{PQ}}}$
Ipcmd_x	x_{Ipcmd}	Algeb	$I_{p,ul}$
Ipcmd_y	y_{Ipcmd}	Algeb	$I_{pmax} z_u^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) + x_{Ipcmd} z_i^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1)$
Iqcmd_x	x_{Iqcmd}	Algeb	$I_{q,ul}$
Iqcmd_y	y_{Iqcmd}	Algeb	$-I_{qmax} z_l^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) + I_{qmax} z_u^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1)$
Ipmin	I_{pmin}	Algeb	$(z_u^{SOClim} - 1) (I_{alim} s_1^{SW_{PQ}} + \sqrt{I_{pmax0}^2 s_0^{SW_{PQ}}})$
a	θ	ExtAlgeb	
v	V	ExtAlgeb	
f	f	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
Ipout_y	y_{Ipout}	State	$1.0y_{IpCmd} - y_{Ipout}$	T_{ip}
Iqout_y	y_{Iqout}	State	$1.0y_{IqCmd} - y_{Iqout}$	T_{iq}
pIG_y	y_{pIG}	State	$\frac{S_{b,sys} \left(-H_C V y_{Ipout} z_1^{LTN} - \frac{V y_{Ipout} z_0^{LTN}}{H_D} \right)}{3600 E_n}$	T_f
SOC	SOC	AliasState	0	

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
fHz	f_{Hz}	Al- geb	$f f_n - f_{Hz}$
Ffl	F_{fl}	Al- geb	$-F_{fl} + K_{ft01} z_i^{FL1} (f_{Hz} - f_{t0}) + z_u^{FL1}$
Ffh	F_{fh}	Al- geb	$-F_{fh} + z_i^{FL2} (K_{ft23} (-f_{Hz} + f_{t2}) + 1) + z_l^{FL2}$
Fdev	f_{dev}	Al- geb	$f_n - f_{Hz} - f_{dev}$
DB_y	y_{DB}	Al- geb	$D_{dn} \left(f_{dev} z_u^{db_{DB}} + z_l^{db_{DB}} (-f_{dbd} + f_{dev}) \right) - y_{DB}$
Fvl	F_{vl}	Al- geb	$-F_{vl} + K_{vt01} z_i^{VL1} (V - V_{t0}) + z_u^{VL1}$
Fvh	F_{vh}	Al- geb	$-F_{vh} + z_i^{VL2} (K_{vt23} (-V + V_{t2}) + 1) + z_l^{VL2}$
vp	V_p	Al- geb	$V z_i^{VLo} - V_p + 0.01 z_l^{VLo}$
Pext	P_{ext}	Al- geb	$P_{ext0} u - P_{ext}$
Pref	P_{ref}	Al- geb	$P_{ref0} u - P_{ref}$
Psum	P_{tot}	Al- geb	$-P_{tot} + u (P_{ext} + P_{ref} + y_{DB})$
Qdrp	Q_{drp}	Al- geb	$-Q_{drp} + dq/dv z_i^{VQ2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ2} + q_{mx} u z_l^{VQ1} +$ $u z_i^{VQ1} (dq/dv (-V_{comp} + V_{qu}) + q_{mx})$
Qref	Q_{ref}	Al- geb	$Q_{ref0} u - Q_{ref}$
Qsum	Q_{tot}	Al- geb	$-Q_{tot} + u (Q_{drp} + Q_{ref})$
Ipul	$I_{p,ul}$	Al- geb	$-I_{p,ul} + \frac{P_{tot} z_i^{PHL} + p_{mx} z_u^{PHL}}{V_p}$
Iqul	$I_{q,ul}$	Al- geb	$-I_{q,ul} + \frac{Q_{tot}}{V_p}$
Ip- max	I_{pmax}	Al- geb	$-I_{pmax} + (1 - z_l^{SOClim}) \left(I_{alim} s_1^{SWPQ} + \sqrt{I_{pmax}^2 s_0^{SWPQ}} \right)$
Iq- max	I_{qmax}	Al- geb	$I_{alim} s_0^{SWPQ} - I_{qmax} + \sqrt{I_{qmax}^2 s_1^{SWPQ}}$
Ipcmc	x_{Ipcmd}	Al- geb	$I_{p,ul} - x_{Ipcmd}$
Ipcmc	y_{Ipcmd}	Al- geb	$I_{pmax} z_u^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) +$ $x_{Ipcmd} z_i^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) - y_{Ipcmd}$
Iqcmc	x_{Iqcmd}	Al- geb	$I_{q,ul} - x_{Iqcmd}$
Iqcmc	y_{Iqcmd}	Al- geb	$-I_{qmax} z_l^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) +$ $I_{qmax} z_u^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) +$ $x_{Iqcmd} z_i^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) - y_{Iqcmd}$

Services

Name	Sym- bol	Equation	Type
pref0	P_{ref0}	$P_{0s}\gamma_p$	ConstService
qref0	Q_{ref0}	$Q_{0s}\gamma_q$	ConstService
Kft01	K_{ft01}	$\frac{1}{-f_{t0}+f_{t1}}$	ConstService
Kft23	K_{ft23}	$\frac{1}{-f_{t2}+f_{t3}}$	ConstService
Kvt01	K_{vt01}	$\frac{1}{-V_{t0}+V_{t1}}$	ConstService
Kvt23	K_{vt23}	$\frac{1}{-V_{t2}+V_{t3}}$	ConstService
Pext0	P_{ext0}	0	ConstService
Vcomp	V_{comp}	$ Ve^{i\theta} + ix_c(y_{Ipout} + iy_{Iqout}) $	VarService
Vqu	V_{qu}	$v_1 - \frac{Q_{ref0}-q_{mn}}{dq/dv}$	ConstService
Vql	V_{ql}	$v_0 + \frac{-Q_{ref0}+q_{mx}}{dq/dv}$	ConstService
Ipmxsq	I_{pmax}^2	$\text{FixPiecewise}\left(\left(0, I_{alim}^2 - (y_{Iqcmd})^2 \leq 0\right), \left(I_{alim}^2 - (y_{Iqcmd})^2, \text{True}\right)\right)$	VarService
Ip- maxsq0	I_{pmax0}^2	$\text{FixPiecewise}\left(\left(0, I_{alim}^2 - \frac{Q_{ref0}^2 u^2}{V^2} \leq 0\right), \left(I_{alim}^2 - \frac{Q_{ref0}^2 u^2}{V^2}, \text{True}\right)\right)$	ConstService
Iqmaxsq	I_{qmax}^2	$\text{FixPiecewise}\left(\left(0, I_{alim}^2 - (y_{Ipcmd})^2 \leq 0\right), \left(I_{alim}^2 - (y_{Ipcmd})^2, \text{True}\right)\right)$	VarService
Iq- maxsq0	I_{qmax0}^2	$\text{FixPiecewise}\left(\left(0, I_{alim}^2 - \frac{P_{ref0}^2 u^2}{V^2} \leq 0\right), \left(I_{alim}^2 - \frac{P_{ref0}^2 u^2}{V^2}, \text{True}\right)\right)$	ConstService

Discretes

Name	Symbol	Type	Info
SWPQ	SW_{PQ}	Switcher	
FL1	$FL1$	Limiter	Under frequency comparer
FL2	$FL2$	Limiter	Over frequency comparer
DB_db	db_{DB}	DeadBand	
VL1	$VL1$	Limiter	Under voltage comparer
VL2	$VL2$	Limiter	Over voltage comparer
VLo	VLo	Limiter	Voltage lower limit (0.01) flag
PHL	PHL	Limiter	limiter for Psum in [0, pmx]
VQ1	$VQ1$	Limiter	Under voltage comparer for Q droop
VQ2	$VQ2$	Limiter	Over voltage comparer for Q droop
Ipcmd_lim	lim_{Ipcmd}	HardLimiter	
Iqcmd_lim	lim_{Iqcmd}	HardLimiter	
LTN	LTN	LessThan	
SOClim	$SOClim$	HardLimiter	

Blocks

Name	Symbol	Type	Info
DB	DB	DeadBand1	frequency deviation deadband with gain
Ipcmd	I^{pcmd}	GainLimiter	Ip with limiter and coeff.
Iqcmd	I^{qcmd}	GainLimiter	Iq with limiter and coeff.
Ipout	$Ipout$	Lag	Output Ip filter
Iqout	$Iqout$	Lag	Output Iq filter
pIG	pIG	Integrator	State of charge

Config Fields in [ESD1]

Option	Sym- bol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
ad- just_upper		1	adjust upper limit	(0, 1)
plim	P_{lim}	1	enable input power limit check bound by [0, pmx]	(0, 1)

5.8.3 EV1

Electric vehicle model type 1.

Modified from ESD1 model by adding the minimum power limit pmn . Like pmx , pmn acts on $Psum$, the sum of the active power references.

The limiter that uses pmx and pmn is enabled by default.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
Sn	S_n	device MVA rating	100	<i>MVA</i>	
fn	f_n	nominal frequency	60	<i>Hz</i>	
busf		Optional BusFreq measurement device idx			
xc	x_c	coupling reactance	0	<i>p.u.</i>	z
pqflag		P/Q priority for I limit; 0-Q priority, 1-P priority		<i>bool</i>	mandatory
igreg		Remote bus idx for droop response, None for local			
qmx	q_{mx}	Max. reactive power command	0.330	<i>pu</i>	power
qmn	q_{mn}	Min. reactive power command	-0.330	<i>pu</i>	power
pmx	p_{mx}	maximum power limit	9999	<i>pu</i>	power
v0	v_0	Lower limit of deadband for Vdroop response	0.800	<i>pu</i>	non_zero
v1	v_1	Upper limit of deadband for Vdroop response	1.100	<i>pu</i>	non_zero
dqdv	dq/dv	Q-V droop characteristics (negative)	-1		non_zero,power
fdbd	f_{dbd}	frequency deviation deadband	-0.017	<i>Hz</i>	non_positive
ddn	D_{dn}	Gain after f deadband	0	<i>pu (MW)/Hz</i>	non_negative,pow
ialim	I_{alim}	Apparent power limit	1.300		non_zero,non_ne
vt0	V_{t0}	Voltage tripping response curve point 0	0.880	<i>p.u.</i>	non_zero,non_ne
vt1	V_{t1}	Voltage tripping response curve point 1	0.900	<i>p.u.</i>	non_zero,non_ne
vt2	V_{t2}	Voltage tripping response curve point 2	1.100	<i>p.u.</i>	non_zero,non_ne
vt3	V_{t3}	Voltage tripping response curve point 3	1.200	<i>p.u.</i>	non_zero,non_ne
vrflag	z_{VR}	V-trip is latching (0) or self-resetting (0-1)	0		
ft0	f_{t0}	Frequency tripping response curve point 0	59.500	<i>Hz</i>	non_zero,non_ne
ft1	f_{t1}	Frequency tripping response curve point 1	59.700	<i>Hz</i>	non_zero,non_ne
ft2	f_{t2}	Frequency tripping response curve point 2	60.300	<i>Hz</i>	non_zero,non_ne
ft3	f_{t3}	Frequency tripping response curve point 3	60.500	<i>Hz</i>	non_zero,non_ne
frflag	z_{FR}	f-trip is latching (0) or self-resetting (0-1)	0		
tip	T_{ip}	Inverter active current lag time constant	0.020	<i>s</i>	non_negative
tiq	T_{iq}	Inverter reactive current lag time constant	0.020	<i>s</i>	non_negative
gammap	γ_p	Ratio of PVD1.pref0 w.r.t to that of static PV	1		

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Table 6 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
gammaq	γ_q	Ratio of PVD1.qref0 w.r.t to that of static PV	1		
recflag	z_{rec}	Enable flag for voltage and frequency recovery limiters	1		
Tf	T_f	Integrator constant for SOC model	1		
SOCmin	SOC_{min}	Minimum required value for SOC in limiter	0		
SOCmax	SOC_{max}	Maximum allowed value for SOC in limiter	1		
SOCinit	SOC_{init}	Initial state of charge	0.500		
En	E_n	Rated energy capacity	100	MWh	
EtaC	Eta_C	Efficiency during charging	1		
EtaD	Eta_D	Efficiency during discharging	1		
pmn	p_{mn}	minimum power limit	-999	pu	power

Variables

Name	Symbol	Type	Description	Unit	Properties
Ipout_y	y_{Ipout}	State	State in lag transfer function		v_str
Iqout_y	y_{Iqout}	State	State in lag transfer function		v_str
pIG_y	y_{pIG}	State	Integrator output		v_str
SOC	SOC	AliasState	Alias for state of charge		
fHz	f_{Hz}	Algeb	frequency in Hz	Hz	v_str
Ffl	F_{fl}	Algeb	Coeff. for under frequency		v_str
Ffh	F_{fh}	Algeb	Coeff. for over frequency		v_str
Fdev	f_{dev}	Algeb	Frequency deviation	Hz	v_str
DB_y	y_{DB}	Algeb	Deadband type 1 output		v_str
Fvl	F_{vl}	Algeb	Coeff. for under voltage		v_str
Fvh	F_{vh}	Algeb	Coeff. for over voltage		v_str
vp	V_p	Algeb	Sensed positive voltage		v_str
Pext	P_{ext}	Algeb	External power signal (for AGC)		v_str
Pref	P_{ref}	Algeb	Reference power signal (for scheduling setpoint)		v_str
Psum	P_{tot}	Algeb	Sum of P signals		v_str
Qdrp	Q_{drp}	Algeb	External power signal (for AGC)		v_str
Qref	Q_{ref}	Algeb	Reference power signal (for scheduling setpoint)		v_str
Qsum	Q_{tot}	Algeb	Sum of Q signals		v_str
Ipul	$I_{p,ul}$	Algeb	Ipcmd before Ip hard limit		v_str
Iqul	$I_{q,ul}$	Algeb	Iqcmd before Iq hard limit		v_str
Ipmax	I_{pmax}	Algeb	Upper limit of Ip		v_str
Iqmax	I_{qmax}	Algeb	Upper limit of Iq		v_str
Ipcmd_x	x_{Ipcmd}	Algeb	Value before limiter		v_str
Ipcmd_y	y_{Ipcmd}	Algeb	Output after limiter and post gain		v_str
Iqcmd_x	x_{Iqcmd}	Algeb	Value before limiter		v_str
Iqcmd_y	y_{Iqcmd}	Algeb	Output after limiter and post gain		v_str
Ipmin	I_{pmin}	Algeb	Minimum value of Ip		v_str

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Table 7 – continued from previous page

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb	bus (or igreg) phase angle	<i>rad.</i>	
v	V	ExtAlgeb	bus (or igreg) terminal voltage	<i>p.u.</i>	
f	f	ExtAlgeb	Bus frequency	<i>p.u.</i>	

Initialization Equations

Name	Symbol	Type	Initial Value
Ipout_y	y_{Ipout}	State	$1.0y_{Ipcmd}$
Iqout_y	y_{Iqout}	State	$1.0y_{Iqcmd}$
pIG_y	y_{pIG}	State	SOC_{init}
SOC	SOC	AliasState	
fHz	f_{Hz}	Algeb	$f f_n$
Ffl	F_{fl}	Algeb	$K_{ft01} z_i^{FL1} (f_{Hz} - f_{t0}) + z_u^{FL1}$
Ffh	F_{fh}	Algeb	$z_i^{FL2} (K_{ft23} (-f_{Hz} + f_{t2}) + 1) + z_l^{FL2}$
Fdev	f_{dev}	Algeb	$f_n - f_{Hz}$
DB_y	y_{DB}	Algeb	$D_{dn} \left(f_{dev} z_u^{db_{DB}} + z_l^{db_{DB}} (-f_{dbd} + f_{dev}) \right)$
Fvl	F_{vl}	Algeb	$K_{vt01} z_i^{VL1} (V - V_{t0}) + z_u^{VL1}$
Fvh	F_{vh}	Algeb	$z_i^{VL2} (K_{vt23} (-V + V_{t2}) + 1) + z_l^{VL2}$
vp	V_p	Algeb	$V z_i^{VLo} + 0.01 z_l^{VLo}$
Pext	P_{ext}	Algeb	$P_{ext0} u$
Pref	P_{ref}	Algeb	$P_{ref0} u$
Psum	P_{tot}	Algeb	$u (P_{ext} + P_{ref} + y_{DB})$
Qdrp	Q_{drp}	Algeb	$dq/dv u z_i^{VQ2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ2} + q_{mx} u z_l^{VQ1} + u z_i^{VQ1} (dq/dv (-V_{comp} + V_{ref}))$
Qref	Q_{ref}	Algeb	$Q_{ref0} u$
Qsum	Q_{tot}	Algeb	$u \left(Q_{ref0} + dq/dv u z_i^{VQ2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ2} + q_{mx} u z_l^{VQ1} + u z_i^{VQ1} (dq/dv (-V_{comp} + V_{ref})) \right)$
Ipul	$I_{p,ul}$	Algeb	$\frac{P_{tot} z_i^{PHL} + p_{mn} z_l^{PHL} + p_{mx} z_u^{PHL}}{V_p}$
Iqul	$I_{q,ul}$	Algeb	$\frac{Q_{tot}}{V_p}$
Ipmax	I_{pmax}	Algeb	$(1 - z_l^{SOClim}) \left(I_{alim} s_1^{SWPQ} + \sqrt{I_{pmax0}^2 s_0^{SWPQ}} \right)$
Iqmax	I_{qmax}	Algeb	$I_{alim} s_0^{SWPQ} + \sqrt{I_{qmax0}^2 s_1^{SWPQ}}$
Ipcmd_x	x_{Ipcmd}	Algeb	$I_{p,ul}$
Ipcmd_y	y_{Ipcmd}	Algeb	$I_{pmax} z_u^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) + x_{Ipcmd} z_i^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1)$
Iqcmd_x	x_{Iqcmd}	Algeb	$I_{q,ul}$
Iqcmd_y	y_{Iqcmd}	Algeb	$-I_{qmax} z_l^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) + I_{qmax} z_u^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1)$
Ipmin	I_{pmin}	Algeb	$(z_u^{SOClim} - 1) \left(I_{alim} s_1^{SWPQ} + \sqrt{I_{pmax0}^2 s_0^{SWPQ}} \right)$
a	θ	ExtAlgeb	
v	V	ExtAlgeb	
f	f	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
Ipout_y	y_{Ipout}	State	$1.0y_{IpCmd} - y_{Ipout}$	T_{ip}
Iqout_y	y_{Iqout}	State	$1.0y_{IqCmd} - y_{Iqout}$	T_{iq}
pIG_y	y_{pIG}	State	$\frac{S_{b,sys} \left(-H_C V y_{Ipout} z_1^{LTN} - \frac{V y_{Ipout} z_0^{LTN}}{H_D} \right)}{3600 E_n}$	T_f
SOC	SOC	AliasState	0	

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
fHz	f_{Hz}	Al- geb	$f f_n - f_{Hz}$
Ffl	F_{fl}	Al- geb	$-F_{fl} + K_{ft01} z_i^{FL1} (f_{Hz} - f_{t0}) + z_u^{FL1}$
Ffh	F_{fh}	Al- geb	$-F_{fh} + z_i^{FL2} (K_{ft23} (-f_{Hz} + f_{t2}) + 1) + z_l^{FL2}$
Fdev	f_{dev}	Al- geb	$f_n - f_{Hz} - f_{dev}$
DB_y	y_{DB}	Al- geb	$D_{dn} \left(f_{dev} z_u^{db_{DB}} + z_l^{db_{DB}} (-f_{dbd} + f_{dev}) \right) - y_{DB}$
Fvl	F_{vl}	Al- geb	$-F_{vl} + K_{vt01} z_i^{VL1} (V - V_{t0}) + z_u^{VL1}$
Fvh	F_{vh}	Al- geb	$-F_{vh} + z_i^{VL2} (K_{vt23} (-V + V_{t2}) + 1) + z_l^{VL2}$
vp	V_p	Al- geb	$V z_i^{VLo} - V_p + 0.01 z_l^{VLo}$
Pext	P_{ext}	Al- geb	$P_{ext0} u - P_{ext}$
Pref	P_{ref}	Al- geb	$P_{ref0} u - P_{ref}$
Psum	P_{tot}	Al- geb	$-P_{tot} + u (P_{ext} + P_{ref} + y_{DB})$
Qdrp	Q_{drp}	Al- geb	$-Q_{drp} + dq/dv z_i^{VQ2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ2} + q_{mx} u z_l^{VQ1} +$ $u z_i^{VQ1} (dq/dv (-V_{comp} + V_{qu}) + q_{mx})$
Qref	Q_{ref}	Al- geb	$Q_{ref0} u - Q_{ref}$
Qsum	Q_{tot}	Al- geb	$-Q_{tot} + u (Q_{drp} + Q_{ref})$
Ipul	$I_{p,ul}$	Al- geb	$-I_{p,ul} + \frac{P_{tot} z_i^{PHL} + p_{mn} z_l^{PHL} + p_{mx} z_u^{PHL}}{V_p}$
Iqul	$I_{q,ul}$	Al- geb	$-I_{q,ul} + \frac{Q_{tot}}{V_p}$
Ip- max	I_{pmax}	Al- geb	$-I_{pmax} + (1 - z_l^{SOClim}) \left(I_{alim} s_1^{SWPQ} + \sqrt{I_{pmax}^2 s_0^{SWPQ}} \right)$
Iq- max	I_{qmax}	Al- geb	$I_{alim} s_0^{SWPQ} - I_{qmax} + \sqrt{I_{qmax}^2 s_1^{SWPQ}}$
Ipcmc	x_{Ipcmd}	Al- geb	$I_{p,ul} - x_{Ipcmd}$
Ipcmc	y_{Ipcmd}	Al- geb	$I_{pmax} z_u^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) +$ $x_{Ipcmd} z_i^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) - y_{Ipcmd}$
Iqcmc	x_{Iqcmd}	Al- geb	$I_{q,ul} - x_{Iqcmd}$
Iqcmc	y_{Iqcmd}	Al- geb	$-I_{qmax} z_l^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) +$ $I_{qmax} z_u^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) +$ $x_{Iqcmd} z_i^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) - y_{Iqcmd}$

Services

Name	Sym- bol	Equation	Type
pref0	P_{ref0}	$P_{0s}\gamma_p$	ConstSer- vice
qref0	Q_{ref0}	$Q_{0s}\gamma_q$	ConstSer- vice
Kft01	K_{ft01}	$\frac{1}{-f_{t0}+f_{t1}}$	ConstSer- vice
Kft23	K_{ft23}	$\frac{1}{-f_{t2}+f_{t3}}$	ConstSer- vice
Kvt01	K_{vt01}	$\frac{1}{-V_{t0}+V_{t1}}$	ConstSer- vice
Kvt23	K_{vt23}	$\frac{1}{-V_{t2}+V_{t3}}$	ConstSer- vice
Pext0	P_{ext0}	0	ConstSer- vice
Vcomp	V_{comp}	$ Ve^{i\theta} + ix_c(y_{Ipout} + iy_{Iqout}) $	VarService
Vqu	V_{qu}	$v_1 - \frac{Q_{ref0}-q_{mn}}{dq/dv}$	ConstSer- vice
Vql	V_{ql}	$v_0 + \frac{-Q_{ref0}+q_{mx}}{dq/dv}$	ConstSer- vice
Ipmxsq	I_{pmax}^2	$\text{FixPiecewise} \left(\left(0, I_{alim}^2 - (y_{Iqcmd})^2 \leq 0 \right), \left(I_{alim}^2 - (y_{Iqcmd})^2, \text{True} \right) \right)$	VarService
Ip- maxsq0	I_{pmax0}^2	$\text{FixPiecewise} \left(\left(0, I_{alim}^2 - \frac{Q_{ref0}^2 u^2}{V^2} \leq 0 \right), \left(I_{alim}^2 - \frac{Q_{ref0}^2 u^2}{V^2}, \text{True} \right) \right)$	ConstSer- vice
Iqmaxsq	I_{qmax}^2	$\text{FixPiecewise} \left(\left(0, I_{alim}^2 - (y_{Ipcmd})^2 \leq 0 \right), \left(I_{alim}^2 - (y_{Ipcmd})^2, \text{True} \right) \right)$	VarService
Iq- maxsq0	I_{qmax0}^2	$\text{FixPiecewise} \left(\left(0, I_{alim}^2 - \frac{P_{ref0}^2 u^2}{V^2} \leq 0 \right), \left(I_{alim}^2 - \frac{P_{ref0}^2 u^2}{V^2}, \text{True} \right) \right)$	ConstSer- vice

Discretes

Name	Symbol	Type	Info
SWPQ	SW_{PQ}	Switcher	
FL1	$FL1$	Limiter	Under frequency comparer
FL2	$FL2$	Limiter	Over frequency comparer
DB_db	db_{DB}	DeadBand	
VL1	$VL1$	Limiter	Under voltage comparer
VL2	$VL2$	Limiter	Over voltage comparer
VLo	VLo	Limiter	Voltage lower limit (0.01) flag
PHL	PHL	Limiter	limiter for Psum in [pmn, pmx]
VQ1	$VQ1$	Limiter	Under voltage comparer for Q droop
VQ2	$VQ2$	Limiter	Over voltage comparer for Q droop
Ipcmd_lim	lim_{Ipcmd}	HardLimiter	
Iqcmd_lim	lim_{Iqcmd}	HardLimiter	
LTN	LTN	LessThan	
SOClim	$SOClim$	HardLimiter	

Blocks

Name	Symbol	Type	Info
DB	DB	DeadBand1	frequency deviation deadband with gain
Ipcmd	$Ipcmd$	GainLimiter	Ip with limiter and coeff.
Iqcmd	$Iqcmd$	GainLimiter	Iq with limiter and coeff.
Ipout	$Ipout$	Lag	Output Ip filter
Iqout	$Iqout$	Lag	Output Iq filter
pIG	pIG	Integrator	State of charge

Config Fields in [EV1]

Option	Sym- bol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
ad- just_upper		1	adjust upper limit	(0, 1)
plim	P_{lim}	1	enable input power limit check bound by [0, pmx]	(0, 1)

5.8.4 EV2

Electric vehicle model type 2.

Derived from EV1, EV2 introduces $pcap$ multiplied to pmx .

P_{sum} will be limited to $[pmn, pmx * pcap]$.

The model does not check the signs or values of pmn , pmx , or $pcap$. The input data is required to satisfy $pmn \leq pmx * pcap$.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
Sn	S_n	device MVA rating	100	<i>MVA</i>	
fn	f_n	nominal frequency	60	<i>Hz</i>	
busf		Optional BusFreq measurement device idx			
xc	x_c	coupling reactance	0	<i>p.u.</i>	z
pqflag		P/Q priority for I limit; 0-Q priority, 1-P priority		<i>bool</i>	mandatory
igreg		Remote bus idx for droop response, None for local			
qmx	q_{mx}	Max. reactive power command	0.330	<i>pu</i>	power
qmn	q_{mn}	Min. reactive power command	-0.330	<i>pu</i>	power
pmx	p_{mx}	maximum power limit	9999	<i>pu</i>	power
v0	v_0	Lower limit of deadband for Vdroop response	0.800	<i>pu</i>	non_zero
v1	v_1	Upper limit of deadband for Vdroop response	1.100	<i>pu</i>	non_zero
dqdv	dq/dv	Q-V droop characteristics (negative)	-1		non_zero,power
fdbd	f_{dbd}	frequency deviation deadband	-0.017	<i>Hz</i>	non_positive
ddn	D_{dn}	Gain after f deadband	1	<i>pu (MW)/Hz</i>	non_negative,pow
ialim	I_{alim}	Apparent power limit	1.300		non_zero,non_ne
vt0	V_{t0}	Voltage tripping response curve point 0	0.880	<i>p.u.</i>	non_zero,non_ne
vt1	V_{t1}	Voltage tripping response curve point 1	0.900	<i>p.u.</i>	non_zero,non_ne
vt2	V_{t2}	Voltage tripping response curve point 2	1.100	<i>p.u.</i>	non_zero,non_ne
vt3	V_{t3}	Voltage tripping response curve point 3	1.200	<i>p.u.</i>	non_zero,non_ne
vrflag	z_{VR}	V-trip is latching (0) or self-resetting (0-1)	0		
ft0	f_{t0}	Frequency tripping response curve point 0	59.500	<i>Hz</i>	non_zero,non_ne
ft1	f_{t1}	Frequency tripping response curve point 1	59.700	<i>Hz</i>	non_zero,non_ne
ft2	f_{t2}	Frequency tripping response curve point 2	60.300	<i>Hz</i>	non_zero,non_ne
ft3	f_{t3}	Frequency tripping response curve point 3	60.500	<i>Hz</i>	non_zero,non_ne
frflag	z_{FR}	f-trip is latching (0) or self-resetting (0-1)	0		
tip	T_{ip}	Inverter active current lag time constant	0.020	<i>s</i>	non_negative
tiq	T_{iq}	Inverter reactive current lag time constant	0.020	<i>s</i>	non_negative

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Table 9 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
gammap	γ_p	Ratio of PVD1.pref0 w.r.t to that of static PV	1		
gammaq	γ_q	Ratio of PVD1.qref0 w.r.t to that of static PV	1		
recflag	z_{rec}	Enable flag for voltage and frequency recovery limiters	1		
Tf	T_f	Integrator constant for SOC model	1		
SOCmin	SOC_{min}	Minimum required value for SOC in limiter	0		
SOCmax	SOC_{max}	Maximum allowed value for SOC in limiter	1		
SOCinit	SOC_{init}	Initial state of charge	0.500		
En	E_n	Rated energy capacity	100	MWh	
EtaC	Eta_C	Efficiency during charging	1		
EtaD	Eta_D	Efficiency during discharging	1		
pmn	p_{mn}	minimum power limit	-999	pu	power
pcap	p_{cap}	power ratio multiplied to pmx in [-1, 1]	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
Ipout_y	y_{Ipout}	State	State in lag transfer function		v_str
Iqout_y	y_{Iqout}	State	State in lag transfer function		v_str
pIG_y	y_{pIG}	State	Integrator output		v_str
SOC	SOC	AliasState	Alias for state of charge		
fHz	f_{Hz}	Algeb	frequency in Hz	Hz	v_str
Ffl	F_{fl}	Algeb	Coeff. for under frequency		v_str
Ffh	F_{fh}	Algeb	Coeff. for over frequency		v_str
Fdev	f_{dev}	Algeb	Frequency deviation	Hz	v_str
DB_y	y_{DB}	Algeb	Deadband type 1 output		v_str
Fvl	F_{vl}	Algeb	Coeff. for under voltage		v_str
Fvh	F_{vh}	Algeb	Coeff. for over voltage		v_str
vp	V_p	Algeb	Sensed positive voltage		v_str
Pext	P_{ext}	Algeb	External power signal (for AGC)		v_str
Pref	P_{ref}	Algeb	Reference power signal (for scheduling setpoint)		v_str
Psum	P_{tot}	Algeb	Sum of P signals		v_str
Qdrp	Q_{drp}	Algeb	External power signal (for AGC)		v_str
Qref	Q_{ref}	Algeb	Reference power signal (for scheduling setpoint)		v_str
Qsum	Q_{tot}	Algeb	Sum of Q signals		v_str
Ipul	$I_{p,ul}$	Algeb	Ipcmd before Ip hard limit		v_str
Iqul	$I_{q,ul}$	Algeb	Iqcmd before Iq hard limit		v_str
Ipmax	I_{pmax}	Algeb	Upper limit of Ip		v_str
Iqmax	I_{qmax}	Algeb	Upper limit of Iq		v_str
Ipcmd_x	x_{Ipcmd}	Algeb	Value before limiter		v_str
Ipcmd_y	y_{Ipcmd}	Algeb	Output after limiter and post gain		v_str
Iqcmd_x	x_{Iqcmd}	Algeb	Value before limiter		v_str

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Table 10 – continued from previous page

Name	Symbol	Type	Description	Unit	Properties
Iqcmd_y	y_{Iqcmd}	Algeb	Output after limiter and post gain		v_str
Ipmin	I_{pmin}	Algeb	Minimum value of Ip		v_str
PHLup	PHL_{upper}	Algeb	PHL upper limit		v_str
a	θ	ExtAlgeb	bus (or igreg) phase angle	rad.	
v	V	ExtAlgeb	bus (or igreg) terminal voltage	p.u.	
f	f	ExtAlgeb	Bus frequency	p.u.	

Initialization Equations

Name	Symbol	Type	Initial Value
Ipout_y	y_{Ipout}	State	$1.0y_{Ipcmd}$
Iqout_y	y_{Iqout}	State	$1.0y_{Iqcmd}$
pIG_y	y_{pIG}	State	SOC_{init}
SOC	SOC	AliasState	
fHz	f_{Hz}	Algeb	$f f_n$
Ffl	F_{fl}	Algeb	$K_{ft01} z_i^{FL1} (f_{Hz} - f_{t0}) + z_u^{FL1}$
Ffh	F_{fh}	Algeb	$z_i^{FL2} (K_{ft23} (-f_{Hz} + f_{t2}) + 1) + z_l^{FL2}$
Fdev	f_{dev}	Algeb	$f_n - f_{Hz}$
DB_y	y_{DB}	Algeb	$D_{dn} (f_{dev} z_u^{db_{DB}} + z_l^{db_{DB}} (-f_{dbd} + f_{dev}))$
Fvl	F_{vl}	Algeb	$K_{vt01} z_i^{VL1} (V - V_{t0}) + z_u^{VL1}$
Fvh	F_{vh}	Algeb	$z_i^{VL2} (K_{vt23} (-V + V_{t2}) + 1) + z_l^{VL2}$
vp	V_p	Algeb	$V z_i^{VLo} + 0.01 z_l^{VLo}$
Pext	P_{ext}	Algeb	$P_{ext0} u$
Pref	P_{ref}	Algeb	$P_{ref0} u$
Psum	P_{tot}	Algeb	$u (P_{ext} + P_{ref} + y_{DB})$
Qdrp	Q_{drp}	Algeb	$dq/dv u z_i^{VQ2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ2} + q_{mx} u z_l^{VQ1} + u z_i^{VQ1} (dq/dv (-V_{comp} +$
Qref	Q_{ref}	Algeb	$Q_{ref0} u$
Qsum	Q_{tot}	Algeb	$u (Q_{ref0} + dq/dv u z_i^{VQ2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ2} + q_{mx} u z_l^{VQ1} + u z_i^{VQ1} (dq/dv$
Ipul	$I_{p,ul}$	Algeb	$\frac{PHL_{upper} z_u^{PHL2} + P_{tot} z_i^{PHL2} + p_{mn} z_l^{PHL2}}{V_p}$
Iqul	$I_{q,ul}$	Algeb	$\frac{Q_{tot}}{V_p}$
Ipmax	I_{pmax}	Algeb	$(1 - z_l^{SOClim}) (I_{alim} s_1^{SWPQ} + \sqrt{I_{pmax0}^2 s_0^{SWPQ}})$
Iqmax	I_{qmax}	Algeb	$I_{alim} s_0^{SWPQ} + \sqrt{I_{qmax0}^2 s_1^{SWPQ}}$
Ipcmd_x	x_{Ipcmd}	Algeb	$I_{p,ul}$
Ipcmd_y	y_{Ipcmd}	Algeb	$I_{pmax} z_u^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) + x_{Ipcmd} z_i^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1)$
Iqcmd_x	x_{Iqcmd}	Algeb	$I_{q,ul}$
Iqcmd_y	y_{Iqcmd}	Algeb	$-I_{qmax} z_l^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) + I_{qmax} z_u^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1)$
Ipmin	I_{pmin}	Algeb	$(z_u^{SOClim} - 1) (I_{alim} s_1^{SWPQ} + \sqrt{I_{pmax0}^2 s_0^{SWPQ}})$
PHLup	PHL_{upper}	Algeb	$p_{cap} p_{mx}$

Table 11 – continued from previous page

Name	Symbol	Type	Initial Value
a	θ	ExtAlgeb	
v	V	ExtAlgeb	
f	f	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
Ipout_y	y_{Ipout}	State	$1.0y_{Ipcmd} - y_{Ipout}$	T_{ip}
Iqout_y	y_{Iqout}	State	$1.0y_{Iqcmd} - y_{Iqout}$	T_{iq}
pIG_y	y_{pIG}	State	$\frac{S_{b,sys} \left(-H_C V y_{Ipout} z_1^{LTN} - \frac{V y_{Ipout} z_0^{LTN}}{H_D} \right)}{3600 E_n}$	T_f
SOC	SOC	AliasState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
fHz	f_{Hz}	Algeb	$f f_n - f_{Hz}$
Ffl	F_{fl}	Algeb	$-F_{fl} + K_{ft01} z_i^{FL1} (f_{Hz} - f_{t0}) + z_u^{FL1}$
Ffh	F_{fh}	Algeb	$-F_{fh} + z_i^{FL2} (K_{ft23} (-f_{Hz} + f_{t2}) + 1) + z_l^{FL2}$
Fdev	f_{dev}	Algeb	$f_n - f_{Hz} - f_{dev}$
DB_y	y_{DB}	Algeb	$D_{dn} \left(f_{dev} z_u^{db_{DB}} + z_l^{db_{DB}} (-f_{dbd} + f_{dev}) \right) - y_{DB}$
Fvl	F_{vl}	Algeb	$-F_{vl} + K_{vt01} z_i^{VL1} (V - V_{t0}) + z_u^{VL1}$
Fvh	F_{vh}	Algeb	$-F_{vh} + z_i^{VL2} (K_{vt23} (-V + V_{t2}) + 1) + z_l^{VL2}$
vp	V_p	Algeb	$V z_i^{VLo} - V_p + 0.01 z_l^{VLo}$
Pext	P_{ext}	Algeb	$P_{ext0} u - P_{ext}$
Pref	P_{ref}	Algeb	$P_{ref0} u - P_{ref}$
Psum	P_{tot}	Algeb	$-P_{tot} + u (P_{ext} + P_{ref} + y_{DB})$
Qdrp	Q_{drp}	Algeb	$-Q_{drp} + dq/dv u z_i^{VQ2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ2} + q_{mx} u z_l^{VQ1} + u z_i^{VQ1} (dq/dv (-V_{comp} + V_{qu}) + q_{mx})$
Qref	Q_{ref}	Algeb	$Q_{ref0} u - Q_{ref}$
Qsum	Q_{tot}	Algeb	$-Q_{tot} + u (Q_{drp} + Q_{ref})$
Ipul	$I_{p,ul}$	Algeb	$-I_{p,ul} + \frac{PHL_{upper} z_u^{PHL2} + P_{tot} z_i^{PHL2} + p_{mn} z_l^{PHL2}}{V_p}$
Iqul	$I_{q,ul}$	Algeb	$-I_{q,ul} + \frac{Q_{tot}}{V_p}$
Ip-max	I_{pmax}	Algeb	$-I_{pmax} + (1 - z_i^{SOClim}) \left(I_{alim} s_1^{SWPQ} + \sqrt{I_{pmax}^2 s_0^{SWPQ}} \right)$
Iq-max	I_{qmax}	Algeb	$I_{alim} s_0^{SWPQ} - I_{qmax} + \sqrt{I_{qmax}^2 s_1^{SWPQ}}$
Ipcmc	x_{Ipcmd}	Algeb	$I_{p,ul} - x_{Ipcmd}$
Ipcmc	y_{Ipcmd}	Algeb	$I_{pmax} z_u^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) + x_{Ipcmd} z_i^{lim_{Ipcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) - y_{Ipcmd}$
Iqcmc	x_{Iqcmd}	Algeb	$I_{q,ul} - x_{Iqcmd}$
Iqcmc	y_{Iqcmd}	Algeb	$-I_{qmax} z_l^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) + I_{qmax} z_u^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) + x_{Iqcmd} z_i^{lim_{Iqcmd}} (F_{fh} F_{fl} F_{vh} F_{vl} z_{rec} - z_{rec} + 1) - y_{Iqcmd}$

Services

Name	Sym- bol	Equation	Type
pref0	P_{ref0}	$P_{0s}\gamma_p$	ConstService
qref0	Q_{ref0}	$Q_{0s}\gamma_q$	ConstService
Kft01	K_{ft01}	$\frac{1}{-f_{t0}+f_{t1}}$	ConstService
Kft23	K_{ft23}	$\frac{1}{-f_{t2}+f_{t3}}$	ConstService
Kvt01	K_{vt01}	$\frac{1}{-V_{t0}+V_{t1}}$	ConstService
Kvt23	K_{vt23}	$\frac{1}{-V_{t2}+V_{t3}}$	ConstService
Pext0	P_{ext0}	0	ConstService
Vcomp	V_{comp}	$ Ve^{i\theta} + ix_c(y_{Ipout} + iy_{Iqout}) $	VarService
Vqu	V_{qu}	$v_1 - \frac{Q_{ref0}-q_{mn}}{dq/dv}$	ConstService
Vql	V_{ql}	$v_0 + \frac{-Q_{ref0}+q_{mx}}{dq/dv}$	ConstService
Ipmxsq	I_{pmax}^2	$\text{FixPiecewise}\left(\left(0, I_{alim}^2 - (y_{Iqcmd})^2 \leq 0\right), \left(I_{alim}^2 - (y_{Iqcmd})^2, \text{True}\right)\right)$	VarService
Ip-maxsq0	I_{pmax0}^2	$\text{FixPiecewise}\left(\left(0, I_{alim}^2 - \frac{Q_{ref0}^2 u^2}{V^2} \leq 0\right), \left(I_{alim}^2 - \frac{Q_{ref0}^2 u^2}{V^2}, \text{True}\right)\right)$	ConstService
Iqmaxsq	I_{qmax}^2	$\text{FixPiecewise}\left(\left(0, I_{alim}^2 - (y_{Ipcmd})^2 \leq 0\right), \left(I_{alim}^2 - (y_{Ipcmd})^2, \text{True}\right)\right)$	VarService
Iq-maxsq0	I_{qmax0}^2	$\text{FixPiecewise}\left(\left(0, I_{alim}^2 - \frac{P_{ref0}^2 u^2}{V^2} \leq 0\right), \left(I_{alim}^2 - \frac{P_{ref0}^2 u^2}{V^2}, \text{True}\right)\right)$	ConstService

Discretes

Name	Symbol	Type	Info
SWPQ	SW_{PQ}	Switcher	
FL1	$FL1$	Limiter	Under frequency comparer
FL2	$FL2$	Limiter	Over frequency comparer
DB_db	db_{DB}	DeadBand	
VL1	$VL1$	Limiter	Under voltage comparer
VL2	$VL2$	Limiter	Over voltage comparer
VLo	VLo	Limiter	Voltage lower limit (0.01) flag
PHL	PHL	Limiter	limiter for Psum in [pmn, pmx]
VQ1	$VQ1$	Limiter	Under voltage comparer for Q droop
VQ2	$VQ2$	Limiter	Over voltage comparer for Q droop
Ipcmd_lim	lim_{Ipcmd}	HardLimiter	
Iqcmd_lim	lim_{Iqcmd}	HardLimiter	
LTN	LTN	LessThan	
SOClim	$SOClim$	HardLimiter	
PHL2	$PHL2$	Limiter	limiter for Psum in [pmn, pcap * pmx]

Blocks

Name	Symbol	Type	Info
DB	DB	DeadBand1	frequency deviation deadband with gain
Ipcmd	$Ipcmd$	GainLimiter	Ip with limiter and coeff.
Iqcmd	$Iqcmd$	GainLimiter	Iq with limiter and coeff.
Ipout	$Ipout$	Lag	Output Ip filter
Iqout	$Iqout$	Lag	Output Iq filter
pIG	pIG	Integrator	State of charge

Config Fields in [EV2]

Option	Sym- bol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
ad- just_upper		1	adjust upper limit	(0, 1)
plim	P_{lim}	1	enable input power limit check bound by [0, pmx]	(0, 1)

5.9 DGProtection

Protection model for DG.

Common Parameters: `u`, `name`

Available models: *DGPRCT1*, *DGPRCTExt*

5.9.1 DGPRCT1

DGPRCT1 model, follow IEEE-1547-2018. DGPRCT stands for DG protection.

A demo is provided: `examples/demonstration/1.1 demo_DGPRCT1.ipynb`

Target device (limited to DG group) `Psum` and `Qsum` will decrease to zero immediately when frequency/voltage protection flag is raised. Once the lock is released, `Psum` and `Qsum` will return to normal immediately.

DG group base model `PVD1` already has a degrading function which is used to degrade output under abnormal condition. it is recommended to turn it off by setting `recflag = 0`.

`fen` and `Ven` are protection enabling parameters. 1/0 is on/off.

`ue` is lock flag signal.

It should be noted that, the lock only lock the `fHz` (frequency read value) of DG model. The source values (which come from `BusFreq`) remain unchanged.)

Protection sensors (e.g., `IAWfl1`) are instances of `IntergratorAntiWindup`. All the protection sensors will be reset after `ue` returns to 0. Resetting action takes `Tres` to finish.

The model does not check the shedding points sequence. The input parameters are required to satisfy $f_{l3} < f_{l2} < f_{l1} < f_{u1} < f_{u2} < f_{u3}$, and $u_{l4} < u_{l3} < u_{l2} < u_{l1} < u_{u1} < u_{u2} < u_{u3}$.

Default settings:

Frequency (Hz):

$(f_{l3}, f_{l2}), T_{fl2}$ [(50.0, 57.5), 10s]

$(f_{l2}, f_{l1}), T_{fl1}$ [(57.5, 59.2), 300s]

$(f_{u1}, f_{u2}), T_{fu1}$ [(60.5, 61.5), 300s]

$(f_{u2}, f_{u3}), T_{fu2}$ [(61.5, 70.0), 10s]

Voltage (p.u.):

$(v_{l4}, v_{l3}), T_{vl3}$ [(0.10, 0.45), 0.16s]

$(v_{l3}, v_{l2}), T_{vl2}$ [(0.45, 0.60), 1s]

$(v_{l2}, v_{l1}), T_{vl1}$ [(0.60, 0.88), 2s]

$(v_{u1}, v_{u2}), T_{vu1}$ [(1.10, 1.20), 1s]

$(v_{u2}, v_{u3}), T_{vu2}$ [(1.20, 2.00), 0.16s]

Reference:

NERC. Bulk Power System Reliability Perspectives on the Adoption of IEEE 1547-2018. March 2020. Available:

https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Guideline_IEEE_1547-2018_BPS_Perspectives.pdf

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	<i>u</i>	connection status	1	<i>bool</i>	
name		device name			
dev		idx of the target device			mandatory
busfreq		Target device interface bus measurement device idx			
fen	<i>fen</i>	Frequency deviation protection enable. 1 for enable, 0 for disable.	1		
Ven	<i>Ven</i>	Voltage deviation protection enable. 1 for enable, 0 for disable.	0		
fl3	<i>fl3</i>	Under frequency shadding point 3	50	<i>Hz</i>	
fl2	<i>fl2</i>	Over frequency shadding point 2	57.500	<i>Hz</i>	
fl1	<i>fl1</i>	Under frequency shadding point 1	59.200	<i>Hz</i>	
fu1	<i>fu1</i>	Over frequency shadding point 1	60.500	<i>Hz</i>	
fu2	<i>fu2</i>	Over frequency shadding point 2	61.500	<i>Hz</i>	
fu3	<i>fu3</i>	Over frequency shadding point 3	70	<i>Hz</i>	
Tfl1	<i>T_{fl1}</i>	Stand time for (fl2, fl1)	300		non_negative
Tfl2	<i>T_{fl2}</i>	Stand time for (fl3, fl2)	10		non_negative
Tfu1	<i>T_{fu1}</i>	Stand time for (fu1, fu2)	300		non_negative
Tfu2	<i>T_{fu2}</i>	Stand time for (fu2, fu3)	10		non_negative
vl4	<i>vl4</i>	Under voltage shadding point 4	0.100	<i>p.u.</i>	
vl3	<i>vl3</i>	Under voltage shadding point 3	0.450	<i>p.u.</i>	
vl2	<i>vl2</i>	Under voltage shadding point 2	0.600	<i>p.u.</i>	
vl1	<i>vl1</i>	Under voltage shadding point 1	0.880	<i>p.u.</i>	
vu1	<i>vu1</i>	Over voltage shadding point 1	1.100	<i>p.u.</i>	
vu2	<i>vu2</i>	Over voltage shadding point 2	1.200	<i>p.u.</i>	
vu3	<i>vu3</i>	Over voltage shadding point 3	2	<i>p.u.</i>	
Tvl1	<i>T_{vl1}</i>	Stand time for (vl2, vl1)	2		non_negative
Tvl2	<i>T_{vl2}</i>	Stand time for (vl3, vl2)	1		non_negative
Tvl3	<i>T_{vl3}</i>	Stand time for (vl4, vl3)	0.160		non_negative
Tvu1	<i>T_{vu1}</i>	Stand time for (vu1, vu2)	1		non_negative
Tvu2	<i>T_{vu2}</i>	Stand time for (vu2, vu3)	0.160		non_negative
Tres		Integrator reset time	0.050		
bus			0		
fn			0		

Variables

Name	Symbol	Type	Description	Unit	Properties
IAWfl1_y	y_{IAWfl1}	State	AW Integrator output		v_str
IAWfl2_y	y_{IAWfl2}	State	AW Integrator output		v_str
IAWfu1_y	y_{IAWfu1}	State	AW Integrator output		v_str
IAWfu2_y	y_{IAWfu2}	State	AW Integrator output		v_str
IAWVl1_y	y_{IAWVl1}	State	AW Integrator output		v_str
IAWVl2_y	y_{IAWVl2}	State	AW Integrator output		v_str
IAWVl3_y	y_{IAWVl3}	State	AW Integrator output		v_str
IAWVu1_y	y_{IAWVu1}	State	AW Integrator output		v_str
IAWVu2_y	y_{IAWVu2}	State	AW Integrator output		v_str
fHz	f_{Hz}	Algeb	frequency in Hz		v_str
dsum	d_{tot}	Algeb	lock signal summation		v_str
ue	ue	Algeb	lock flag		v_str
f	f	ExtAlgeb	DG frequency read value	$p.u.$	
fin	f_{in}	ExtAlgeb	original f from DG		
fHzl	f_{Hzl}	ExtAlgeb	Frequency measure lock		
Pext	P_{ext}	ExtAlgeb	original Pext from DG		
Pref	P_{ref}	ExtAlgeb	original Pref from DG		
Pdrp	P_{drp}	ExtAlgeb	original Pdrp from DG		
Psum	P_{sum}	ExtAlgeb	Active power lock		
Qdrp	Q_{drp}	ExtAlgeb	original Qdrp from DG		
Qref	Q_{ref}	ExtAlgeb	original Qref from DG		
Qsum	Q_{sum}	ExtAlgeb	Reactive power lock		
v	v	ExtAlgeb	Bus voltage	$p.u.$	

Initialization Equations

Name	Symbol	Type	Initial Value
IAWfl1_y	y_{IAWfl1}	State	0
IAWfl2_y	y_{IAWfl2}	State	0
IAWfu1_y	y_{IAWfu1}	State	0
IAWfu2_y	y_{IAWfu2}	State	0
IAWVl1_y	y_{IAWVl1}	State	0
IAWVl2_y	y_{IAWVl2}	State	0
IAWVl3_y	y_{IAWVl3}	State	0
IAWVu1_y	y_{IAWVu1}	State	0
IAWVu2_y	y_{IAWVu2}	State	0
fHz	f_{Hz}	Algeb	ffn
dsum	d_{tot}	Algeb	0
ue	ue	Algeb	0
f	f	ExtAlgeb	
fin	fin	ExtAlgeb	
fHzl	f_{Hzl}	ExtAlgeb	
Pext	P_{ext}	ExtAlgeb	
Pref	P_{ref}	ExtAlgeb	
Pdrp	P_{drp}	ExtAlgeb	
Psum	P_{sum}	ExtAlgeb	
Qdrp	Q_{drp}	ExtAlgeb	
Qref	Q_{ref}	ExtAlgeb	
Qsum	Q_{sum}	ExtAlgeb	
v	v	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
IAWfl1_y	y_{IAWfl1}	State	$-\frac{T_{fl1}res}{T_{res}} + z_i^{Lfl1} \cdot (1 - res)$	1
IAWfl2_y	y_{IAWfl2}	State	$-\frac{T_{fl2}res}{T_{res}} + z_i^{Lfl2} \cdot (1 - res)$	1
IAWfu1_y	y_{IAWfu1}	State	$-\frac{T_{fu1}res}{T_{res}} + z_i^{Lfu1} \cdot (1 - res)$	1
IAWfu2_y	y_{IAWfu2}	State	$-\frac{T_{fu2}res}{T_{res}} + z_i^{Lfu2} \cdot (1 - res)$	1
IAWVl1_y	y_{IAWVl1}	State	$-\frac{T_{vl1}res}{T_{res}} + z_i^{LVl1} \cdot (1 - res)$	1
IAWVl2_y	y_{IAWVl2}	State	$-\frac{T_{vl2}res}{T_{res}} + z_i^{LVl2} \cdot (1 - res)$	1
IAWVl3_y	y_{IAWVl3}	State	$-\frac{T_{vl3}res}{T_{res}} + z_i^{LVl3} \cdot (1 - res)$	1
IAWVu1_y	y_{IAWVu1}	State	$-\frac{T_{vu1}res}{T_{res}} + z_i^{LVu1} \cdot (1 - res)$	1
IAWVu2_y	y_{IAWVu2}	State	$-\frac{T_{vu2}res}{T_{res}} + z_i^{LVu2} \cdot (1 - res)$	1

Algebraic Equations

Nam	Sym	Type	RHS of Equation "0 = g(x, y)"
bol			
fHz	f_{Hz}	Al- geb	$ffn - f_{Hz}$
dsum	d_{tot}	Al- geb	$Ven \left(z_i^{LVl1} z_u^{lim_{IAWVl1}} + z_i^{LVl2} z_u^{lim_{IAWVl2}} + z_i^{LVl3} z_u^{lim_{IAWVl3}} + z_i^{LVu1} z_u^{lim_{IAWVu1}} + z_i^{LVu2} z_u^{lim_{IAWVu2}} \right) + d_{tot} + fen \left(z_i^{Lfl1} z_u^{lim_{IAWfl1}} + z_i^{Lfl2} z_u^{lim_{IAWfl2}} + z_i^{Lfu1} z_u^{lim_{IAWfu1}} + z_i^{Lfu2} z_u^{lim_{IAWfu2}} \right)$
ue	ue	Al- geb	$-ue + z_u^{Ldsum}$
f	f	Ex- tAl- geb	0
fin	fin	Ex- tAl- geb	0
fHzl	f_{Hz}	Ex- tAl- geb	$-ffnue$
Pext	P_{ext}	Ex- tAl- geb	0
Pref	P_{rej}	Ex- tAl- geb	0
Pdrp	P_{drp}	Ex- tAl- geb	0
Psum	P_{sum}	Ex- tAl- geb	$-ue (P_{drp} + P_{ext} + P_{ref})$
Qdrp	Q_{drp}	Ex- tAl- geb	0
Qref	Q_{rej}	Ex- tAl- geb	0
Qsun	Q_{sun}	Ex- tAl- geb	$-ue (Q_{drp} + Q_{ref})$
v	v	Ex- tAl- geb	0

Services

Name	Symbol	Equation	Type
ltu	<i>ltu</i>	0.8	ConstService
ltl	<i>ltl</i>	0.2	ConstService
zero	<i>zero</i>	0	ConstService
res	<i>res</i>	0	ExtendedEvent

Discretes

Name	Symbol	Type	Info
Ldsum	<i>Ldsum</i>	Limiter	lock signal comparer, zu is to act
Lfl1	<i>Lfl1</i>	Limiter	Frequency comparer for (fl3, fl1)
Lfl2	<i>Lfl2</i>	Limiter	Frequency comparer for (fl3, fl2)
Lfu1	<i>Lfu1</i>	Limiter	Frequency comparer for (fu1, fu3)
Lfu2	<i>Lfu2</i>	Limiter	Frequency comparer for (fu2, fu3)
IAWfl1_lim	<i>lim_{IAWfl1}</i>	AntiWindup	Limiter in integrator
IAWfl2_lim	<i>lim_{IAWfl2}</i>	AntiWindup	Limiter in integrator
IAWfu1_lim	<i>lim_{IAWfu1}</i>	AntiWindup	Limiter in integrator
IAWfu2_lim	<i>lim_{IAWfu2}</i>	AntiWindup	Limiter in integrator
LVl1	<i>LVl1</i>	Limiter	Voltage comparer for (vl4, vl1)
LVl2	<i>LVl2</i>	Limiter	Voltage comparer for (vl4, vl2)
LVl3	<i>LVl3</i>	Limiter	Voltage comparer for (vl4, vl3)
LVu1	<i>LVu1</i>	Limiter	Voltage comparer for (vu1, vu3)
LVu2	<i>LVu2</i>	Limiter	Voltage comparer for (vu2, vu3)
IAWVl1_lim	<i>lim_{IAWVl1}</i>	AntiWindup	Limiter in integrator
IAWVl2_lim	<i>lim_{IAWVl2}</i>	AntiWindup	Limiter in integrator
IAWVl3_lim	<i>lim_{IAWVl3}</i>	AntiWindup	Limiter in integrator
IAWVu1_lim	<i>lim_{IAWVu1}</i>	AntiWindup	Limiter in integrator
IAWVu2_lim	<i>lim_{IAWVu2}</i>	AntiWindup	Limiter in integrator

Blocks

Name	Symbol	Type	Info
IAWfl1	<i>IAWfl1</i>	IntegratorAntiWindup	condition check for (fl3, fl1)
IAWfl2	<i>IAWfl2</i>	IntegratorAntiWindup	condition check for (fl3, fl2)
IAWfu1	<i>IAWfu1</i>	IntegratorAntiWindup	condition check for (fu1, fu3)
IAWfu2	<i>IAWfu2</i>	IntegratorAntiWindup	condition check for (fu2, fu3)
IAWVl1	<i>IAWVl1</i>	IntegratorAntiWindup	condition check for (Vl3, Vl1)
IAWVl2	<i>IAWVl2</i>	IntegratorAntiWindup	condition check for (Vl3, Vl2)
IAWVl3	<i>IAWVl3</i>	IntegratorAntiWindup	condition check for (Vl3, Vl2)
IAWVu1	<i>IAWVu1</i>	IntegratorAntiWindup	condition check for (Vu1, Vu3)
IAWVu2	<i>IAWVu2</i>	IntegratorAntiWindup	condition check for (Vu2, Vu3)

Config Fields in [DGPRCT1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.9.2 DGPRCTExt

DGPRCT External model, follow IEEE-1547-2018. DGPRCT stands for DG protection.

Similar to DGPRCT1, but the measured voltage can be manipulated.

A demo is provided: examples/demonstration/1.2 demo_DGPRCTExt.ipynb

This model can be applied to co-simulation, where you can input the external votage signal into ANDES. If no extertal value is applied, the votalge will remain as the initialized value.

Target device (limited to DG group) P_{sum} and Q_{sum} will decrease to zero immediately when frequency/voltage protection flag is raised. Once the lock is released, P_{sum} and Q_{sum} will return to normal immediately.

DG group base model PVD1 already has a degrading function which is used to degrade output under abnormal condition. it is recommended to turn it off by setting *recflag* = 0.

f_{en} and *V_{en}* are protection enabling parameters. 1/0 is on/off.

ue is lock flag signal.

It should be noted that, the lock only lock the *fHz* (frequency read value) of DG model. The source values (which come from *BusFreq* remain unchanged.)

Protection sensors (e.g., IAWfl1) are instances of *IntergratorAntiWindup*. All the protection sensors will be reset after *ue* returns to 0. Resetting action takes *T_{res}* to finish.

The model does not check the shedding points sequence. The input parameters are required to satisfy $fl3 < fl2 < fl1 < fu1 < fu2 < fu3$, and $ul4 < ul3 < ul2 < ul1 < uu1 < uu2 < uu3$.

Default settings:

Frequency (Hz):

$(fl3, fl2), Tfl2$ [(50.0, 57.5), 10s]

$(fl2, fl1), Tfl1$ [(57.5, 59.2), 300s]

$(fu1, fu2), Tfu1$ [(60.5, 61.5), 300s]

$(fu2, fu3), Tfu2$ [(61.5, 70.0), 10s]

Voltage (p.u.):

$(vl4, vl3), Tvl3$ [(0.10, 0.45), 0.16s]

$(vl3, vl2), Tvl2$ [(0.45, 0.60), 1s]

$(vl2, vl1), Tvl1$ [(0.60, 0.88), 2s]

$(vu1, vu2), Tvul$ [(1.10, 1.20), 1s]

$(vu2, vu3), Tvu2$ [(1.20, 2.00), 0.16s]

Reference:

NERC. Bulk Power System Reliability Perspectives on the Adoption of IEEE 1547-2018. March 2020. Available:

https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Guideline_IEEE_1547-2018_BPS_Perspectives.pdf

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
dev		idx of the target device			mandatory
busfreq		Target device interface bus measurement device idx			
fen	fen	Frequency deviation protection enable. 1 for enable, 0 for disable.	1		
Ven	Ven	Voltage deviation protection enable. 1 for enable, 0 for disable.	0		
fl3	$fl3$	Under frequency shadding point 3	50	Hz	
fl2	$fl2$	Over frequency shadding point 2	57.500	Hz	
fl1	$fl1$	Under frequency shadding point 1	59.200	Hz	
fu1	$fu1$	Over frequency shadding point 1	60.500	Hz	
fu2	$fu2$	Over frequency shadding point 2	61.500	Hz	
fu3	$fu3$	Over frequency shadding point 3	70	Hz	
Tfl1	$Tfl1$	Stand time for (fl2, fl1)	300		non_negative
Tfl2	$Tfl2$	Stand time for (fl3, fl2)	10		non_negative
Tfu1	$Tfu1$	Stand time for (fu1, fu2)	300		non_negative

continues on next page

Table 13 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
Tfu2	T_{fu2}	Stand time for (fu2, fu3)	10		non_negative
vl4	$vl4$	Under voltage shadding point 4	0.100	<i>p.u.</i>	
vl3	$vl3$	Under voltage shadding point 3	0.450	<i>p.u.</i>	
vl2	$vl2$	Under voltage shadding point 2	0.600	<i>p.u.</i>	
vl1	$vl1$	Under voltage shadding point 1	0.880	<i>p.u.</i>	
vu1	$vu1$	Over voltage shadding point 1	1.100	<i>p.u.</i>	
vu2	$vu2$	Over voltage shadding point 2	1.200	<i>p.u.</i>	
vu3	$vu3$	Over voltage shadding point 3	2	<i>p.u.</i>	
Tvl1	T_{vl1}	Stand time for (vl2, vl1)	2		non_negative
Tvl2	T_{vl2}	Stand time for (vl3, vl2)	1		non_negative
Tvl3	T_{vl3}	Stand time for (vl4, vl3)	0.160		non_negative
Tvu1	T_{vu1}	Stand time for (vu1, vu2)	1		non_negative
Tvu2	T_{vu2}	Stand time for (vu2, vu3)	0.160		non_negative
Tres		Integrator reset time	0.050		
bus			0		
fn			0		

Variables

Name	Symbol	Type	Description	Unit	Properties
IAWfl1_y	y_{IAWfl1}	State	AW Integrator output	v_str	
IAWfl2_y	y_{IAWfl2}	State	AW Integrator output	v_str	
IAWfu1_y	y_{IAWfu1}	State	AW Integrator output	v_str	
IAWfu2_y	y_{IAWfu2}	State	AW Integrator output	v_str	
IAWVl1_y	y_{IAWVl1}	State	AW Integrator output	v_str	
IAWVl2_y	y_{IAWVl2}	State	AW Integrator output	v_str	
IAWVl3_y	y_{IAWVl3}	State	AW Integrator output	v_str	
IAWVu1_y	y_{IAWVu1}	State	AW Integrator output	v_str	
IAWVu2_y	y_{IAWVu2}	State	AW Integrator output	v_str	
fHz	f_{Hz}	Algeb	frequency in Hz	v_str	
dsum	d_{tot}	Algeb	lock signal summation	v_str	
ue	ue	Algeb	lock flag	v_str	
f	f	ExtAlgeb	DG frequency read value	<i>p.u.</i>	
fin	fin	ExtAlgeb	original f from DG		
fHzl	f_{Hzl}	ExtAlgeb	Frequency measure lock		
Pext	P_{ext}	ExtAlgeb	original Pext from DG		
Pref	P_{ref}	ExtAlgeb	original Pref from DG		
Pdrp	P_{drp}	ExtAlgeb	original Pdrp from DG		
Psum	P_{sum}	ExtAlgeb	Active power lock		
Qdrp	Q_{drp}	ExtAlgeb	original Qdrp from DG		
Qref	Q_{ref}	ExtAlgeb	original Qref from DG		
Qsum	Q_{sum}	ExtAlgeb	Reactive power lock		

Initialization Equations

Name	Symbol	Type	Initial Value
IAWfl1_y	y_{IAWfl1}	State	0
IAWfl2_y	y_{IAWfl2}	State	0
IAWfu1_y	y_{IAWfu1}	State	0
IAWfu2_y	y_{IAWfu2}	State	0
IAWVl1_y	y_{IAWVl1}	State	0
IAWVl2_y	y_{IAWVl2}	State	0
IAWVl3_y	y_{IAWVl3}	State	0
IAWVu1_y	y_{IAWVu1}	State	0
IAWVu2_y	y_{IAWVu2}	State	0
fHz	f_{Hz}	Algeb	ffn
dsum	d_{tot}	Algeb	0
ue	ue	Algeb	0
f	f	ExtAlgeb	
fin	fin	ExtAlgeb	
fHzl	f_{Hzl}	ExtAlgeb	
Pext	P_{ext}	ExtAlgeb	
Pref	P_{ref}	ExtAlgeb	
Pdrp	P_{drp}	ExtAlgeb	
Psum	P_{sum}	ExtAlgeb	
Qdrp	Q_{drp}	ExtAlgeb	
Qref	Q_{ref}	ExtAlgeb	
Qsum	Q_{sum}	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
IAWfl1_y	y_{IAWfl1}	State	$-\frac{T_{fl1}res}{T_{res}} + z_i^{Lfl1} \cdot (1 - res)$	1
IAWfl2_y	y_{IAWfl2}	State	$-\frac{T_{fl2}res}{T_{res}} + z_i^{Lfl2} \cdot (1 - res)$	1
IAWfu1_y	y_{IAWfu1}	State	$-\frac{T_{fu1}res}{T_{res}} + z_i^{Lfu1} \cdot (1 - res)$	1
IAWfu2_y	y_{IAWfu2}	State	$-\frac{T_{fu2}res}{T_{res}} + z_i^{Lfu2} \cdot (1 - res)$	1
IAWVl1_y	y_{IAWVl1}	State	$-\frac{T_{vl1}res}{T_{res}} + z_i^{LVl1} \cdot (1 - res)$	1
IAWVl2_y	y_{IAWVl2}	State	$-\frac{T_{vl2}res}{T_{res}} + z_i^{LVl2} \cdot (1 - res)$	1
IAWVl3_y	y_{IAWVl3}	State	$-\frac{T_{vl3}res}{T_{res}} + z_i^{LVl3} \cdot (1 - res)$	1
IAWVu1_y	y_{IAWVu1}	State	$-\frac{T_{vu1}res}{T_{res}} + z_i^{LVu1} \cdot (1 - res)$	1
IAWVu2_y	y_{IAWVu2}	State	$-\frac{T_{vu2}res}{T_{res}} + z_i^{LVu2} \cdot (1 - res)$	1

Algebraic Equations

Nam	Sym	Type	RHS of Equation "0 = g(x, y)"
bol			
fHz	f_{Hz}	Al- geb	$ffn - f_{Hz}$
dsum	d_{tot}	Al- geb	$Ven \left(z_i^{LVl1} z_u^{lim_{IAWVl1}} + z_i^{LVl2} z_u^{lim_{IAWVl2}} + z_i^{LVl3} z_u^{lim_{IAWVl3}} + z_i^{LVu1} z_u^{lim_{IAWVu1}} + z_i^{LVu2} z_u^{lim_{IAWVu2}} \right) + d_{tot} + fen \left(z_i^{Lfl1} z_u^{lim_{IAWfl1}} + z_i^{Lfl2} z_u^{lim_{IAWfl2}} + z_i^{Lfu1} z_u^{lim_{IAWfu1}} + z_i^{Lfu2} z_u^{lim_{IAWfu2}} \right)$
ue	ue	Al- geb	$-ue + z_u^{Ldsum}$
f	f	Ex- tAl- geb	0
fin	fin	Ex- tAl- geb	0
fHzl	f_{Hz}	Ex- tAl- geb	$-ffnue$
Pext	P_{ext}	Ex- tAl- geb	0
Pref	P_{rej}	Ex- tAl- geb	0
Pdrp	P_{drp}	Ex- tAl- geb	0
Psum	P_{sum}	Ex- tAl- geb	$-ue (P_{drp} + P_{ext} + P_{ref})$
Qdrp	Q_{drp}	Ex- tAl- geb	0
Qref	Q_{rej}	Ex- tAl- geb	0
Qsun	Q_{sun}	Ex- tAl- geb	$-ue (Q_{drp} + Q_{ref})$

Services

Name	Symbol	Equation	Type
ltu	<i>ltu</i>	0.8	ConstService
ltl	<i>ltl</i>	0.2	ConstService
zero	<i>zero</i>	0	ConstService
res	<i>res</i>	0	ExtendedEvent

Discretes

Name	Symbol	Type	Info
Ldsum	<i>Ldsum</i>	Limiter	lock signal comparer, zu is to act
Lfl1	<i>Lfl1</i>	Limiter	Frequency comparer for (fl3, fl1)
Lfl2	<i>Lfl2</i>	Limiter	Frequency comparer for (fl3, fl2)
Lfu1	<i>Lfu1</i>	Limiter	Frequency comparer for (fu1, fu3)
Lfu2	<i>Lfu2</i>	Limiter	Frequency comparer for (fu2, fu3)
IAWfl1_lim	<i>lim_{IAWfl1}</i>	AntiWindup	Limiter in integrator
IAWfl2_lim	<i>lim_{IAWfl2}</i>	AntiWindup	Limiter in integrator
IAWfu1_lim	<i>lim_{IAWfu1}</i>	AntiWindup	Limiter in integrator
IAWfu2_lim	<i>lim_{IAWfu2}</i>	AntiWindup	Limiter in integrator
LVl1	<i>LVl1</i>	Limiter	Voltage comparer for (vl4, vl1)
LVl2	<i>LVl2</i>	Limiter	Voltage comparer for (vl4, vl2)
LVl3	<i>LVl3</i>	Limiter	Voltage comparer for (vl4, vl3)
LVu1	<i>LVu1</i>	Limiter	Voltage comparer for (vu1, vu3)
LVu2	<i>LVu2</i>	Limiter	Voltage comparer for (vu2, vu3)
IAWVl1_lim	<i>lim_{IAWVl1}</i>	AntiWindup	Limiter in integrator
IAWVl2_lim	<i>lim_{IAWVl2}</i>	AntiWindup	Limiter in integrator
IAWVl3_lim	<i>lim_{IAWVl3}</i>	AntiWindup	Limiter in integrator
IAWVu1_lim	<i>lim_{IAWVu1}</i>	AntiWindup	Limiter in integrator
IAWVu2_lim	<i>lim_{IAWVu2}</i>	AntiWindup	Limiter in integrator

Blocks

Name	Symbol	Type	Info
IAWfl1	<i>IAWfl1</i>	IntegratorAntiWindup	condition check for (fl3, fl1)
IAWfl2	<i>IAWfl2</i>	IntegratorAntiWindup	condition check for (fl3, fl2)
IAWfu1	<i>IAWfu1</i>	IntegratorAntiWindup	condition check for (fu1, fu3)
IAWfu2	<i>IAWfu2</i>	IntegratorAntiWindup	condition check for (fu2, fu3)
IAWVl1	<i>IAWVl1</i>	IntegratorAntiWindup	condition check for (Vl3, Vl1)
IAWVl2	<i>IAWVl2</i>	IntegratorAntiWindup	condition check for (Vl3, Vl2)
IAWVl3	<i>IAWVl3</i>	IntegratorAntiWindup	condition check for (Vl3, Vl2)
IAWVu1	<i>IAWVu1</i>	IntegratorAntiWindup	condition check for (Vu1, Vu3)
IAWVu2	<i>IAWVu2</i>	IntegratorAntiWindup	condition check for (Vu2, Vu3)

Config Fields in [DGPRCTExt]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.10 DataSeries

Group for TimeSeries models.

Available models: *TimeSeries*

5.10.1 TimeSeries

Model for applying time-series data.

A TimeSeries device takes a *xlsx* data spreadsheet and applies the data to the specified device. The spreadsheet can contain multiple sheets, each with a column named *t* and multiple user-defined columns for the data. The values will be applied at the exact time instant.

The *xlsx* data spreadsheet is assumed in the same folder as the case file.

Regarding the parameters for the TimeSeries device:

- The column names in the *xlsx* data file need to be specified through the *fields* parameter, separated by commas.
- The parameter/service names of the device which is to be updated need to be specified through the *dests* parameter, separated by commas.

There are a few caveats with the current TimeSeries implementation:

- TimeSeries will not be applied power flow.
- The interpolation mode has yet to be implemented.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Proper- ties
idx		unique device idx			
u	<i>u</i>	connection status	1	<i>bool</i>	
name		device name			
mode		Mode for applying timeseries. 1: exact time, 2: interpolated	1		
path		Path to timeseries.xlsx file.			mandatory
sheet		Sheet name to use			mandatory
fields		comma-separated field names in timeseries data			mandatory
tkey		Key for timestamps	t		
model		Model to link to			mandatory
dev		Idx of device to link to			mandatory
dests		comma-separated device fields as destinations			mandatory

Discretes

Name	Symbol	Type	Info
SW	<i>SW</i>	Switcher	mode switcher

Config Fields in [TimeSeries]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
silent		1	suppress output messages if is not zero	(0, 1)

5.11 DynLoad

Dynamic load group.

Common Parameters: *u*, *name*

Available models: *ZIP*, *FLoad*

5.11.1 ZIP

ZIP load model (polynomial load). This model is initialized after power flow.

Please check the config of PQ to avoid double counting. If this ZIP model is in use, one should typically set $p2p=1.0$ and $q2q=1.0$ while leaving the others ($p2i$, $p2z$, $q2i$, $q2z$, and $pq2z$) as zeros. This setting allows one to impose the desired powers by the static PQ and to convert them based on the percentage specified in the ZIP.

The percentages for active power, (kpp , kpi , and kpz) must sum up to 100. Otherwise, initialization will fail. The same applies to the reactive power percentages.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
pq		idx of the PQ to replace			mandatory
kpp	K_{pp}	Percentage of active power			mandatory
kpi	K_{pi}	Percentage of active current			mandatory
kpz	K_{pz}	Percentage of conductance			mandatory
kqp	K_{qp}	Percentage of reactive power			mandatory
kqi	K_{qi}	Percentage of reactive current			mandatory
kqz	K_{qz}	Percentage of susceptance			mandatory
bus		retrieved bus idx	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Initialization Equations

Name	Symbol	Type	Initial Value
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation " $0 = g(x, y)$ "
a	θ	ExtAlgeb	$P_{i0}V + P_{p0} + P_{z0}V^2$
v	V	ExtAlgeb	$Q_{i0}V + Q_{p0} + Q_{z0}V^2$

Services

Name	Symbol	Equation	Type
kps	K_{psum}	$K_{pi} + K_{pp} + K_{pz}$	ConstService
kqs	K_{qsum}	$K_{qi} + K_{qp} + K_{qz}$	ConstService
rpp	r_{pp}	$\frac{K_{pp}u}{100}$	ConstService
rpi	r_{pi}	$\frac{K_{pi}u}{100}$	ConstService
rpz	r_{pz}	$\frac{K_{pz}u}{100}$	ConstService
rqp	r_{qp}	$\frac{K_{qp}u}{100}$	ConstService
rqi	r_{qi}	$\frac{K_{qi}u}{100}$	ConstService
rqz	r_{qz}	$\frac{K_{qz}u}{100}$	ConstService
pp0	P_{p0}	$P_0 r_{pp}$	ConstService
pi0	P_{i0}	$\frac{P_0 r_{pi}}{V_0}$	ConstService
pz0	P_{z0}	$\frac{P_0 r_{pz}}{V_0^2}$	ConstService
qp0	Q_{p0}	$Q_0 r_{qp}$	ConstService
qi0	Q_{i0}	$\frac{Q_0 r_{qi}}{V_0}$	ConstService
qz0	Q_{z0}	$\frac{Q_0 r_{qz}}{V_0^2}$	ConstService

Config Fields in [ZIP]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.11.2 FLoad

Voltage and frequency dependent load.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
pq		idx of the PQ to replace			mandatory
busf		optional idx of the BusFreq device to use			
kp		active power percentage	100	%	
kq		active power percentage	100	%	
Tf		filter time constant	0.020	s	non_negative
ap		active power voltage exponent	1		
aq		reactive power voltage exponent	0		
bp		active power frequency exponent	0		
bq		reactive power frequency exponent	0		
bus			0		

Variables

Name	Symbol	Type	Description	Unit	Properties
f	f	ExtAlgeb			
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Initialization Equations

Name	Symbol	Type	Initial Value
f	f	ExtAlgeb	
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
f	f	ExtAlgeb	0
a	θ	ExtAlgeb	$V^{ap} f^{bp} pv_0$
v	V	ExtAlgeb	$V^{aq} f^{bq} qv_0$

Services

Name	Symbol	Equation	Type
pv0	pv_0	$\frac{P_0 V_0^{-ap} k_{pu}}{100}$	ConstService
qv0	qv_0	$\frac{Q_0 V_0^{-aq} k_{qu}}{100}$	ConstService

Config Fields in [FLoad]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12 Exciter

Exciter group for synchronous generators.

Common Parameters: u, name, syn

Common Variables: vout, vi

Available models: *EXDC2*, *IEEEX1*, *ESDC1A*, *ESDC2A*, *EXST1*, *ESST3A*, *SEXs*, *IEEET1*, *EXAC1*, *EXAC2*, *EXAC4*, *ESST4B*, *AC8B*, *IEEET3*, *ESAC1A*, *ESST1A*, *ESAC5A*

5.12.1 EXDC2

EXDC2 model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.010	<i>p.u.</i>	
TA	T_A	Lag time constant in anti-windup lag	0.040	<i>p.u.</i>	
TC	T_C	Lead time constant in lead-lag	1	<i>p.u.</i>	
TB	T_B	Lag time constant in lead-lag	1	<i>p.u.</i>	
TE	T_E	Exciter integrator time constant	0.800	<i>p.u.</i>	
TF1	T_{F1}	Feedback washout time constant	1	<i>p.u.</i>	non_zero
KF1	K_{F1}	Feedback washout gain	0.030	<i>p.u.</i>	
KA	K_A	Gain in anti-windup lag TF	40	<i>p.u.</i>	
KE	K_E	Gain added to saturation	1	<i>p.u.</i>	
VRMAX	V_{RMAX}	Maximum excitation limit	7.300	<i>p.u.</i>	
VRMIN	V_{RMIN}	Minimum excitation limit	-7.300	<i>p.u.</i>	
E1	E_1	First saturation point	0	<i>p.u.</i>	
SE1	S_{E1}	Value at first saturation point	0	<i>p.u.</i>	
E2	E_2	Second saturation point	1	<i>p.u.</i>	
SE2	S_{E2}	Value at second saturation point	1	<i>p.u.</i>	
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	bus	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
vp	V_p	State	Voltage after saturation feedback, before speed term	<i>p.u.</i>	v_str
LS_y	y_{LS}	State	State in lag transfer function		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
LA_y	y_{LA}	State	State in lag TF		v_str
W_x	x'_W	State	State in washout filter		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
vref	V_{ref}	Algeb	Reference voltage input	<i>p.u.</i>	v_str
Se	$S_e(V_{out})$	Algeb	saturation output		v_str
vi	V_i	Algeb	Total input voltages	<i>p.u.</i>	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
W_y	y_W	Algeb	Output of washout filter		v_str
vf	v_f	ExtAl- geb	Excitation field voltage to generator		
Xad- Ifd	$X_{ad}I_{fd}$	ExtAl- geb	Armature excitation current		
a	θ	ExtAl- geb	Bus voltage phase angle		
vbus	V	ExtAl- geb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
vp	V_p	State	v_{f0}
LS_y	y_{LS}	State	$1.0E_{term}$
LL_x	x'_{LL}	State	V_i
LA_y	y_{LA}	State	$K_A y_{LL}$
W_x	x'_W	State	V_p
omega	ω	ExtState	
v	E_{term}	Algeb	V
vout	v_{out}	Algeb	$u_e v_{f0}$
vref	V_{ref}	Algeb	$E_{term} + V_{b0}$
Se	$S_e(V_{out})$	Algeb	S_{e0}
vi	V_i	Algeb	V_{b0}
LL_y	y_{LL}	Algeb	V_i
W_y	y_W	Algeb	0
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
vbus	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
vp	V_p	State	$u_e (-K_E V_p - S_e(V_{out}) V_p + y_{LA})$	T_E
LS_y	y_{LS}	State	$1.0E_{term} - y_{LS}$	T_R
LL_x	x'_{LL}	State	$V_i - x'_{LL}$	T_B
LA_y	y_{LA}	State	$K_A y_{LL} - y_{LA}$	T_A
W_x	x'_W	State	$V_p - x'_W$	T_{F1}
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algeb	$-E_{term} + V$
vout	v_{out}	Algeb	$V_p \omega u_e - v_{out}$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
Se	$S_e(V_{out})$	Algeb	$B_{SAT}^q z_0^{SL} (-A_{SAT}^q + V_p)^2 - S_e(V_{out}) V_p$
vi	V_i	Algeb	$-V_i + V_{ref} - y_{LS} - y_W$
LL_y	y_{LL}	Algeb	$T_B x'_{LL} - T_B y_{LL} + T_C (V_i - x'_{LL}) + (z_1^{LT_{LL}})^2 (-x'_{LL} + y_{LL})$
W_y	y_W	Algeb	$K_{F1} (V_p - x'_W) - T_{F1} y_W$
vf	v_f	ExtAlgeb	$u_e (-v_{f0} + v_{out})$
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	0
a	θ	ExtAlgeb	0
vbus	V	ExtAlgeb	0

Services

Name	Sym- bol	Equation	Type
ue	u_e	uu_g	ConstService
SAT_E1	E_{SAT}^{1c}	E_1	ConstService
SAT_E2	E_{SAT}^{2c}	$E_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_SE1	SE_{SAT}^{1c}	S_{E1}	ConstService
SAT_SE2	SE_{SAT}^{2c}	$S_{E2} - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E_{SAT}^{1c} SE_{SAT}^{1c}}{E_{SAT}^{2c} SE_{SAT}^{2c}}} (\text{Indicator}(SE_{SAT}^{2c} > 0) + \text{Indicator}(SE_{SAT}^{2c} < 0))$	ConstService
SAT_A	A_{SAT}^q	$E_{SAT}^{2c} - \frac{E_{SAT}^{1c} - E_{SAT}^{2c}}{a_{SAT} - 1}$	ConstService
SAT_B	B_{SAT}^q	$\frac{E_{SAT}^{2c} SE_{SAT}^{2c} (a_{SAT} - 1)^2 (\text{Indicator}(a_{SAT} > 0) + \text{Indicator}(a_{SAT} < 0))}{(E_{SAT}^{1c} - E_{SAT}^{2c})^2}$	ConstService
Se0	S_{e0}	$\frac{B_{SAT}^q (A_{SAT}^q - v_{f0})^2 \text{Indicator}(v_{f0} > A_{SAT}^q)}{-u_g + v_{f0} + 1}$	ConstService
vr0	V_{r0}	$v_{f0} (K_E + S_{e0})$	ConstService
vb0	V_{b0}	$\frac{V_{r0}}{K_A}$	ConstService
vref0	V_{ref0}	V_{ref}	PostInitService

Discretes

Name	Symbol	Type	Info
SL	SL	LessThan	
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
LA_lim	lim_{LA}	AntiWindup	Limiter in Lag

Blocks

Name	Symbol	Type	Info
SAT	SAT	ExcQuadSat	Field voltage saturation
LS	LS	Lag	Sensing lag TF
LL	LL	LeadLag	Lead-lag for internal delays
LA	LA	LagAntiWindup	Anti-windup lag
W	W	Washout	Signal conditioner

Config Fields in [EXDC2]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.2 IEEEEX1

IEEEEX1 Type 1 exciter (DC)

Derived from EXDC2 by varying the limiter bounds.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.010	<i>p.u.</i>	
TA	T_A	Lag time constant in anti-windup lag	0.040	<i>p.u.</i>	
TC	T_C	Lead time constant in lead-lag	1	<i>p.u.</i>	
TB	T_B	Lag time constant in lead-lag	1	<i>p.u.</i>	
TE	T_E	Exciter integrator time constant	0.800	<i>p.u.</i>	
TF1	T_{F1}	Feedback washout time constant	1	<i>p.u.</i>	non_zero
KF1	K_{F1}	Feedback washout gain	0.030	<i>p.u.</i>	
KA	K_A	Gain in anti-windup lag TF	40	<i>p.u.</i>	
KE	K_E	Gain added to saturation	1	<i>p.u.</i>	
VRMAX	V_{RMAX}	Maximum excitation limit	7.300	<i>p.u.</i>	
VRMIN	V_{RMIN}	Minimum excitation limit	-7.300	<i>p.u.</i>	
E1	E_1	First saturation point	0	<i>p.u.</i>	
SE1	S_{E1}	Value at first saturation point	0	<i>p.u.</i>	
E2	E_2	Second saturation point	1	<i>p.u.</i>	
SE2	S_{E2}	Value at second saturation point	1	<i>p.u.</i>	
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	<i>bus</i>	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
vp	V_p	State	Voltage after saturation feedback, before speed term	<i>p.u.</i>	v_str
LS_y	y_{LS}	State	State in lag transfer function		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
LA_y	y_{LA}	State	State in lag TF		v_str
W_x	x'_W	State	State in washout filter		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
vref	V_{ref}	Algeb	Reference voltage input	<i>p.u.</i>	v_str
Se	$S_e(V_{out})$	Algeb	saturation output		v_str
vi	V_i	Algeb	Total input voltages	<i>p.u.</i>	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
W_y	y_W	Algeb	Output of washout filter		v_str
vf	v_f	ExtAl- geb	Excitation field voltage to generator		
Xad- Ifd	$X_{ad}I_{fd}$	ExtAl- geb	Armature excitation current		
a	θ	ExtAl- geb	Bus voltage phase angle		
vbus	V	ExtAl- geb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
vp	V_p	State	v_{f0}
LS_y	y_{LS}	State	$1.0E_{term}$
LL_x	x'_{LL}	State	V_i
LA_y	y_{LA}	State	$K_A y_{LL}$
W_x	x'_W	State	V_p
omega	ω	ExtState	
v	E_{term}	Algeb	V
vout	v_{out}	Algeb	$u_e v_{f0}$
vref	V_{ref}	Algeb	$E_{term} + V_{b0}$
Se	$S_e(V_{out})$	Algeb	S_{e0}
vi	V_i	Algeb	V_{b0}
LL_y	y_{LL}	Algeb	V_i
W_y	y_W	Algeb	0
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
vbus	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
vp	V_p	State	$u_e (-K_E V_p - S_e(V_{out}) V_p + y_{LA})$	T_E
LS_y	y_{LS}	State	$1.0E_{term} - y_{LS}$	T_R
LL_x	x'_{LL}	State	$V_i - x'_{LL}$	T_B
LA_y	y_{LA}	State	$K_A y_{LL} - y_{LA}$	T_A
W_x	x'_W	State	$V_p - x'_W$	T_{F1}
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algeb	$-E_{term} + V$
vout	v_{out}	Algeb	$V_p u_e - v_{out}$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
Se	$S_e(V_{out})$	Algeb	$B_{SAT}^q z_0^{SL} (-A_{SAT}^q + V_p)^2 - S_e(V_{out}) V_p$
vi	V_i	Algeb	$-V_i + V_{ref} - y_{LS} - y_W$
LL_y	y_{LL}	Algeb	$T_B x'_{LL} - T_B y_{LL} + T_C (V_i - x'_{LL}) + (z_1^{LT_{LL}})^2 (-x'_{LL} + y_{LL})$
W_y	y_W	Algeb	$K_{F1} (V_p - x'_W) - T_{F1} y_W$
vf	v_f	ExtAlgeb	$u_e (-v_{f0} + v_{out})$
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	0
a	θ	ExtAlgeb	0
vbus	V	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
ue	u_e	$u u_g$	ConstService
SAT_E1	E_{SAT}^{1c}	E_1	ConstService
SAT_E2	E_{SAT}^{2c}	$E_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_SE1	SE_{SAT}^{1c}	SE_1	ConstService
SAT_SE2	SE_{SAT}^{2c}	$SE_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E_{SAT}^{1c} SE_{SAT}^{1c}}{E_{SAT}^{2c} SE_{SAT}^{2c}}} (\text{Indicator}(SE_{SAT}^{2c} > 0) + \text{Indicator}(SE_{SAT}^{2c} < 0))$	ConstService
SAT_A	A_{SAT}^q	$E_{SAT}^{2c} - \frac{E_{SAT}^{1c} - E_{SAT}^{2c}}{a_{SAT} - 1}$	ConstService
SAT_B	B_{SAT}^q	$\frac{E_{SAT}^{2c} SE_{SAT}^{2c} (a_{SAT} - 1)^2 (\text{Indicator}(a_{SAT} > 0) + \text{Indicator}(a_{SAT} < 0))}{(E_{SAT}^{1c} - E_{SAT}^{2c})^2}$	ConstService
Se0	S_{e0}	$\frac{B_{SAT}^q (A_{SAT}^q - v_{f0})^2 \text{Indicator}(v_{f0} > A_{SAT}^q)}{-u_g + v_{f0} + 1}$	ConstService
vr0	V_{r0}	$v_{f0} (K_E + S_{e0})$	ConstService
vb0	V_{b0}	$\frac{V_{r0}}{K_A}$	ConstService
vref0	V_{ref0}	V_{ref}	PostInitService
VRT-MAX	$V_{RMAX} V_T$	$E_{term} V_{RMAX}$	VarService
VRTMIN	$V_{RMIN} V_T$	$E_{term} V_{RMIN}$	VarService

Discretes

Name	Symbol	Type	Info
SL	SL	LessThan	
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
LA_lim	lim_{LA}	AntiWindup	Limiter in Lag

Blocks

Name	Symbol	Type	Info
SAT	SAT	ExcQuadSat	Field voltage saturation
LS	LS	Lag	Sensing lag TF
LL	LL	LeadLag	Lead-lag for internal delays
LA	LA	LagAntiWindup	Anti-windup lag
W	W	Washout	Signal conditioner

Config Fields in [IEEEX1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.3 ESDC1A

ESDC1A model.

This model derives from ESDC2A and changes the regular limits to "VRMAX" and "VRMIN".

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.010	<i>p.u.</i>	
KA	K_A	Regulator gain	80		
TA	T_A	Lag time constant in regulator	0.040	<i>p.u.</i>	
TB	T_B	Lag time constant in lead-lag	1	<i>p.u.</i>	
TC	T_C	Lead time constant in lead-lag	1	<i>p.u.</i>	
VRMAX	V_{RMAX}	Max. exc. limit (0-unlimited)	7.300	<i>p.u.</i>	
VRMIN	V_{RMIN}	Min. excitation limit	-7.300	<i>p.u.</i>	
KE	K_E	Saturation feedback gain	1	<i>p.u.</i>	
TE	T_E	Integrator time constant	0.800	<i>p.u.</i>	
KF	K_F	Feedback gain	0.100		
TF1	T_{F1}	Feedback washout time constant	1	<i>p.u.</i>	non_zero,non_negative
Switch	S_w	Switch that PSS/E did not implement	0	<i>bool</i>	
E1	E_1	First saturation point	0	<i>p.u.</i>	
SE1	S_{E1}	Value at first saturation point	0	<i>p.u.</i>	
E2	E_2	Second saturation point	0	<i>p.u.</i>	
SE2	S_{E2}	Value at second saturation point	0	<i>p.u.</i>	
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	bus	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
LA_y	y_{LA}	State	State in lag TF		v_str
INT_y	y_{INT}	State	Integrator output		v_str
WF_x	x'_{WF}	State	State in washout filter		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
vref	V_{ref}	Algeb	Reference voltage input	p.u.	v_str
vi	V_i	Algeb	Total input voltages	p.u.	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
UEL	U_{EL}	Algeb	Interface var for under exc. limiter		v_str
HG_y	y_{HG}	Algeb	HVGate output		v_str
Se	$V_{out} * S_e(V_{out})$	Algeb	saturation output		v_str
VFE	V_{FE}	Algeb	Combined saturation feedback	p.u.	v_str
WF_y	y_{WF}	Algeb	Output of washout filter		v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
LL_x	x'_{LL}	State	V_i
LA_y	y_{LA}	State	K_{AyLL}
INT_y	y_{INT}	State	v_{f0}
WF_x	x'_{WF}	State	y_{INT}
omega	ω	ExtState	
v	E_{term}	Algeb	V
vout	v_{out}	Algeb	$u_e v_{f0}$
vref	V_{ref}	Algeb	$E_{term} + \frac{V_{FE0}}{K_A}$
vi	V_i	Algeb	$\frac{V_{FE0}}{K_A}$
LL_y	y_{LL}	Algeb	V_i
UEL	U_{EL}	Algeb	0
HG_y	y_{HG}	Algeb	$U_{EL}z_0^{NoneHG} + y_{LL}z_1^{NoneHG}$
Se	$V_{out} * S_e(V_{out})$	Algeb	S_{e0}
VFE	V_{FE}	Algeb	V_{FE0}
WF_y	y_{WF}	Algeb	0
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
vbus	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
LL_x	x'_{LL}	State	$V_i - x'_{LL}$	T_B
LA_y	y_{LA}	State	$K_{AyLL} - y_{LA}$	T_A
INT_y	y_{INT}	State	$u_e (-V_{FE} + y_{LA})$	T_E
WF_x	x'_{WF}	State	$-x'_{WF} + y_{INT}$	T_{F1}
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algeb	$-E_{term} + V$
vout	v_{out}	Algeb	$-v_{out} + y_{INT}$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
vi	V_i	Algeb	$-E_{term} - V_i + V_{ref} - y_{WF}$
LL_y	y_{LL}	Algeb	$T_B x'_{LL} - T_B y_{LL} + T_C (V_i - x'_{LL}) + (z_1^{LT_{LL}})^2 (-x'_{LL} + y_{LL})$
UEL	U_{EL}	Algeb	$-U_{EL}$
HG_y	y_{HG}	Algeb	$U_{EL} z_0^{None_{HG}} - y_{HG} + y_{LL} z_1^{None_{HG}}$
Se	$V_{out} * S_e(V_{out})$	Algeb	$B_{SAT}^q z_0^{SL} (-A_{SAT}^q + y_{INT})^2 - V_{out} * S_e(V_{out})$
VFE	V_{FE}	Algeb	$K_E y_{INT} - V_{FE} + V_{out} * S_e(V_{out})$
WF_y	y_{WF}	Algeb	$K_F (-x'_{WF} + y_{INT}) - T_{F1} y_{WF}$
vf	v_f	ExtAl- geb	$u_e (-v_{f0} + v_{out})$
Xad- Ifd	$X_{ad} I_{fd}$	ExtAl- geb	0
a	θ	ExtAl- geb	0
vbus	V	ExtAl- geb	0

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
VR- MAXc	$VRMAXc$	$VRMAX - 999z_{VRMAX} + 999$	ConstService
SAT_E1	E_{SAT}^{1c}	E_1	ConstService
SAT_E2	E_{SAT}^{2c}	$E_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_SE1	SE_{SAT}^{1c}	S_{E1}	ConstService
SAT_SE2	SE_{SAT}^{2c}	$S_{E2} - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E_{SAT}^{1c} SE_{SAT}^{1c}}{E_{SAT}^{2c} SE_{SAT}^{2c}}} (\text{Indicator}(SE_{SAT}^{2c} > 0) + \text{Indicator}(SE_{SAT}^{2c} < 0))$	ConstService
SAT_A	A_{SAT}^q	$E_{SAT}^{2c} - \frac{E_{SAT}^{1c} - E_{SAT}^{2c}}{a_{SAT} - 1}$	ConstService
SAT_B	B_{SAT}^q	$\frac{E_{SAT}^{2c} SE_{SAT}^{2c} (a_{SAT} - 1)^2 (\text{Indicator}(a_{SAT} > 0) + \text{Indicator}(a_{SAT} < 0))}{(E_{SAT}^{1c} - E_{SAT}^{2c})^2}$	ConstService
Se0	S_{e0}	$B_{SAT}^q (A_{SAT}^q - v_{f0})^2 \text{Indicator}(v_{f0} > A_{SAT}^q)$	ConstService
vfe0	V_{FE0}	$K_E v_{f0} + S_{e0}$	ConstService
vref0	V_{ref0}	V_{ref}	PostInitService
VRU	$VRMAX$	$VRMAXc$	ConstService
VRL	$VRMIN$	$VRMIN$	ConstService

Discretes

Name	Symbol	Type	Info
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
HG_lt	$None_{HG}$	LessThan	
LA_lim	lim_{LA}	AntiWindup	Limiter in Lag
SL	SL	LessThan	

Blocks

Name	Symbol	Type	Info
LG	LG	Lag	Transducer delay
SAT	SAT	ExcQuadSat	Field voltage saturation
LL	LL	LeadLag	Lead-lag compensator
HG	HG	HVGate	HVGate for under excitation
LA	LA	LagAntiWindup	Anti-windup lag
INT	INT	Integrator	Integrator
WF	WF	Washout	Feedback to input

Config Fields in [ESDC1A]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.4 ESDC2A

ESDC2A model.

This model is implemented as described in the PSS/E manual, except that the HVGate is not in use. Due to the HVGate and saturation function, the results are close to but different from TSAT.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.010	<i>p.u.</i>	
KA	K_A	Regulator gain	80		
TA	T_A	Lag time constant in regulator	0.040	<i>p.u.</i>	
TB	T_B	Lag time constant in lead-lag	1	<i>p.u.</i>	
TC	T_C	Lead time constant in lead-lag	1	<i>p.u.</i>	
VRMAX	V_{RMAX}	Max. exc. limit (0-unlimited)	7.300	<i>p.u.</i>	
VRMIN	V_{RMIN}	Min. excitation limit	-7.300	<i>p.u.</i>	
KE	K_E	Saturation feedback gain	1	<i>p.u.</i>	
TE	T_E	Integrator time constant	0.800	<i>p.u.</i>	
KF	K_F	Feedback gain	0.100		
TF1	T_{F1}	Feedback washout time constant	1	<i>p.u.</i>	non_zero,non_negative
Switch	S_w	Switch that PSS/E did not implement	0	<i>bool</i>	
E1	E_1	First saturation point	0	<i>p.u.</i>	
SE1	S_{E1}	Value at first saturation point	0	<i>p.u.</i>	
E2	E_2	Second saturation point	0	<i>p.u.</i>	
SE2	S_{E2}	Value at second saturation point	0	<i>p.u.</i>	
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	<i>bus</i>	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
LA_y	y_{LA}	State	State in lag TF		v_str
INT_y	y_{INT}	State	Integrator output		v_str
WF_x	x'_{WF}	State	State in washout filter		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
vref	V_{ref}	Algeb	Reference voltage input	p.u.	v_str
vi	V_i	Algeb	Total input voltages	p.u.	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
UEL	U_{EL}	Algeb	Interface var for under exc. limiter		v_str
HG_y	y_{HG}	Algeb	HVGate output		v_str
Se	$V_{out} * S_e(V_{out})$	Algeb	saturation output		v_str
VFE	V_{FE}	Algeb	Combined saturation feedback	p.u.	v_str
WF_y	y_{WF}	Algeb	Output of washout filter		v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
LL_x	x'_{LL}	State	V_i
LA_y	y_{LA}	State	K_{AYLL}
INT_y	y_{INT}	State	v_{f0}
WF_x	x'_{WF}	State	y_{INT}
omega	ω	ExtState	
v	E_{term}	Algeb	V
vout	v_{out}	Algeb	$u_e v_{f0}$
vref	V_{ref}	Algeb	$E_{term} + \frac{V_{FE0}}{K_A}$
vi	V_i	Algeb	$\frac{V_{FE0}}{K_A}$
LL_y	y_{LL}	Algeb	V_i
UEL	U_{EL}	Algeb	0
HG_y	y_{HG}	Algeb	$U_{EL} z_0^{NoneHG} + y_{LL} z_1^{NoneHG}$
Se	$V_{out} * S_e(V_{out})$	Algeb	S_{e0}
VFE	V_{FE}	Algeb	V_{FE0}
WF_y	y_{WF}	Algeb	0
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
vbus	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
LL_x	x'_{LL}	State	$V_i - x'_{LL}$	T_B
LA_y	y_{LA}	State	$K_{AYLL} - y_{LA}$	T_A
INT_y	y_{INT}	State	$u_e (-V_{FE} + y_{LA})$	T_E
WF_x	x'_{WF}	State	$-x'_{WF} + y_{INT}$	T_{F1}
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algeb	$-E_{term} + V$
vout	v_{out}	Algeb	$-v_{out} + y_{INT}$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
vi	V_i	Algeb	$-E_{term} - V_i + V_{ref} - y_{WF}$
LL_y	y_{LL}	Algeb	$T_B x'_{LL} - T_B y_{LL} + T_C (V_i - x'_{LL}) + (z_1^{LT_{LL}})^2 (-x'_{LL} + y_{LL})$
UEL	U_{EL}	Algeb	$-U_{EL}$
HG_y	y_{HG}	Algeb	$U_{EL} z_0^{None_{HG}} - y_{HG} + y_{LL} z_1^{None_{HG}}$
Se	$V_{out} * S_e(V_{out})$	Algeb	$B_{SAT}^q z_0^{SL} (-A_{SAT}^q + y_{INT})^2 - V_{out} * S_e(V_{out})$
VFE	V_{FE}	Algeb	$K_E y_{INT} - V_{FE} + V_{out} * S_e(V_{out})$
WF_y	y_{WF}	Algeb	$K_F (-x'_{WF} + y_{INT}) - T_{F1} y_{WF}$
vf	v_f	ExtAl- geb	$u_e (-v_{f0} + v_{out})$
Xad- Ifd	$X_{ad} I_{fd}$	ExtAl- geb	0
a	θ	ExtAl- geb	0
vbus	V	ExtAl- geb	0

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
VR-MAXc	$VRMAXc$	$VRMAX - 999z_{VRMAX} + 999$	ConstService
SAT_E1	E_{SAT}^{1c}	E_1	ConstService
SAT_E2	E_{SAT}^{2c}	$E_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_SE1	SE_{SAT}^{1c}	S_{E1}	ConstService
SAT_SE2	SE_{SAT}^{2c}	$S_{E2} - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E_{SAT}^{1c} SE_{SAT}^{1c}}{E_{SAT}^{2c} SE_{SAT}^{2c}}} (\text{Indicator}(SE_{SAT}^{2c} > 0) + \text{Indicator}(SE_{SAT}^{2c} < 0))$	ConstService
SAT_A	A_{SAT}^q	$E_{SAT}^{2c} - \frac{E_{SAT}^{1c} - E_{SAT}^{2c}}{a_{SAT} - 1}$	ConstService
SAT_B	B_{SAT}^q	$\frac{E_{SAT}^{2c} SE_{SAT}^{2c} (a_{SAT} - 1)^2 (\text{Indicator}(a_{SAT} > 0) + \text{Indicator}(a_{SAT} < 0))}{(E_{SAT}^{1c} - E_{SAT}^{2c})^2}$	ConstService
Se0	S_{e0}	$B_{SAT}^q (A_{SAT}^q - v_{f0})^2 \text{Indicator}(v_{f0} > A_{SAT}^q)$	ConstService
vfe0	V_{FE0}	$K_E v_{f0} + S_{e0}$	ConstService
vref0	V_{ref0}	V_{ref}	PostInitService
VRU	$V_T V_{RMAX}$	$E_{term} VRMAXc$	VarService
VRL	$V_T V_{RMIN}$	$E_{term} V_{RMIN}$	VarService

Discretes

Name	Symbol	Type	Info
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
HG_lt	$None_{HG}$	LessThan	
LA_lim	lim_{LA}	AntiWindup	Limiter in Lag
SL	SL	LessThan	

Blocks

Name	Symbol	Type	Info
LG	LG	Lag	Transducer delay
SAT	SAT	ExcQuadSat	Field voltage saturation
LL	LL	LeadLag	Lead-lag compensator
HG	HG	HVGate	HVGate for under excitation
LA	LA	LagAntiWindup	Anti-windup lag
INT	INT	Integrator	Integrator
WF	WF	Washout	Feedback to input

Config Fields in [ESDC2A]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.5 EXST1

EXST1-type static excitation system.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Measurement delay	0.010		
VIMAX	V_{IMAX}	Max. input voltage	0.200		
VIMIN	V_{IMIN}	Min. input voltage	0		
TC	T_C	LL numerator	1		
TB	T_B	LL denominator	1		
KA	K_A	Regulator gain	80		
TA	T_A	Regulator delay	0.050		
VRMAX	V_{RMAX}	Max. regulator output	8		
VRMIN	V_{RMIN}	Min. regulator output	-3		
KC	K_C	Coef. for Ifd	0.200		
KF	K_F	Feedback gain	0.100		
TF	T_F	Feedback delay	1		non_zero,non_negative
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	<i>bus</i>	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
LR_y	y_{LR}	State	State in lag transfer function		v_str
WF_x	x'_{WF}	State	State in washout filter		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
vref	V_{ref}	Algeb	Reference voltage input	p.u.	v_str
vi	V_i	Algeb	Total input voltages	p.u.	v_str
vl	V_l	Algeb	Input after limiter		v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
WF_y	y_{WF}	Algeb	Output of washout filter		v_str
vfmax	V_{fmax}	Algeb	Upper bound of output limiter		v_str
vfmin	V_{fmin}	Algeb	Lower bound of output limiter		v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
LL_x	x'_{LL}	State	V_l
LR_y	y_{LR}	State	$K_A y_{LL}$
WF_x	x'_{WF}	State	y_{LR}
omega	ω	ExtState	
v	E_{term}	Algeb	V
vout	v_{out}	Algeb	$u_e v_{f0}$
vref	V_{ref}	Algeb	$E_{term} + \frac{v_{f0}}{K_A}$
vi	V_i	Algeb	$\frac{v_{f0}}{K_A}$
vl	V_l	Algeb	$V_i z_i^{HLI} + V_{IMAX} z_u^{HLI} + V_{IMIN} z_l^{HLI}$
LL_y	y_{LL}	Algeb	V_l
WF_y	y_{WF}	Algeb	0
vfmax	V_{fmax}	Algeb	$-K_C X_{ad} I_{fd} + V_{RMAX}$
vfmin	V_{fmin}	Algeb	$-K_C X_{ad} I_{fd} + V_{RMIN}$
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
vbus	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
LL_x	x'_{LL}	State	$V_l - x'_{LL}$	T_B
LR_y	y_{LR}	State	$K_{AyLL} - y_{LR}$	T_A
WF_x	x'_{WF}	State	$-x'_{WF} + y_{LR}$	T_F
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algeb	$-E_{term} + V$
vout	v_{out}	Algeb	$u_e (V_{fmax} z_u^{HLR} + V_{fmin} z_l^{HLR} + y_{LR} z_i^{HLR}) - v_{out}$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
vi	V_i	Algeb	$-V_i + V_{ref} - y_{LG} - y_{WF}$
vl	V_l	Algeb	$V_i z_i^{HLI} - V_l + V_{IMAX} z_u^{HLI} + V_{IMIN} z_l^{HLI}$
LL_y	y_{LL}	Algeb	$T_B x'_{LL} - T_B y_{LL} + T_C (V_l - x'_{LL}) + (z_1^{LTLL})^2 (-x'_{LL} + y_{LL})$
WF_y	y_{WF}	Algeb	$K_F (-x'_{WF} + y_{LR}) - T_F y_{WF}$
vfmax	V_{fmax}	Algeb	$-K_C X_{ad} I_{fd} + V_{RMAX} - V_{fmax}$
vfmin	V_{fmin}	Algeb	$-K_C X_{ad} I_{fd} + V_{RMIN} - V_{fmin}$
vf	v_f	ExtAlgeb	$u_e (-v_{f0} + v_{out})$
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	0
a	θ	ExtAlgeb	0
vbus	V	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
vref0	V_{ref0}	V_{ref}	PostInitService

Discretes

Name	Symbol	Type	Info
HLI	<i>HLI</i>	HardLimiter	Hard limiter on input
LL_LT1	<i>LT_{LL}</i>	LessThan	
LL_LT2	<i>LT_{LL}</i>	LessThan	
HLR	<i>HLR</i>	HardLimiter	Hard limiter on regulator output

Blocks

Name	Symbol	Type	Info
LG	<i>LG</i>	Lag	Sensing delay
LL	<i>LL</i>	LeadLag	Lead-lag compensator
LR	<i>LR</i>	Lag	Regulator
WF	<i>WF</i>	Washout	Stablizing circuit feedback

Config Fields in [EXST1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.6 ESST3A

Static exciter type 3A model

Parameters

Name	Sym- bol	Description	De- fault	Unit	Proper- ties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory
TR	T_R	Sensing time constant	0.010	<i>p.u.</i>	
VIMAX	V_{IMAX}	Max. input voltage	0.800		
VIMIN	V_{IMIN}	Min. input voltage	-0.100		
KM	K_M	Forward gain constant	500		
TC	T_C	Lead time constant in lead-lag	3		
TB	T_B	Lag time constant in lead-lag	15		
KA	K_A	Gain in anti-windup lag TF	50		
TA	T_A	Lag time constant in anti-windup lag	0.100		
VR- MAX	V_{RMAX}	Maximum excitation limit	8	<i>p.u.</i>	
VRMIN	V_{RMIN}	Minimum excitation limit	0	<i>p.u.</i>	
KG	K_G	Feedback gain of inner field regulator	1		
KP	K_P	Potential circuit gain coeff.	4		
KI	K_I	Potential circuit gain coeff.	0.100		
VB- MAX	V_{BMAX}	VB upper limit	18	<i>p.u.</i>	
KC	K_C	Rectifier loading factor proportional to commutating reactance	0.100		
XL	X_L	Potential source reactance	0.010		
VG- MAX	V_{GMAX}	VG upper limit	4	<i>p.u.</i>	
THETAP	θ_P	Rectifier firing angle	0	<i>de- gree</i>	
TM	K_C	Inner field regulator forward time constant	0.100		
VM- MAX	V_{MMAX}	Maximum VM limit	1	<i>p.u.</i>	
VM- MIN	V_{RMIN}	Minimum VM limit	0.100	<i>p.u.</i>	
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	bus	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
LAW1_y	y_{LAW1}	State	State in lag TF		v_str
LAW2_y	y_{LAW2}	State	State in lag TF		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
UEL	U_{EL}	Algeb	Interface var for under exc. limiter		v_str
IN	I_N	Algeb	Input to FEX		v_str
FEX_y	y_{FEX}	Algeb	Output of piecewise		v_str
VB_x	x_{VB}	Algeb	Value before limiter		v_str
VB_y	y_{VB}	Algeb	Output after limiter and post gain		v_str
VG_x	x_{VG}	Algeb	Value before limiter		v_str
VG_y	y_{VG}	Algeb	Output after limiter and post gain		v_str
vrs	V_{RS}	Algeb	VR subtract feedback VG		v_str
vref	V_{ref}	Algeb	Reference voltage input	p.u.	v_str
vi	V_i	Algeb	Total input voltages	p.u.	v_str
vil	V_{il}	Algeb	Input voltage after limit		v_str
HG_y	y_{HG}	Algeb	HVGate output		v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		
vd	V_d	ExtAlgeb	d-axis machine voltage		
vq	V_q	ExtAlgeb	q-axis machine voltage		
Id	I_d	ExtAlgeb	d-axis machine current		
Iq	I_q	ExtAlgeb	q-axis machine current		

Initialization Equations

Name	Sym- bol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
LL_x	x'_{LL}	State	y_{HG}
LAW1	y_{LAW}	State	$K_A y_{LL}$
LAW2	y_{LAW}	State	$K_M V_{RS}$
omega	ω	ExtStat	
v	E_{term}	Al- geb	V
vout	v_{out}	Al- geb	$u_e v_{f0}$
UEL	U_{EL}	Al- geb	U_{EL0}
IN	I_N	Al- geb	$\text{safe}_{div}(K_C X_{ad} I_{fd}, V_E)$
FEX_y	y_{FEX}	Al- geb	$\text{FixPiecewise}\left(\left(1, I_N \leq 0\right), \left(1 - 0.577 I_N, I_N \leq 0.433\right), \left(\sqrt{0.75 - I_N^2}, I_N \leq 0.75\right), \left(1.732 - \right.\right.$
VB_x	x_{VB}	Al- geb	$V_E y_{FEX}$
VB_y	y_{VB}	Al- geb	$V_{BMAX} z_u^{lim_{VB}} + x_{VB} z_i^{lim_{VB}}$
VG_x	x_{VG}	Al- geb	$K_G v_{out}$
VG_y	y_{VG}	Al- geb	$V_{GMAX} z_u^{lim_{VG}} + x_{VG} z_i^{lim_{VG}}$
vrs	V_{RS}	Al- geb	$\frac{\text{safe}_{div}(v_{f0}, y_{VB})}{K_M}$
vref	V_{ref}	Al- geb	$E_{term} + \frac{V_{RS} + y_{VG}}{K_A}$
vi	V_i	Al- geb	$-E_{term} + V_{ref}$
vil	V_{il}	Al- geb	$V_i z_i^{HLI} + V_{IMAX} z_u^{HLI} + V_{IMIN} z_l^{HLI}$
HG_y	y_{HG}	Al- geb	$U_{EL} z_0^{None_{HG}} + V_{il} z_1^{None_{HG}}$
LL_y	y_{LL}	Al- geb	y_{HG}
vf	v_f	Ex- tAl- geb	
Xad- Ifd	$X_{ad} I_{fd}$	Ex- tAl- geb	
a	θ	Ex- tAl- geb	
534		geb	
vbus	V	Ex- tAl- geb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
LL_x	x'_{LL}	State	$-x'_{LL} + y_{HG}$	T_B
LAW1_y	y_{LAW1}	State	$K_A y_{LL} - y_{LAW1}$	T_A
LAW2_y	y_{LAW2}	State	$K_M V_{RS} - y_{LAW2}$	K_C
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algebraic	$-E_{term} + V$
vout	v_{out}	Algebraic	$u_e y_{LAW2} y_{VB} - v_{out}$
UEL	U_{EL}	Algebraic	$U_{EL0} - U_{EL}$
IN	I_N	Algebraic	$u_e (-I_N V_E + K_C X_{ad} I_{fd})$
FEX_	y_{FEX}	Algebraic	$-y_{FEX} + \text{FixPiecewise} \left((1, I_N \leq 0), (1 - 0.577 I_N, I_N \leq 0.433), \left(\sqrt{0.75 - I_N^2}, I_N \leq 0.75 \right), (0, I_N > 0.75) \right)$
VB_x	x_{VB}	Algebraic	$V_E y_{FEX} - x_{VB}$
VB_y	y_{VB}	Algebraic	$V_{BMAX} z_u^{lim_{VB}} + x_{VB} z_i^{lim_{VB}} - y_{VB}$
VG_x	x_{VG}	Algebraic	$K_G v_{out} - x_{VG}$
VG_y	y_{VG}	Algebraic	$V_{GMAX} z_u^{lim_{VG}} + x_{VG} z_i^{lim_{VG}} - y_{VG}$
vrs	V_{RS}	Algebraic	$-V_{RS} + y_{LAW1} - y_{VG}$
vref	V_{ref}	Algebraic	$V_{ref0} - V_{ref}$
vi	V_i	Algebraic	$-V_i + V_{ref} - y_{LG}$
vil	V_{il}	Algebraic	$V_i z_i^{HLI} + V_{IMAX} z_u^{HLI} + V_{IMIN} z_l^{HLI} - V_{il}$
HG_y	y_{HG}	Algebraic	$U_{EL} z_0^{None_{HG}} + V_{il} z_1^{None_{HG}} - y_{HG}$
LL_y	y_{LL}	Algebraic	$T_B x'_{LL} - T_B y_{LL} + T_C (-x'_{LL} + y_{HG}) + \left(z_1^{LT_{LL}} \right)^2 (-x'_{LL} + y_{LL})$
vf	v_f	ExtAlgebraic	$u_e (-v_{f0} + v_{out})$
Xad-I _{fd}	$X_{ad} I_f$	ExtAlgebraic	0
a	θ	ExtAlgebraic	0
vbus	V	ExtAlgebraic	0
vd	V_d	ExtAlgebraic	0
vq	V_q	ExtAlgebraic	0

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
KPC	K_{PC}	$K_P e^{i \text{radians}(\theta_P)}$	ConstService
UEL0	U_{EL0}	-9999	ConstService
VE	V_E	$ K_{PC}(V_d + iV_q) + i(I_d + iI_q)(K_I + K_{PC}X_L) $	VarService
vref0	V_{ref0}	V_{ref}	PostInitService

Discretes

Name	Symbol	Type	Info
VB_lim	lim_{VB}	HardLimiter	
VG_lim	lim_{VG}	HardLimiter	
HG_lt	$None_{HG}$	LessThan	
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
LAW1_lim	lim_{LAW1}	AntiWindup	Limiter in Lag
HLI	HLI	HardLimiter	Input limiter
LAW2_lim	lim_{LAW2}	AntiWindup	Limiter in Lag

Blocks

Name	Symbol	Type	Info
LG	LG	Lag	Voltage transducer
FEX	FEX	Piecewise	Piecewise function FEX
VB	VB	GainLimiter	VB with limiter
VG	VG	GainLimiter	Feedback gain with HL
HG	HG	HVGate	HVGate for under excitation
LL	LL	LeadLag	Regulator
LAW1	$LAW1$	LagAntiWindup	Lag AW on VR
LAW2	$LAW2$	LagAntiWindup	Lag AW on VM

Config Fields in [ESST3A]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.7 SEXS

Simplified Excitation System

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TATB	T_A/T_B	Time constant TA/TB	0.400		
TB	T_B	Time constant TB in LL	5		
K	K	Gain	20		non_zero
TE	T_E	AW Lag time constant	1		
EMIN	E_{MIN}	lower limit	-99		
EMAX	E_{MAX}	upper limit	99		
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	bus	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LL_x	x'_{LL}	State	State in lead-lag		v_str
LAW_y	y_{LAW}	State	State in lag TF		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
vref	V_{ref}	Algeb	Reference voltage input	<i>p.u.</i>	v_str
vi	V_i	Algeb	Total input voltages	<i>p.u.</i>	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
LL_x	x'_{LL}	State	V_i
LAW_y	y_{LAW}	State	$K y_{LL}$
omega	ω	ExtState	
v	E_{term}	Algeb	V
vout	v_{out}	Algeb	$u_e v_{f0}$
vref	V_{ref}	Algeb	$E_{term} + \frac{v_{f0}}{K}$
vi	V_i	Algeb	$\frac{v_{f0}}{K}$
LL_y	y_{LL}	Algeb	V_i
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
vbus	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LL_x	x'_{LL}	State	$V_i - x'_{LL}$	T_B
LAW_y	y_{LAW}	State	$K y_{LL} - y_{LAW}$	T_E
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algeb	$-E_{term} + V$
vout	v_{out}	Algeb	$u_e y_{LAW} - v_{out}$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
vi	V_i	Algeb	$-E_{term} - V_i + V_{ref}$
LL_y	y_{LL}	Algeb	$T_A (V_i - x'_{LL}) + T_B x'_{LL} - T_B y_{LL} + \left(z_1^{LT_{LL}}\right)^2 (-x'_{LL} + y_{LL})$
vf	v_f	ExtAlgeb	$u_e (-v_{f0} + v_{out})$
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	0
a	θ	ExtAlgeb	0
vbus	V	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
TA	TA	$T_{A/TB}T_B$	ConstService
vref0	V_{ref0}	V_{ref}	PostInitService

Discretes

Name	Symbol	Type	Info
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
LAW_lim	lim_{LAW}	AntiWindup	Limiter in Lag

Blocks

Name	Symbol	Type	Info
LL	LL	LeadLag	
LAW	LAW	LagAntiWindup	

Config Fields in [SEXS]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.8 IEEE1

IEEE1 exciter.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.020	<i>p.u.</i>	
KA	K_A	Regulator gain	5	<i>p.u.</i>	
TA	T_A	Lag time constant in anti-windup lag	0.040	<i>p.u.</i>	
VRMAX	V_{RMAX}	Maximum excitation limit	7.300	<i>p.u.</i>	
VRMIN	V_{RMIN}	Minimum excitation limit	-7.300	<i>p.u.</i>	
KE	K_E	Gain added to saturation	1	<i>p.u.</i>	
TE	T_E	Exciter integrator time constant	0.800	<i>p.u.</i>	
KF	K_F	Feedback gain	0.100		
TF	T_F	Feedback delay	1		non_zero,non_negative
Switch	S_w	Switch unused in PSS/E	0	<i>bool</i>	
E1	E_1	First saturation point	0	<i>p.u.</i>	
SE1	S_{E1}	Value at first saturation point	0	<i>p.u.</i>	
E2	E_2	Second saturation point	1	<i>p.u.</i>	
SE2	S_{E2}	Value at second saturation point	1	<i>p.u.</i>	
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	bus	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
LA_y	y_{LA}	State	State in lag TF		v_str
INT_y	y_{INT}	State	Integrator output		v_str
WF_x	x'_{WF}	State	State in washout filter		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
vref	V_{ref}	Algeb	Reference voltage input	p.u.	v_str
vi	V_i	Algeb	Total input voltages	p.u.	v_str
VFE	V_{FE}	Algeb	Combined saturation feedback	p.u.	v_str
Se	$S_e(V_{out})$	Algeb	saturation output		v_str
WF_y	y_{WF}	Algeb	Output of washout filter		v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
LA_y	y_{LA}	State	$K_A u_e (V_i - y_{WF})$
INT_y	y_{INT}	State	v_{f0}
WF_x	x'_{WF}	State	v_{out}
omega	ω	ExtState	
v	E_{term}	Algeb	V
vout	v_{out}	Algeb	$u_e v_{f0}$
vref	V_{ref}	Algeb	$E_{term} + V_{b0}$
vi	V_i	Algeb	$-E_{term} + V_{ref}$
VFE	V_{FE}	Algeb	V_{FE0}
Se	$S_e(V_{out})$	Algeb	S_{e0}
WF_y	y_{WF}	Algeb	0
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
vbus	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
LA_y	y_{LA}	State	$K_A u_e (V_i - y_{WF}) - y_{LA}$	T_A
INT_y	y_{INT}	State	$u_e (-V_{FE} + y_{LA})$	T_E
WF_x	x'_{WF}	State	$v_{out} - x'_{WF}$	T_F
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algeb	$-E_{term} + V$
vout	v_{out}	Algeb	$u_e (-v_{out} + y_{INT})$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
vi	V_i	Algeb	$u_e (-V_i + V_{ref} - y_{LG})$
VFE	V_{FE}	Algeb	$u_e (K_E y_{INT} + S_e(V_{out}) - V_{FE})$
Se	$S_e(V_{out})$	Algeb	$B_{SAT}^q z_0^{SL} (-A_{SAT}^q + y_{INT})^2 - S_e(V_{out})$
WF_y	y_{WF}	Algeb	$K_F (v_{out} - x'_{WF}) - T_F y_{WF}$
vf	v_f	ExtAlgeb	$u_e (-v_{f0} + v_{out})$
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	0
a	θ	ExtAlgeb	0
vbus	V	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
VR-MAXc	$VRMAXc$	$VRMAX - 999z_{VRMAX} + 999$	ConstService
SAT_E1	E_{SAT}^{1c}	E_1	ConstService
SAT_E2	E_{SAT}^{2c}	$E_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_SE1	SE_{SAT}^{1c}	S_{E1}	ConstService
SAT_SE2	SE_{SAT}^{2c}	$S_{E2} - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E_{SAT}^{1c} SE_{SAT}^{1c}}{E_{SAT}^{2c} SE_{SAT}^{2c}}} (\text{Indicator}(SE_{SAT}^{2c} > 0) + \text{Indicator}(SE_{SAT}^{2c} < 0))$	ConstService
SAT_A	A_{SAT}^q	$E_{SAT}^{2c} - \frac{E_{SAT}^{1c} - E_{SAT}^{2c}}{a_{SAT} - 1}$	ConstService
SAT_B	B_{SAT}^q	$\frac{E_{SAT}^{2c} SE_{SAT}^{2c} (a_{SAT} - 1)^2 (\text{Indicator}(a_{SAT} > 0) + \text{Indicator}(a_{SAT} < 0))}{(E_{SAT}^{1c} - E_{SAT}^{2c})^2}$	ConstService
Se0	S_{e0}	$B_{SAT}^q (A_{SAT}^q - v_{f0})^2 \text{Indicator}(v_{f0} > A_{SAT}^q)$	ConstService
vr0	V_{r0}	$K_E v_{f0} + S_{e0}$	ConstService
vb0	V_{b0}	$\frac{V_{r0}}{K_A}$	ConstService
vfe0	V_{FE0}	$K_E v_{f0} + S_{e0}$	ConstService
vref0	V_{ref0}	V_{ref}	PostInitService

Discretes

Name	Symbol	Type	Info
LA_lim	lim_{LA}	AntiWindup	Limiter in Lag
SL	SL	LessThan	

Blocks

Name	Symbol	Type	Info
SAT	SAT	ExcQuadSat	Field voltage saturation
LG	LG	Lag	Sensing delay
LA	LA	LagAntiWindup	Anti-windup lag
INT	INT	Integrator	Integrator
WF	WF	Washout	Stablizing circuit feedback

Config Fields in [IEEET1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.9 EXAC1

EXAC1 model.

Ref: https://www.powerworld.com/WebHelp/Content/TransientModels_HTML/Exciter%20EXAC1.htm

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.010	<i>p.u.</i>	
TB	T_B	Lag time constant in lead-lag	1	<i>p.u.</i>	
TC	T_C	Lead time constant in lead-lag	1	<i>p.u.</i>	
KA	K_A	Regulator gain	80		
TA	T_A	Lag time constant in regulator	0.040	<i>p.u.</i>	
VR- MAX	V_{RMAX}	Maximum regulator output	8	<i>p.u.</i>	
VR- MIN	V_{RMIN}	Minimum regulator output	0	<i>p.u.</i>	
TE	T_E	Exciter integrator time constant	0.800	<i>p.u.</i>	non_negative
KF	K_F	Feedback gain	0.100		
TF	T_F	Feedback delay	1		non_zero,non_negative
KC	K_C	Rectifier loading factor proportional to commutating reactance	0.100		
KD	K_C	Ifd feedback gain	0		
KE	K_E	Saturation feedback gain	1	<i>p.u.</i>	
E1	E_1	First saturation point	0	<i>p.u.</i>	
SE1	S_{E1}	Value at first saturation point	0	<i>p.u.</i>	
E2	E_2	Second saturation point	1	<i>p.u.</i>	
SE2	S_{E2}	Value at second saturation point	1	<i>p.u.</i>	
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	<i>bus</i>	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
LA_y	y_{LA}	State	State in lag TF		v_str
INT_y	y_{INT}	State	Integrator output		v_str,v_iter
WF_x	x'_{WF}	State	State in washout filter		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
IN	I_N	Algeb	Input to FEX		v_str,v_iter
FEX_y	y_{FEX}	Algeb	Output of piecewise		v_str,v_iter
vi	V_i	Algeb	Total input voltages	<i>p.u.</i>	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
Se	$V_{out} * S_e(V_{out})$	Algeb	saturation output		v_str
VFE	V_{FE}	Algeb	Combined saturation feedback	<i>p.u.</i>	v_str
vref	V_{ref}	Algeb	Reference voltage input	<i>p.u.</i>	v_str
WF_y	y_{WF}	Algeb	Output of washout filter		v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Nam	Symbol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
LL_x	x'_{LL}	State	V_i
LA_y	y_{LA}	State	$K_A y_{LL}$
INT_	y_{INT}	State	$-v_{f0} + y_{FEX} y_{INT}$
WF_	x'_{WF}	State	V_{FE}
omeg	ω	ExtSta	
v	E_{term}	Al-geb	V
vout	v_{out}	Al-geb	$u_e v_{f0}$
IN	I_N	Al-geb	$-I_N y_{INT} + K_C X_{ad} I_{fd}$
FEX_	y_{FEX}	Al-geb	$-y_{FEX} + \text{FixPiecewise} \left((1, I_N \leq 0), (1 - 0.577 I_N, I_N \leq 0.433), \left(\sqrt{0.75 - I_N^2}, I_N \leq 0.75 \right) \right)$
vi	V_i	Al-geb	$-E_{term} + V_{ref}$
LL_y	y_{LL}	Al-geb	V_i
Se	$V_{out} * S_e(V_{out})$	Al-geb	$B_{SAT}^q (-A_{SAT}^q + y_{INT})^2 \text{Indicator}(y_{INT} > A_{SAT}^q)$
VFE	V_{FE}	Al-geb	$K_C X_{ad} I_{fd} + K_E y_{INT} + V_{out} * S_e(V_{out})$
vref	V_{ref}	Al-geb	$E_{term} + \frac{V_{FE}}{K_A}$
WF_	y_{WF}	Al-geb	0
vf	v_f	ExtAl-geb	
Xad-Ifd	$X_{ad} I_{fd}$	ExtAl-geb	
a	θ	ExtAl-geb	
vbus	V	ExtAl-geb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
LL_x	x'_{LL}	State	$V_i - x'_{LL}$	T_B
LA_y	y_{LA}	State	$K_{AyLL} - y_{LA}$	T_A
INT_y	y_{INT}	State	$u_e (-V_{FE} + y_{LA})$	T_E
WF_x	x'_{WF}	State	$V_{FE} - x'_{WF}$	T_F
omega	ω	ExtState	0	

Algebraic Equations

Nam	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Al-geb	$-E_{term} + V$
vout	v_{out}	Al-geb	$u_e(-v_{out} + y_{FEX}y_{INT})$
IN	I_N	Al-geb	$u_e(-I_N y_{INT} + K_C X_{ad} I_{fd})$
FEX_	y_{FEX}	Al-geb	$-y_{FEX} + \text{FixPiecewise}\left((1, I_N \leq 0), (1 - 0.577 I_N, I_N \leq 0.433), \left(\sqrt{0.75 - I_N^2}, I_N \leq 0.75\right)\right)$
vi	V_i	Al-geb	$u_e(-E_{term} - V_i + V_{ref} - y_{WF})$
LL_y	y_{LL}	Al-geb	$T_B x'_{LL} - T_B y_{LL} + T_C (V_i - x'_{LL}) + \left(z_1^{LT_{LL}}\right)^2 (-x'_{LL} + y_{LL})$
Se	$V_{out} * S_e(V_{out})$	Al-geb	$u_e\left(B_{SAT}^q z_0^{SL} (-A_{SAT}^q + y_{INT})^2 - V_{out} * S_e(V_{out})\right)$
VFE	V_{FE}	Al-geb	$u_e(K_C X_{ad} I_{fd} + K_E y_{INT} - V_{FE} + V_{out} * S_e(V_{out}))$
vref	V_{ref}	Al-geb	$V_{ref0} - V_{ref}$
WF_	y_{WF}	Al-geb	$K_F (V_{FE} - x'_{WF}) - T_F y_{WF}$
vf	v_f	ExtAl-geb	$u_e(-v_{f0} + v_{out})$
Xad-I _{fd}	$X_{ad} I_{fd}$	ExtAl-geb	0
a	θ	ExtAl-geb	0
vbus	V	ExtAl-geb	0

Services

Name	Sym- bol	Equation	Type
ue	u_e	uu_g	ConstService
SAT_E1	E_{SAT}^{1c}	E_1	ConstService
SAT_E2	E_{SAT}^{2c}	$E_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_SE1	SE_{SAT}^{1c}	S_{E1}	ConstService
SAT_SE2	SE_{SAT}^{2c}	$S_{E2} - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E_{SAT}^{1c} SE_{SAT}^{1c}}{E_{SAT}^{2c} SE_{SAT}^{2c}}} (\text{Indicator}(SE_{SAT}^{2c} > 0) + \text{Indicator}(SE_{SAT}^{2c} < 0))$	ConstService
SAT_A	A_{SAT}^q	$E_{SAT}^{2c} - \frac{E_{SAT}^{1c} - E_{SAT}^{2c}}{a_{SAT} - 1}$	ConstService
SAT_B	B_{SAT}^q	$\frac{E_{SAT}^{2c} SE_{SAT}^{2c} (a_{SAT} - 1)^2 (\text{Indicator}(a_{SAT} > 0) + \text{Indicator}(a_{SAT} < 0))}{(E_{SAT}^{1c} - E_{SAT}^{2c})^2}$	ConstService
vref0	V_{ref0}	V_{ref}	PostInitService

Discretes

Name	Symbol	Type	Info
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
LA_lim	lim_{LA}	AntiWindup	Limiter in Lag
SL	SL	LessThan	

Blocks

Name	Symbol	Type	Info
SAT	SAT	ExcQuadSat	Field voltage saturation
FEX	FEX	Piecewise	Piecewise function FEX
LG	LG	Lag	Voltage transducer
LL	LL	LeadLag	Regulator
LA	LA	LagAntiWindup	Lag AW on VR
INT	INT	Integrator	Integrator
WF	WF	Washout	Stablizing circuit feedback

Config Fields in [EXAC1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.10 EXAC2

EXAC2 model.

Ref: https://www.powerworld.com/WebHelp/Content/TransientModels_HTML/Exciter%20EXAC2.htm

Notes

VLR is an input parameter, but to initialize the LVGate, an internal VLR_x will be computed as a constant upon initialization. The constant VLR_x will be used in the place of VLR in the block diagram.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.010	<i>p.u.</i>	
TB	T_B	Lag time constant in lead-lag	1	<i>p.u.</i>	
TC	T_C	Lead time constant in lead-lag	1	<i>p.u.</i>	
KA	K_A	Regulator gain	80		
TA	T_A	Lag time constant in regulator	0.040	<i>p.u.</i>	
VRMAX	V_{RMAX}	Maximum regulator output	8	<i>p.u.</i>	
VRMIN	V_{RMIN}	Minimum regulator output	0	<i>p.u.</i>	
TE	T_E	Exciter integrator time constant	0.800	<i>p.u.</i>	non_negative
KF	K_F	Feedback gain	0.100		
TF	T_F	Feedback delay	1		non_zero,non_neg
KC	K_C	Rectifier loading factor proportional to commutating reactance	0.100		
KD	K_C	Ifd feedback gain	0		
KE	K_E	Saturation feedback gain	1	<i>p.u.</i>	
E1	E_1	First saturation point	0	<i>p.u.</i>	
SE1	S_{E1}	Value at first saturation point	0	<i>p.u.</i>	
E2	E_2	Second saturation point	1	<i>p.u.</i>	
SE2	S_{E2}	Value at second saturation point	1	<i>p.u.</i>	
VAMAX	V_{RMAX}	Maximum KA block output	8	<i>p.u.</i>	
VAMIN	V_{RMIN}	Minimum KA block output	0	<i>p.u.</i>	

continues on next

Table 14 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
VLR	V_{LR}	low voltage constant	0	<i>p.u.</i>	
KL	K_L	gain for low voltage	1	<i>p.u.</i>	
KH	K_H	gain for high voltage	1	<i>p.u.</i>	
KB	K_B	gain KB for regulator	1	<i>p.u.</i>	non_negative
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	bus	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
LA_y	y_{LA}	State	State in lag TF		v_str
INT_y	y_{INT}	State	Integrator output		v_str,v_iter
WF_x	x'_{WF}	State	State in washout filter		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
IN	I_N	Algeb	Input to FEX		v_str,v_iter
FEX_y	y_{FEX}	Algeb	Output of piecewise		v_str,v_iter
vi	V_i	Algeb	Total input voltages	<i>p.u.</i>	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
Se	$V_{out} * S_e(V_{out})$	Algeb	saturation output		v_str
VFE	V_{FE}	Algeb	Combined saturation feedback	<i>p.u.</i>	v_str
vref	V_{ref}	Algeb	Reference voltage input	<i>p.u.</i>	v_str
WF_y	y_{WF}	Algeb	Output of washout filter		v_str
VHA	V_{HA}	Algeb			v_str
VL	V_L	Algeb			v_str
LVG_y	y_{LVG}	Algeb	LVGate output		v_str
VR_x	x_{VR}	Algeb	Value before limiter		v_str
VR_y	y_{VR}	Algeb	Output after limiter and post gain		v_str
VLRx	V_{LRx}	Algeb			v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Nam	Symbol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
LL_x	x'_{LL}	State	V_i
LA_y	y_{LA}	State	$K_A y_{LL}$
INT_	y_{INT}	State	$-v_{f0} + y_{FEX} y_{INT}$
WF_	x'_{WF}	State	V_{FE}
omeg	ω	ExtSta	
v	E_{term}	Al-geb	V
vout	v_{out}	Al-geb	$u_e v_{f0}$
IN	I_N	Al-geb	$-I_N y_{INT} + K_C X_{ad} I_{fd}$
FEX_	y_{FEX}	Al-geb	$-y_{FEX} + \text{FixPiecewise}\left((1, I_N \leq 0), (1 - 0.577 I_N, I_N \leq 0.433), \left(\sqrt{0.75 - I_N^2}, I_N \leq 0.75\right)\right)$
vi	V_i	Al-geb	$-E_{term} + V_{ref}$
LL_y	y_{LL}	Al-geb	V_i
Se	$V_{out} * S_e(V_{out})$	Al-geb	$B_{SAT}^q (-A_{SAT}^q + y_{INT})^2 \text{Indicator}(y_{INT} > A_{SAT}^q)$
VFE	V_{FE}	Al-geb	$K_C X_{ad} I_{fd} + K_E y_{INT} + V_{out} * S_e(V_{out})$
vref	V_{ref}	Al-geb	$E_{term} + \frac{K_L V_{FE} + \frac{V_{FE}}{K_B}}{K_A}$
WF_	y_{WF}	Al-geb	0
VHA	V_{HA}	Al-geb	$-K_H V_{FE} + y_{LA}$
VL	V_L	Al-geb	$K_L (V_{LR} x - V_{FE})$
LVG_	y_{LVG}	Al-geb	$V_H A z_1^{NoneLVG} + V_L z_0^{NoneLVG}$
VR_	x_{VR}	Al-geb	$K_B y_{LVG}$
VR_	y_{VR}	Al-geb	$V_{RMAX} z_u^{limVR} + V_{RMIN} z_l^{limVR} + x_{VR} z_i^{limVR}$
VLR:	$V_{LR} x$	Al-geb	$V_{LR} \text{Indicator}\left(V_{FE} + \frac{V_{FE}}{K_B K_L} < V_{LR}\right) + \left(V_{FE} + \frac{V_{FE}}{K_B K_L}\right) \text{Indicator}\left(V_{FE} + \frac{V_{FE}}{K_B K_L} > V_{LR}\right)$
vf	v_f	ExtAl-geb	
Xad-Ifd	$X_{ad} I_{fd}$	ExtAl-geb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
LL_x	x'_{LL}	State	$V_i - x'_{LL}$	T_B
LA_y	y_{LA}	State	$K_{AyLL} - y_{LA}$	T_A
INT_y	y_{INT}	State	$u_e (-V_{FE} + y_{VR})$	T_E
WF_x	x'_{WF}	State	$V_{FE} - x'_{WF}$	T_F
omega	ω	ExtState	0	

Algebraic Equations

Nam	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Al-geb	$-E_{term} + V$
vout	v_{out}	Al-geb	$u_e(-v_{out} + y_{FEX}y_{INT})$
IN	I_N	Al-geb	$u_e(-I_N y_{INT} + K_C X_{ad} I_{fd})$
FEX_	y_{FEX}	Al-geb	$-y_{FEX} + \text{FixPiecewise}\left(\left(1, I_N \leq 0\right), \left(1 - 0.577 I_N, I_N \leq 0.433\right), \left(\sqrt{0.75 - I_N^2}, I_N \leq 0.75\right)\right)$
vi	V_i	Al-geb	$u_e(-E_{term} - V_i + V_{ref} - y_{WF})$
LL_y	y_{LL}	Al-geb	$T_B x'_{LL} - T_B y_{LL} + T_C (V_i - x'_{LL}) + \left(z_1^{LT_{LL}}\right)^2 (-x'_{LL} + y_{LL})$
Se	$V_{out} * S_e(V_{out})$	Al-geb	$u_e\left(B_{SAT}^q z_0^{SL} (-A_{SAT}^q + y_{INT})^2 - V_{out} * S_e(V_{out})\right)$
VFE	V_{FE}	Al-geb	$u_e(K_C X_{ad} I_{fd} + K_E y_{INT} - V_{FE} + V_{out} * S_e(V_{out}))$
vref	V_{ref}	Al-geb	$V_{ref0} - V_{ref}$
WF_	y_{WF}	Al-geb	$K_F (V_{FE} - x'_{WF}) - T_F y_{WF}$
VHA	V_{HA}	Al-geb	$-K_H V_{FE} - V_{HA} + y_{LA}$
VL	V_L	Al-geb	$K_L (V_{LRx} - V_{FE}) - V_L$
LVG_	y_{LVG}	Al-geb	$V_{HA} z_1^{None_{LVG}} + V_L z_0^{None_{LVG}} - y_{LVG}$
VR_	x_{VR}	Al-geb	$K_B y_{LVG} - x_{VR}$
VR_	y_{VR}	Al-geb	$V_{RMAX} z_u^{lim_{VR}} + V_{RMIN} z_l^{lim_{VR}} + x_{VR} z_i^{lim_{VR}} - y_{VR}$
VLR:	V_{LRx}	Al-geb	$V_{LR0} - V_{LRx}$
vf	v_f	ExtAl-geb	$u_e(-v_{f0} + v_{out})$
Xad-Ifd	$X_{ad} I_{fd}$	ExtAl-geb	0
a	θ	ExtAl-geb	0
vbus	V	ExtAl-geb	0

Services

Name	Sym- bol	Equation	Type
ue	u_e	uu_g	ConstService
SAT_E1	E_{SAT}^{1c}	E_1	ConstService
SAT_E2	E_{SAT}^{2c}	$E_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_SE1	SE_{SAT}^{1c}	S_{E1}	ConstService
SAT_SE2	SE_{SAT}^{2c}	$S_{E2} - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E_{SAT}^{1c} SE_{SAT}^{1c}}{E_{SAT}^{2c} SE_{SAT}^{2c}}} (\text{Indicator}(SE_{SAT}^{2c} > 0) + \text{Indicator}(SE_{SAT}^{2c} < 0))$	ConstService
SAT_A	A_{SAT}^q	$E_{SAT}^{2c} - \frac{E_{SAT}^{1c} - E_{SAT}^{2c}}{a_{SAT} - 1}$	ConstService
SAT_B	B_{SAT}^q	$\frac{E_{SAT}^{2c} SE_{SAT}^{2c} (a_{SAT} - 1)^2 (\text{Indicator}(a_{SAT} > 0) + \text{Indicator}(a_{SAT} < 0))}{(E_{SAT}^{1c} - E_{SAT}^{2c})^2}$	ConstService
vref0	V_{ref0}	V_{ref}	PostInitService
VLR0	$VLR0$	$VLRx$	PostInitService

Discretes

Name	Symbol	Type	Info
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
LA_lim	lim_{LA}	AntiWindup	Limiter in Lag
SL	SL	LessThan	
LVG_lt	$None_{LVG}$	LessThan	
VR_lim	lim_{VR}	HardLimiter	

Blocks

Name	Symbol	Type	Info
SAT	SAT	ExcQuadSat	Field voltage saturation
FEX	FEX	Piecewise	Piecewise function FEX
LG	LG	Lag	Voltage transducer
LL	LL	LeadLag	Regulator
LA	LA	LagAntiWindup	Lag AW on VR
INT	INT	Integrator	Integrator
WF	WF	Washout	Stablizing circuit feedback
LVG	LVG	LVGate	
VR	VR	GainLimiter	

Config Fields in [EXAC2]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.11 EXAC4

IEEE Type AC4 excitation system model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.010	<i>p.u.</i>	
VIMAX	V_{IMAX}	Max. input voltage	5		
VIMIN	V_{IMIN}	Min. input voltage	-0.100		
TC	T_C	Lead time constant in lead-lag	1	<i>p.u.</i>	
TB	T_B	Lag time constant in lead-lag	1	<i>p.u.</i>	
KA	K_A	Regulator gain	80		
TA	T_A	Lag time constant in regulator	0.040	<i>p.u.</i>	
VRMAX	V_{RMAX}	Maximum excitation limit	8	<i>p.u.</i>	
VRMIN	V_{RMIN}	Minimum excitation limit	0	<i>p.u.</i>	
KC	K_C	Reactive power compensation gain	0		
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	<i>bus</i>	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
LR_y	y_{LR}	State	State in lag transfer function		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
vi	V_i	Algeb	Total input voltages	<i>p.u.</i>	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
vfmax	V_{fmax}	Algeb	Upper bound of output limiter		v_str
vfmin	V_{fmin}	Algeb	Lower bound of output limiter		v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
LL_x	x'_{LL}	State	$V_i z_i^{HLI} + V_{IMAX} z_u^{HLI} + V_{IMIN} z_l^{HLI}$
LR_y	y_{LR}	State	$K_A y_{LL}$
omega	ω	ExtState	
v	E_{term}	Algeb	V
vout	v_{out}	Algeb	$u_e v_{f0}$
vi	V_i	Algeb	$\frac{v_{f0}}{K_A}$
LL_y	y_{LL}	Algeb	$V_i z_i^{HLI} + V_{IMAX} z_u^{HLI} + V_{IMIN} z_l^{HLI}$
vfmax	V_{fmax}	Algeb	$-K_C X_{ad} I_{fd} + V_{RMAX}$
vfmin	V_{fmin}	Algeb	$-K_C X_{ad} I_{fd} + V_{RMIN}$
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
vbus	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
LL_x	x'_{LL}	State	$V_i z_i^{HLI} + V_{IMAX} z_u^{HLI} + V_{IMIN} z_l^{HLI} - x'_{LL}$	T_B
LR_y	y_{LR}	State	$K_{AyLL} - y_{LR}$	T_A
omega	ω	ExtState	0	

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algeb	$-E_{term} + V$
vout	v_{out}	Algeb	$u_e (V_{fmax} z_u^{HLR} + V_{fmin} z_l^{HLR} + y_{LR} z_i^{HLR}) - v_{out}$
vi	V_i	Algeb	$-V_i + V_{ref0} - y_{LG}$
LL_y	y_{LL}	Algeb	$T_B x'_{LL} - T_B y_{LL} + T_C (V_i z_i^{HLI} + V_{IMAX} z_u^{HLI} + V_{IMIN} z_l^{HLI} - x'_{LL}) + (z_1^{LTLL})^2 (-x'_{LL} + y_{LL})$
vf-max	V_{fmax}	Algeb	$-K_C X_{ad} I_{fd} + V_{RMAX} - V_{fmax}$
vfmin	V_{fmin}	Algeb	$-K_C X_{ad} I_{fd} + V_{RMIN} - V_{fmin}$
vf	v_f	ExtAl- geb	$u_e (-v_{f0} + v_{out})$
Xad- Ifd	$X_{ad} I_{fd}$	ExtAl- geb	0
a	θ	ExtAl- geb	0
vbus	V	ExtAl- geb	0

Services

Name	Symbol	Equation	Type
ue	u_e	$u u_g$	ConstService
vref0	V_{ref0}	$E_{term} + \frac{v_{f0}}{K_A}$	PostInitService

Discretes

Name	Symbol	Type	Info
HLI	<i>HLI</i>	HardLimiter	Hard limiter on input
LL_LT1	<i>LT_{LL}</i>	LessThan	
LL_LT2	<i>LT_{LL}</i>	LessThan	
HLR	<i>HLR</i>	HardLimiter	Hard limiter on regulator output

Blocks

Name	Symbol	Type	Info
LG	<i>LG</i>	Lag	Sensing delay
LL	<i>LL</i>	LeadLag	Lead-lag compensator
LR	<i>LR</i>	Lag	Regulator

Config Fields in [EXAC4]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.12 ESST4B

Parameters

Name	Sym- bol	Description	De- fault	Unit	Proper- ties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory
TR	T_R	Sensing time constant	0.010	<i>p.u.</i>	
KPR	K_{PR}	Proportional gain 1	1	<i>p.u.</i>	
KIR	K_{IR}	Integral gain 1	0	<i>p.u.</i>	
VR- MAX	V_{RMAX}	Maximum regulator limit	8	<i>p.u.</i>	
VRMIN	V_{RMIN}	Minimum regulator limit	0	<i>p.u.</i>	
TA	T_A	Lag time constant	0.100		
KPM	K_{PM}	Proportional gain 2	1	<i>p.u.</i>	
KIM	K_{IM}	Integral gain 2	0	<i>p.u.</i>	
VM- MAX	V_{RMAX}	Maximum inner loop limit	8	<i>p.u.</i>	
VM- MIN	V_{RMIN}	Minimum inner loop limit	0	<i>p.u.</i>	
KG	K_G	Feedback gain of inner field regulator	1		
KP	K_P	Potential circuit gain coeff.	4		
KI	K_I	Potential circuit gain coeff.	0.100		
VB- MAX	V_{BMAX}	VB upper limit	18	<i>p.u.</i>	
KC	K_C	Rectifier loading factor proportional to commutating reactance	0.100		
XL	X_L	Potential source reactance	0.010		
THETAP	θ_P	Rectifier firing angle	0	<i>de- gree</i>	
VG- MAX	V_{GMAX}	VG upper limit	20	<i>p.u.</i>	
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	bus	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
PI1_xi	x_{iPI1}	State	Integrator output		v_str
LA_y	y_{LA}	State	State in lag transfer function		v_str
PI2_xi	x_{iPI2}	State	Integrator output		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
UEL	U_{EL}	Algeb	Interface var for under exc. limiter		v_str
IN	I_N	Algeb	Input to FEX		v_str
FEX_y	y_{FEX}	Algeb	Output of piecewise		v_str
VB_x	x_{VB}	Algeb	Value before limiter		v_str
VB_y	y_{VB}	Algeb	Output after limiter and post gain		v_str
VG_x	x_{VG}	Algeb	Value before limiter		v_str
VG_y	y_{VG}	Algeb	Output after limiter and post gain		v_str
vref	V_{ref}	Algeb	Reference voltage input	p.u.	v_str
vi	V_i	Algeb	Total input voltages	p.u.	v_str
PI1_ys	y_{sPI1}	Algeb	PI summation before limit		v_str
PI1_y	y_{PI1}	Algeb	PI output		v_str
PI2_ys	y_{sPI2}	Algeb	PI summation before limit		v_str
PI2_y	y_{PI2}	Algeb	PI output		v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		
vd	V_d	ExtAlgeb	d-axis machine voltage		
vq	V_q	ExtAlgeb	q-axis machine voltage		
Id	I_d	ExtAlgeb	d-axis machine current		
Iq	I_q	ExtAlgeb	q-axis machine current		

Initialization Equations

Name	Sym- bol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
PI1_x	x_{iPI1}	State	y_{VG}
LA_y	y_{LA}	State	$1.0y_{PI1}$
PI2_x	x_{iPI2}	State	$\text{safe}_{div}(v_{f0}, y_{VB})$
omega	ω	ExtStat	
v	E_{term}	Al- geb	V
vout	v_{out}	Al- geb	$u_e v_{f0}$
UEL	U_{EL}	Al- geb	0
IN	I_N	Al- geb	$\text{safe}_{div}(K_C X_{ad} I_{fd}, V_E)$
FEX_	y_{FEX}	Al- geb	$\text{FixPiecwise}\left((1, I_N \leq 0), (1 - 0.577I_N, I_N \leq 0.433), \left(\sqrt{0.75 - I_N^2}, I_N \leq 0.75\right), (1.732 - \right.$
VB_x	x_{VB}	Al- geb	$V_E y_{FEX}$
VB_y	y_{VB}	Al- geb	$V_{BMAX} z_u^{lim_{VB}} + x_{VB} z_i^{lim_{VB}}$
VG_x	x_{VG}	Al- geb	$K_G v_{out}$
VG_y	y_{VG}	Al- geb	$V_{GMAX} z_u^{lim_{VG}} + x_{VG} z_i^{lim_{VG}}$
vref	V_{ref}	Al- geb	E_{term}
vi	V_i	Al- geb	$-E_{term} + V_{ref}$
PI1_y	y_{SPI1}	Al- geb	$K_{PR} V_i + y_{VG}$
PI1_y	y_{PI1}	Al- geb	$V_{RMAX} z_u^{lim_{PI1}} + V_{RMIN} z_l^{lim_{PI1}} + y_{SPI1} z_i^{lim_{PI1}}$
PI2_y	y_{SPI2}	Al- geb	$K_{PM}(y_{LA} - y_{VG}) + \text{safe}_{div}(v_{f0}, y_{VB})$
PI2_y	y_{PI2}	Al- geb	$V_{RMAX} z_u^{lim_{PI2}} + V_{RMIN} z_l^{lim_{PI2}} + y_{SPI2} z_i^{lim_{PI2}}$
vf	v_f	Ex- tAl- geb	
Xad- Ifd	$X_{ad} I_f$	Ex- tAl- geb	
a	θ	Ex- tAl- geb	
564 vbus	V	Ex- tAl- geb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
PI1_xi	xi_{PI1}	State	$K_{IR} (V_i + 2y_{PI1} - 2ys_{PI1})$	
LA_y	y_{LA}	State	$-y_{LA} + 1.0y_{PI1}$	T_A
PI2_xi	xi_{PI2}	State	$K_{IM} (y_{LA} + 2y_{PI2} - y_{VG} - 2ys_{PI2})$	
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algeb	$-E_{term} + V$
vout	v_{out}	Algeb	$u_e y_{PI2} y_{VB} - v_{out}$
UEL	U_{EL}	Algeb	$-U_{EL}$
IN	I_N	Algeb	$u_e (-I_N V_E + K_C X_{ad} I_{fd})$
FEX_	y_{FEX}	Algeb	$-y_{FEX} + \text{FixPiecewise} \left((1, I_N \leq 0), (1 - 0.577 I_N, I_N \leq 0.433), \left(\sqrt{0.75 - I_N^2}, I_N \leq 0.75 \right), (0, I_N > 0.75) \right)$
VB_x	x_{VB}	Algeb	$V_E y_{FEX} - x_{VB}$
VB_y	y_{VB}	Algeb	$V_{BMAX} z_u^{lim_{VB}} + x_{VB} z_i^{lim_{VB}} - y_{VB}$
VG_x	x_{VG}	Algeb	$K_G v_{out} - x_{VG}$
VG_y	y_{VG}	Algeb	$V_{GMAX} z_u^{lim_{VG}} + x_{VG} z_i^{lim_{VG}} - y_{VG}$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
vi	V_i	Algeb	$-V_i + V_{ref} - y_{LG}$
PI1_y	y_{SPI1}	Algeb	$K_{PR} V_i + x_{iPI1} - y_{SPI1}$
PI1_y	y_{PI1}	Algeb	$V_{RMAX} z_u^{lim_{PI1}} + V_{RMIN} z_l^{lim_{PI1}} - y_{PI1} + y_{SPI1} z_i^{lim_{PI1}}$
PI2_y	y_{SPI2}	Algeb	$K_{PM} (y_{LA} - y_{VG}) + x_{iPI2} - y_{SPI2}$
PI2_y	y_{PI2}	Algeb	$V_{RMAX} z_u^{lim_{PI2}} + V_{RMIN} z_l^{lim_{PI2}} - y_{PI2} + y_{SPI2} z_i^{lim_{PI2}}$
vf	v_f	ExtAlgeb	$u_e (-v_{f0} + v_{out})$
Xad-I _{fd}	$X_{ad} I_f$	ExtAlgeb	0
a	θ	ExtAlgeb	0
vbus	V	ExtAlgeb	0
vd	V_d	ExtAlgeb	0
vq	V_q	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
KPC	K_{PC}	$K_P e^{i \text{radians}(\theta_P)}$	ConstService
VE	V_E	$ K_{PC}(V_d + iV_q) + i(I_d + iI_q)(K_I + K_{PC}X_L) $	VarService
vref0	V_{ref0}	V_{ref}	PostInitService

Discretes

Name	Symbol	Type	Info
VB_lim	lim_{VB}	HardLimiter	
VG_lim	lim_{VG}	HardLimiter	
PI1_lim	lim_{PI1}	HardLimiter	
PI2_lim	lim_{PI2}	HardLimiter	

Blocks

Name	Symbol	Type	Info
LG	LG	Lag	Voltage transducer
FEX	FEX	Piecewise	Piecewise function FEX
VB	VB	GainLimiter	VB with limiter
VG	VG	GainLimiter	Feedback gain with HL
PI1	$PI1$	PITrackAW	
LA	LA	Lag	Regulation delay
PI2	$PI2$	PITrackAW	

Config Fields in [ESST4B]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
ksr	K_{sr}	2	Tracking gain for outer PI controller	
ksm	K_{sm}	2	Tracking gain for inner PI controller	

5.12.13 AC8B

Exciter AC8B model.

Reference:^{1, 2}

Parameters

Name	Symbol	Description	De- fault	Unit	Proper- ties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory
TR	T_R	Sensing time constant	0.010	<i>p.u.</i>	
kP	k_P	PID proportional coeff.	10		
kI	k_I	PID integrative coeff.	10		
kD	k_D	PID derivative coeff.	10		
Td	T_d	PID derivative time constant.	0.200		
VPMAX	V_{PMAX}	PID maximum limit	999	<i>p.u.</i>	
VPMIN	V_{PMIN}	PID minimum limit	-999	<i>p.u.</i>	
VR- MAX	V_{RMAX}	Maximum regulator limit	7.300	<i>p.u.</i>	
VRMIN	V_{RMIN}	Minimum regulator limit	1	<i>p.u.</i>	
VFE- MAX	V_{FEMAX}	Exciter field current limit	999	<i>p.u.</i>	
VEMIN	V_{EMIN}	Minimum exciter voltage output	-999	<i>p.u.</i>	
TA	T_A	Lag time constant in anti-windup lag	0.040	<i>p.u.</i>	
KA	K_A	Gain in anti-windup lag TF	40	<i>p.u.</i>	
TE	T_E	Exciter integrator time constant	0.800	<i>p.u.</i>	
E1	E_1	First saturation point	0	<i>p.u.</i>	
SE1	S_{E1}	Value at first saturation point	0	<i>p.u.</i>	
E2	E_2	Second saturation point	1	<i>p.u.</i>	
SE2	S_{E2}	Value at second saturation point	1	<i>p.u.</i>	
KE	K_E	Gain added to saturation	1	<i>p.u.</i>	
KD	K_D	Ifd feedback gain	0		
KC	K_C	Rectifier loading factor proportional to commutating reactance	0.100		
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	bus	Bus idx of the generators	0		

¹ Powerworld, Exciter AC8B, [Online], Available: https://www.powerworld.com/WebHelp/Content/TransientModels_HTML/Exciter%20AC8B.htm

² NEPLAN, Exciters Models, [Online], Available: https://www.neplan.ch/wp-content/uploads/2015/08/Nep_EXCITERS1.pdf

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
PID_xi	xi_{PID}	State	Integrator output		v_str
PID_WO_x	$x'_{PID\ WO_{PID}}$	State	State in washout filter		v_str
LA_y	y_{LA}	State	State in lag TF		v_str
INT_y	y_{INT}	State	Integrator output		v_str,v_iter
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
IN	I_N	Algeb	Input to FEX		v_str,v_iter
FEX_y	y_{FEX}	Algeb	Output of piecewise		v_str,v_iter
UEL	U_{EL}	Algeb	Interface var for under exc. limiter		v_str
OEL	O_{EL}	Algeb	Interface var for over exc. limiter		v_str
Vs	V_s	Algeb	Voltage compensation from PSS		v_str
vref	V_{ref}	Algeb	Reference voltage input	p.u.	v_str
vi	V_i	Algeb	Total input voltages	p.u.	v_str
PID_uin	uin_{PID}	Algeb	PID input		v_str
PID_WO_y	$y_{PID\ WO_{PID}}$	Algeb	Output of washout filter		v_str
PID_ys	ys_{PID}	Algeb	PI summation before limit		v_str
PID_y	y_{PID}	Algeb	PI output		v_str
Se	$V_{out} * S_e(V_{out})$	Algeb	saturation output		v_str
VFE	V_{FE}	Algeb	Combined saturation feedback	p.u.	v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
PID_xi	xi_{PID}	State	$\frac{V_{FE}}{K_A}$
PID_W	x'_{PIDWO_i}	State	uin_{PID}
LA_y	y_{LA}	State	$K_A y_{PID}$
INT_y	y_{INT}	State	$-v_{f0} + y_{FEX} y_{INT}$
omega	ω	ExtSta	
v	E_{term}	Al-geb	V
vout	v_{out}	Al-geb	$u_e v_{f0}$
IN	I_N	Al-geb	$-I_N y_{INT} + K_C X_{ad} I_{fd}$
FEX_y	y_{FEX}	Al-geb	$-y_{FEX} + \text{FixPiecewise} \left((1, I_N \leq 0), (1 - 0.577 I_N, I_N \leq 0.433), \left(\sqrt{0.75 - I_N^2}, I_N \leq 0 \right) \right)$
UEL	U_{EL}	Al-geb	U_{EL0}
OEL	O_{EL}	Al-geb	O_{EL0}
Vs	V_s	Al-geb	0
vref	V_{ref}	Al-geb	E_{term}
vi	V_i	Al-geb	$-E_{term} + V_{ref}$
PID_uir	uin_{PID}	Al-geb	V_i
PID_W	y_{PIDWO_f}	Al-geb	0
PID_ys	ys_{PID}	Al-geb	$V_i k_P + \frac{V_{FE}}{K_A}$
PID_y	y_{PID}	Al-geb	$V_{PMAX} z_u^{lim_{PID}} + V_{PMIN} z_l^{lim_{PID}} + y_{SPID} z_i^{lim_{PID}}$
Se	$V_{out} * S_e(V_{out})$	Al-geb	$B_{SAT}^q (-A_{SAT}^q + y_{INT})^2 \text{Indicator}(y_{INT} > A_{SAT}^q)$
VFE	V_{FE}	Al-geb	$K_D X_{ad} I_{fd} + K_E y_{INT} + V_{out} * S_e(V_{out})$
vf	v_f	ExtAl-geb	
Xad-Ifd	$X_{ad} I_{fd}$	ExtAl-geb	
a	θ	ExtAl-	
570		geb	
vbus	V	ExtAl-geb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
PID_xi	x_{iPID}	State	$k_I (V_i + 2y_{PID} - 2ys_{PID})$	
PID_WO_x	$x'_{PID\ WO_{PID}}$	State	$u_{inPID} - x'_{PID\ WO_{PID}}$	T_d
LA_y	y_{LA}	State	$K_A y_{PID} - y_{LA}$	T_A
INT_y	y_{INT}	State	$u_e (-V_{FE} + y_{LA})$	T_E
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Al-geb	$-E_{term} + V$
vout	v_{out}	Al-geb	$u_e(-v_{out} + y_{FEX}y_{INT})$
IN	I_N	Al-geb	$u_e(-I_N y_{INT} + K_C X_{ad} I_{fd})$
FEX_y	y_{FEX}	Al-geb	$-y_{FEX} + \text{FixPiecewise}\left((1, I_N \leq 0), (1 - 0.577 I_N, I_N \leq 0.433), \left(\sqrt{0.75 - I_N^2}, I_N \leq 0\right)\right)$
UEL	U_{EL}	Al-geb	$U_{EL0} - U_{EL}$
OEL	O_{EL}	Al-geb	$O_{EL0} - O_{EL}$
Vs	V_s	Al-geb	$-V_s$
vref	V_{ref}	Al-geb	$V_{ref0} - V_{ref}$
vi	V_i	Al-geb	$u_e(O_{EL} + U_{EL} - V_i + V_{ref} + V_s - y_{LG})$
PID_uir	u_{inPID}	Al-geb	$V_i - u_{inPID}$
PID_W	$y_{PID WO_F}$	Al-geb	$-T_d y_{PID WO_{PID}} + k_D (u_{inPID} - x'_{PID WO_{PID}})$
PID_ys	y_{SPID}	Al-geb	$V_i k_P + x_{iPID} + y_{PID WO_{PID}} - y_{SPID}$
PID_y	y_{PID}	Al-geb	$V_{PMAX} z_u^{limPID} + V_{PMIN} z_l^{limPID} - y_{PID} + y_{SPID} z_i^{limPID}$
Se	$V_{out} * S_e(V_{out})$	Al-geb	$u_e\left(B_{SAT}^q z_0^{SL} (-A_{SAT}^q + y_{INT})^2 - V_{out} * S_e(V_{out})\right)$
VFE	V_{FE}	Al-geb	$u_e(K_D X_{ad} I_{fd} + K_E y_{INT} - V_{FE} + V_{out} * S_e(V_{out}))$
vf	v_f	ExtAl-geb	$u_e(-v_{f0} + v_{out})$
Xad-Ifd	$X_{ad} I_{fd}$	ExtAl-geb	0
a	θ	ExtAl-geb	0
vbus	V	ExtAl-geb	0

Services

Name	Sym- bol	Equation	Type
ue	u_e	uu_g	ConstService
UEL0	$UEL0$	0	ConstService
OEL0	$OEL0$	0	ConstService
SAT_E1	E_{SAT}^{1c}	E_1	ConstService
SAT_E2	E_{SAT}^{2c}	$E_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_SE1	SE_{SAT}^{1c}	S_{E1}	ConstService
SAT_SE2	SE_{SAT}^{2c}	$S_{E2} - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E_{SAT}^{1c} SE_{SAT}^{1c}}{E_{SAT}^{2c} SE_{SAT}^{2c}}} (\text{Indicator}(SE_{SAT}^{2c} > 0) + \text{Indicator}(SE_{SAT}^{2c} < 0))$	ConstService
SAT_A	A_{SAT}^q	$E_{SAT}^{2c} - \frac{E_{SAT}^{1c} - E_{SAT}^{2c}}{a_{SAT} - 1}$	ConstService
SAT_B	B_{SAT}^q	$\frac{E_{SAT}^{2c} SE_{SAT}^{2c} (a_{SAT} - 1)^2 (\text{Indicator}(a_{SAT} > 0) + \text{Indicator}(a_{SAT} < 0))}{(E_{SAT}^{1c} - E_{SAT}^{2c})^2}$	ConstService
vref0	V_{ref0}	E_{term}	PostInitService

Discretes

Name	Symbol	Type	Info
PID_lim	lim_{PID}	HardLimiter	
LA_lim	lim_{LA}	AntiWindup	Limiter in Lag
SL	SL	LessThan	

Blocks

Name	Symbol	Type	Info
FEX	FEX	Piecewise	Piecewise function FEX
LG	LG	Lag	Voltage transducer
PID	PID	PIDTrackAW	PID
PID_WO	$PID WO_{PID}$	Washout	Washout
LA	LA	LagAntiWindup	V_{R}, Anti-windup lag
SAT	SAT	ExcQuadSat	Field voltage saturation
INT	INT	Integrator	V_E, integrator

Config Fields in [AC8B]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
ks		2	Tracking gain for PID controller	

5.12.14 IEEE T3

Exciter IEEE T3.

Reference:

[1] PowerWorld, Exciter IEEE T3, [Online],

[2] NEPLAN, Exciters Models, [Online],

Available:

https://www.powerworld.com/WebHelp/Content/TransientModels_HTML/Exciter%20IEEE T3.htm

https://www.neplan.ch/wp-content/uploads/2015/08/Nep_EXCITERS1.pdf

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.020	<i>p.u.</i>	
KA	K_A	Regulator gain	5	<i>p.u.</i>	
TA	T_A	Lag time constant in anti-windup lag	0.040	<i>p.u.</i>	
VRMAX	V_{RMAX}	Maximum regulator limit	7.300	<i>p.u.</i>	
VRMIN	V_{RMIN}	Minimum regulator limit	-7.300	<i>p.u.</i>	
VBMAX	V_{BMAX}	VB upper limit	18	<i>p.u.</i>	
KE	K_E	Exciter integrator constant	1	<i>p.u.</i>	
TE	T_E	Exciter integrator time constant	1	<i>p.u.</i>	
KF	K_F	Feedback gain	0.100		
TF	T_F	Feedback delay	1		non_zero, non_negative
KP	K_P	Potential circuit gain coeff.	4		
KI	K_I	Potential circuit gain coeff.	0.100		
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	bus	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
LA3_y	y_{LA3}	State	State in lag TF		v_str
LA1_y	y_{LA1}	State	State in lag transfer function		v_str
WF_x	x'_{WF}	State	State in washout filter		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
UEL	U_{EL}	Algeb	Interface var for under exc. limiter		v_str
OEL	O_{EL}	Algeb	Interface var for over exc. limiter		v_str
Vs	V_s	Algeb	Voltage compensation from PSS		v_str
vref	V_{ref}	Algeb	Reference voltage input	<i>p.u.</i>	v_str
vi	V_i	Algeb	Total input voltages	<i>p.u.</i>	v_str
WF_y	y_{WF}	Algeb	Output of washout filter		v_str
SQE	SQE	Algeb	Square of error after mul		v_str
VB_y	y_{VB}	Algeb	Output of piecewise		v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		
vd	V_d	ExtAlgeb	d-axis machine voltage		
vq	V_q	ExtAlgeb	q-axis machine voltage		
Id	I_d	ExtAlgeb	d-axis machine current		
Iq	I_q	ExtAlgeb	q-axis machine current		

Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
LA3_y	y_{LA3}	State	$K_A u_e (V_i - y_{WF})$
LA1_y	y_{LA1}	State	$\frac{u_e (V_{BMAX} z_u^{HL} + y_{VB} z_i^{HL})}{K_E}$
WF_x	x'_{WF}	State	y_{LA1}
omega	ω	ExtState	
v	E_{term}	Algeb	V
vout	v_{out}	Algeb	$u_e v_{f0}$
UEL	U_{EL}	Algeb	UEL_0
OEL	O_{EL}	Algeb	OEL_0
Vs	V_s	Algeb	0
vref	V_{ref}	Algeb	$E_{term} + V_{b0}$
vi	V_i	Algeb	$-E_{term} + V_{ref}$
WF_y	y_{WF}	Algeb	0
SQE	SQE	Algeb	$V_E^2 - 0.6084 X_{ad} I_{fd}^2$
VB_y	y_{VB}	Algeb	$\text{FixPiecewise}((u_e y_{LA3}, SQE \leq 0), (u_e (\sqrt{SQE} + y_{LA3}), \text{True}))$
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
vbus	V	ExtAlgeb	
vd	V_d	ExtAlgeb	
vq	V_q	ExtAlgeb	
Id	I_d	ExtAlgeb	
Iq	I_q	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
LA3_y	y_{LA3}	State	$K_A u_e (V_i - y_{WF}) - y_{LA3}$	T_A
LA1_y	y_{LA1}	State	$-K_E y_{LA1} + u_e (V_{BMAX} z_u^{HL} + y_{VB} z_i^{HL})$	T_E
WF_x	x'_{WF}	State	$-x'_{WF} + y_{LA1}$	T_F
omega	ω	ExtState	0	

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algeb	$-E_{term} + V$
vout	v_{out}	Algeb	$u_e(-v_{out} + y_{LA1})$
UEL	U_{EL}	Algeb	$UEL_0 - U_{EL}$
OEL	O_{EL}	Algeb	$OEL_0 - O_{EL}$
Vs	V_s	Algeb	$-V_s$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
vi	V_i	Algeb	$u_e(O_{EL} + U_{EL} - V_i + V_{ref} + V_s - y_{LG})$
WF_y	y_{WF}	Algeb	$K_F(-x'_{WF} + y_{LA1}) - T_F y_{WF}$
SQE	SQE	Algeb	$-SQE + V_E^2 - 0.6084 X_{ad} I_{fd}^2$
VB_y	y_{VB}	Algeb	$-y_{VB} + \text{FixPiecewise}((u_e y_{LA3}, SQE \leq 0), (u_e(\sqrt{SQE} + y_{LA3}), \text{True}))$
vf	v_f	ExtAl- geb	$u_e(-v_{f0} + v_{out})$
Xad- Ifd	$X_{ad} I_{fd}$	ExtAl- geb	0
a	θ	ExtAl- geb	0
vbus	V	ExtAl- geb	0
vd	V_d	ExtAl- geb	0
vq	V_q	ExtAl- geb	0
Id	I_d	ExtAl- geb	0
Iq	I_q	ExtAl- geb	0

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
VE	V_E	$ iK_I(I_d + iI_q) + K_P(V_d + iV_q) $	VarService
V40	V_{40}	$\sqrt{V_E^2 - 0.6084X_{ad}I_{fd}^2}$	ConstService
VR0	V_{R0}	$K_E v_{f0} - V_{40}$	ConstService
vb0	V_{b0}	$\frac{V_{R0}}{K_A}$	ConstService
VRMAXc	$VRMAXc$	$VRMAX - 999z_{VRMAX} + 999$	ConstService
UEL0	$UEL0$	0	ConstService
OEL0	$OEL0$	0	ConstService
vref0	V_{ref0}	V_{ref}	PostInitService
zeros	$zeros$	0.0	ConstService

Discretes

Name	Symbol	Type	Info
LA3_lim	lim_{LA3}	AntiWindup	Limiter in Lag
SL	SL	LessThan	
HL	HL	HardLimiter	Hard limiter for VB

Blocks

Name	Symbol	Type	Info
LG	LG	Lag	Sensing delay
LA3	$LA3$	LagAntiWindup	$V_{\{R\}}$, Lag Anti-Windup
LA1	$LA1$	Lag	
WF	WF	Washout	V_F , stablizing circuit feedback, washout
VB	VB	Piecewise	

Config Fields in [IEEET3]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.15 ESAC1A

Exciter ESAC1A.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.010	<i>p.u.</i>	
TB	T_B	Lag time constant in lead-lag	1	<i>p.u.</i>	non_negative
TC	T_C	Lead time constant in lead-lag	1	<i>p.u.</i>	non_negative
VA- MAX	V_{AMAX}	V_A upper limit	999	<i>p.u.</i>	
VAMIN	V_{AMIN}	V_A lower limit	-999	<i>p.u.</i>	
KA	K_A	Regulator gain	80		
TA	T_A	Lag time constant in regulator	0.040	<i>p.u.</i>	non_negative
VR- MAX	V_{RMAX}	Max. exc. limit (0-unlimited)	7.300	<i>p.u.</i>	
VR- MIN	V_{RMIN}	Min. excitation limit	- 7.300	<i>p.u.</i>	
TE	T_E	Integrator time constant	0.800	<i>p.u.</i>	non_negative
E1	E_1	First saturation point	0	<i>p.u.</i>	
SE1	S_{E1}	Value at first saturation point	0	<i>p.u.</i>	
E2	E_2	Second saturation point	1	<i>p.u.</i>	
SE2	S_{E2}	Value at second saturation point	1	<i>p.u.</i>	
KC	K_C	Rectifier loading factor proportional to commutat- ing reactance	0.100		
KD	K_D	Ifd feedback gain	0		
KE	K_E	Gain added to saturation	1		
KF	K_F	Feedback gain	0.100		
TF	T_{F1}	Feedback washout time constant	1	<i>p.u.</i>	non_zero,non_negative
Switch	S_w	Switch that PSS/E did not implement	0	<i>bool</i>	
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	bus	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
LA_y	y_{LA}	State	State in lag TF		v_str
INT_y	y_{INT}	State	Integrator output		v_str,v_iter
WF_x	x'_{WF}	State	State in washout filter		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
UEL	U_{EL}	Algeb	Interface var for under exc. limiter		v_str
OEL	O_{EL}	Algeb	Interface var for over exc. limiter		v_str
Vs	V_s	Algeb	Voltage compensation from PSS		v_str
vref	V_{ref}	Algeb	Reference voltage input	p.u.	v_str
IN	I_N	Algeb	Input to FEX		v_str,v_iter
FEX_y	y_{FEX}	Algeb	Output of piecewise		v_str,v_iter
vi	V_i	Algeb	Total input voltages	p.u.	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
HVG_y	y_{HVG}	Algeb	HVGate output		v_str
LVG_y	y_{LVG}	Algeb	LVGate output		v_str
Se	$V_{out} * S_e(V_{out})$	Algeb	saturation output		v_str
VFE	V_{FE}	Algeb	Combined saturation feedback	p.u.	v_str
WF_y	y_{WF}	Algeb	Output of washout filter		v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
LL_x	x'_{LL}	State	V_i
LA_y	y_{LA}	State	$K_A y_{LL}$
INT_	y_{INT}	State	$-v_{f0} + y_{FEX} y_{INT}$
WF_	x'_{WF}	State	V_{FE}
omeg	ω	ExtSta	
v	E_{term}	Al-geb	V
vout	v_{out}	Al-geb	$u_e v_{f0}$
UEL	U_{EL}	Al-geb	UEL_0
OEL	O_{EL}	Al-geb	OEL_0
Vs	V_s	Al-geb	0
vref	V_{ref}	Al-geb	$E_{term} + \frac{V_{FE}}{K_A}$
IN	I_N	Al-geb	$-I_N y_{INT} + K_C X_{ad} I_{fd}$
FEX_	y_{FEX}	Al-geb	$-y_{FEX} + \text{FixPiecewise} \left((1, I_N \leq 0), (1 - 0.577 I_N, I_N \leq 0.433), \left(\sqrt{0.75 - I_N^2}, I_N \leq 0.75 \right) \right)$
vi	V_i	Al-geb	$-E_{term} + V_{ref}$
LL_y	y_{LL}	Al-geb	V_i
HVG_	y_{HVG}	Al-geb	$U_{EL} z_0^{NoneHVG} + y_{LA} z_1^{NoneHVG}$
LVG_	y_{LVG}	Al-geb	$O_{EL} z_0^{NoneLVG} + y_{HVG} z_1^{NoneLVG}$
Se	$V_{out} * S_e(V_{out})$	Al-geb	$B_{SAT}^q (-A_{SAT}^q + y_{INT})^2 \text{Indicator}(y_{INT} > A_{SAT}^q)$
VFE	V_{FE}	Al-geb	$K_D X_{ad} I_{fd} + K_E y_{INT} + V_{out} * S_e(V_{out})$
WF_	y_{WF}	Al-geb	0
vf	v_f	ExtAl-geb	
Xad-Ifd	$X_{ad} I_{fd}$	ExtAl-geb	
a	θ	ExtAl-geb	
5.12. Exciter		geb	
vbus	V	ExtAl-geb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
LL_x	x'_{LL}	State	$V_i - x'_{LL}$	T_B
LA_y	y_{LA}	State	$K_{AyLL} - y_{LA}$	T_A
INT_y	y_{INT}	State	$u_e(-V_{FE} + y_{LVG})$	T_E
WF_x	x'_{WF}	State	$V_{FE} - x'_{WF}$	T_{F1}
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Al-geb	$-E_{term} + V$
vout	v_{out}	Al-geb	$u_e y_{FEX} y_{INT} - v_{out}$
UEL	U_{EL}	Al-geb	$UEL_0 - U_{EL}$
OEL	O_{EL}	Al-geb	$OEL_0 - O_{EL}$
Vs	V_s	Al-geb	$-V_s$
vref	V_{ref}	Al-geb	$V_{ref0} - V_{ref}$
IN	I_N	Al-geb	$u_e (-I_N y_{INT} + K_C X_{ad} I_{fd})$
FEX_	y_{FEX}	Al-geb	$-y_{FEX} + \text{FixPiecewise} \left((1, I_N \leq 0), (1 - 0.577 I_N, I_N \leq 0.433), \left(\sqrt{0.75 - I_N^2}, I_N \leq 0.75 \right) \right)$
vi	V_i	Al-geb	$u_e (O_{EL} + U_{EL} - V_i + V_{ref} + V_s - y_{LG})$
LL_y	y_{LL}	Al-geb	$T_B x'_{LL} - T_B y_{LL} + T_C (V_i - x'_{LL}) + \left(z_1^{LT_{LL}} \right)^2 (-x'_{LL} + y_{LL})$
HVG_	y_{HVG}	Al-geb	$U_{EL} z_0^{None_{HVG}} - y_{HVG} + y_{LA} z_1^{None_{HVG}}$
LVG_	y_{LVG}	Al-geb	$O_{EL} z_0^{None_{LVG}} + y_{HVG} z_1^{None_{LVG}} - y_{LVG}$
Se	$V_{out} * S_e(V_{out})$	Al-geb	$u_e \left(B_{SAT}^q z_0^{SL} (-A_{SAT}^q + y_{INT})^2 - V_{out} * S_e(V_{out}) \right)$
VFE	V_{FE}	Al-geb	$u_e (K_D X_{ad} I_{fd} + K_E y_{INT} - V_{FE} + V_{out} * S_e(V_{out}))$
WF_	y_{WF}	Al-geb	$K_F (V_{FE} - x'_{WF}) - T_{F1} y_{WF}$
vf	v_f	ExtAl-geb	$u_e (-v_{f0} + v_{out})$
Xad-Ifd	$X_{ad} I_{fd}$	ExtAl-geb	0
a	θ	ExtAl-geb	0
vbus	V	ExtAl-geb	0

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
UEL0	$UEL0$	-999	ConstService
OEL0	$OEL0$	999	ConstService
VA-MAXu	$VAMAXu$	$VAMAXu_e - 999u_e + 999$	ConstService
VAMINu	$VAMINu$	$VAMINu_e + 999u_e - 999$	ConstService
SAT_E1	E_{SAT}^{1c}	E_1	ConstService
SAT_E2	E_{SAT}^{2c}	$E_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_SE1	SE_{SAT}^{1c}	SE_1	ConstService
SAT_SE2	SE_{SAT}^{2c}	$SE_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E_{SAT}^{1c} SE_{SAT}^{1c}}{E_{SAT}^{2c} SE_{SAT}^{2c}}} (\text{Indicator}(SE_{SAT}^{2c} > 0) + \text{Indicator}(SE_{SAT}^{2c} < 0))$	ConstService
SAT_A	A_{SAT}^q	$E_{SAT}^{2c} - \frac{E_{SAT}^{1c} - E_{SAT}^{2c}}{a_{SAT} - 1}$	ConstService
SAT_B	B_{SAT}^q	$\frac{E_{SAT}^{2c} SE_{SAT}^{2c} (a_{SAT} - 1)^2 (\text{Indicator}(a_{SAT} > 0) + \text{Indicator}(a_{SAT} < 0))}{(E_{SAT}^{1c} - E_{SAT}^{2c})^2}$	ConstService
vref0	V_{ref0}	V_{ref}	PostInitService

Discretes

Name	Symbol	Type	Info
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
LA_lim	lim_{LA}	AntiWindup	Limiter in Lag
HVG_lt	$None_{HVG}$	LessThan	
LVG_lt	$None_{LVG}$	LessThan	
SL	SL	LessThan	

Blocks

Name	Symbol	Type	Info
FEX	<i>FEX</i>	Piecewise	Piecewise function FEX
LG	<i>LG</i>	Lag	Voltage transducer
LL	<i>LL</i>	LeadLag	V_A, Lead-lag compensator
LA	<i>LA</i>	LagAntiWindup	V_A, Anti-windup lag
HVG	<i>HVG</i>	HVGate	HVGate for under excitation
LVG	<i>LVG</i>	LVGate	HVGate for under excitation
SAT	<i>SAT</i>	ExcQuadSat	Field voltage saturation
INT	<i>INT</i>	Integrator	V_E, integrator
WF	<i>WF</i>	Washout	Stablizing circuit feedback

Config Fields in [ESAC1A]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.16 ESST1A

Exciter ESST1A model.

Reference:

[1] PowerWorld, Exciter ESST1A, [Online],

[2] NEPLAN, Exciters Models, [Online],

Available: https://www.powerworld.com/WebHelp/Content/TransientModels_HTML/Exciter%20ESST1A.htm

https://www.neplan.ch/wp-content/uploads/2015/08/Nep_EXCITERS1.pdf

Parameters

Name	Sym- bol	Description	De- fault	Unit	Proper- ties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory
TR	T_R	Sensing time constant	0.010		
VI- MAX	V_{IMAX}	Max. input voltage	0.800		
VIMIN	V_{IMIN}	Min. input voltage	-0.100		
TB	T_B	Lag time constant in lead-lag	1		
TC	T_C	Lead time constant in lead-lag	1		
TB1	T_{B1}	Lag time constant in lead-lag 1	1		
TC1	T_{C1}	Lead time constant in lead-lag 1	1		
VA- MAX	V_{AMAX}	V_A upper limit	999	<i>p.u.</i>	
VAMIN	V_{AMIN}	V_A lower limit	-999	<i>p.u.</i>	
KA	K_A	Regulator gain	80		
TA	T_A	Lag time constant in regulator	0.040		
ILR	I_{LR}	Exciter output current limite reference	1		
KLR	K_{LR}	Exciter output current limiter gain	1		
VR- MAX	V_{RMAX}	Maximum voltage regulator output limit	7.300	<i>p.u.</i>	
VR- MIN	V_{RMIN}	Minimum voltage regulator output limit	-7.300	<i>p.u.</i>	
KF	K_F	Feedback gain	0.100		
TF	T_F	Feedback washout time constant	1		
KC	K_C	Rectifier loading factor proportional to commutating re- actance	0.100		
UELc	UEL_c	Alternate UEL inputs, input code 1-3	1		
VOSc	VOS_c	Alternate Stabilizer inputs, input code 1-2	1		
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	bus	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
LL1_x	x'_{LL1}	State	State in lead-lag		v_str
LA_y	y_{LA}	State	State in lag TF		v_str
WF_x	x'_{WF}	State	State in washout filter		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
UEL	U_{EL}	Algeb	Interface var for under exc. limiter		v_str
OEL	O_{EL}	Algeb	Interface var for over exc. limiter		v_str
Vs	V_s	Algeb	Voltage compensation from PSS		v_str
vref	V_{ref}	Algeb	Reference voltage input	p.u.	v_str,v_iter
SG	SG	Algeb	SG		v_str
LR_x	x_{LR}	Algeb	Value before limiter		v_str
LR_y	y_{LR}	Algeb	Output after limiter and post gain		v_str
vi	V_i	Algeb	Total input voltages	p.u.	v_str,v_iter
vil_x	x_{vil}	Algeb	Value before limiter		v_str
vil_y	y_{vil}	Algeb	Output after limiter and post gain		v_str
UEL2	U_{EL2}	Algeb	UEL_2 as HVG1 u1		v_str
HVG1_y	y_{HVG1}	Algeb	HVGate output		v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
LL1_y	y_{LL1}	Algeb	Output of lead-lag		v_str
vas	V_{As}	Algeb	V_A after subtraction, as HVG u2		v_str,v_iter
UEL3	U_{EL3}	Algeb	UEL_3 as HVG u1		v_str
HVG_y	y_{HVG}	Algeb	HVGate output		v_str
LVG_y	y_{LVG}	Algeb	LVGate output		v_str
vol_x	x_{vol}	Algeb	Value before limiter		v_str
vol_y	y_{vol}	Algeb	Output after limiter and post gain		v_str
WF_y	y_{WF}	Algeb	Output of washout filter		v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		
vd	V_d	ExtAlgeb	d-axis machine voltage		
vq	V_q	ExtAlgeb	q-axis machine voltage		

Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	E_{term}
LL_x	x'_{LL}	State	y_{HVG1}
LL1_x	x'_{LL1}	State	y_{LL}
LA_y	y_{LA}	State	$K_A y_{LL1}$
WF_x	x'_{WF}	State	y_{LVG}
omega	ω	ExtState	
v	E_{term}	Algeb	V
vout	v_{out}	Algeb	$u_e v_{f0}$
UEL	U_{EL}	Algeb	UEL_0
OEL	O_{EL}	Algeb	OEL_0
Vs	V_s	Algeb	0
vref	V_{ref}	Algeb	$u_e \left(E_{term} - SGs_1^{SW_{VOS}} - U_{EL}s_1^{SW_{UEL}} + \frac{-SGs_2^{SW_{VOS}+v_{f0}+y_{LR}}}{K_A} \right)$
SG	SG	Algeb	SG_0
LR_x	x_{LR}	Algeb	$K_{LR} (-I_{LR} + X_{ad}I_{fd})$
LR_y	y_{LR}	Algeb	$x_{LR}z_i^{lim_{LR}} + z_l^{lim_{LR}} zero$
vi	V_i	Algeb	$u_e \left(SGs_1^{SW_{VOS}} + U_{EL}s_1^{SW_{UEL}} + V_{ref} + V_s - y_{LG} - y_{WF} \right)$
vil_x	x_{vil}	Algeb	V_i
vil_y	y_{vil}	Algeb	$V_{IMAX}z_u^{lim_{vil}} + V_{IMIN}z_l^{lim_{vil}} + x_{vil}z_i^{lim_{vil}}$
UEL2	UEL_2	Algeb	$u_e \left(U_{EL}s_2^{SW_{UEL}} + llim \left(1 - s_2^{SW_{UEL}} \right) \right)$
HVG1_y	y_{HVG1}	Algeb	$UEL_2z_0^{None_{HVG1}} + y_{vil}z_1^{None_{HVG1}}$
LL_y	y_{LL}	Algeb	y_{HVG1}
LL1_y	y_{LL1}	Algeb	y_{LL}
vas	V_{As}	Algeb	$u_e \left(SGs_2^{SW_{VOS}} + y_{LA} - y_{LR} \right)$
UEL3	UEL_3	Algeb	$u_e \left(U_{EL}s_3^{SW_{UEL}} + llim \left(1 - s_3^{SW_{UEL}} \right) \right)$
HVG_y	y_{HVG}	Algeb	$UEL_3z_0^{None_{HVG}} + V_{As}z_1^{None_{HVG}}$
LVG_y	y_{LVG}	Algeb	$O_{EL}z_0^{None_{LVG}} + y_{HVG}z_1^{None_{LVG}}$
vol_x	x_{vol}	Algeb	y_{LVG}
vol_y	y_{vol}	Algeb	$efd_lz_l^{lim_{vol}} + efd_uz_u^{lim_{vol}} + x_{vol}z_i^{lim_{vol}}$
WF_y	y_{WF}	Algeb	0
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
vbus	V	ExtAlgeb	
vd	V_d	ExtAlgeb	
vq	V_q	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$E_{term} - y_{LG}$	T_R
LL_x	x'_{LL}	State	$-x'_{LL} + y_{HVG1}$	T_B
LL1_x	x'_{LL1}	State	$-x'_{LL1} + y_{LL}$	T_{B1}
LA_y	y_{LA}	State	$K_A y_{LL1} - y_{LA}$	T_A
WF_x	x'_{WF}	State	$-x'_{WF} + y_{LVG}$	T_F
omega	ω	ExtState	0	

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algeb	$-E_{term} + V$
vout	v_{out}	Algeb	$u_e y_{vol} - v_{out}$
UEL	U_{EL}	Algeb	$UEL_0 - U_{EL}$
OEL	O_{EL}	Algeb	$OEL_0 - O_{EL}$
Vs	V_s	Algeb	$-V_s$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
SG	SG	Algeb	$-SG + SG_0$
LR_x	x_{LR}	Algeb	$K_{LR}(-I_{LR} + X_{ad}I_{fd}) - x_{LR}$
LR_y	y_{LR}	Algeb	$x_{LR}z_i^{lim_{LR}} - y_{LR} + z_l^{lim_{LR}} zero$
vi	V_i	Algeb	$-V_i + u_e \left(SGs_1^{SW_{VOS}} + U_{EL}s_1^{SW_{UEL}} + V_{ref} + V_s - y_{LG} - y_{WF} \right)$
vil_x	x_{vil}	Algeb	$V_i - x_{vil}$
vil_y	y_{vil}	Algeb	$V_{IMAX}z_u^{lim_{vil}} + V_{IMIN}z_l^{lim_{vil}} + x_{vil}z_i^{lim_{vil}} - y_{vil}$
UEL2	UEL_2	Algeb	$-UEL_2 + u_e \left(U_{EL}s_2^{SW_{UEL}} + llim \left(1 - s_2^{SW_{UEL}} \right) \right)$
HVG1_y	y_{HVG1}	Algeb	$UEL_2z_0^{None_{HVG1}} - y_{HVG1} + y_{vil}z_1^{None_{HVG1}}$
LL_y	y_{LL}	Algeb	$T_Bx'_{LL} - T_By_{LL} + T_C(-x'_{LL} + y_{HVG1}) + \left(z_1^{LT_{LL}} \right)^2 (-x'_{LL} + y_{LL})$
LL1_y	y_{LL1}	Algeb	$T_{B1}x'_{LL1} - T_{B1}y_{LL1} + T_{C1}(-x'_{LL1} + y_{LL1}) + \left(z_1^{LT_{LL1}} \right)^2 (-x'_{LL1} + y_{LL1})$
vas	V_{As}	Algeb	$-V_{As} + u_e \left(SGs_2^{SW_{VOS}} + y_{LA} - y_{LR} \right)$
UEL3	UEL_3	Algeb	$-UEL_3 + u_e \left(U_{EL}s_3^{SW_{UEL}} + llim \left(1 - s_3^{SW_{UEL}} \right) \right)$
HVG_y	y_{HVG}	Algeb	$UEL_3z_0^{None_{HVG}} + V_{As}z_1^{None_{HVG}} - y_{HVG}$
LVG_y	y_{LVG}	Algeb	$O_{EL}z_0^{None_{LVG}} + y_{HVG}z_1^{None_{LVG}} - y_{LVG}$
vol_x	x_{vol}	Algeb	$-x_{vol} + y_{LVG}$
vol_y	y_{vol}	Algeb	$efd_lz_l^{lim_{vol}} + efd_uz_u^{lim_{vol}} + x_{vol}z_i^{lim_{vol}} - y_{vol}$
WF_y	y_{WF}	Algeb	$K_F(-x'_{WF} + y_{LVG}) - T_Fy_{WF}$
vf	v_f	ExtAl- geb	$u_e(-v_{f0} + v_{out})$
XadIfd	$X_{ad}I_{fd}$	ExtAl- geb	0
a	θ	ExtAl- geb	0
vbus	V	ExtAl- geb	0
vd	V_d	ExtAl- geb	0
vq	V_q	ExtAl- geb	0

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
UEL0	$UEL0$	-999	ConstService
OEL0	$OEL0$	999	ConstService
ulim	$ulim$	9999	ConstService
llim	$llim$	-9999	ConstService
SG0	$SG0$	0	ConstService
zero	$zero$	0	ConstService
VA0	V_{A0}	$-SGs_2^{SW_{VOS}} + v_{f0} + y_{LR}$	PostInitService
vref0	V_{ref0}	V_{ref}	PostInitService
efdu	efd_u	$-K_C X_{ad} I_{fd} + V_{RMAX} V_d + iV_q $	VarService
efdl	efd_l	$V_{RMIN} V_d + iV_q $	VarService

Discretes

Name	Symbol	Type	Info
SWUEL	SW_{UEL}	Switcher	
SWVOS	SW_{VOS}	Switcher	
LR_lim	lim_{LR}	HardLimiter	
vil_lim	lim_{vil}	HardLimiter	
HVG1_lt	$None_{HVG1}$	LessThan	
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
LL1_LT1	LT_{LL1}	LessThan	
LL1_LT2	LT_{LL1}	LessThan	
LA_lim	lim_{LA}	AntiWindup	Limiter in Lag
HVG_lt	$None_{HVG}$	LessThan	
LVG_lt	$None_{LVG}$	LessThan	
vol_lim	lim_{vol}	HardLimiter	

Blocks

Name	Symbol	Type	Info
LG	<i>LG</i>	Lag	Voltage transducer
LR	<i>LR</i>	GainLimiter	Exciter output current gain limiter
vil	<i>vil</i>	GainLimiter	Exciter voltage input limiter
HVG1	<i>HVG1</i>	HVGate	HVGate after V_I
LL	<i>LL</i>	LeadLag	Lead-lag compensator
LL1	<i>LL1</i>	LeadLag	Lead-lag compensator 1
LA	<i>LA</i>	LagAntiWindup	V_A, Anti-windup lag
HVG	<i>HVG</i>	HVGate	HVGate for under excitation
LVG	<i>LVG</i>	LVGate	HVGate for over excitation
vol	<i>vol</i>	GainLimiter	Exciter output limiter
WF	<i>WF</i>	Washout	V_F, Stabilizing circuit feedback

Config Fields in [ESST1A]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.12.17 ESAC5A

Exciter ESAC5A.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing Time Constant	0.010	<i>p.u</i>	
TA	T_A	Voltage Regulator Time Constant	0.040	<i>p.u</i>	
KA	K_A	Voltage Regulator Gain	80		
VRMIN	V_{Rmin}	V_R lower limit	-7.300	<i>p.u</i>	
VRMAX	V_{Rmax}	V_R upper limit	7.300	<i>p.u</i>	
TE	T_E	Integrator Time Constant	0.800	<i>p.u</i>	non_negative
KF	K_F	Feedback Gain	0.030		
TF1	T_{F1}	Lag Time Constant	1	<i>p.u</i>	
TF2	T_{F2}	Lead-Lag Time Constant (pole)	0.800	<i>p.u</i>	
TF3	T_{F3}	Lead-Lag Time Constant (zero)	1	<i>p.u</i>	
KE	K_E	Exciter Feedback Gain	1		
E1	E_1	First saturation point	0	<i>p.u.</i>	
SE1	S_{E1}	Value at first saturation point	0	<i>p.u.</i>	
E2	E_2	Second saturation point	1	<i>p.u.</i>	
SE2	S_{E2}	Value at second saturation point	1	<i>p.u.</i>	
ug	u_g	Generator online status	0	<i>bool</i>	
Sn	S_m	Rated power from generator	0	<i>MVA</i>	
Vn	V_m	Rated voltage from generator	0	<i>kV</i>	
bus	bus	Bus idx of the generators	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
LP_y	y_{LP}	State	State in lag transfer function		v_str
VR_y	y_{VR}	State	State in lag TF		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
WF_x	x'_{WF}	State	State in washout filter		v_str
INT_y	y_{INT}	State	Integrator output		v_str
omega	ω	ExtState	Generator speed		
v	E_{term}	Algeb	Input to exciter (bus v or Eterm)		v_str
vout	v_{out}	Algeb	Exciter final output voltage		v_str
UEL	U_{EL}	Algeb	Interface var for under exc. limiter		v_str
OEL	O_{EL}	Algeb	Interface var for over exc. limiter		v_str
Vs	V_s	Algeb	Voltage compensation from PSS		v_str
vref	V_{ref}	Algeb	Reference voltage input	p.u.	v_str
vi	v_i	Algeb	Total voltage input	pu	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
WF_y	y_{WF}	Algeb	Output of washout filter		v_str
Se	$V_{out} * S_e(V_{out})$	Algeb	saturation output		v_str
VFE	V_{FE}	Algeb	Combined saturation feedback	p.u.	v_str
vf	v_f	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
vbus	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
LP_y	y_{LP}	State	E_{term}
VR_y	y_{VR}	State	$K_A v_i$
LL_x	x'_{LL}	State	y_{VR}
WF_x	x'_{WF}	State	y_{LL}
INT_y	y_{INT}	State	v_{f0}
omega	ω	ExtState	
v	E_{term}	Algeb	V
vout	v_{out}	Algeb	$u_e v_{f0}$
UEL	U_{EL}	Algeb	U_{EL0}
OEL	O_{EL}	Algeb	O_{EL0}
Vs	V_s	Algeb	0
vref	V_{ref}	Algeb	$E_{term} + \frac{V_{FE}}{K_A}$
vi	v_i	Algeb	$u_e (-E_{term} + V_{ref})$
LL_y	y_{LL}	Algeb	y_{VR}
WF_y	y_{WF}	Algeb	0
Se	$V_{out} * S_e(V_{out})$	Algeb	$B_{SAT}^q (-A_{SAT}^q + y_{INT})^2 \text{Indicator}(y_{INT} > A_{SAT}^q)$
VFE	V_{FE}	Algeb	$K_E y_{INT} + V_{out} * S_e(V_{out})$
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
vbus	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LP_y	y_{LP}	State	$E_{term} - y_{LP}$	T_R
VR_y	y_{VR}	State	$K_A v_i - y_{VR}$	T_A
LL_x	x'_{LL}	State	$-x'_{LL} + y_{VR}$	T_{F2}
WF_x	x'_{WF}	State	$-x'_{WF} + y_{LL}$	T_{F1}
INT_y	y_{INT}	State	$u_e (-V_{FE} + y_{VR})$	T_E
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
v	E_{term}	Algeb	$-E_{term} + V$
vout	v_{out}	Algeb	$u_e y_{INT} - v_{out}$
UEL	U_{EL}	Algeb	$UEL_0 - U_{EL}$
OEL	O_{EL}	Algeb	$OEL_0 - O_{EL}$
Vs	V_s	Algeb	$-V_s$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
vi	v_i	Algeb	$u_e (V_{ref} + V_s - y_{LP} - y_{WF}) - v_i$
LL_y	y_{LL}	Algeb	$T_{F2} x'_{LL} - T_{F2} y_{LL} + T_{F3} (-x'_{LL} + y_{VR}) +$ $(z_1^{LTLL})^2 (-x'_{LL} + y_{LL})$
WF_y	y_{WF}	Algeb	$K_F (-x'_{WF} + y_{LL}) - T_{F1} y_{WF}$
Se	V_{out} $S_e(V_{out})$	* Algeb	$u_e \left(B_{SAT}^q z_0^{SL} (-A_{SAT}^q + y_{INT})^2 - V_{out} * S_e(V_{out}) \right)$
VFE	V_{FE}	Algeb	$u_e (K_E y_{INT} - V_{FE} + V_{out} * S_e(V_{out}))$
vf	v_f	ExtAl- geb	$u_e (-v_{f0} + v_{out})$
Xad- Ifd	$X_{ad} I_{fd}$	ExtAl- geb	0
a	θ	ExtAl- geb	0
vbus	V	ExtAl- geb	0

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
UEL0	$UEL0$	0	ConstService
OEL0	$OEL0$	0	ConstService
VR- MAXu	$VRMAXu$	$V_{Rmax}u_e - 999u_e + 999$	ConstService
VRMINu	$VRMINu$	$V_{Rmin}u_e + 999u_e - 999$	ConstService
SAT_E1	E_{SAT}^{1c}	E_1	ConstService
SAT_E2	E_{SAT}^{2c}	$E_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_SE1	SE_{SAT}^{1c}	SE_1	ConstService
SAT_SE2	SE_{SAT}^{2c}	$SE_2 - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E_{SAT}^{1c}SE_{SAT}^{1c}}{E_{SAT}^{2c}SE_{SAT}^{2c}}} (\text{Indicator}(SE_{SAT}^{2c} > 0) + \text{Indicator}(SE_{SAT}^{2c} < 0))$	ConstService
SAT_A	A_{SAT}^q	$E_{SAT}^{2c} - \frac{E_{SAT}^{1c} - E_{SAT}^{2c}}{a_{SAT} - 1}$	ConstService
SAT_B	B_{SAT}^q	$\frac{E_{SAT}^{2c}SE_{SAT}^{2c}(a_{SAT}-1)^2(\text{Indicator}(a_{SAT}>0)+\text{Indicator}(a_{SAT}<0))}{(E_{SAT}^{1c}-E_{SAT}^{2c})^2}$	ConstService
vref0	V_{ref0}	V_{ref}	PostInitService

Discretes

Name	Symbol	Type	Info
VR_lim	lim_{VR}	AntiWindup	Limiter in Lag
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
SL	SL	LessThan	

Blocks

Name	Symbol	Type	Info
LP	LP	Lag	Voltage transducer
VR	VR	LagAntiWindup	
LL	LL	LeadLag	
WF	WF	Washout	
SAT	SAT	ExcQuadSat	Field voltage saturation
INT	INT	Integrator	V_E, integrator

Config Fields in [ESAC5A]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.13 Experimental

Experimental group

Common Parameters: u, name

5.14 FreqMeasurement

Frequency measurements.

Common Parameters: u, name

Common Variables: f

Available models: *BusFreq*, *BusROCOF*

5.14.1 BusFreq

Bus frequency measurement. Outputs frequency in per unit value.

The bus frequency output variable is f . The frequency deviation variable is WO_y .

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		bus idx			mandatory
Tf	T_f	input digital filter time const	0.020	<i>sec</i>	
Tw	T_w	washout time const	0.020	<i>sec</i>	
fn	f_n	nominal frequency	60	<i>Hz</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
L_y	y_L	State	State in lag transfer function		v_str
WO_x	x'_{WO}	State	State in washout filter		v_str
WO_y	y_{WO}	Algeb	frequency deviation	<i>p.u. (Hz)</i>	v_str
f	f	Algeb	frequency output	<i>p.u. (Hz)</i>	v_str
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Initialization Equations

Name	Symbol	Type	Initial Value
L_y	y_L	State	$\theta - \theta_0$
WO_x	x'_{WO}	State	y_L
WO_y	y_{WO}	Algeb	0
f	f	Algeb	1
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
L_y	y_L	State	$\theta - \theta_0 - y_L$	T_f
WO_x	x'_{WO}	State	$-x'_{WO} + y_L$	T_w

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
WO_y	y_{WO}	Algeb	$1/\omega_n (-x'_{WO} + y_L) - T_w y_{WO}$
f	f	Algeb	$-f + y_{WO} + 1$
a	θ	ExtAlgeb	0
v	V	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
iwn	$1/\omega_n$	$\frac{u}{2\pi f_n}$	ConstService

Blocks

Name	Symbol	Type	Info
L	L	Lag	digital filter
WO	WO	Washout	angle washout

Config Fields in [BusFreq]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.14.2 BusROCOF

Bus frequency and ROCOF measurement.

The ROCOF output variable is Wf_y .

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		bus idx			mandatory
Tf	T_f	input digital filter time const	0.020	<i>sec</i>	
Tw	T_w	washout time const	0.020	<i>sec</i>	
fn	f_n	nominal frequency	60	<i>Hz</i>	
Tr	T_r	frequency washout time constant	0.100		

Variables

Name	Symbol	Type	Description	Unit	Properties
L_y	y_L	State	State in lag transfer function		v_str
WO_x	x'_{WO}	State	State in washout filter		v_str
Wf_x	x'_{Wf}	State	State in washout filter		v_str
WO_y	y_{WO}	Algeb	frequency deviation	<i>p.u. (Hz)</i>	v_str
f	f	Algeb	frequency output	<i>p.u. (Hz)</i>	v_str
Wf_y	y_{Wf}	Algeb	Output of washout filter		v_str
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Initialization Equations

Name	Symbol	Type	Initial Value
L_y	y_L	State	$\theta - \theta_0$
WO_x	x'_{WO}	State	y_L
Wf_x	x'_{Wf}	State	f
WO_y	y_{WO}	Algeb	0
f	f	Algeb	1
Wf_y	y_{Wf}	Algeb	0
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
L_y	y_L	State	$\theta - \theta_0 - y_L$	T_f
WO_x	x'_{WO}	State	$-x'_{WO} + y_L$	T_w
Wf_x	x'_{Wf}	State	$f - x'_{Wf}$	T_r

Algebraic Equations

Name	Symbol	Type	RHS of Equation " $0 = g(x, y)$ "
WO_y	y_{WO}	Algeb	$1/\omega_n (-x'_{WO} + y_L) - T_w y_{WO}$
f	f	Algeb	$-f + y_{WO} + 1$
Wf_y	y_{Wf}	Algeb	$-T_r y_{Wf} + f - x'_{Wf}$
a	θ	ExtAlgeb	0
v	V	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
iwn	$1/\omega_n$	$\frac{u}{2\pi f_n}$	ConstService

Blocks

Name	Symbol	Type	Info
L	L	Lag	digital filter
WO	WO	Washout	angle washout
Wf	Wf	Washout	frequency washout yielding ROCOF

Config Fields in [BusROCOF]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.15 Information

Group for information container models.

Available models: [Summary](#)

5.15.1 Summary

Class for storing system summary. Can be used for random information or notes.

Parameters

Name	Symbol	Description	Default	Unit	Properties
field		field name			
comment		information, comment, or anything			
comment2		comment field 2			
comment3		comment field 3			
comment4		comment field 4			

Config Fields in [Summary]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.16 Interface

Group for interface models.

Available models: *Fortescue*

5.16.1 Fortescue

Fortescue's symmetric component interface.

This model interfaces a positive-sequence, single-phase-equivalent bus with three buses representing three phases. It is effectively a transformer with one terminal on the primary side and three on the secondary. Only the positive sequence component on the secondary winding is used for simulation.

The positive-sequence voltage magnitude and angle of the secondary winding are named v_p and a_p .

The negative and zero sequence variables given in the d- and q-axis due the angle being undefined when the voltage is zero. The negative sequence voltages are v_{nd} and v_{nq} for the d- and q-axis, respectively. Likewise, the zero-sequence voltages are v_{zd} and v_{zq} .

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		bus idx for the single-phase equivalent			mandatory
busa		bus idx for phase a			mandatory
busb		bus idx for phase b			mandatory
busc		bus idx for phase c			mandatory
Sn	S_n	Power rating	100	<i>MW</i>	non_zero
r	r	resistance	0.001	<i>p.u.</i>	z
x	x	short-circuit reactance	0.025	<i>p.u.</i>	non_zero,z
g		iron loss	0	<i>p.u.</i>	y
b		magnetizing susceptance	0.005	<i>p.u.</i>	y

Variables

Name	Symbol	Type	Description	Unit	Properties
vp	V_p	Algeb	positive sequence voltage magnitude		v_str
ap	θ_p	Algeb	positive sequence voltage phase		v_str
vnd	V_{nd}	Algeb	negative sequence voltage on d-axis (cos)		v_str
vnq	V_{nq}	Algeb	negative sequence voltage on q-axis (sin)		v_str
vzd	V_{zd}	Algeb	zero sequence voltage on d-axis (cos)		v_str
vzq	V_{zq}	Algeb	zero sequence voltage on q-axis (sin)		v_str
a	θ_1	ExtAlgeb	phase angle of single-phase eq. bus		
aa	θ_a	ExtAlgeb	phase angle of bus for phase a		
ab	θ_b	ExtAlgeb	phase angle of bus for phase b		
ac	θ_c	ExtAlgeb	phase angle of bus for phase c		
v	V_1	ExtAlgeb	voltage of single-phase eq. bus		
va	V_a	ExtAlgeb	voltage of bus for phase a		
vb	V_b	ExtAlgeb	voltage of bus for phase b		
vc	V_c	ExtAlgeb	voltage of bus for phase c		

Initialization Equations

Name	Symbol	Type	Initial Value
vp	V_p	Algeb	$\frac{V_a}{3} + \frac{V_b}{3} + \frac{V_c}{3}$
ap	θ_p	Algeb	$\theta_a + \theta_b + \theta_c$
vnd	V_{nd}	Algeb	0.0
vnq	V_{nq}	Algeb	0.0
vzd	V_{zd}	Algeb	0.0
vzq	V_{zq}	Algeb	0.0
a	θ_1	ExtAlgeb	
aa	θ_a	ExtAlgeb	
ab	θ_b	ExtAlgeb	
ac	θ_c	ExtAlgeb	
v	V_1	ExtAlgeb	
va	V_a	ExtAlgeb	
vb	V_b	ExtAlgeb	
vc	V_c	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
vp	V_p	Algeb	$-V_p + \sqrt{(V_b \sin(120^\circ - \theta_a + \theta_b) - V_c \sin(120^\circ + \theta_a - \theta_c))^2 + (V_a + V_b \cos(120^\circ - \theta_a + \theta_b) + V_c \cos(120^\circ + \theta_a - \theta_c))^2}$
ap	θ_p	Algeb	$\theta_a - \theta_p + \text{atan2}(V_b \sin(120^\circ - \theta_a + \theta_b) - V_c \sin(120^\circ + \theta_a - \theta_c), V_a + V_b \cos(120^\circ - \theta_a + \theta_b) + V_c \cos(120^\circ + \theta_a - \theta_c))$
vnd	V_{nd}	Algeb	$V_a \cos(\theta_a) + V_b \cos(120^\circ - \theta_b) + V_c \cos(120^\circ + \theta_c) - V_{nd}$
vnq	V_{nq}	Algeb	$V_a \sin(\theta_a) - V_b \sin(120^\circ - \theta_b) + V_c \sin(120^\circ + \theta_c) - V_{nq}$
vzd	V_{zd}	Algeb	$V_a \cos(\theta_a) + V_b \cos(\theta_b) + V_c \cos(\theta_c) - V_{zd}$
vzq	V_{zq}	Algeb	$V_a \sin(\theta_a) + V_b \sin(\theta_b) + V_c \sin(\theta_c) - V_{zq}$
a	θ_1	ExtAlgeb	$u(V_1^2(g + g_{hk}) - V_1 V_p(b_{hk} \sin(\theta_1 - \theta_p) + g_{hk} \cos(\theta_1 - \theta_p)))$
aa	θ_a	ExtAlgeb	$\frac{u(-V_1 V_a(-b_{hk} \sin(\theta_1 - \theta_a) + g_{hk} \cos(\theta_1 - \theta_a)) + V_a^2(g + g_{hk}))}{3}$
ab	θ_b	ExtAlgeb	$\frac{u(-V_1 V_b(b_{hk} \sin(120^\circ - \theta_1 + \theta_b) + g_{hk} \cos(120^\circ - \theta_1 + \theta_b)) + V_b^2(g + g_{hk}))}{3}$
ac	θ_c	ExtAlgeb	$\frac{u(-V_1 V_c(-b_{hk} \sin(120^\circ + \theta_1 - \theta_c) + g_{hk} \cos(120^\circ + \theta_1 - \theta_c)) + V_c^2(g + g_{hk}))}{3}$
v	V_1	ExtAlgeb	$u(-V_1^2(b + b_{hk}) - V_1 V_p(-b_{hk} \cos(\theta_1 - \theta_p) + g_{hk} \sin(\theta_1 - \theta_p)))$
va	V_a	ExtAlgeb	$\frac{u(V_1 V_a(b_{hk} \cos(\theta_1 - \theta_a) + g_{hk} \sin(\theta_1 - \theta_a)) - V_a^2(b + b_{hk}))}{3}$
vb	V_b	ExtAlgeb	$\frac{u(V_1 V_b(b_{hk} \cos(120^\circ - \theta_1 + \theta_b) - g_{hk} \sin(120^\circ - \theta_1 + \theta_b)) - V_b^2(b + b_{hk}))}{3}$
vc	V_c	ExtAlgeb	$\frac{u(V_1 V_c(b_{hk} \cos(120^\circ + \theta_1 - \theta_c) + g_{hk} \sin(120^\circ + \theta_1 - \theta_c)) - V_c^2(b + b_{hk}))}{3}$

Services

Name	Symbol	Equation	Type
yhk	y_{hk}	$\frac{u}{r+ix}$	ConstService
ghk	g_{hk}	$\text{re}(y_{hk})$	ConstService
bhk	b_{hk}	$\text{im}(y_{hk})$	ConstService
d120	120°	$\frac{2\pi}{3}$	ConstService

Config Fields in [Fortescue]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.17 Motor

Induction Motor group

Common Parameters: u, name

Available models: *Motor3*, *Motor5*

5.17.1 Motor3

Third-order induction motor model.

See "Power System Modelling and Scripting" by F. Milano.

To simulate motor startup, set the motor status u to 0 and use a `Toggle` to control the model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
Sn	S_n	Power rating	100		
Vn	V_n	AC voltage rating	110		
fn	f	rated frequency	60		
rs	r_s	rotor resistance	0.010		non_zero,z
xs	x_s	rotor reactance	0.150		non_zero,z
rr1	r_{R1}	1st cage rotor resistance	0.050		non_zero,z
xr1	x_{R1}	1st cage rotor reactance	0.150		non_zero,z
rr2	r_{R2}	2st cage rotor resistance	0.001		non_zero,z
xr2	x_{R2}	2st cage rotor reactance	0.040		non_zero,z
xm	x_m	magnetization reactance	5		non_zero,z
Hm	H_m	Inertia constant	3	<i>kWs/KVA</i>	power
c1	c_1	1st coeff. of Tm(w)	0.100		
c2	c_2	2nd coeff. of Tm(w)	0.020		
c3	c_3	3rd coeff. of Tm(w)	0.020		
zb	z_b	Allow working as brake	1		

Variables

Name	Symbol	Type	Description	Unit	Properties
slip	σ	State			v_str
e1d	e'_d	State	real part of 1st cage voltage		v_str
e1q	e'_q	State	imaginary part of 1st cage voltage		v_str
vd	V_d	Algeb	d-axis voltage		
vq	V_q	Algeb	q-axis voltage		
p	P	Algeb			v_str
q	Q	Algeb			v_str
Id	I_d	Algeb			v_str
Iq	I_q	Algeb			
te	τ_e	Algeb			v_str
tm	τ_m	Algeb			v_str
a	θ	ExtAlgeb	Bus voltage phase angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
slip	σ	State	$1.0u$
e1d	e'_d	State	$0.05u$
e1q	e'_q	State	$0.9u$
vd	V_d	Algeb	
vq	V_q	Algeb	
p	P	Algeb	$u(I_d V_d + I_q V_q)$
q	Q	Algeb	$u(I_d V_q - I_q V_d)$
Id	I_d	Algeb	1
Iq	I_q	Algeb	
te	τ_e	Algeb	$u(I_d e'_d + I_q e'_q)$
tm	τ_m	Algeb	$u(\alpha + \beta\sigma + \sigma^2 c_2)$
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
slip	σ	State	$u(-\tau_e + \tau_m)$	M
e1d	e'_d	State	$u\left(\omega_b \sigma e'_q - \frac{I_q(-x' + x_0) + e'_d}{T'_0}\right)$	
e1q	e'_q	State	$u\left(-\omega_b \sigma e'_d - \frac{-I_d(-x' + x_0) + e'_q}{T'_0}\right)$	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
vd	V_d	Algeb	$-Vu \sin(\theta) - V_d$
vq	V_q	Algeb	$Vu \cos(\theta) - V_q$
p	P	Algeb	$-P + u(I_d V_d + I_q V_q)$
q	Q	Algeb	$-Q + u(I_d V_q - I_q V_d)$
Id	I_d	Algeb	$u(-I_d r_s + I_q x' + V_d - e'_d)$
Iq	I_q	Algeb	$u(-I_d x' - I_q r_s + V_q - e'_q)$
te	τ_e	Algeb	$-\tau_e + u(I_d e'_d + I_q e'_q)$
tm	τ_m	Algeb	$-\tau_m + u(\alpha + \beta\sigma + \sigma^2 c_2)$
a	θ	ExtAlgeb	P
v	V	ExtAlgeb	Q

Services

Name	Symbol	Equation	Type
wb	ω_b	$2\pi f$	ConstService
x0	x_0	$x_m + x_s$	ConstService
x1	x'	$\frac{x_m x_{R1}}{x_m + x_{R1}} + x_s$	ConstService
T10	T'_0	$\frac{x_m + x_{R1}}{\omega_b r_{R1}}$	ConstService
M	M	$2H_m$	ConstService
aa	α	$c_1 + c_2 + c_3$	ConstService
bb	β	$-c_2 - 2c_3$	ConstService

Config Fields in [Motor3]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.17.2 Motor5

Fifth-order induction motor model.

See "Power System Modelling and Scripting" by F. Milano.

To simulate motor startup, set the motor status `u` to 0 and use a `Toggle` to control the model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
Sn	S_n	Power rating	100		
Vn	V_n	AC voltage rating	110		
fn	f	rated frequency	60		
rs	r_s	rotor resistance	0.010		non_zero,z
xs	x_s	rotor reactance	0.150		non_zero,z
rr1	r_{R1}	1st cage rotor resistance	0.050		non_zero,z
xr1	x_{R1}	1st cage rotor reactance	0.150		non_zero,z
rr2	r_{R2}	2st cage rotor resistance	0.001		non_zero,z
xr2	x_{R2}	2st cage rotor reactance	0.040		non_zero,z
xm	x_m	magnetization reactance	5		non_zero,z
Hm	H_m	Inertia constant	3	<i>kWs/KVA</i>	power
c1	c_1	1st coeff. of Tm(w)	0.100		
c2	c_2	2nd coeff. of Tm(w)	0.020		
c3	c_3	3rd coeff. of Tm(w)	0.020		
zb	z_b	Allow working as brake	1		

Variables

Name	Symbol	Type	Description	Unit	Properties
slip	σ	State			v_str
e1d	e'_d	State	real part of 1st cage voltage		v_str
e1q	e'_q	State	imaginary part of 1st cage voltage		v_str
e2d	e''_d	State	real part of 2nd cage voltage		v_str
e2q	e''_q	State	imag part of 2nd cage voltage		v_str
vd	V_d	Algeb	d-axis voltage		
vq	V_q	Algeb	q-axis voltage		
p	P	Algeb			v_str
q	Q	Algeb			v_str
Id	I_d	Algeb			v_str
Iq	I_q	Algeb			v_str
te	τ_e	Algeb			v_str
tm	τ_m	Algeb			v_str
a	θ	ExtAlgeb	Bus voltage phase angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
slip	σ	State	$1.0u$
e1d	e'_d	State	$0.05u$
e1q	e'_q	State	$0.9u$
e2d	e''_d	State	$0.05u$
e2q	e''_q	State	$0.9u$
vd	V_d	Algeb	
vq	V_q	Algeb	
p	P	Algeb	$u(I_d V_d + I_q V_q)$
q	Q	Algeb	$u(I_d V_q - I_q V_d)$
Id	I_d	Algeb	$0.9u$
Iq	I_q	Algeb	$0.1u$
te	τ_e	Algeb	$u(I_d e''_d + I_q e''_q)$
tm	τ_m	Algeb	$u(\alpha + \beta \sigma + \sigma^2 c_2)$
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Differential Equations

Name	Sym- bol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
slip	σ	State	$u(-\tau_e + \tau_m)$	M
e1d	e'_d	State	$u\left(\omega_b \sigma e'_q - \frac{I_q(-x' + x_0) + e'_d}{T'_0}\right)$	
e1q	e'_q	State	$u\left(-\omega_b \sigma e'_d - \frac{-I_d(-x' + x_0) + e'_q}{T'_0}\right)$	
e2d	e''_d	State	$u\left(\omega_b \sigma e'_q - \omega_b \sigma (-e''_q + e'_q) - \frac{I_q(-x' + x_0) + e'_d}{T'_0} + \frac{-I_q(x' - x'') - e''_d + e'_d}{T''_0}\right)$	
e2q	e''_q	State	$u\left(-\omega_b \sigma e'_d + \omega_b \sigma (-e''_d + e'_d) - \frac{-I_d(-x' + x_0) + e'_q}{T'_0} + \frac{I_d(x' - x'') - e''_q + e'_q}{T''_0}\right)$	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
vd	V_d	Algeb	$-Vu \sin(\theta) - V_d$
vq	V_q	Algeb	$Vu \cos(\theta) - V_q$
p	P	Algeb	$-P + u(I_d V_d + I_q V_q)$
q	Q	Algeb	$-Q + u(I_d V_q - I_q V_d)$
Id	I_d	Algeb	$u(-I_d r_s + I_q x'' + V_d - e_d'')$
Iq	I_q	Algeb	$u(-I_d x'' - I_q r_s + V_q - e_q'')$
te	τ_e	Algeb	$-\tau_e + u(I_d e_d'' + I_q e_q'')$
tm	τ_m	Algeb	$-\tau_m + u(\alpha + \beta \sigma + \sigma^2 c_2)$
a	θ	ExtAlgeb	P
v	V	ExtAlgeb	Q

Services

Name	Symbol	Equation	Type
wb	ω_b	$2\pi f$	ConstService
x0	x_0	$x_m + x_s$	ConstService
x1	x'	$\frac{x_m x_{R1}}{x_m + x_{R1}} + x_s$	ConstService
T10	T'_0	$\frac{x_m + x_{R1}}{\omega_b r_{R1}}$	ConstService
M	M	$2H_m$	ConstService
aa	α	$c_1 + c_2 + c_3$	ConstService
bb	β	$-c_2 - 2c_3$	ConstService
x2	x''	$\frac{x_m x_{R1} x_{R2}}{x_m x_{R1} + x_m x_{R2} + x_{R1} x_{R2}} + x_s$	ConstService
T20	T''_0	$\frac{\frac{x_m x_{R1}}{x_m + x_{R1}} + x_{R2}}{\omega_b r_{R2}}$	ConstService

Config Fields in [Motor5]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.18 OutputSelect

Group for selecting outputs.

Available models: *Output*

5.18.1 Output

Model for specifying output models and/or variables.

Parameters

Name	Symbol	Description	Default	Unit	Properties
model		Name of the model			mandatory
varname		Variable name			
dev		Device name			

Config Fields in [Output]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.19 PLL

Phase-locked loop models.

Common Parameters: u, name

Common Variables: am

Available models: *PLL1*, *PLL2*

5.19.1 PLL1

Simple Phasor Lock Loop (PLL) using one PI controller. The PI controller minimizes the error between the input and output angle.

Input bus angle signal -> Lag filter 1 with T_f -> Output angle af_y .

$(af_y - am)$ -> PI Controller (K_p , K_i) -> PI_y

Estimated angle $ae = (2 * \pi * fn * PI_y)$ -> Lag filter 2 with T_p -> am .

The output signal is am , a state variable.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		bus idx			mandatory
fn	f_n	nominal frequency	60	<i>Hz</i>	
Kp	K_p	proportional gain	0.100		
Ki	K_i	integral gain	0.100		
Tf	T_f	input digital filter time const	0.050	<i>sec</i>	
Tp	T_p	output filter time const.	0.050	<i>sec</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
af_y	y_{af}	State	State in lag transfer function		v_str
PI_xi	xi_{PI}	State	Integrator output		v_str
ae	θ_{est}	State	PLL angle output before filter		v_str
am	θ_m	State	PLL output angle after filtering		v_str
PI_y	y_{PI}	Algeb	PI output		v_str
a	θ	ExtAlgeb	Bus voltage angle		

Initialization Equations

Name	Symbol	Type	Initial Value
af_y	y_{af}	State	θ
PI_xi	xi_{PI}	State	0.0
ae	θ_{est}	State	θ
am	θ_m	State	θ
PI_y	y_{PI}	Algeb	$K_p u(-\theta_m + y_{af})$
a	θ	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
af_y	y_{af}	State	$\theta - y_{af}$	T_f
PI_xi	xi_{PI}	State	$K_i u(-\theta_m + y_{af})$	
ae	θ_{est}	State	$2\pi f_n y_{PI}$	
am	θ_m	State	$\theta_{est} - \theta_m$	T_p

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
PI_y	y_{PI}	Algeb	$K_p u(-\theta_m + y_{af}) + xi_{PI} - y_{PI}$
a	θ	ExtAlgeb	0

Blocks

Name	Symbol	Type	Info
af	af	Lag	input angle signal filter
PI	PI	PIController	PI controller

Config Fields in [PLL1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.19.2 PLL2

Synchronously-rotating Reference Frame (SRF) Phasor Lock Loop (PLL).

The PLL minimizes $v_q = v \sin(a - a_m)$ using a PI controller.

The output signal is a_m , a state variable.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		bus idx			mandatory
fn	f_n	nominal frequency	60	<i>Hz</i>	
Kp	K_p	proportional gain	0.100		
Ki	K_i	integral gain	0.100		

Variables

Name	Symbol	Type	Description	Unit	Properties
PI_xi	xi_{PI}	State	Integrator output		v_str
am	θ_m	State	PLL angle output		v_str
PI_y	y_{PI}	Algeb	PI output		v_str
a	θ	ExtAlgeb	Bus voltage angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
PI_xi	xi_{PI}	State	0
am	θ_m	State	θ
PI_y	y_{PI}	Algeb	$K_p V \sin(\theta - \theta_m)$
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
PI_xi	xi_{PI}	State	$K_i V \sin(\theta - \theta_m)$	
am	θ_m	State	$2\pi f_n y_{PI}$	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
PI_y	y_{PI}	Algeb	$K_p V \sin(\theta - \theta_m) + xi_{PI} - y_{PI}$
a	θ	ExtAlgeb	0
v	V	ExtAlgeb	0

Blocks

Name	Symbol	Type	Info
PI	PI	PIController	

Config Fields in [PLL2]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.20 PSS

Power system stabilizer group.

Common Parameters: u, name

Common Variables: vsout

Available models: *IEEEEST*, *ST2CUT*

5.20.1 IEEEEST

IEEEEST stabilizer model. Automatically adds frequency measurement devices if not provided.

Input signals (MODE):

1. Rotor speed deviation (p.u.),
2. Bus frequency deviation (p.u.) (*),
3. Generator P electrical in Gen MVABase (p.u.),
4. Generator accelerating power (p.u.),
5. Bus voltage (p.u.),
6. Derivative of p.u. bus voltage.

(*) Due to the frequency measurement implementation difference, mode 2 is likely to yield different results across software.

Note: Blocks are named *F1*, *F2*, *LL1*, *LL2* and *WO* in sequence. Two limiters are named *VLIM* and *OLIM* in sequence.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
avr		Exciter idx			mandatory
MODE		Input signal			mandatory
busr		Optional remote bus idx			
busf		BusFreq idx for mode 2			
A1	A_1	filter time const. (pole)	1		
A2	A_2	filter time const. (pole)	1		
A3	A_3	filter time const. (pole)	1		
A4	A_4	filter time const. (pole)	1		
A5	A_5	filter time const. (zero)	1		
A6	A_6	filter time const. (zero)	1		
T1	T_1	first leadlag time const. (zero)	1		
T2	T_2	first leadlag time const. (pole)	1		
T3	T_3	second leadlag time const. (pole)	1		
T4	T_4	second leadlag time const. (pole)	1		
T5	T_5	washout time const. (zero)	1		
T6	T_6	washout time const. (pole)	1		
KS	K_S	Gain before washout	1		
LSMAX	L_{SMAX}	Max. output limit	0.300		
LSMIN	L_{SMIN}	Min. output limit	-0.300		
VCU	V_{CU}	Upper enabling bus voltage	999	<i>p.u.</i>	
VCL	V_{CL}	Upper enabling bus voltage	-999	<i>p.u.</i>	
syn		Retrieved generator idx	0		
bus		Retrieved bus idx			
Sn	S_n	Generator power base	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
F1_x	x'_{F1}	State	State in 2nd order LPF		v_str
F1_y	y_{F1}	State	Output of 2nd order LPF		v_str
F2_x1	x'_{F2}	State	State #1 in 2nd order lead-lag		v_str
F2_x2	x''_{F2}	State	State #2 in 2nd order lead-lag		v_str
LL1_x	x'_{LL1}	State	State in lead-lag		v_str
LL2_x	x'_{LL2}	State	State in lead-lag		v_str
WO_x	x'_{WO}	State	State in washout filter		v_str
omega	ω	ExtState	Generator speed	<i>p.u.</i>	
vsout	v_{sout}	Algeb	PSS output voltage to exciter		
sig	S_{ig}	Algeb	Input signal		v_str
F2_y	y_{F2}	Algeb	Output of 2nd order lead-lag		v_str
LL1_y	y_{LL1}	Algeb	Output of lead-lag		v_str
LL2_y	y_{LL2}	Algeb	Output of lead-lag		v_str
Vks_y	y_{Vks}	Algeb	Gain output		v_str
WO_y	y_{WO}	Algeb	Output of washout filter		v_str
Vss	V_{ss}	Algeb	Voltage output before output limiter		
tm	τ_m	ExtAlgeb	Generator mechanical input		
te	τ_e	ExtAlgeb	Generator electrical output		
v	V	ExtAlgeb	Bus (or busr, if given) terminal voltage		
f	f	ExtAlgeb	Bus frequency		
vi	v_i	ExtAlgeb	Exciter input voltage		

Initialization Equations

Name	Symbol	Type	Initial Value
F1_x	x'_{F1}	State	0
F1_y	y_{F1}	State	S_{ig}
F2_x1	x'_{F2}	State	0
F2_x2	x''_{F2}	State	y_{F1}
LL1_x	x'_{LL1}	State	y_{F2}
LL2_x	x'_{LL2}	State	y_{LL1}
WO_x	x'_{WO}	State	y_{Vks}
omega	ω	ExtState	
vsout	v_{sout}	Algeb	
sig	S_{ig}	Algeb	$u_e \left(V s_5^{SW} + s_1^{SW} (\omega - 1) + s_4^{SW} (\tau_m - \tau_{m0}) + \frac{\tau_{m0} s_3^{SW}}{(Sb/Sn)} \right)$
F2_y	y_{F2}	Algeb	y_{F1}
LL1_y	y_{LL1}	Algeb	y_{F2}
LL2_y	y_{LL2}	Algeb	y_{LL1}
Vks_y	y_{Vks}	Algeb	$K_S y_{LL2}$
WO_y	y_{WO}	Algeb	$x'_{WO} z_1^{LTWO}$
Vss	V_{ss}	Algeb	
tm	τ_m	ExtAlgeb	
te	τ_e	ExtAlgeb	
v	V	ExtAlgeb	
f	f	ExtAlgeb	
vi	v_i	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
F1_x	x'_{F1}	State	$-A_1 x'_{F1} + S_{ig} - y_{F1}$	A_2
F1_y	y_{F1}	State	x'_{F1}	
F2_x1	x'_{F2}	State	$-A_3 x'_{F2} - x''_{F2} + y_{F1}$	A_4
F2_x2	x''_{F2}	State	x'_{F2}	
LL1_x	x'_{LL1}	State	$-x'_{LL1} + y_{F2}$	T_2
LL2_x	x'_{LL2}	State	$-x'_{LL2} + y_{LL1}$	T_4
WO_x	x'_{WO}	State	$-x'_{WO} + y_{Vks}$	T_6
omega	ω	ExtState	0	

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
vsout	v_{sout}	Algeb	$V_{ss}u_e z_i^{OLIM} - v_{sout}$
sig	S_{ig}	Algeb	$-S_{ig} + u_e \left(V s_5^{SW} + s_1^{SW} (\omega - 1) + s_2^{SW} (f - 1) + s_4^{SW} (\tau_m - \tau_{m0}) + s_6^{SW} v^{dV/dt} + \frac{\tau_e s_3^{SW}}{(Sb/Sn)} \right)$
F2_y	y_{F2}	Algeb	$A_4 A_5 x'_{F2} + A_4 x''_{F2} - A_4 y_{F2} + A_6 (-A_3 x'_{F2} - x''_{F2} + y_{F1}) + \left(z_1^{LT_{F2}} \right)^4 (-x''_{F2} + y_{F2})$
LL1_y	y_{LL1}	Algeb	$T_1 (-x'_{LL1} + y_{F2}) + T_2 x'_{LL1} - T_2 y_{LL1} + \left(z_1^{LT_{LL1}} \right)^2 (-x'_{LL1} + y_{LL1})$
LL2_y	y_{LL2}	Algeb	$T_3 (-x'_{LL2} + y_{LL1}) + T_4 x'_{LL2} - T_4 y_{LL2} + \left(z_1^{LT_{LL2}} \right)^2 (-x'_{LL2} + y_{LL2})$
Vks_y	y_{Vks}	Algeb	$K_S y_{LL2} - y_{Vks}$
WO_y	y_{WO}	Algeb	$T_5 z_0^{LT_{WO}} (-x'_{WO} + y_{Vks}) + T_6 x'_{WO} z_1^{LT_{WO}} - T_6 y_{WO}$
Vss	V_{ss}	Algeb	$L_{SMAX} z_u^{VLIM} + L_{SMIN} z_l^{VLIM} - V_{ss} + y_{WO} z_i^{VLIM}$
tm	τ_m	ExtAl- geb	0
te	τ_e	ExtAl- geb	0
v	V	ExtAl- geb	0
f	f	ExtAl- geb	0
vi	v_i	ExtAl- geb	$u_e v_{sout}$

Services

Name	Symbol	Equation	Type
ue	u_e	$u u_{ee}$	ConstService

Discretes

Name	Symbol	Type	Info
dv	dV/dt	Derivative	Finite difference of bus voltage
SW	SW	Switcher	
F2_LT1	LT_{F2}	LessThan	
F2_LT2	LT_{F2}	LessThan	
F2_LT3	LT_{F2}	LessThan	
F2_LT4	LT_{F2}	LessThan	
LL1_LT1	LT_{LL1}	LessThan	
LL1_LT2	LT_{LL1}	LessThan	
LL2_LT1	LT_{LL2}	LessThan	
LL2_LT2	LT_{LL2}	LessThan	
WO_LT	LT_{WO}	LessThan	
VLIM	$VLIM$	Limiter	Vss limiter
OLIM	$OLIM$	Limiter	output limiter

Blocks

Name	Symbol	Type	Info
F1	$F1$	Lag2ndOrd	
F2	$F2$	LeadLag2ndOrd	
LL1	$LL1$	LeadLag	
LL2	$LL2$	LeadLag	
Vks	Vks	Gain	
WO	WO	WashoutOrLag	

Config Fields in [IEEEEST]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
freq_model		BusFreq	default freq. measurement model	('BusFreq',)

5.20.2 ST2CUT

ST2CUT stabilizer model. Automatically adds frequency measurement devices if not provided.

Input signals (MODE and MODE2):

0 - Disable input signal 1 (s1) - Rotor speed deviation (p.u.), 2 (s2) - Bus frequency deviation (*) (p.u.), 3 (s3) - Generator P electrical in Gen MVABase (p.u.), 4 (s4) - Generator accelerating power (p.u.), 5 (s5) - Bus voltage (p.u.), 6 (s6) - Derivative of p.u. bus voltage.

(*) Due to the frequency measurement implementation difference, mode 2 is likely to yield different results across software.

Blocks are named *LL1*, *LL2*, *LL3*, *LL4* in sequence. Two limiters are named *VSS_lim* and *OLIM* in sequence.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
avr		Exciter idx			mandatory
MODE		Input signal 1			mandatory
busr		Remote bus 1			
busf		BusFreq idx for signal 1 mode 2			
MODE2		Input signal 2			
busr2		Remote bus 2			
busf2		BusFreq idx for signal 2 mode 2			
K1	K_1	Transducer 1 gain	1		
K2	K_2	Transducer 2 gain	1		
T1	T_1	Transducer 1 time const.	1		
T2	T_2	Transducer 2 time const.	1		
T3	T_3	Washout int. time const.	1		
T4	T_4	Washout delay time const.	0.200		
T5	T_5	Leadlag 1 time const. (1)	1		
T6	T_6	Leadlag 1 time const. (2)	0.500		
T7	T_7	Leadlag 2 time const. (1)	1		
T8	T_8	Leadlag 2 time const. (2)	1		
T9	T_9	Leadlag 3 time const. (1)	1		
T10	T_{10}	Leadlag 3 time const. (2)	0.200		
LSMAX	L_{SMAX}	Max. output limit	0.300		
LSMIN	L_{SMIN}	Min. output limit	-0.300		
VCU	V_{CU}	Upper enabling bus voltage	999	<i>p.u.</i>	
VCL	V_{CL}	Upper enabling bus voltage	-999	<i>p.u.</i>	
syn		Retrieved generator idx	0		
bus		Retrieved bus idx			
Sn	S_n	Generator power base	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
L1_y	y_{L1}	State	State in lag transfer function		v_str
L2_y	y_{L2}	State	State in lag transfer function		v_str
WO_x	x'_{WO}	State	State in washout filter		v_str
LL1_x	x'_{LL1}	State	State in lead-lag		v_str
LL2_x	x'_{LL2}	State	State in lead-lag		v_str
LL3_x	x'_{LL3}	State	State in lead-lag		v_str
omega	ω	ExtState	Generator speed	<i>p.u.</i>	
vsout	v_{sout}	Algeb	PSS output voltage to exciter		
sig	S_{ig}	Algeb	Input signal		v_str
sig2	S_{ig2}	Algeb	Input signal 2		v_str
IN	I_N	Algeb	Sum of inputs		v_str
WO_y	y_{WO}	Algeb	Output of washout filter		v_str
LL1_y	y_{LL1}	Algeb	Output of lead-lag		v_str
LL2_y	y_{LL2}	Algeb	Output of lead-lag		v_str
LL3_y	y_{LL3}	Algeb	Output of lead-lag		v_str
VSS_x	x_{VSS}	Algeb	Value before limiter		v_str
VSS_y	y_{VSS}	Algeb	Output after limiter and post gain		v_str
tm	τ_m	ExtAlgeb	Generator mechanical input		
te	τ_e	ExtAlgeb	Generator electrical output		
v	V	ExtAlgeb	Bus (or busr, if given) terminal voltage		
f	f	ExtAlgeb	Bus frequency		
vi	v_i	ExtAlgeb	Exciter input voltage		
v2	V	ExtAlgeb	Bus (or busr2, if given) terminal voltage		
f2	f_2	ExtAlgeb	Bus frequency 2		

Initialization Equations

Name	Symbol	Type	Initial Value
L1_y	y_{L1}	State	$K_1 S_{ig}$
L2_y	y_{L2}	State	$K_2 S_{ig2}$
WO_x	x'_{WO}	State	I_N
LL1_x	x'_{LL1}	State	y_{WO}
LL2_x	x'_{LL2}	State	y_{LL1}
LL3_x	x'_{LL3}	State	y_{LL2}
omega	ω	ExtState	
vsout	v_{sout}	Algeb	
sig	S_{ig}	Algeb	$V s_5^{SW} + s_1^{SW} (\omega - 1) + s_4^{SW} (\tau_m - \tau_{m0}) + \frac{\tau_{m0} s_3^{SW}}{(Sb/Sn)}$
sig2	S_{ig2}	Algeb	$V s_5^{SW2} + s_1^{SW2} (\omega - 1) + s_4^{SW2} (\tau_m - \tau_{m0}) + \frac{\tau_{m0} s_3^{SW2}}{(Sb/Sn)}$
IN	I_N	Algeb	$u_e (y_{L1} + y_{L2})$
WO_y	y_{WO}	Algeb	$x'_{WO} z_1^{LT_{WO}}$
LL1_y	y_{LL1}	Algeb	y_{WO}
LL2_y	y_{LL2}	Algeb	y_{LL1}
LL3_y	y_{LL3}	Algeb	y_{LL2}
VSS_x	x_{VSS}	Algeb	y_{LL3}
VSS_y	y_{VSS}	Algeb	$L_{SMAX} z_u^{lim_{VSS}} + L_{SMIN} z_i^{lim_{VSS}} + x_{VSS} z_i^{lim_{VSS}}$
tm	τ_m	ExtAlgeb	
te	τ_e	ExtAlgeb	
v	V	ExtAlgeb	
f	f	ExtAlgeb	
vi	v_i	ExtAlgeb	
v2	V	ExtAlgeb	
f2	f_2	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
L1_y	y_{L1}	State	$K_1 S_{ig} - y_{L1}$	T_1
L2_y	y_{L2}	State	$K_2 S_{ig2} - y_{L2}$	T_2
WO_x	x'_{WO}	State	$I_N - x'_{WO}$	T_4
LL1_x	x'_{LL1}	State	$-x'_{LL1} + y_{WO}$	T_6
LL2_x	x'_{LL2}	State	$-x'_{LL2} + y_{LL1}$	T_8
LL3_x	x'_{LL3}	State	$-x'_{LL3} + y_{LL2}$	T_{10}
omega	ω	ExtState	0	

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
vsout	v_{sout}	Algeb	$u_e y_{VSS} z_i^{OLIM} - v_{sout}$
sig	S_{ig}	Algeb	$-S_{ig} + V s_5^{SW} + s_1^{SW} (\omega - 1) + s_2^{SW} (f - 1) + s_4^{SW} (\tau_m - \tau_{m0}) + s_6^{SW} v^{dv} + \frac{\tau_e s_3^{SW}}{(Sb/Sn)}$
sig2	S_{ig2}	Algeb	$-S_{ig2} + V s_5^{SW2} + s_1^{SW2} (\omega - 1) + s_2^{SW2} (f_2 - 1) + s_4^{SW2} (\tau_m - \tau_{m0}) + s_6^{SW2} v^{dv2} + \frac{\tau_e s_3^{SW2}}{(Sb/Sn)}$
IN	I_N	Algeb	$-I_N + u_e (y_{L1} + y_{L2})$
WO_y	y_{WO}	Algeb	$T_3 z_0^{LTWO} (I_N - x'_{WO}) + T_4 x'_{WO} z_1^{LTWO} - T_4 y_{WO}$
LL1_y	y_{LL1}	Algeb	$T_5 (-x'_{LL1} + y_{WO}) + T_6 x'_{LL1} - T_6 y_{LL1} + \left(z_1^{LT_{LL1}}\right)^2 (-x'_{LL1} + y_{LL1})$
LL2_y	y_{LL2}	Algeb	$T_7 (-x'_{LL2} + y_{LL1}) + T_8 x'_{LL2} - T_8 y_{LL2} + \left(z_1^{LT_{LL2}}\right)^2 (-x'_{LL2} + y_{LL2})$
LL3_y	y_{LL3}	Algeb	$T_9 (-x'_{LL3} + y_{LL2}) + T_{10} x'_{LL3} - T_{10} y_{LL3} + \left(z_1^{LT_{LL3}}\right)^2 (-x'_{LL3} + y_{LL3})$
VSS_x	x_{VSS}	Algeb	$-x_{VSS} + y_{LL3}$
VSS_y	y_{VSS}	Algeb	$L_{SMAX} z_u^{lim_{VSS}} + L_{SMIN} z_l^{lim_{VSS}} + x_{VSS} z_i^{lim_{VSS}} - y_{VSS}$
tm	τ_m	ExtAl- geb	0
te	τ_e	ExtAl- geb	0
v	V	ExtAl- geb	0
f	f	ExtAl- geb	0
vi	v_i	ExtAl- geb	$u_e v_{sout}$
v2	V	ExtAl- geb	0
f2	f_2	ExtAl- geb	0

Services

Name	Symbol	Equation	Type
ue	u_e	uu_{ee}	ConstService
VOU	VOU	$VCUr + V_0$	ConstService
VOL	VOL	$VCLr + V_0$	ConstService

Discretes

Name	Symbol	Type	Info
dv	dv	Derivative	
dv2	$dv2$	Derivative	
SW	SW	Switcher	
SW2	$SW2$	Switcher	
WO_LT	LT_{WO}	LessThan	
LL1_LT1	LT_{LL1}	LessThan	
LL1_LT2	LT_{LL1}	LessThan	
LL2_LT1	LT_{LL2}	LessThan	
LL2_LT2	LT_{LL2}	LessThan	
LL3_LT1	LT_{LL3}	LessThan	
LL3_LT2	LT_{LL3}	LessThan	
VSS_lim	lim_{VSS}	HardLimiter	
OLIM	$OLIM$	Limiter	output limiter

Blocks

Name	Symbol	Type	Info
L1	$L1$	Lag	Transducer 1
L2	$L2$	Lag	Transducer 2
WO	WO	WashoutOrLag	
LL1	$LL1$	LeadLag	
LL2	$LL2$	LeadLag	
LL3	$LL3$	LeadLag	
VSS	VSS	GainLimiter	

Config Fields in [ST2CUT]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
freq_model		BusFreq	default freq. measurement model	('BusFreq',)

5.21 PhasorMeasurement

Phasor measurements

Common Parameters: u, name

Common Variables: am, vm

Available models: *PMU*

5.21.1 PMU

Simple phasor measurement unit model.

This model tracks the bus voltage magnitude and phase angle, each using a low-pass filter.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		bus idx			mandatory
Ta	T_a	angle filter time constant	0.100		
Tv	T_v	voltage filter time constant	0.100		

Variables

Name	Symbol	Type	Description	Unit	Properties
am	θ_m	State	phase angle measurement	<i>rad.</i>	v_str
vm	V_m	State	voltage magnitude measurement	<i>p.u.(kV)</i>	v_str
a	θ	ExtAlgeb	Bus voltage phase angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
am	θ_m	State	θ
vm	V_m	State	V
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation " $\dot{x} = f(x, y)$ "	T (LHS)
am	θ_m	State	$\dot{\theta} - \theta_m$	T_a
vm	V_m	State	$\dot{V} - V_m$	T_v

Algebraic Equations

Name	Symbol	Type	RHS of Equation " $0 = g(x, y)$ "
a	θ	ExtAlgeb	0
v	V	ExtAlgeb	0

Config Fields in [PMU]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.22 RenAerodynamics

Renewable aerodynamics group.

Common Parameters: u, name, rego

Common Variables: theta

Available models: *WTARA1*, *WTARV1*

5.22.1 WTARA1

Wind turbine aerodynamics model (no wind speed details).

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
rego		Renewable governor idx			mandatory
Ka	K_a	Aerodynamics gain	1	<i>p.u./deg.</i>	non_negative
theta0	θ_0	Initial pitch angle	0	<i>deg.</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
theta	θ	Algeb	Pitch angle	<i>rad</i>	v_str
Pmg	Pmg	ExtAlgeb			

Initialization Equations

Name	Symbol	Type	Initial Value
theta	θ	Algeb	θ_{0r}
Pmg	Pmg	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
theta	θ	Algeb	$-\theta + \theta_{0r}$
Pmg	Pmg	ExtAlgeb	$-K_a \theta (\theta - \theta_0)$

Services

Name	Symbol	Equation	Type
theta0r	θ_{0r}	$\frac{\pi \theta_0}{180}$	ConstService

Config Fields in [WTARA1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.22.2 WTARV1

Wind turbine aerodynamics model with wind velocity details.

Work is in progress.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
rego		Renewable governor idx			mandatory
nblade		number of blades	3		
ngen		number of wind generator units	50		
npole		number of poles in generator	4		
R		rotor radius	30	<i>m</i>	
ngb		gear box ratio	5		
rho		air density	1.200	<i>kg/m3</i>	
Sn	S_n		0		

Variables

Name	Symbol	Type	Description	Unit	Properties
theta	θ	Algeb	Pitch angle	<i>rad</i>	
Pmg	P_{mg}	ExtAlgeb			

Initialization Equations

Name	Symbol	Type	Initial Value
theta	θ	Algeb	
Pmg	P_{mg}	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation " $0 = g(x, y)$ "
theta	θ	Algeb	0
Pmg	P_{mg}	ExtAlgeb	0

Config Fields in [WTARV1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.23 RenExciter

Renewable electrical control (exciter) group.

Common Parameters: u, name, reg

Common Variables: Pref, Qref, wg, Pord

Available models: *REECA1*, *REECA1E*, *REECA1G*

5.23.1 REECA1

Renewable energy electrical control.

There are two user-defined voltages: *Vref0* and *Vref1*.

- The difference between the initial bus voltage and *Vref0* should be within the voltage deadbands *dbd1* and *dbd2*.
- If *VFLAG=0*, the input to the second PI controller will be *Vref1*.

Regarding the additional reactive current injection during voltage dip:

- Exercise caution when coordinating the parameters *dbd1*, *dbd2*, *Vdip*, and *Vup* to avoid unintended responses.

- K_{qv} in pu current / pu voltage deviation controls the intensity of reactive power injection. The parameter needs to be tuned properly to avoid voltage overshoot.
- When multiple renewable generators are connected to the same bus, K_{qv} shall be reduced accordingly to avoid excessive reactive power injection.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
reg		Renewable generator idx			mandatory
busr		Optional remote bus for voltage control			
PFLAG		Power factor control flag; 1-PF control, 0-Q control		<i>bool</i>	mandatory
VFLAG		Voltage control flag; 1-Q control, 0-V control		<i>bool</i>	mandatory
QFLAG		Q control flag; 1-V or Q control, 0-const. PF or Q		<i>bool</i>	mandatory
PFLAG		P speed-dependency flag; 1-has speed dep., 0-no dep.		<i>bool</i>	mandatory
PQFLAG		P/Q priority flag for I limit; 0-Q priority, 1-P priority		<i>bool</i>	mandatory
Vdip	V_{dip}	Low V threshold to activate Iqinj logic	0.800	<i>p.u.</i>	
Vup	V_{up}	V threshold above which to activate Iqinj logic	1.200	<i>p.u.</i>	
Trv	T_{rv}	Voltage filter time constant	0.020		
dbd1	$dbd1$	Lower bound of the voltage deadband (≤ 0)	-0.020		
dbd2	$dbd2$	Upper bound of the voltage deadband (≥ 0)	0.020		
Kqv	K_{qv}	Gain to compute Iqinj from V error (caution!!)	1		
Iqh1	I_{qh1}	Upper limit on Iqinj	999		
Iql1	I_{ql1}	Lower limit on Iqinj	-999		
Vref0	V_{ref0}	User defined Vref (if 0, use initial bus V)	1		
Iqfrz	I_{qfrz}	Hold Iqinj at the value for Thld (>0) seconds following a Vdip	0		
Thld	T_{hld}	Time for which Iqinj is held. Hold at Iqinj if >0 ; hold at State 1 if <0	0	<i>s</i>	
Thld2	T_{hld2}	Time for which IPMAX is held after voltage dip ends	0	<i>s</i>	
Tp	T_p	Filter time constant for Pe	0.020	<i>s</i>	
QMax	Q_{max}	Upper limit for reactive power regulator	999		
QMin	Q_{min}	Lower limit for reactive power regulator	-999		
VMAX	V_{max}	Upper limit for voltage control	999		
VMIN	V_{min}	Lower limit for voltage control	-999		
Kqp	K_{qp}	Proportional gain for reactive power error	1		
Kqi	K_{qi}	Integral gain for reactive power error	0.100		
Kvp	K_{vp}	Proportional gain for voltage error	1		
Kvi	K_{vi}	Integral gain for voltage error	0.100		
Vref1	V_{ref1}	Voltage ref. if VFLAG=0	1		non_zero
Tiq	T_{iq}	Filter time constant for Iq	0.020		
dPmax	dP_{max}	Power reference max. ramp rate (>0)	999		
dPmin	dP_{min}	Power reference min. ramp rate (<0)	-999		
PMAX	P_{max}	Max. active power limit >0	999		

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Table 17 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
PMIN	P_{min}	Min. active power limit	0		
Imax	I_{max}	Max. apparent current limit	999		current
Tpord	T_{pord}	Filter time constant for power setpoint	0.020		
Vq1	V_{q1}	Reactive power V-I pair (point 1), voltage	0.200		
Iq1	I_{q1}	Reactive power V-I pair (point 1), current	2		current
Vq2	V_{q2}	Reactive power V-I pair (point 2), voltage	0.400		
Iq2	I_{q2}	Reactive power V-I pair (point 2), current	4		current
Vq3	V_{q3}	Reactive power V-I pair (point 3), voltage	0.800		
Iq3	I_{q3}	Reactive power V-I pair (point 3), current	8		current
Vq4	V_{q4}	Reactive power V-I pair (point 4), voltage	1		
Iq4	I_{q4}	Reactive power V-I pair (point 4), current	10		current
Vp1	V_{p1}	Active power V-I pair (point 1), voltage	0.200		
Ip1	I_{p1}	Active power V-I pair (point 1), current	2		current
Vp2	V_{p2}	Active power V-I pair (point 2), voltage	0.400		
Ip2	I_{p2}	Active power V-I pair (point 2), current	4		current
Vp3	V_{p3}	Active power V-I pair (point 3), voltage	0.800		
Ip3	I_{p3}	Active power V-I pair (point 3), current	8		current
Vp4	V_{p4}	Active power V-I pair (point 4), voltage	1		
Ip4	I_{p4}	Active power V-I pair (point 4), current	12		current
bus		Retrieved bus idx			
gen		Retrieved StaticGen idx			
Sn	S_n		0		

Variables

Name	Symbol	Type	Description	Unit	Properties
s0_y	y_{s0}	State	State in lag transfer function		v_str
S1_y	y_{S1}	State	State in lag transfer function		v_str
PIQ_xi	xi_{PIQ}	State	Integrator output		v_str
s4_y	y_{s4}	State	State in lag transfer function		v_str
pfilt_y	$y_{P_{filt}}$	State	State in lag TF		v_str
s5_y	y_{s5}	State	State in lag TF		v_str
PIV_xi	xi_{PIV}	State	Integrator output		v_str
Pord	P_{ord}	AliasState	Alias of s5_y		
vp	V_p	Algeb	Sensed lower-capped voltage		v_str
pfaref	Φ_{ref}	Algeb	power factor angle ref	rad	v_str
Qref	Q_{ref}	Algeb	external Q ref	p.u.	v_str
Qcpf	Q_{cpf}	Algeb	Q calculated from P and power factor	p.u.	v_str
PFsel	PF_{sel}	Algeb	Output of PFFLAG selector		v_str
Qerr	Q_{err}	Algeb	Reactive power error		v_str
PIQ_ys	y_{SPIQ}	Algeb	PI summation before limit		v_str

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Table 18 – continued from previous page

Name	Symbol	Type	Description	Unit	Properties
PIQ_y	y_{PIQ}	Algeb	PI output		v_str
Vsel_x	$x_{V_{sel}}$	Algeb	Value before limiter		v_str
Vsel_y	$y_{V_{sel}}$	Algeb	Output after limiter and post gain		v_str
Verr	V_{err}	Algeb	Voltage error (Vref0)		v_str
dbV_y	y_{dbV}	Algeb	Deadband type 1 output		v_str
Iqinj	I_{qinj}	Algeb	Additional Iq signal during under- or over-voltage		v_str
wg	ω_g	Algeb	Drive train generator speed		v_str
Pref	P_{ref}	Algeb	external P ref	<i>p.u.</i>	v_str
Psel	P_{sel}	Algeb	Output selection of PFLAG		v_str
VDL1_y	$y_{V_{DL1}}$	Algeb	Output of piecewise		v_str
VDL2_y	$y_{V_{DL2}}$	Algeb	Output of piecewise		v_str
Ipmax	I_{pmax}	Algeb	Upper limit on Ipcmd		v_str
Iqmax	I_{qmax}	Algeb	Upper limit on Iqcmd		v_str
PIV_ys	y_{sPIV}	Algeb	PI summation before limit		v_str
PIV_y	y_{PIV}	Algeb	PI output		v_str
Qsel	Q_{sel}	Algeb	Selection output of QFLAG		v_str
IpHL_x	x_{IpHL}	Algeb	Value before limiter		v_str
IpHL_y	y_{IpHL}	Algeb	Output after limiter and post gain		v_str
IqHL_x	x_{IqHL}	Algeb	Value before limiter		v_str
IqHL_y	y_{IqHL}	Algeb	Output after limiter and post gain		v_str
a	θ	ExtAlgeb	Bus voltage angle		
v	V_d	ExtAlgeb	d-axis bus voltage magnitude		
Pe	Pe	ExtAlgeb	Retrieved Pe of RenGen		
Qe	Qe	ExtAlgeb	Retrieved Qe of RenGen		
Ipcmd	$Ipcmd$	ExtAlgeb	Retrieved Ipcmd of RenGen		
Iqcmd	$Iqcmd$	ExtAlgeb	Retrieved Iqcmd of RenGen		

Initialization Equations

Name	Symbol	Type	Initial Value
s0_y	y_{s0}	State	V_d
S1_y	y_{S_1}	State	Pe
PIQ_xi	x_{iPIQ}	State	0.0
s4_y	y_{s4}	State	$\frac{PF_{sel}}{V_p}$
pfilt_y	$y_{P_{filt}}$	State	P_{ref}
s5_y	y_{s5}	State	P_{sel}
PIV_xi	x_{iPIV}	State	$-Iqcmd_0 s_1^{SWV}$
Pord	$Pord$	AliasState	
vp	V_p	Algeb	$V_d z_i^{V_{Lower}} + 0.01 z_l^{V_{Lower}}$
pfaref	Φ_{ref}	Algeb	Φ_{ref0}
Qref	Q_{ref}	Algeb	$-q_{ref0}$

Table 19 – continued from previous page

Name	Symbol	Type	Initial Value
Qcpf	Q_{cpf}	Algeb	Q_0
PFsel	PF_{sel}	Algeb	$Q_{cpf}s_1^{SW_{PF}} + Q_{ref}s_0^{SW_{PF}}$
Qerr	Q_{err}	Algeb	$PF_{sel}z_i^{PF_{lim}} + Q_{max}z_u^{PF_{lim}} + Q_{min}z_l^{PF_{lim}} - Q_e$
PIQ_ys	y_{SPIQ}	Algeb	$K_{qp}Q_{err}s_1^{SW_V}$
PIQ_y	y_{PIQ}	Algeb	$V_{max}z_u^{lim_{PIQ}} + V_{min}z_l^{lim_{PIQ}} + y_{SPIQ}z_i^{lim_{PIQ}}$
Vsel_x	$x_{V_{sel}}$	Algeb	$s_0^{SW_V} \left(Q_{cpf}s_1^{SW_{PF}} + Q_{ref}s_0^{SW_{PF}} + V_{ref1} \right) + s_1^{SW_V}y_{PIQ}$
Vsel_y	$y_{V_{sel}}$	Algeb	$V_{max}z_u^{lim_{V_{sel}}} + V_{min}z_l^{lim_{V_{sel}}} + x_{V_{sel}}z_i^{lim_{V_{sel}}}$
Verr	V_{err}	Algeb	$V_{ref0} - y_{s0}$
dbV_y	y_{dbV}	Algeb	$1.0z_l^{db_{abV}}(V_{err} - d_{bd1}) + 1.0z_u^{db_{abV}}(V_{err} - d_{bd2})$
Iqinj	I_{qinj}	Algeb	$K_{qv}y_{dbV}z_{Vdip} + fThld(1 - z_{Vdip})(I_{qfrz}pThld + K_{qv}nThldy_{dbV})$
wg	ω_g	Algeb	1.0
Pref	P_{ref}	Algeb	$\frac{P_0}{\omega_g}$
Psel	P_{sel}	Algeb	$\omega_g s_1^{SW_P} y_{P_{filt}} + s_0^{SW_P} y_{P_{filt}}$
VDL1_y	y_{VDL1}	Algeb	$FixPiecewise((I_{q1}, V_{q1} \geq y_{s0}), (I_{q1} + k_{Vq12}(-V_{q1} + y_{s0}), V_{q2} \geq y_{s0}), (I_{q2} + k_{Vq23}(-V_{q2} + y_{s0}), V_{q3} \geq y_{s0}), (I_{q3} + k_{Vq34}(-V_{q3} + y_{s0}), V_{q4} \geq y_{s0}), (I_{q4} + k_{Vq45}(-V_{q4} + y_{s0}), V_{q5} \geq y_{s0}), (I_{q5} + k_{Vq56}(-V_{q5} + y_{s0}), V_{q6} \geq y_{s0}), (I_{q6} + k_{Vq67}(-V_{q6} + y_{s0}), V_{q7} \geq y_{s0}), (I_{q7} + k_{Vq78}(-V_{q7} + y_{s0}), V_{q8} \geq y_{s0}), (I_{q8} + k_{Vq89}(-V_{q8} + y_{s0}), V_{q9} \geq y_{s0}), (I_{q9} + k_{Vq90}(-V_{q9} + y_{s0}), V_{q10} \geq y_{s0}), (I_{q10} + k_{Vq101}(-V_{q10} + y_{s0}), V_{q11} \geq y_{s0}), (I_{q11} + k_{Vq112}(-V_{q11} + y_{s0}), V_{q12} \geq y_{s0}), (I_{q12} + k_{Vq123}(-V_{q12} + y_{s0}), V_{q13} \geq y_{s0}), (I_{q13} + k_{Vq134}(-V_{q13} + y_{s0}), V_{q14} \geq y_{s0}), (I_{q14} + k_{Vq145}(-V_{q14} + y_{s0}), V_{q15} \geq y_{s0}), (I_{q15} + k_{Vq156}(-V_{q15} + y_{s0}), V_{q16} \geq y_{s0}), (I_{q16} + k_{Vq167}(-V_{q16} + y_{s0}), V_{q17} \geq y_{s0}), (I_{q17} + k_{Vq178}(-V_{q17} + y_{s0}), V_{q18} \geq y_{s0}), (I_{q18} + k_{Vq189}(-V_{q18} + y_{s0}), V_{q19} \geq y_{s0}), (I_{q19} + k_{Vq190}(-V_{q19} + y_{s0}), V_{q20} \geq y_{s0}), (I_{q20} + k_{Vq201}(-V_{q20} + y_{s0}), V_{q21} \geq y_{s0}), (I_{q21} + k_{Vq212}(-V_{q21} + y_{s0}), V_{q22} \geq y_{s0}), (I_{q22} + k_{Vq223}(-V_{q22} + y_{s0}), V_{q23} \geq y_{s0}), (I_{q23} + k_{Vq234}(-V_{q23} + y_{s0}), V_{q24} \geq y_{s0}), (I_{q24} + k_{Vq245}(-V_{q24} + y_{s0}), V_{q25} \geq y_{s0}), (I_{q25} + k_{Vq256}(-V_{q25} + y_{s0}), V_{q26} \geq y_{s0}), (I_{q26} + k_{Vq267}(-V_{q26} + y_{s0}), V_{q27} \geq y_{s0}), (I_{q27} + k_{Vq278}(-V_{q27} + y_{s0}), V_{q28} \geq y_{s0}), (I_{q28} + k_{Vq289}(-V_{q28} + y_{s0}), V_{q29} \geq y_{s0}), (I_{q29} + k_{Vq290}(-V_{q29} + y_{s0}), V_{q30} \geq y_{s0}), (I_{q30} + k_{Vq301}(-V_{q30} + y_{s0}), V_{q31} \geq y_{s0}), (I_{q31} + k_{Vq312}(-V_{q31} + y_{s0}), V_{q32} \geq y_{s0}), (I_{q32} + k_{Vq323}(-V_{q32} + y_{s0}), V_{q33} \geq y_{s0}), (I_{q33} + k_{Vq334}(-V_{q33} + y_{s0}), V_{q34} \geq y_{s0}), (I_{q34} + k_{Vq345}(-V_{q34} + y_{s0}), V_{q35} \geq y_{s0}), (I_{q35} + k_{Vq356}(-V_{q35} + y_{s0}), V_{q36} \geq y_{s0}), (I_{q36} + k_{Vq367}(-V_{q36} + y_{s0}), V_{q37} \geq y_{s0}), (I_{q37} + k_{Vq378}(-V_{q37} + y_{s0}), V_{q38} \geq y_{s0}), (I_{q38} + k_{Vq389}(-V_{q38} + y_{s0}), V_{q39} \geq y_{s0}), (I_{q39} + k_{Vq390}(-V_{q39} + y_{s0}), V_{q40} \geq y_{s0}), (I_{q40} + k_{Vq401}(-V_{q40} + y_{s0}), V_{q41} \geq y_{s0}), (I_{q41} + k_{Vq412}(-V_{q41} + y_{s0}), V_{q42} \geq y_{s0}), (I_{q42} + k_{Vq423}(-V_{q42} + y_{s0}), V_{q43} \geq y_{s0}), (I_{q43} + k_{Vq434}(-V_{q43} + y_{s0}), V_{q44} \geq y_{s0}), (I_{q44} + k_{Vq445}(-V_{q44} + y_{s0}), V_{q45} \geq y_{s0}), (I_{q45} + k_{Vq456}(-V_{q45} + y_{s0}), V_{q46} \geq y_{s0}), (I_{q46} + k_{Vq467}(-V_{q46} + y_{s0}), V_{q47} \geq y_{s0}), (I_{q47} + k_{Vq478}(-V_{q47} + y_{s0}), V_{q48} \geq y_{s0}), (I_{q48} + k_{Vq489}(-V_{q48} + y_{s0}), V_{q49} \geq y_{s0}), (I_{q49} + k_{Vq490}(-V_{q49} + y_{s0}), V_{q50} \geq y_{s0}), (I_{q50} + k_{Vq501}(-V_{q50} + y_{s0}), V_{q51} \geq y_{s0}), (I_{q51} + k_{Vq512}(-V_{q51} + y_{s0}), V_{q52} \geq y_{s0}), (I_{q52} + k_{Vq523}(-V_{q52} + y_{s0}), V_{q53} \geq y_{s0}), (I_{q53} + k_{Vq534}(-V_{q53} + y_{s0}), V_{q54} \geq y_{s0}), (I_{q54} + k_{Vq545}(-V_{q54} + y_{s0}), V_{q55} \geq y_{s0}), (I_{q55} + k_{Vq556}(-V_{q55} + y_{s0}), V_{q56} \geq y_{s0}), (I_{q56} + k_{Vq567}(-V_{q56} + y_{s0}), V_{q57} \geq y_{s0}), (I_{q57} + k_{Vq578}(-V_{q57} + y_{s0}), V_{q58} \geq y_{s0}), (I_{q58} + k_{Vq589}(-V_{q58} + y_{s0}), V_{q59} \geq y_{s0}), (I_{q59} + k_{Vq590}(-V_{q59} + y_{s0}), V_{q60} \geq y_{s0}), (I_{q60} + k_{Vq601}(-V_{q60} + y_{s0}), V_{q61} \geq y_{s0}), (I_{q61} + k_{Vq612}(-V_{q61} + y_{s0}), V_{q62} \geq y_{s0}), (I_{q62} + k_{Vq623}(-V_{q62} + y_{s0}), V_{q63} \geq y_{s0}), (I_{q63} + k_{Vq634}(-V_{q63} + y_{s0}), V_{q64} \geq y_{s0}), (I_{q64} + k_{Vq645}(-V_{q64} + y_{s0}), V_{q65} \geq y_{s0}), (I_{q65} + k_{Vq656}(-V_{q65} + y_{s0}), V_{q66} \geq y_{s0}), (I_{q66} + k_{Vq667}(-V_{q66} + y_{s0}), V_{q67} \geq y_{s0}), (I_{q67} + k_{Vq678}(-V_{q67} + y_{s0}), V_{q68} \geq y_{s0}), (I_{q68} + k_{Vq689}(-V_{q68} + y_{s0}), V_{q69} \geq y_{s0}), (I_{q69} + k_{Vq690}(-V_{q69} + y_{s0}), V_{q70} \geq y_{s0}), (I_{q70} + k_{Vq701}(-V_{q70} + y_{s0}), V_{q71} \geq y_{s0}), (I_{q71} + k_{Vq712}(-V_{q71} + y_{s0}), V_{q72} \geq y_{s0}), (I_{q72} + k_{Vq723}(-V_{q72} + y_{s0}), V_{q73} \geq y_{s0}), (I_{q73} + k_{Vq734}(-V_{q73} + y_{s0}), V_{q74} \geq y_{s0}), (I_{q74} + k_{Vq745$

Differential Equations

Name	Sym- bol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
s0_y	y_{s0}	State	$V_d - y_{s0}$	T_{rv}
S1_y	y_{S1}	State	$Pe - y_{S1}$	T_p
PIQ_xi	xi_{PIQ}	State	$K_{qi} (1 - z_{Vdip}) (Q_{err} s_1^{SW_V} + 2y_{PIQ} - 2ys_{PIQ})$	
s4_y	y_{s4}	State	$(1 - z_{Vdip}) \left(\frac{PF_{sel}}{V_p} - y_{s4} \right)$	T_{iq}
pfilt_y	$y_{P_{filt}}$	State	$P_{ref} - y_{P_{filt}}$	0.02
s5_y	y_{s5}	State	$(1 - z_{Vdip}) (P_{sel} - y_{s5})$	T_{pord}
PIV_xi	xi_{PIV}	State	$K_{vi} (1 - z_{Vdip}) \left(s_1^{SW_V} \left(-s_0^{SW_V} y_{s0} + y_{V_{sel}} \right) + 2y_{PIV} - 2ys_I \right)$	
Pord	$Pord$	AliasState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
vp	V_p	Algeb	$V_d z_i^{V_{Lower}} - V_p + 0.01 z_l^{V_{Lower}}$
pfaref	Φ_{ref}	Algeb	$\Phi_{ref0} - \Phi_{ref}$
Qref	Q_{ref}	Algeb	$-Q_{ref} - q_{ref0}$
Qcpf	Q_{cpf}	Algeb	$(1 - z_1^{z_p}) (-Q_{cpf} + y_{S1} \tan(\Phi_{ref}))$
PFsel	PF_{sel}	Algeb	$-PF_{sel} + Q_{cpf} s_1^{SW_{PF}} + Q_{ref} s_0^{SW_{PF}}$
Qerr	Q_{err}	Algeb	$PF_{sel} z_i^{PF_{lim}} - Q_{err} + Q_{max} z_u^{PF_{lim}} + Q_{min} z_l^{PF_{lim}} - Q_e$
PIQ_ys	ys_{PIQ}	Algeb	$(1 - z_{Vdip}) \left(K_{qp} Q_{err} s_1^{SW_V} + xi_{PIQ} - ys_{PIQ} \right)$
PIQ_y	y_{PIQ}	Algeb	$(1 - z_{Vdip}) \left(V_{max} z_u^{lim_{PIQ}} + V_{min} z_l^{lim_{PIQ}} - y_{PIQ} + ys_{PIQ} z_i^{lim_{PIQ}} \right)$
Vsel_x	$x_{V_{sel}}$	Algeb	$s_0^{SW_V} \left(Q_{cpf} s_1^{SW_{PF}} + Q_{ref} s_0^{SW_{PF}} + V_{ref1} \right) + s_1^{SW_V} y_{PIQ} - x_{V_{sel}}$
Vsel_y	$y_{V_{sel}}$	Algeb	$V_{max} z_u^{lim_{V_{sel}}} + V_{min} z_l^{lim_{V_{sel}}} + x_{V_{sel}} z_i^{lim_{V_{sel}}} - y_{V_{sel}}$
Verr	V_{err}	Algeb	$-V_{err} + V_{ref0} - y_{s0}$
dbV_y	y_{dbV}	Algeb	$-y_{dbV} + 1.0 z_l^{db_{dbV}} (V_{err} - db_{d1}) + 1.0 z_u^{db_{dbV}} (V_{err} - db_{d2})$
Iqinj	I_{qinj}	Algeb	$-I_{qinj} + K_{qv} y_{dbV} z_{Vdip} + fThld (1 - z_{Vdip}) (I_{qfrz} pThld + K_{qv} nThld y_{dbV})$
wg	ω_g	Algeb	$1.0 - \omega_g$
Pref	P_{ref}	Algeb	$\frac{P_0}{\omega_g} - P_{ref}$
Psel	P_{sel}	Algeb	$-P_{sel} + \omega_g s_1^{SW_P} y_{P_{filt}} + s_0^{SW_P} y_{P_{filt}}$
VDL1_y	$y_{V_{DL1}}$	Algeb	$-y_{V_{DL1}} + \text{FixPiecewise}((I_{q1}, V_{q1} \geq y_{s0}), (I_{q1} + k_{Vq12} (-V_{q1} + y_{s0}), V_{q2} \geq y_{s0}), (I_{q1} + k_{Vq12} (-V_{q1} + y_{s0}), V_{q2} < y_{s0}))$
VDL2_y	$y_{V_{DL2}}$	Algeb	$-y_{V_{DL2}} + \text{FixPiecewise}((I_{p1}, V_{p1} \geq y_{s0}), (I_{p1} + k_{Vp12} (-V_{p1} + y_{s0}), V_{p2} \geq y_{s0}), (I_{p1} + k_{Vp12} (-V_{p1} + y_{s0}), V_{p2} < y_{s0}))$
Ipmax	I_{pmax}	Algeb	$-I_{pmax} + Ipmax h fThld_2 + (1 - fThld_2) \left(\sqrt{I_{pmax}^2 s_0^{SW_{PQ}}} + s_1^{SW_{PQ}} (z_{VDL2} (I_{maxr} (1 - VDL1c) + VDL1c y_{V_{DL1}}) - 1) \right)$
Iqmax	I_{qmax}	Algeb	$\sqrt{I_{qmax}^2 s_1^{SW_{PQ}}} - I_{qmax} + s_0^{SW_{PQ}} (z_{VDL1} (I_{maxr} (1 - VDL1c) + VDL1c y_{V_{DL1}}) - 1)$
PIV_ys	ys_{PIV}	Algeb	$(1 - z_{Vdip}) \left(K_{vp} s_1^{SW_V} \left(-s_0^{SW_V} y_{s0} + y_{V_{sel}} \right) + xi_{PIV} - ys_{PIV} \right)$
PIV_y	y_{PIV}	Algeb	$(1 - z_{Vdip}) \left(I_{qmax} z_u^{lim_{PIV}} + I_{qmin} z_l^{lim_{PIV}} - y_{PIV} + ys_{PIV} z_i^{lim_{PIV}} \right)$

Table 20 – continued from previous

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Qsel	Q_{sel}	Algeb	$-Q_{sel} + s_0^{SW_V} y_{s4} + s_1^{SW_V} y_{PIV}$
IpHL_x	x_{IpHL}	Algeb	$-x_{IpHL} + \frac{y_{s5}}{V_p}$
IpHL_y	y_{IpHL}	Algeb	$I_{pmax} z_u^{lim_{IpHL}} + I_{pmin} z_l^{lim_{IpHL}} + x_{IpHL} z_i^{lim_{IpHL}} - y_{IpHL}$
IqHL_x	x_{IqHL}	Algeb	$I_{qinj} + Q_{sel} - x_{IqHL}$
IqHL_y	y_{IqHL}	Algeb	$I_{qmax} z_u^{lim_{IqHL}} + I_{qmin} z_l^{lim_{IqHL}} + x_{IqHL} z_i^{lim_{IqHL}} - y_{IqHL}$
a	θ	ExtAlgeb	0
v	V_d	ExtAlgeb	0
Pe	Pe	ExtAlgeb	0
Qe	Qe	ExtAlgeb	0
Ipcmd	$Ipcmd$	ExtAlgeb	$-Ipcmd_0 + y_{IpHL}$
Iqcmd	$Iqcmd$	ExtAlgeb	$-Iqcmd_0 - y_{IqHL}$

Services

Name	Symbol	Equation	Type
Ipcmd0	$Ipcmd0$	$\frac{P_0}{V_d}$	ConstService
Iqcmd0	$Iqcmd0$	$-\frac{Q_0}{V_d}$	ConstService
pfaref0	Φ_{ref0}	$\text{atan}_2(Q_0, P_0)$	ConstService
Volt_dip	z_{Vdip}	$1 - z_i^{V_{cmp}}$	VarService
qref0	q_{ref0}	$Iqcmd_0 s_0^{SW_V} (V_d z_i^{V_{Lower}} + 0.01 z_l^{V_{Lower}}) + s_1^{SW_V} (V_d - V_{ref1})$	ConstService
PIQ_flag	z_{PIQ}^{flag}	0	EventFlag
s4_flag	z_{s4}^{flag}	0	EventFlag
pThld	p_{Thld}	Indicator($T_{hld} > 0$)	ConstService
nThld	n_{Thld}	Indicator($T_{hld} < 0$)	ConstService
Thld_abs	$ Thld $	$ Thld $	ConstService
fThld	$fThld$	0	ExtendedEvent
s5_flag	z_{s5}^{flag}	0	EventFlag
kVq12	k_{Vq12}	$\frac{-I_{q1} + I_{q2}}{-V_{q1} + V_{q2}}$	ConstService
kVq23	k_{Vq23}	$\frac{-I_{q2} + I_{q3}}{-V_{q2} + V_{q3}}$	ConstService
kVq34	k_{Vq34}	$\frac{-I_{q3} + I_{q4}}{-V_{q3} + V_{q4}}$	ConstService
zVDL1	z_{VDL1}	$I_{q1} \leq I_{q2} \wedge I_{q2} \leq I_{q3} \wedge I_{q3} \leq I_{q4} \wedge V_{q1} \leq V_{q2} \wedge V_{q2} \leq V_{q3} \wedge V_{q3} \leq V_{q4}$	ConstService
kVp12	k_{Vp12}	$\frac{-I_{p1} + I_{p2}}{-V_{p1} + V_{p2}}$	ConstService
kVp23	k_{Vp23}	$\frac{-I_{p2} + I_{p3}}{-V_{p2} + V_{p3}}$	ConstService
kVp34	k_{Vp34}	$\frac{-I_{p3} + I_{p4}}{-V_{p3} + V_{p4}}$	ConstService
zVDL2	z_{VDL2}	$I_{p1} \leq I_{p2} \wedge I_{p2} \leq I_{p3} \wedge I_{p3} \leq I_{p4} \wedge V_{p1} \leq V_{p2} \wedge V_{p2} \leq V_{p3} \wedge V_{p3} \leq V_{p4}$	ConstService
fThld2	$fThld2$	0	ExtendedEvent
VDL1c	$VDL1c$	$y_{VDL1} < I_{maxr}$	VarService
VDL2c	$VDL2c$	$y_{VDL2} < I_{maxr}$	VarService

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Table 21 – continued from previous page

Name	Symbol	Equation	Type
Ipmax2sq0	$I_{pmax20,nn}^2$	$\text{FixPiecewise} \left((0, I_{max}^2 - I_{qcmd_0}^2 \leq 0), (I_{max}^2 - I_{qcmd_0}^2, \text{True}) \right)$	ConstService
Ipmax2sq	I_{pmax2}^2	$\text{FixPiecewise} \left((0, I_{max}^2 - y_{IqHL}^2 \leq 0), (I_{max}^2 - y_{IqHL}^2, \text{True}) \right)$	VarService
Ipmaxh	$Ipmaxh$	0	VarHold
Iqmax2sq0	$I_{qmax,nn}^2$	$\text{FixPiecewise} \left((0, I_{max}^2 - I_{pcmd_0}^2 \leq 0), (I_{max}^2 - I_{pcmd_0}^2, \text{True}) \right)$	ConstService
Iqmax2sq	I_{qmax2}^2	$\text{FixPiecewise} \left((0, I_{max}^2 - y_{IpHL}^2 \leq 0), (I_{max}^2 - y_{IpHL}^2, \text{True}) \right)$	VarService
Ipmin	I_{pmin}	0.0	ConstService
PIV_flag	z_{PIV}^{flag}	0	EventFlag

Discretes

Name	Symbol	Type	Info
SWPF	SW_{PF}	Switcher	
SWV	SW_V	Switcher	
SWQ	SW_V	Switcher	
SWP	SW_P	Switcher	
SWPQ	SW_{PQ}	Switcher	
zp	zp	IsEqual	
Vcmp	V_{cmp}	Limiter	Voltage dip comparator
VLower	V_{Lower}	Limiter	Limiter for lower voltage cap
PFlim	P_{Flim}	Limiter	
PIQ_lim	lim_{PIQ}	HardLimiter	
Vsel_lim	$lim_{V_{sel}}$	HardLimiter	
dbV_db	db_{dbV}	DeadBand	
pfilt_lim	$lim_{P_{filt}}$	RateLimiter	Rate limiter in Lag
s5_lim	lim_{s5}	AntiWindup	Limiter in Lag
PIV_lim	lim_{PIV}	HardLimiter	
IpHL_lim	lim_{IpHL}	HardLimiter	
IqHL_lim	lim_{IqHL}	HardLimiter	

Blocks

Name	Symbol	Type	Info
s0	s_0	Lag	Voltage filter
S1	S_1	Lag	Pe filter
PIQ	PIQ	PITrackAWFreeze	
Vsel	V_{sel}	GainLimiter	Selection output of VFLAG
s4	s_4	LagFreeze	Filter for calculated voltage with freeze
dbV	dbV	DeadBand1	Deadband for voltage error (ref0)
pfilt	P_{filt}	LagRate	Active power filter with rate limits
s5	s_5	LagAWFreeze	
VDL1	V_{DL1}	Piecewise	Piecewise linear characteristics of Vq-Iq
VDL2	V_{DL2}	Piecewise	Piecewise linear characteristics of Vp-Ip
PIV	PIV	PITrackAWFreeze	
IpHL	I_{pHL}	GainLimiter	
IqHL	I_{qHL}	GainLimiter	

Config Fields in [REECA1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
kqs	K_{qs}	2	Q PI controller tracking gain	
kvs	K_{vs}	2	Voltage PI controller tracking gain	
tpfilt	T_{pfilt}	0.020	Time const. for Pref filter	

5.23.2 REECA1E

REGCA1 with inertia emulation and primary frequency droop. Measurements are based on frequency measurement model.

Bus ROCOF obtained from `BusROCOF` devices.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
reg		Renewable generator idx			mandatory

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Table 22 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
busr		Optional remote bus for voltage control			
PFLAG		Power factor control flag; 1-PF control, 0-Q control		<i>bool</i>	mandatory
VFLAG		Voltage control flag; 1-Q control, 0-V control		<i>bool</i>	mandatory
QFLAG		Q control flag; 1-V or Q control, 0-const. PF or Q		<i>bool</i>	mandatory
PFLAG		P speed-dependency flag; 1-has speed dep., 0-no dep.		<i>bool</i>	mandatory
PQFLAG		P/Q priority flag for I limit; 0-Q priority, 1-P priority		<i>bool</i>	mandatory
Vdip	V_{dip}	Low V threshold to activate Iqinj logic	0.800	<i>p.u.</i>	
Vup	V_{up}	V threshold above which to activate Iqinj logic	1.200	<i>p.u.</i>	
Trv	T_{rv}	Voltage filter time constant	0.020		
dbd1	$dbd1$	Lower bound of the voltage deadband (≤ 0)	-0.020		
dbd2	$dbd2$	Upper bound of the voltage deadband (≥ 0)	0.020		
Kqv	K_{qv}	Gain to compute Iqinj from V error (caution!!)	1		
Iqh1	I_{qh1}	Upper limit on Iqinj	999		
Iql1	I_{ql1}	Lower limit on Iqinj	-999		
Vref0	V_{ref0}	User defined Vref (if 0, use initial bus V)	1		
Iqfrz	I_{qfrz}	Hold Iqinj at the value for Thld (>0) seconds following a Vdip	0		
Thld	T_{hld}	Time for which Iqinj is held. Hold at Iqinj if >0 ; hold at State 1 if <0	0	<i>s</i>	
Thld2	T_{hld2}	Time for which IPMAX is held after voltage dip ends	0	<i>s</i>	
Tp	T_p	Filter time constant for Pe	0.020	<i>s</i>	
QMax	Q_{max}	Upper limit for reactive power regulator	999		
QMin	Q_{min}	Lower limit for reactive power regulator	-999		
VMAX	V_{max}	Upper limit for voltage control	999		
VMIN	V_{min}	Lower limit for voltage control	-999		
Kqp	K_{qp}	Proportional gain for reactive power error	1		
Kqi	K_{qi}	Integral gain for reactive power error	0.100		
Kvp	K_{vp}	Proportional gain for voltage error	1		
Kvi	K_{vi}	Integral gain for voltage error	0.100		
Vref1	V_{ref1}	Voltage ref. if VFLAG=0	1		non_zero
Tiq	T_{iq}	Filter time constant for Iq	0.020		
dPmax	dP_{max}	Power reference max. ramp rate (>0)	999		
dPmin	dP_{min}	Power reference min. ramp rate (<0)	-999		
PMAX	P_{max}	Max. active power limit > 0	999		
PMIN	P_{min}	Min. active power limit	0		
Imax	I_{max}	Max. apparent current limit	999		current
Tpord	T_{pord}	Filter time constant for power setpoint	0.020		
Vq1	V_{q1}	Reactive power V-I pair (point 1), voltage	0.200		
Iq1	I_{q1}	Reactive power V-I pair (point 1), current	2		current
Vq2	V_{q2}	Reactive power V-I pair (point 2), voltage	0.400		
Iq2	I_{q2}	Reactive power V-I pair (point 2), current	4		current
Vq3	V_{q3}	Reactive power V-I pair (point 3), voltage	0.800		
Iq3	I_{q3}	Reactive power V-I pair (point 3), current	8		current
Vq4	V_{q4}	Reactive power V-I pair (point 4), voltage	1		
Iq4	I_{q4}	Reactive power V-I pair (point 4), current	10		current
Vp1	V_{p1}	Active power V-I pair (point 1), voltage	0.200		

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Table 22 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
Ip1	I_{p1}	Active power V-I pair (point 1), current	2		current
Vp2	V_{p2}	Active power V-I pair (point 2), voltage	0.400		
Ip2	I_{p2}	Active power V-I pair (point 2), current	4		current
Vp3	V_{p3}	Active power V-I pair (point 3), voltage	0.800		
Ip3	I_{p3}	Active power V-I pair (point 3), current	8		current
Vp4	V_{p4}	Active power V-I pair (point 4), voltage	1		
Ip4	I_{p4}	Active power V-I pair (point 4), current	12		current
Kf	K_{df}	gain for frequency deviation	0		
Kdf	K_{df}	gain for rate-of-change of frequency	0		
busroc		Optional BusROCOF device idx			
bus		Retrieved bus idx			
gen		Retrieved StaticGen idx			
Sn	S_n		0		

Variables

Name	Symbol	Type	Description	Unit	Properties
s0_y	y_{s0}	State	State in lag transfer function		v_str
S1_y	y_{S1}	State	State in lag transfer function		v_str
PIQ_xi	xi_{PIQ}	State	Integrator output		v_str
s4_y	y_{s4}	State	State in lag transfer function		v_str
pfilt_y	$y_{P_{filt}}$	State	State in lag TF		v_str
s5_y	y_{s5}	State	State in lag TF		v_str
PIV_xi	xi_{PIV}	State	Integrator output		v_str
Pord	P_{ord}	AliasState	Alias of s5_y		
vp	V_p	Algeb	Sensed lower-capped voltage		v_str
pfaref	Φ_{ref}	Algeb	power factor angle ref	rad	v_str
Qref	Q_{ref}	Algeb	external Q ref	p.u.	v_str
Qcpf	Q_{cpf}	Algeb	Q calculated from P and power factor	p.u.	v_str
PFsel	PF_{sel}	Algeb	Output of PFFLAG selector		v_str
Qerr	Q_{err}	Algeb	Reactive power error		v_str
PIQ_ys	y_{SPIQ}	Algeb	PI summation before limit		v_str
PIQ_y	y_{PIQ}	Algeb	PI output		v_str
Vsel_x	$x_{V_{sel}}$	Algeb	Value before limiter		v_str
Vsel_y	$y_{V_{sel}}$	Algeb	Output after limiter and post gain		v_str
Verr	V_{err}	Algeb	Voltage error (Vref0)		v_str
dbV_y	y_{dbV}	Algeb	Deadband type 1 output		v_str
Iqinj	I_{qinj}	Algeb	Additional Iq signal during under- or over-voltage		v_str
wg	ω_g	Algeb	Drive train generator speed		v_str
Pref	P_{ref}	Algeb	external P ref	p.u.	v_str
Psel	P_{sel}	Algeb	Output selection of PFLAG		v_str

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Table 23 – continued from previous page

Name	Symbol	Type	Description	Unit	Properties
VDL1_y	y_{VDL1}	Algeb	Output of piecewise		v_str
VDL2_y	y_{VDL2}	Algeb	Output of piecewise		v_str
Ipmax	I_{pmax}	Algeb	Upper limit on Ipcmd		v_str
Iqmax	I_{qmax}	Algeb	Upper limit on Iqcmd		v_str
PIV_ys	y_{SPIV}	Algeb	PI summation before limit		v_str
PIV_y	y_{PIV}	Algeb	PI output		v_str
Qsel	Q_{sel}	Algeb	Selection output of QFLAG		v_str
IpHL_x	x_{IpHL}	Algeb	Value before limiter		v_str
IpHL_y	y_{IpHL}	Algeb	Output after limiter and post gain		v_str
IqHL_x	x_{IqHL}	Algeb	Value before limiter		v_str
IqHL_y	y_{IqHL}	Algeb	Output after limiter and post gain		v_str
a	θ	ExtAlgeb	Bus voltage angle		
v	V_d	ExtAlgeb	d-axis bus voltage magnitude		
Pe	Pe	ExtAlgeb	Retrieved Pe of RenGen		
Qe	Qe	ExtAlgeb	Retrieved Qe of RenGen		
Ipcmd	$Ipcmd$	ExtAlgeb	Retrieved Ipcmd of RenGen		
Iqcmd	$Iqcmd$	ExtAlgeb	Retrieved Iqcmd of RenGen		
df	df	ExtAlgeb	Bus frequency deviation		
dfdt	$dfdt$	ExtAlgeb	Bus ROCOF	<i>p.u.</i>	

Initialization Equations

Name	Symbol	Type	Initial Value
s0_y	y_{s0}	State	V_d
S1_y	y_{S1}	State	Pe
PIQ_xi	x_{iPIQ}	State	0.0
s4_y	y_{s4}	State	$\frac{PF_{sel}}{V_p}$
pfilt_y	$y_{P_{filt}}$	State	P_{ref}
s5_y	y_{s5}	State	P_{sel}
PIV_xi	x_{iPIV}	State	$-Iqcmd_0 s_1^{SW_V}$
Pord	$Pord$	AliasState	
vp	V_p	Algeb	$V_d z_i^{V_{Lower}} + 0.01 z_l^{V_{Lower}}$
pfaref	Φ_{ref}	Algeb	Φ_{ref0}
Qref	Q_{ref}	Algeb	$-q_{ref0}$
Qcpf	Q_{cpf}	Algeb	Q_0
PFsel	PF_{sel}	Algeb	$Q_{cpf} s_1^{SW_{PF}} + Q_{ref} s_0^{SW_{PF}}$
Qerr	Q_{err}	Algeb	$PF_{sel} z_i^{PF_{lim}} + Q_{max} z_u^{PF_{lim}} + Q_{min} z_l^{PF_{lim}} - Q_e$
PIQ_ys	y_{SPIQ}	Algeb	$K_{qp} Q_{err} s_1^{SW_V}$
PIQ_y	y_{PIQ}	Algeb	$V_{max} z_u^{lim_{PIQ}} + V_{min} z_l^{lim_{PIQ}} + y_{SPIQ} z_i^{lim_{PIQ}}$
Vsel_x	$x_{V_{sel}}$	Algeb	$s_0^{SW_V} \left(Q_{cpf} s_1^{SW_{PF}} + Q_{ref} s_0^{SW_{PF}} + V_{ref1} \right) + s_1^{SW_V} y_{PIQ}$

Differential Equations

Name	Sym- bol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
s0_y	y_{s0}	State	$V_d - y_{s0}$	T_{rv}
S1_y	y_{S1}	State	$Pe - y_{S1}$	T_p
PIQ_xi	xi_{PIQ}	State	$K_{qi} (1 - z_{Vdip}) (Q_{err} s_1^{SW_V} + 2y_{PIQ} - 2ys_{PIQ})$	
s4_y	y_{s4}	State	$(1 - z_{Vdip}) \left(\frac{PF_{sel}}{V_p} - y_{s4} \right)$	T_{iq}
pfilt_y	$y_{P_{filt}}$	State	$P_{ref} - y_{P_{filt}}$	0.02
s5_y	y_{s5}	State	$(1 - z_{Vdip}) (P_{sel} - y_{s5})$	T_{pord}
PIV_xi	xi_{PIV}	State	$K_{vi} (1 - z_{Vdip}) \left(s_1^{SW_V} \left(-s_0^{SW_V} y_{s0} + y_{V_{sel}} \right) + 2y_{PIV} - 2ys_I \right)$	
Pord	$Pord$	AliasState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
vp	V_p	Algeb	$V_d z_i^{V_{Lower}} - V_p + 0.01 z_l^{V_{Lower}}$
pfaref	Φ_{ref}	Algeb	$\Phi_{ref0} - \Phi_{ref}$
Qref	Q_{ref}	Algeb	$-Q_{ref} - q_{ref0}$
Qcpf	Q_{cpf}	Algeb	$(1 - z_1^{z_p}) (-Q_{cpf} + y_{S1} \tan(\Phi_{ref}))$
PFsel	PF_{sel}	Algeb	$-PF_{sel} + Q_{cpf} s_1^{SW_{PF}} + Q_{ref} s_0^{SW_{PF}}$
Qerr	Q_{err}	Algeb	$PF_{sel} z_i^{PF_{lim}} - Q_{err} + Q_{max} z_u^{PF_{lim}} + Q_{min} z_l^{PF_{lim}} - Q_e$
PIQ_ys	ys_{PIQ}	Algeb	$(1 - z_{Vdip}) \left(K_{qp} Q_{err} s_1^{SW_V} + xi_{PIQ} - ys_{PIQ} \right)$
PIQ_y	y_{PIQ}	Algeb	$(1 - z_{Vdip}) \left(V_{max} z_u^{lim_{PIQ}} + V_{min} z_l^{lim_{PIQ}} - y_{PIQ} + ys_{PIQ} z_i^{lim_{PIQ}} \right)$
Vsel_x	$x_{V_{sel}}$	Algeb	$s_0^{SW_V} \left(Q_{cpf} s_1^{SW_{PF}} + Q_{ref} s_0^{SW_{PF}} + V_{ref1} \right) + s_1^{SW_V} y_{PIQ} - x_{V_{sel}}$
Vsel_y	$y_{V_{sel}}$	Algeb	$V_{max} z_u^{lim_{V_{sel}}} + V_{min} z_l^{lim_{V_{sel}}} + x_{V_{sel}} z_i^{lim_{V_{sel}}} - y_{V_{sel}}$
Verr	V_{err}	Algeb	$-V_{err} + V_{ref0} - y_{s0}$
dbV_y	y_{dbV}	Algeb	$-y_{dbV} + 1.0 z_l^{db_{dbV}} (V_{err} - db_{d1}) + 1.0 z_u^{db_{dbV}} (V_{err} - db_{d2})$
Iqinj	I_{qinj}	Algeb	$-I_{qinj} + K_{qv} y_{dbV} z_{Vdip} + fThld (1 - z_{Vdip}) (I_{qfrz} pThld + K_{qv} nThld y_{dbV})$
wg	ω_g	Algeb	$1.0 - \omega_g$
Pref	P_{ref}	Algeb	$-K_{df} df - K_{df} df dt + \frac{P_0}{\omega_g} - P_{ref}$
Psel	P_{sel}	Algeb	$-P_{sel} + \omega_g s_1^{SW_P} y_{P_{filt}} + s_0^{SW_P} y_{P_{filt}}$
VDL1_y	$y_{V_{DL1}}$	Algeb	$-y_{V_{DL1}} + \text{FixPiecewise}((I_{q1}, V_{q1} \geq y_{s0}), (I_{q1} + k_{Vq12} (-V_{q1} + y_{s0}), V_{q2} \geq y_{s0}), (I_{q1} - k_{Vq12} (-V_{q1} + y_{s0}), V_{q2} < y_{s0}))$
VDL2_y	$y_{V_{DL2}}$	Algeb	$-y_{V_{DL2}} + \text{FixPiecewise}((I_{p1}, V_{p1} \geq y_{s0}), (I_{p1} + k_{Vp12} (-V_{p1} + y_{s0}), V_{p2} \geq y_{s0}), (I_{p1} - k_{Vp12} (-V_{p1} + y_{s0}), V_{p2} < y_{s0}))$
Ipmax	I_{pmax}	Algeb	$-I_{pmax} + Ipmax hfThld_2 + (1 - fThld_2) \left(\sqrt{I_{pmax}^2 s_0^{SW_{PQ}}} + s_1^{SW_{PQ}} (z_{VDL2} (I_{max} - I_{pmax})) \right)$
Iqmax	I_{qmax}	Algeb	$\sqrt{I_{qmax}^2 s_1^{SW_{PQ}}} - I_{qmax} + s_0^{SW_{PQ}} (z_{VDL1} (I_{max} (1 - VDL1c) + VDL1c y_{V_{DL1}}) - I_{qmax})$
PIV_ys	ys_{PIV}	Algeb	$(1 - z_{Vdip}) \left(K_{vp} s_1^{SW_V} \left(-s_0^{SW_V} y_{s0} + y_{V_{sel}} \right) + xi_{PIV} - ys_{PIV} \right)$
PIV_y	y_{PIV}	Algeb	$(1 - z_{Vdip}) \left(I_{qmax} z_u^{lim_{PIV}} + I_{qmin} z_l^{lim_{PIV}} - y_{PIV} + ys_{PIV} z_i^{lim_{PIV}} \right)$

Table 25 – continued from previous

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Qsel	Q_{sel}	Algeb	$-Q_{sel} + s_0^{SW_V} y_{s4} + s_1^{SW_V} y_{PIV}$
IpHL_x	x_{IpHL}	Algeb	$-x_{IpHL} + \frac{y_{s5}}{V_p}$
IpHL_y	y_{IpHL}	Algeb	$I_{pmax} z_u^{lim_{IpHL}} + I_{pmin} z_l^{lim_{IpHL}} + x_{IpHL} z_i^{lim_{IpHL}} - y_{IpHL}$
IqHL_x	x_{IqHL}	Algeb	$I_{qinj} + Q_{sel} - x_{IqHL}$
IqHL_y	y_{IqHL}	Algeb	$I_{qmax} z_u^{lim_{IqHL}} + I_{qmin} z_l^{lim_{IqHL}} + x_{IqHL} z_i^{lim_{IqHL}} - y_{IqHL}$
a	θ	ExtAlgeb	0
v	V_d	ExtAlgeb	0
Pe	Pe	ExtAlgeb	0
Qe	Qe	ExtAlgeb	0
Ipcmd	$Ipcmd$	ExtAlgeb	$-Ipcmd_0 + y_{IpHL}$
Iqcmd	$Iqcmd$	ExtAlgeb	$-Iqcmd_0 - y_{IqHL}$
df	df	ExtAlgeb	0
dfdt	$dfdt$	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
Ipcmd0	$Ipcmd0$	$\frac{P_0}{V_d}$	ConstService
Iqcmd0	$Iqcmd0$	$-\frac{Q_0}{V_d}$	ConstService
pfaref0	Φ_{ref0}	$\text{atan}_2(Q_0, P_0)$	ConstService
Volt_dip	z_{Vdip}	$1 - z_i^{V_{cmp}}$	VarService
qref0	q_{ref0}	$Iqcmd0 s_0^{SW_V} (V_d z_i^{V_{Lower}} + 0.01 z_l^{V_{Lower}}) + s_1^{SW_V} (V_d - V_{ref1})$	ConstService
PIQ_flag	z_{PIQ}^{flag}	0	EventFlag
s4_flag	z_{s4}^{flag}	0	EventFlag
pThld	$pThld$	Indicator($T_{hld} > 0$)	ConstService
nThld	$nThld$	Indicator($T_{hld} < 0$)	ConstService
Thld_abs	$ Thld $	$ Thld $	ConstService
fThld	$fThld$	0	ExtendedEvent
s5_flag	z_{s5}^{flag}	0	EventFlag
kVq12	kV_{q12}	$\frac{-I_{q1} + I_{q2}}{-V_{q1} + V_{q2}}$	ConstService
kVq23	kV_{q23}	$\frac{-I_{q2} + I_{q3}}{-V_{q2} + V_{q3}}$	ConstService
kVq34	kV_{q34}	$\frac{-I_{q3} + I_{q4}}{-V_{q3} + V_{q4}}$	ConstService
zVDL1	z_{VDL1}	$I_{q1} \leq I_{q2} \wedge I_{q2} \leq I_{q3} \wedge I_{q3} \leq I_{q4} \wedge V_{q1} \leq V_{q2} \wedge V_{q2} \leq V_{q3} \wedge V_{q3} \leq V_{q4}$	ConstService
kVp12	kV_{p12}	$\frac{-I_{p1} + I_{p2}}{-V_{p1} + V_{p2}}$	ConstService
kVp23	kV_{p23}	$\frac{-I_{p2} + I_{p3}}{-V_{p2} + V_{p3}}$	ConstService
kVp34	kV_{p34}	$\frac{-I_{p3} + I_{p4}}{-V_{p3} + V_{p4}}$	ConstService
zVDL2	z_{VDL2}	$I_{p1} \leq I_{p2} \wedge I_{p2} \leq I_{p3} \wedge I_{p3} \leq I_{p4} \wedge V_{p1} \leq V_{p2} \wedge V_{p2} \leq V_{p3} \wedge V_{p3} \leq V_{p4}$	ConstService
fThld2	$fThld2$	0	ExtendedEvent

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Table 26 – continued from previous page

Name	Symbol	Equation	Type
VDL1c	V_{DL1c}	$y_{V_{DL1}} < I_{maxr}$	VarService
VDL2c	V_{DL2c}	$y_{V_{DL2}} < I_{maxr}$	VarService
Ipmax2sq0	$I_{pmax20,nn}^2$	$\text{FixPiecewise} \left((0, I_{max}^2 - I_{qcmd_0}^2 \leq 0), (I_{max}^2 - I_{qcmd_0}^2, \text{True}) \right)$	ConstService
Ipmax2sq	I_{pmax2}^2	$\text{FixPiecewise} \left((0, I_{max}^2 - y_{I_{qHL}}^2 \leq 0), (I_{max}^2 - y_{I_{qHL}}^2, \text{True}) \right)$	VarService
Ipmaxh	I_{pmaxh}	0	VarHold
Iqmax2sq0	$I_{qmax,nn}^2$	$\text{FixPiecewise} \left((0, I_{max}^2 - I_{pcmd_0}^2 \leq 0), (I_{max}^2 - I_{pcmd_0}^2, \text{True}) \right)$	ConstService
Iqmax2sq	I_{qmax2}^2	$\text{FixPiecewise} \left((0, I_{max}^2 - y_{I_{pHL}}^2 \leq 0), (I_{max}^2 - y_{I_{pHL}}^2, \text{True}) \right)$	VarService
Ipmin	I_{pmin}	0.0	ConstService
PIV_flag	z_{PIV}^{flag}	0	EventFlag

Discretes

Name	Symbol	Type	Info
SWPF	SW_{PF}	Switcher	
SWV	SW_V	Switcher	
SWQ	SW_V	Switcher	
SWP	SW_P	Switcher	
SWPQ	SW_{PQ}	Switcher	
zp	zp	IsEqual	
Vcmp	V_{cmp}	Limiter	Voltage dip comparator
VLower	V_{Lower}	Limiter	Limiter for lower voltage cap
PFlim	P_{Flim}	Limiter	
PIQ_lim	lim_{PIQ}	HardLimiter	
Vsel_lim	$lim_{V_{sel}}$	HardLimiter	
dbV_db	db_{dbV}	DeadBand	
pfilt_lim	$lim_{P_{filt}}$	RateLimiter	Rate limiter in Lag
s5_lim	lim_{s5}	AntiWindup	Limiter in Lag
PIV_lim	lim_{PIV}	HardLimiter	
IpHL_lim	$lim_{I_{pHL}}$	HardLimiter	
IqHL_lim	$lim_{I_{qHL}}$	HardLimiter	

Blocks

Name	Symbol	Type	Info
s0	s_0	Lag	Voltage filter
S1	S_1	Lag	Pe filter
PIQ	PIQ	PITrackAWFreeze	
Vsel	V_{sel}	GainLimiter	Selection output of VFLAG
s4	s_4	LagFreeze	Filter for calculated voltage with freeze
dbV	dbV	DeadBand1	Deadband for voltage error (ref0)
pfilt	P_{filt}	LagRate	Active power filter with rate limits
s5	s_5	LagAWFreeze	
VDL1	V_{DL1}	Piecewise	Piecewise linear characteristics of Vq-Iq
VDL2	V_{DL2}	Piecewise	Piecewise linear characteristics of Vp-Ip
PIV	PIV	PITrackAWFreeze	
IpHL	I_{pHL}	GainLimiter	
IqHL	I_{qHL}	GainLimiter	

Config Fields in [REECA1E]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
kqs	K_{qs}	2	Q PI controller tracking gain	
kvs	K_{vs}	2	Voltage PI controller tracking gain	
tpfilt	T_{pfilt}	0.020	Time const. for Pref filter	

5.23.3 REECA1G

REECA1G is a variant of REECA1E.

REECA1G uses speed from synchronous generators.

The application of this model is limited because it is uncommon to connect a SynGen on the same bus as a RenGen.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
reg		Renewable generator idx			mandatory
busr		Optional remote bus for voltage control			
PFFLAG		Power factor control flag; 1-PF control, 0-Q control		<i>bool</i>	mandatory
VFLAG		Voltage control flag; 1-Q control, 0-V control		<i>bool</i>	mandatory
QFLAG		Q control flag; 1-V or Q control, 0-const. PF or Q		<i>bool</i>	mandatory
PFLAG		P speed-dependency flag; 1-has speed dep., 0-no dep.		<i>bool</i>	mandatory
PQFLAG		P/Q priority flag for I limit; 0-Q priority, 1-P priority		<i>bool</i>	mandatory
Vdip	V_{dip}	Low V threshold to activate Iqinj logic	0.800	<i>p.u.</i>	
Vup	V_{up}	V threshold above which to activate Iqinj logic	1.200	<i>p.u.</i>	
Trv	T_{rv}	Voltage filter time constant	0.020		
dbd1	$dbd1$	Lower bound of the voltage deadband (≤ 0)	-0.020		
dbd2	$dbd2$	Upper bound of the voltage deadband (≥ 0)	0.020		
Kqv	K_{qv}	Gain to compute Iqinj from V error (caution!!)	1		
Iqh1	I_{qh1}	Upper limit on Iqinj	999		
Iql1	I_{ql1}	Lower limit on Iqinj	-999		
Vref0	V_{ref0}	User defined Vref (if 0, use initial bus V)	1		
Iqfrz	I_{qfrz}	Hold Iqinj at the value for Thld (>0) seconds following a Vdip	0		
Thld	T_{hld}	Time for which Iqinj is held. Hold at Iqinj if >0 ; hold at State 1 if <0	0	<i>s</i>	
Thld2	T_{hld2}	Time for which IPMAX is held after voltage dip ends	0	<i>s</i>	
Tp	T_p	Filter time constant for Pe	0.020	<i>s</i>	
QMax	Q_{max}	Upper limit for reactive power regulator	999		
QMin	Q_{min}	Lower limit for reactive power regulator	-999		
VMAX	V_{max}	Upper limit for voltage control	999		
VMIN	V_{min}	Lower limit for voltage control	-999		
Kqp	K_{qp}	Proportional gain for reactive power error	1		
Kqi	K_{qi}	Integral gain for reactive power error	0.100		
Kvp	K_{vp}	Proportional gain for voltage error	1		
Kvi	K_{vi}	Integral gain for voltage error	0.100		
Vref1	V_{ref1}	Voltage ref. if VFLAG=0	1		non_zero
Tiq	T_{iq}	Filter time constant for Iq	0.020		
dPmax	dP_{max}	Power reference max. ramp rate (>0)	999		
dPmin	dP_{min}	Power reference min. ramp rate (<0)	-999		
PMAX	P_{max}	Max. active power limit > 0	999		
PMIN	P_{min}	Min. active power limit	0		
Imax	I_{max}	Max. apparent current limit	999		current
Tpord	T_{pord}	Filter time constant for power setpoint	0.020		
Vq1	V_{q1}	Reactive power V-I pair (point 1), voltage	0.200		
Iq1	I_{q1}	Reactive power V-I pair (point 1), current	2		current
Vq2	V_{q2}	Reactive power V-I pair (point 2), voltage	0.400		

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Table 27 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
Iq2	I_{q2}	Reactive power V-I pair (point 2), current	4		current
Vq3	V_{q3}	Reactive power V-I pair (point 3), voltage	0.800		
Iq3	I_{q3}	Reactive power V-I pair (point 3), current	8		current
Vq4	V_{q4}	Reactive power V-I pair (point 4), voltage	1		
Iq4	I_{q4}	Reactive power V-I pair (point 4), current	10		current
Vp1	V_{p1}	Active power V-I pair (point 1), voltage	0.200		
Ip1	I_{p1}	Active power V-I pair (point 1), current	2		current
Vp2	V_{p2}	Active power V-I pair (point 2), voltage	0.400		
Ip2	I_{p2}	Active power V-I pair (point 2), current	4		current
Vp3	V_{p3}	Active power V-I pair (point 3), voltage	0.800		
Ip3	I_{p3}	Active power V-I pair (point 3), current	8		current
Vp4	V_{p4}	Active power V-I pair (point 4), voltage	1		
Ip4	I_{p4}	Active power V-I pair (point 4), current	12		current
Kf	K_{df}	gain for frequency deviation	0		
sg		synchronous gen idx			mandatory
bus		Retrieved bus idx			
gen		Retrieved StaticGen idx			
Sn	S_n		0		

Variables

Name	Symbol	Type	Description	Unit	Properties
s0_y	y_{s0}	State	State in lag transfer function		v_str
S1_y	y_{S1}	State	State in lag transfer function		v_str
PIQ_xi	xi_{PIQ}	State	Integrator output		v_str
s4_y	y_{s4}	State	State in lag transfer function		v_str
pfilt_y	$y_{P_{filt}}$	State	State in lag TF		v_str
s5_y	y_{s5}	State	State in lag TF		v_str
PIV_xi	xi_{PIV}	State	Integrator output		v_str
Pord	P_{ord}	AliasState	Alias of s5_y		
omega	ω	ExtState	generator speed	pu	
vp	V_p	Algeb	Sensed lower-capped voltage		v_str
pfaref	Φ_{ref}	Algeb	power factor angle ref	rad	v_str
Qref	Q_{ref}	Algeb	external Q ref	p.u.	v_str
Qcpf	Q_{cpf}	Algeb	Q calculated from P and power factor	p.u.	v_str
PFsel	PF_{sel}	Algeb	Output of PFFLAG selector		v_str
Qerr	Q_{err}	Algeb	Reactive power error		v_str
PIQ_ys	y_{SPIQ}	Algeb	PI summation before limit		v_str
PIQ_y	y_{PIQ}	Algeb	PI output		v_str
Vsel_x	$x_{V_{sel}}$	Algeb	Value before limiter		v_str
Vsel_y	$y_{V_{sel}}$	Algeb	Output after limiter and post gain		v_str

continues on next page

Table 28 – continued from previous page

Name	Symbol	Type	Description	Unit	Properties
Verr	V_{err}	Algeb	Voltage error (Vref0)		v_str
dbV_y	y_{dbV}	Algeb	Deadband type 1 output		v_str
Iqinj	I_{qinj}	Algeb	Additional Iq signal during under- or over-voltage		v_str
wg	ω_g	Algeb	Drive train generator speed		v_str
Pref	P_{ref}	Algeb	external P ref	<i>p.u.</i>	v_str
Psel	P_{sel}	Algeb	Output selection of PFLAG		v_str
VDL1_y	y_{VDL1}	Algeb	Output of piecewise		v_str
VDL2_y	y_{VDL2}	Algeb	Output of piecewise		v_str
Ipmax	I_{pmax}	Algeb	Upper limit on Ipcmd		v_str
Iqmax	I_{qmax}	Algeb	Upper limit on Iqcmd		v_str
PIV_ys	y_{SPIV}	Algeb	PI summation before limit		v_str
PIV_y	y_{PIV}	Algeb	PI output		v_str
Qsel	Q_{sel}	Algeb	Selection output of QFLAG		v_str
IpHL_x	x_{IpHL}	Algeb	Value before limiter		v_str
IpHL_y	y_{IpHL}	Algeb	Output after limiter and post gain		v_str
IqHL_x	x_{IqHL}	Algeb	Value before limiter		v_str
IqHL_y	y_{IqHL}	Algeb	Output after limiter and post gain		v_str
a	θ	ExtAlgeb	Bus voltage angle		
v	V_d	ExtAlgeb	d-axis bus voltage magnitude		
Pe	Pe	ExtAlgeb	Retrieved Pe of RenGen		
Qe	Qe	ExtAlgeb	Retrieved Qe of RenGen		
Ipcmd	$Ipcmd$	ExtAlgeb	Retrieved Ipcmd of RenGen		
Iqcmd	$Iqcmd$	ExtAlgeb	Retrieved Iqcmd of RenGen		

Initialization Equations

Name	Symbol	Type	Initial Value
s0_y	y_{s0}	State	V_d
S1_y	y_{S1}	State	Pe
PIQ_xi	xi_{PIQ}	State	0.0
s4_y	y_{s4}	State	$\frac{PF_{sel}}{V_p}$
pfilt_y	$y_{P_{filt}}$	State	P_{ref}
s5_y	y_{s5}	State	P_{sel}
PIV_xi	xi_{PIV}	State	$-Iqcmd_0 s_1^{SW_V}$
Pord	$Pord$	AliasState	
omega	ω	ExtState	
vp	V_p	Algeb	$V_d z_i^{V_{Lower}} + 0.01 z_l^{V_{Lower}}$
pfaref	Φ_{ref}	Algeb	Φ_{ref0}
Qref	Q_{ref}	Algeb	$-q_{ref0}$
Qcpf	Q_{cpf}	Algeb	Q_0
PFsel	PF_{sel}	Algeb	$Q_{cpf} s_1^{SW_{PF}} + Q_{ref} s_0^{SW_{PF}}$

Table 29 – continued from previous page

Name	Symbol	Type	Initial Value
Qerr	Q_{err}	Algeb	$PFselz_i^{PFlim} + Q_{max}z_u^{PFlim} + Q_{min}z_l^{PFlim} - Qe$
PIQ_ys	y_{SPIQ}	Algeb	$K_{qp}Q_{err}s_1^{SW_V}$
PIQ_y	y_{PIQ}	Algeb	$V_{max}z_u^{lim_{PIQ}} + V_{min}z_l^{lim_{PIQ}} + y_{SPIQ}z_i^{lim_{PIQ}}$
Vsel_x	x_{Vsel}	Algeb	$s_0^{SW_V} \left(Q_{cpf}s_1^{SW_{PF}} + Q_{ref}s_0^{SW_{PF}} + V_{ref1} \right) + s_1^{SW_V}y_{PIQ}$
Vsel_y	y_{Vsel}	Algeb	$V_{max}z_u^{lim_{Vsel}} + V_{min}z_l^{lim_{Vsel}} + x_{Vsel}z_i^{lim_{Vsel}}$
Verr	V_{err}	Algeb	$V_{ref0} - y_{s0}$
dbV_y	y_{dbV}	Algeb	$1.0z_l^{db_{dbV}}(V_{err} - d_{bd1}) + 1.0z_u^{db_{dbV}}(V_{err} - d_{bd2})$
Iqinj	I_{qinj}	Algeb	$K_{qv}y_{dbV}z_{Vdip} + fThld(1 - z_{Vdip})(I_{qfrz}pThld + K_{qv}nThldy_{dbV})$
wg	ω_g	Algeb	1.0
Pref	P_{ref}	Algeb	$\frac{P_0}{\omega_g}$
Psel	P_{sel}	Algeb	$\omega_g s_1^{SW_P} y_{Pfilt} + s_0^{SW_P} y_{Pfilt}$
VDL1_y	y_{VDL1}	Algeb	$FixPiecewise((I_{q1}, V_{q1} \geq y_{s0}), (I_{q1} + k_{Vq12}(-V_{q1} + y_{s0}), V_{q2} \geq y_{s0}), (I_{q2} + k_{Vq23}(-V_{q2} + y_{s0}), V_{q3} \geq y_{s0}), (I_{q3} + k_{Vq34}(-V_{q3} + y_{s0}), V_{q4} \geq y_{s0}), (I_{q4} + k_{Vq45}(-V_{q4} + y_{s0}), V_{q5} \geq y_{s0}), (I_{q5} + k_{Vq56}(-V_{q5} + y_{s0}), V_{q6} \geq y_{s0}), (I_{q6} + k_{Vq67}(-V_{q6} + y_{s0}), V_{q7} \geq y_{s0}), (I_{q7} + k_{Vq78}(-V_{q7} + y_{s0}), V_{q8} \geq y_{s0}), (I_{q8} + k_{Vq89}(-V_{q8} + y_{s0}), V_{q9} \geq y_{s0}), (I_{q9} + k_{Vq90}(-V_{q9} + y_{s0}), V_{q10} \geq y_{s0}), (I_{q10} + k_{Vq101}(-V_{q10} + y_{s0}), V_{q11} \geq y_{s0}), (I_{q11} + k_{Vq112}(-V_{q11} + y_{s0}), V_{q12} \geq y_{s0}), (I_{q12} + k_{Vq123}(-V_{q12} + y_{s0}), V_{q13} \geq y_{s0}), (I_{q13} + k_{Vq134}(-V_{q13} + y_{s0}), V_{q14} \geq y_{s0}), (I_{q14} + k_{Vq145}(-V_{q14} + y_{s0}), V_{q15} \geq y_{s0}), (I_{q15} + k_{Vq156}(-V_{q15} + y_{s0}), V_{q16} \geq y_{s0}), (I_{q16} + k_{Vq167}(-V_{q16} + y_{s0}), V_{q17} \geq y_{s0}), (I_{q17} + k_{Vq178}(-V_{q17} + y_{s0}), V_{q18} \geq y_{s0}), (I_{q18} + k_{Vq189}(-V_{q18} + y_{s0}), V_{q19} \geq y_{s0}), (I_{q19} + k_{Vq190}(-V_{q19} + y_{s0}), V_{q20} \geq y_{s0}), (I_{q20} + k_{Vq201}(-V_{q20} + y_{s0}), V_{q21} \geq y_{s0}), (I_{q21} + k_{Vq212}(-V_{q21} + y_{s0}), V_{q22} \geq y_{s0}), (I_{q22} + k_{Vq223}(-V_{q22} + y_{s0}), V_{q23} \geq y_{s0}), (I_{q23} + k_{Vq234}(-V_{q23} + y_{s0}), V_{q24} \geq y_{s0}), (I_{q24} + k_{Vq245}(-V_{q24} + y_{s0}), V_{q25} \geq y_{s0}), (I_{q25} + k_{Vq256}(-V_{q25} + y_{s0}), V_{q26} \geq y_{s0}), (I_{q26} + k_{Vq267}(-V_{q26} + y_{s0}), V_{q27} \geq y_{s0}), (I_{q27} + k_{Vq278}(-V_{q27} + y_{s0}), V_{q28} \geq y_{s0}), (I_{q28} + k_{Vq289}(-V_{q28} + y_{s0}), V_{q29} \geq y_{s0}), (I_{q29} + k_{Vq290}(-V_{q29} + y_{s0}), V_{q30} \geq y_{s0}), (I_{q30} + k_{Vq301}(-V_{q30} + y_{s0}), V_{q31} \geq y_{s0}), (I_{q31} + k_{Vq312}(-V_{q31} + y_{s0}), V_{q32} \geq y_{s0}), (I_{q32} + k_{Vq323}(-V_{q32} + y_{s0}), V_{q33} \geq y_{s0}), (I_{q33} + k_{Vq334}(-V_{q33} + y_{s0}), V_{q34} \geq y_{s0}), (I_{q34} + k_{Vq345}(-V_{q34} + y_{s0}), V_{q35} \geq y_{s0}), (I_{q35} + k_{Vq356}(-V_{q35} + y_{s0}), V_{q36} \geq y_{s0}), (I_{q36} + k_{Vq367}(-V_{q36} + y_{s0}), V_{q37} \geq y_{s0}), (I_{q37} + k_{Vq378}(-V_{q37} + y_{s0}), V_{q38} \geq y_{s0}), (I_{q38} + k_{Vq389}(-V_{q38} + y_{s0}), V_{q39} \geq y_{s0}), (I_{q39} + k_{Vq390}(-V_{q39} + y_{s0}), V_{q40} \geq y_{s0}), (I_{q40} + k_{Vq401}(-V_{q40} + y_{s0}), V_{q41} \geq y_{s0}), (I_{q41} + k_{Vq412}(-V_{q41} + y_{s0}), V_{q42} \geq y_{s0}), (I_{q42} + k_{Vq423}(-V_{q42} + y_{s0}), V_{q43} \geq y_{s0}), (I_{q43} + k_{Vq434}(-V_{q43} + y_{s0}), V_{q44} \geq y_{s0}), (I_{q44} + k_{Vq445}(-V_{q44} + y_{s0}), V_{q45} \geq y_{s0}), (I_{q45} + k_{Vq456}(-V_{q45} + y_{s0}), V_{q46} \geq y_{s0}), (I_{q46} + k_{Vq467}(-V_{q46} + y_{s0}), V_{q47} \geq y_{s0}), (I_{q47} + k_{Vq478}(-V_{q47} + y_{s0}), V_{q48} \geq y_{s0}), (I_{q48} + k_{Vq489}(-V_{q48} + y_{s0}), V_{q49} \geq y_{s0}), (I_{q49} + k_{Vq490}(-V_{q49} + y_{s0}), V_{q50} \geq y_{s0}), (I_{q50} + k_{Vq501}(-V_{q50} + y_{s0}), V_{q51} \geq y_{s0}), (I_{q51} + k_{Vq512}(-V_{q51} + y_{s0}), V_{q52} \geq y_{s0}), (I_{q52} + k_{Vq523}(-V_{q52} + y_{s0}), V_{q53} \geq y_{s0}), (I_{q53} + k_{Vq534}(-V_{q53} + y_{s0}), V_{q54} \geq y_{s0}), (I_{q54} + k_{Vq545}(-V_{q54} + y_{s0}), V_{q55} \geq y_{s0}), (I_{q55} + k_{Vq556}(-V_{q55} + y_{s0}), V_{q56} \geq y_{s0}), (I_{q56} + k_{Vq567}(-V_{q56} + y_{s0}), V_{q57} \geq y_{s0}), (I_{q57} + k_{Vq578}(-V_{q57} + y_{s0}), V_{q58} \geq y_{s0}), (I_{q58} + k_{Vq589}(-V_{q58} + y_{s0}), V_{q59} \geq y_{s0}), (I_{q59} + k_{Vq590}(-V_{q59} + y_{s0}), V_{q60} \geq y_{s0}), (I_{q60} + k_{Vq601}(-V_{q60} + y_{s0}), V_{q61} \geq y_{s0}), (I_{q61} + k_{Vq612}(-V_{q61} + y_{s0}), V_{q62} \geq y_{s0}), (I_{q62} + k_{Vq623}(-V_{q62} + y_{s0}), V_{q63} \geq y_{s0}), (I_{q63} + k_{Vq634}(-V_{q63} + y_{s0}), V_{q64} \geq y_{s0}), (I_{q64} + k_{Vq645}(-V_{q64} + y_{s0}), V_{q65} \geq y_{s0}), (I_{q65} + k_{Vq656}(-V_{q65} + y_{s0}), V_{q66} \geq y_{s0}), (I_{q66} + k_{Vq667}(-V_{q66} + y_{s0}), V_{q67} \geq y_{s0}), (I_{q67} + k_{Vq678}(-V_{q67} + y_{s0}), V_{q68} \geq y_{s0}), (I_{q68} + k_{Vq689}(-V_{q68} + y_{s0}), V_{q69} \geq y_{s0}), (I_{q69} + k_{Vq690}(-V_{q69} + y_{s0}), V_{q70} \geq y_{s0}), (I_{q70} + k_{Vq701}(-V_{q70} + y_{s0}), V_{q71} \geq y_{s0}), (I_{q71} + k_{Vq712}(-V_{q71} + y_{s0}), V_{q72} \geq y_{s0}), (I_{q72} + k_{Vq723}(-V_{q72} + y_{s0}), V_{q73} \geq y_{s0}), (I_{q73} + k_{Vq734}(-V_{q73} + y_{s0}), V_{q74} \geq y_{s0}), (I_{q74} + k_{Vq745}(-V_{q74} + y_{s0}), V_{q75} \geq y_{s0}), (I_{q75} + k_{Vq756}(-V_{q75} + y_{s0}), V_{q76} \geq y_{s0}), (I_{q76} + k_{Vq767}(-V_{q76} + y_{s0}), V_{q77} \geq y_{s0}), (I_{q77}$

Differential Equations

Name	Sym- bol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
s0_y	y_{s0}	State	$V_d - y_{s0}$	T_{rv}
S1_y	y_{S1}	State	$Pe - y_{S1}$	T_p
PIQ_xi	xi_{PIQ}	State	$K_{qi} (1 - z_{Vdip}) (Q_{err} s_1^{SW_V} + 2y_{PIQ} - 2ys_{PIQ})$	
s4_y	y_{s4}	State	$(1 - z_{Vdip}) \left(\frac{PF_{sel}}{V_p} - y_{s4} \right)$	T_{iq}
pfilt_y	$y_{P_{filt}}$	State	$P_{ref} - y_{P_{filt}}$	0.02
s5_y	y_{s5}	State	$(1 - z_{Vdip}) (P_{sel} - y_{s5})$	T_{pord}
PIV_xi	xi_{PIV}	State	$K_{vi} (1 - z_{Vdip}) \left(s_1^{SW_V} \left(-s_0^{SW_V} y_{s0} + y_{V_{sel}} \right) + 2y_{PIV} - 2ys_I \right)$	
Pord	$Pord$	AliasState	0	
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
vp	V_p	Algeb	$V_d z_i^{V_{Lower}} - V_p + 0.01 z_l^{V_{Lower}}$
pfaref	Φ_{ref}	Algeb	$\Phi_{ref0} - \Phi_{ref}$
Qref	Q_{ref}	Algeb	$-Q_{ref} - q_{ref0}$
Qcpf	Q_{cpf}	Algeb	$(1 - z_1^{z_p}) (-Q_{cpf} + y_{S1} \tan(\Phi_{ref}))$
PFsel	PF_{sel}	Algeb	$-PF_{sel} + Q_{cpf} s_1^{SW_{PF}} + Q_{ref} s_0^{SW_{PF}}$
Qerr	Q_{err}	Algeb	$PF_{sel} z_i^{PF_{lim}} - Q_{err} + Q_{max} z_u^{PF_{lim}} + Q_{min} z_l^{PF_{lim}} - Q_e$
PIQ_ys	ys_{PIQ}	Algeb	$(1 - z_{Vdip}) \left(K_{qp} Q_{err} s_1^{SW_V} + xi_{PIQ} - ys_{PIQ} \right)$
PIQ_y	y_{PIQ}	Algeb	$(1 - z_{Vdip}) \left(V_{max} z_u^{lim_{PIQ}} + V_{min} z_l^{lim_{PIQ}} - y_{PIQ} + ys_{PIQ} z_i^{lim_{PIQ}} \right)$
Vsel_x	$x_{V_{sel}}$	Algeb	$s_0^{SW_V} \left(Q_{cpf} s_1^{SW_{PF}} + Q_{ref} s_0^{SW_{PF}} + V_{ref1} \right) + s_1^{SW_V} y_{PIQ} - x_{V_{sel}}$
Vsel_y	$y_{V_{sel}}$	Algeb	$V_{max} z_u^{lim_{V_{sel}}} + V_{min} z_l^{lim_{V_{sel}}} + x_{V_{sel}} z_i^{lim_{V_{sel}}} - y_{V_{sel}}$
Verr	V_{err}	Algeb	$-V_{err} + V_{ref0} - y_{s0}$
dbV_y	y_{dbV}	Algeb	$-y_{dbV} + 1.0 z_l^{db_{dbV}} (V_{err} - d_{bd1}) + 1.0 z_u^{db_{dbV}} (V_{err} - d_{bd2})$
Iqinj	I_{qinj}	Algeb	$-I_{qinj} + K_{qv} y_{dbV} z_{Vdip} + fThld (1 - z_{Vdip}) (I_{qfrz} pThld + K_{qv} nThld y_{dbV})$
wg	ω_g	Algeb	$1.0 - \omega_g$
Pref	P_{ref}	Algeb	$-K_{df} (\omega - 1) + \frac{P_0}{\omega_g} - P_{ref}$
Psel	P_{sel}	Algeb	$-P_{sel} + \omega_g s_1^{SW_P} y_{P_{filt}} + s_0^{SW_P} y_{P_{filt}}$
VDL1_y	y_{VDL1}	Algeb	$-y_{VDL1} + \text{FixPiecewise}((I_{q1}, V_{q1} \geq y_{s0}), (I_{q1} + k_{Vq12} (-V_{q1} + y_{s0}), V_{q2} \geq y_{s0}), (I_{q1} - k_{Vq12} (-V_{q1} + y_{s0}), V_{q2} < y_{s0}))$
VDL2_y	y_{VDL2}	Algeb	$-y_{VDL2} + \text{FixPiecewise}((I_{p1}, V_{p1} \geq y_{s0}), (I_{p1} + k_{Vp12} (-V_{p1} + y_{s0}), V_{p2} \geq y_{s0}), (I_{p1} - k_{Vp12} (-V_{p1} + y_{s0}), V_{p2} < y_{s0}))$
Ipmax	I_{pmax}	Algeb	$-I_{pmax} + Ipmax hfThld_2 + (1 - fThld_2) \left(\sqrt{I_{pmax}^2 s_0^{SW_{PQ}}} + s_1^{SW_{PQ}} (z_{VDL2} (I_{max} - I_{pmax})) \right)$
Iqmax	I_{qmax}	Algeb	$\sqrt{I_{qmax}^2 s_1^{SW_{PQ}}} - I_{qmax} + s_0^{SW_{PQ}} (z_{VDL1} (I_{max} (1 - VDL1c) + VDL1c y_{VDL1}) - I_{qmax})$
PIV_ys	ys_{PIV}	Algeb	$(1 - z_{Vdip}) \left(K_{vp} s_1^{SW_V} \left(-s_0^{SW_V} y_{s0} + y_{V_{sel}} \right) + xi_{PIV} - ys_{PIV} \right)$

Table 30 – continued from previous

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
PIV_y	y_{PIV}	Algeb	$(1 - z_{Vdip}) \left(I_{qmax} z_u^{lim_{PIV}} + I_{qmin} z_l^{lim_{PIV}} - y_{PIV} + y_{SPIV} z_i^{lim_{PIV}} \right)$
Qsel	Q_{sel}	Algeb	$-Q_{sel} + s_0^{SW_V} y_{s4} + s_1^{SW_V} y_{PIV}$
IpHL_x	x_{IpHL}	Algeb	$-x_{IpHL} + \frac{y_{s5}}{V_p}$
IpHL_y	y_{IpHL}	Algeb	$I_{pmax} z_u^{lim_{IpHL}} + I_{pmin} z_l^{lim_{IpHL}} + x_{IpHL} z_i^{lim_{IpHL}} - y_{IpHL}$
IqHL_x	x_{IqHL}	Algeb	$I_{qinj} + Q_{sel} - x_{IqHL}$
IqHL_y	y_{IqHL}	Algeb	$I_{qmax} z_u^{lim_{IqHL}} + I_{qmin} z_l^{lim_{IqHL}} + x_{IqHL} z_i^{lim_{IqHL}} - y_{IqHL}$
a	θ	ExtAlgeb	0
v	V_d	ExtAlgeb	0
Pe	Pe	ExtAlgeb	0
Qe	Qe	ExtAlgeb	0
Ipcmd	$Ipcmd$	ExtAlgeb	$-Ipcmd_0 + y_{IpHL}$
Iqcmd	$Iqcmd$	ExtAlgeb	$-Iqcmd_0 - y_{IqHL}$

Services

Name	Symbol	Equation	Type
Ipcmd0	$Ipcmd0$	$\frac{P_0}{V_d}$	ConstService
Iqcmd0	$Iqcmd0$	$-\frac{Q_0}{V_d}$	ConstService
pfaref0	Φ_{ref0}	$\text{atan}_2(Q_0, P_0)$	ConstService
Volt_dip	z_{Vdip}	$1 - z_i^{V_{cmp}}$	VarService
qref0	q_{ref0}	$Iqcmd_0 s_0^{SW_V} (V_d z_i^{V_{Lower}} + 0.01 z_l^{V_{Lower}}) + s_1^{SW_V} (V_d - V_{ref1})$	ConstService
PIQ_flag	z_{PIQ}^{flag}	0	EventFlag
s4_flag	z_{s4}^{flag}	0	EventFlag
pThld	p_{Thld}	Indicator($T_{hld} > 0$)	ConstService
nThld	n_{Thld}	Indicator($T_{hld} < 0$)	ConstService
Thld_abs	$ Thld $	$ Thld $	ConstService
fThld	f_{Thld}	0	ExtendedEvent
s5_flag	z_{s5}^{flag}	0	EventFlag
kVq12	k_{Vq12}	$\frac{-I_{q1} + I_{q2}}{-V_{q1} + V_{q2}}$	ConstService
kVq23	k_{Vq23}	$\frac{-I_{q2} + I_{q3}}{-V_{q2} + V_{q3}}$	ConstService
kVq34	k_{Vq34}	$\frac{-I_{q3} + I_{q4}}{-V_{q3} + V_{q4}}$	ConstService
zVDL1	z_{VDL1}	$I_{q1} \leq I_{q2} \wedge I_{q2} \leq I_{q3} \wedge I_{q3} \leq I_{q4} \wedge V_{q1} \leq V_{q2} \wedge V_{q2} \leq V_{q3} \wedge V_{q3} \leq V_{q4}$	ConstService
kVp12	k_{Vp12}	$\frac{-I_{p1} + I_{p2}}{-V_{p1} + V_{p2}}$	ConstService
kVp23	k_{Vp23}	$\frac{-I_{p2} + I_{p3}}{-V_{p2} + V_{p3}}$	ConstService
kVp34	k_{Vp34}	$\frac{-I_{p3} + I_{p4}}{-V_{p3} + V_{p4}}$	ConstService
zVDL2	z_{VDL2}	$I_{p1} \leq I_{p2} \wedge I_{p2} \leq I_{p3} \wedge I_{p3} \leq I_{p4} \wedge V_{p1} \leq V_{p2} \wedge V_{p2} \leq V_{p3} \wedge V_{p3} \leq V_{p4}$	ConstService
fThld2	f_{Thld2}	0	ExtendedEvent
VDL1c	$VDL1c$	$y_{VDL1} < I_{maxr}$	VarService

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Table 31 – continued from previous page

Name	Symbol	Equation	Type
VDL2c	$VDL2c$	$y_{VDL2} < I_{max}$	VarService
Ipmax2sq0	$I_{pmax20,nn}^2$	FixPiecewise $((0, I_{max}^2 - I_{qcmd_0}^2 \leq 0), (I_{max}^2 - I_{qcmd_0}^2, \text{True}))$	ConstService
Ipmax2sq	I_{pmax2}^2	FixPiecewise $((0, I_{max}^2 - y_{IqHL}^2 \leq 0), (I_{max}^2 - y_{IqHL}^2, \text{True}))$	VarService
Ipmaxh	$Ipmaxh$	0	VarHold
Iqmax2sq0	$I_{qmax,nn}^2$	FixPiecewise $((0, I_{max}^2 - I_{pcmd_0}^2 \leq 0), (I_{max}^2 - I_{pcmd_0}^2, \text{True}))$	ConstService
Iqmax2sq	I_{qmax2}^2	FixPiecewise $((0, I_{max}^2 - y_{IpHL}^2 \leq 0), (I_{max}^2 - y_{IpHL}^2, \text{True}))$	VarService
Ipmin	I_{pmin}	0.0	ConstService
PIV_flag	z_{PIV}^{flag}	0	EventFlag

Discretes

Name	Symbol	Type	Info
SWPF	SW_{PF}	Switcher	
SWV	SW_V	Switcher	
SWQ	SW_V	Switcher	
SWP	SW_P	Switcher	
SWPQ	SW_{PQ}	Switcher	
zp	zp	IsEqual	
Vcmp	V_{cmp}	Limiter	Voltage dip comparator
VLower	V_{Lower}	Limiter	Limiter for lower voltage cap
PFlim	P_{Flim}	Limiter	
PIQ_lim	lim_{PIQ}	HardLimiter	
Vsel_lim	$lim_{V_{sel}}$	HardLimiter	
dbV_db	db_{dbV}	DeadBand	
pfilt_lim	$lim_{P_{filt}}$	RateLimiter	Rate limiter in Lag
s5_lim	lim_{s5}	AntiWindup	Limiter in Lag
PIV_lim	lim_{PIV}	HardLimiter	
IpHL_lim	lim_{IpHL}	HardLimiter	
IqHL_lim	lim_{IqHL}	HardLimiter	

Blocks

Name	Symbol	Type	Info
s0	s_0	Lag	Voltage filter
S1	S_1	Lag	Pe filter
PIQ	PIQ	PITrackAWFreeze	
Vsel	V_{sel}	GainLimiter	Selection output of VFLAG
s4	s_4	LagFreeze	Filter for calculated voltage with freeze
dbV	dbV	DeadBand1	Deadband for voltage error (ref0)
pfilt	P_{filt}	LagRate	Active power filter with rate limits
s5	s_5	LagAWFreeze	
VDL1	V_{DL1}	Piecewise	Piecewise linear characteristics of Vq-Iq
VDL2	V_{DL2}	Piecewise	Piecewise linear characteristics of Vp-Ip
PIV	PIV	PITrackAWFreeze	
IpHL	I_{pHL}	GainLimiter	
IqHL	I_{qHL}	GainLimiter	

Config Fields in [REECA1G]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
kqs	K_{qs}	2	Q PI controller tracking gain	
kvs	K_{vs}	2	Voltage PI controller tracking gain	
tpfilt	T_{pfilt}	0.020	Time const. for Pref filter	

5.24 RenGen

Renewable generator (converter) group.

See [SynGen](#) for the notes on replacing StaticGen and setting the power ratio parameters.

Attention is needed for the power base S_n . When replacing a synchronous generator, the renewable generator should have the same or larger S_n . Improper S_n will cause the initial values to exceed typical per-unit ranges and cause the initialization to fail.

Common Parameters: u, name, bus, gen, S_n

Common Variables: Pe, Qe

Available models: [REGCA1](#), [REGCP1](#), [REGCV1](#), [REGCV2](#), [REGF1](#), [REGF2](#), [REGF3](#)

5.24.1 REGCA1

Renewable energy generator model type A.

Implements REGCA1 in PSS/E, or REGC_A in PSLF and Powerworld.

Volim is the voltage limit for high voltage reactive current management, which should be large than static bus voltage ($\text{Volim} > v$), or initialization error will occur.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Proper- ties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			manda- tory
gen		static generator index			manda- tory
Sn	S_n	Model MVA base	100	<i>MVA</i>	
Tg	T_g	converter time const.	0.100	<i>s</i>	
Rrpwr	R_{rpwr}	Low voltage power logic (LVPL) ramp limit	10	<i>p.u.</i>	
Brkpt	B_{rkpt}	LVPL characteristic voltage 2	1	<i>p.u.</i>	
Zerox	Z_{erox}	LVPL characteristic voltage 1	0.500	<i>p.u.</i>	
Lv- plsw	z_{Lvplsw}	Low volt. P logic: 1-enable, 0-disable	1	<i>bool</i>	
Lvpl1	L_{vpl1}	LVPL gain at Brkpt	1	<i>p.u.</i>	
Volim	V_{olim}	Voltage lim for high volt. reactive current mgnt.	1.200	<i>p.u.</i>	
Lvpnt1	L_{vpnt1}	High volt. point for low volt. active current mgnt.	0.800	<i>p.u.</i>	
Lvpnt0	L_{vpnt0}	Low volt. point for low volt. active current mgnt.	0.400	<i>p.u.</i>	
Iolim	I_{olim}	lower current limit for high volt. reactive current mgnt.	- 1.500	<i>p.u.</i> (<i>mach</i> <i>base</i>)	current
Tfltr	T_{fltr}	Voltage filter T const for low volt. active current mgnt.	0.100	<i>s</i>	
Khv	K_{hv}	Overvolt. compensation gain in high volt. reactive current mgnt.	0.700		
Iqr- max	I_{qrmax}	Upper limit on the ROC for reactive current	1	<i>p.u.</i>	current
Iqr- min	I_{qrmin}	Lower limit on the ROC for reactive current	-1	<i>p.u.</i>	current
Accel	A_{ccel}	Acceleration factor	0		
gamma _p	γ_P	P ratio of linked static gen	1		
gamma _q	γ_Q	Q ratio of linked static gen	1		
ra	r_a		0		
xs	x_s		0		

Variables

Name	Symbol	Type	Description	Unit	Properties
S1_y	y_{S_1}	State	State in lag TF		v_str
S2_y	y_{S_2}	State	State in lag transfer function		v_str
S0_y	y_{S_0}	State	State in lag TF		v_str
LVG_y	y_{LVG}	Algeb	Output of piecewise		v_str
Ipcmd	I_{pcmd}	Algeb	current component for active power		v_str
Iqcmd	I_{qcmd}	Algeb	current component for reactive power		v_str
LVPL_y	y_{LVPL}	Algeb	Output of piecewise		v_str
Ipout	I_{pout}	Algeb	Output Ip current		v_str
HVG_x	x_{HVG}	Algeb	Value before limiter		v_str
HVG_y	y_{HVG}	Algeb	Output after limiter and post gain		v_str
Iqout_x	x_{Iqout}	Algeb	Value before limiter		v_str
Iqout_y	y_{Iqout}	Algeb	Output after limiter and post gain		v_str
Pe	P_e	Algeb	Active power output		v_str
Qe	Q_e	Algeb	Reactive power output		v_str
a	θ	ExtAlgeb	Bus voltage angle		
v	V	ExtAlgeb	Bus voltage magnitude		
vd	vd	AliasAlgeb	Alias of v		

Initialization Equations

Name	Sym- bol	Type	Initial Value
S1_y	y_{S_1}	State	$-I_{qcmd}$
S2_y	y_{S_2}	State	$1.0V$
S0_y	y_{S_0}	State	I_{pcmd}
LVG_	y_{LVG}	Algeb	$\text{FixPiecewise}((0, L_{vpnt0} \geq V), (k_{LVG}(-L_{vpnt0} + V), L_{vpnt1} \geq V), (1, \text{True}))$
Ipcmd	I_{pcmd}	Algeb	$\frac{I_{pcmd0} \text{Indicator}(y_{LVG} > 0)}{y_{LVG}} + \text{Indicator}(y_{LVG} \leq 0)$
Iqcmd	I_{qcmd}	Algeb	I_{qcmd0}
LVPL	y_{LVPL}	Algeb	$\text{FixPiecewise}((9999 - 9999z_{Lvplsw}, Z_{erox} \geq y_{S_2}), (k_{LVPL}(-Z_{erox} + y_{S_2}) - 9999z_{Lvplsw} + 9$
Ipout	I_{pout}	Algeb	$I_{pcmd}y_{LVG}$
HVG_	x_{HVG}	Algeb	$K_{hv}(V - V_{olim})$
HVG_	y_{HVG}	Algeb	$x_{HVG}z_i^{lim_{HVG}}$
Iqout_	x_{Iqout}	Algeb	$-y_{HVG} + y_{S_1}$
Iqout_	y_{Iqout}	Algeb	$I_{olim}z_i^{lim_{Iqout}} + x_{Iqout}z_i^{lim_{Iqout}}$
Pe	P_e	Algeb	P_0
Qe	Q_e	Algeb	Q_0
a	θ	Ex- tAlgeb	
v	V	Ex- tAlgeb	
vd	vd	AliasAl- geb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
S1_y	y_{S_1}	State	$-I_{qcmd} - y_{S_1}$	T_g
S2_y	y_{S_2}	State	$1.0V - y_{S_2}$	T_{fltr}
S0_y	y_{S_0}	State	$I_{pcmd} - y_{S_0}$	T_g

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
LVG_	y_{LVG}	Algeb	$-y_{LVG} + \text{FixPiecewise}((0, L_{vpnt0} \geq V), (k_{LVG}(-L_{vpnt0} + V), L_{vpnt1} \geq V), (1, \text{True}))$
Ipcmd	I_{pcmd}	Algeb	$-I_{pcmd} + I_{pcmd0LVG}$
Iqcmd	I_{qcmd}	Algeb	$I_{qcmd0} - I_{qcmd}$
LVPL	y_{LVPL}	Algeb	$-y_{LVPL} + \text{FixPiecewise}((9999 - 9999z_{Lvplsw}, Z_{erox} \geq y_{S2}), (k_{LVPL}(-Z_{erox} + y_{S2}) - 9999z_{L$
Ipout	I_{pout}	Algeb	$-I_{pout} + y_{LVG}y_{S0}$
HVG_	x_{HVG}	Algeb	$K_{hv}(V - V_{olim}) - x_{HVG}$
HVG_	y_{HVG}	Algeb	$x_{HVG}z_i^{lim_{HVG}} - y_{HVG}$
Iqout_	x_{Iqout}	Algeb	$-x_{Iqout} - y_{HVG} + y_{S1}$
Iqout_	y_{Iqout}	Algeb	$I_{olim}z_l^{lim_{Iqout}} + x_{Iqout}z_i^{lim_{Iqout}} - y_{Iqout}$
Pe	P_e	Algeb	$I_{pout}V - P_e$
Qe	Q_e	Algeb	$-Q_e + Vy_{Iqout}$
a	θ	Ex- tAl- geb	$-P_e$
v	V	Ex- tAl- geb	$-Q_e$
vd	vd	AliasAl geb	0

Services

Name	Symbol	Equation	Type
p0	P_0	$P_{0s}\gamma_P$	ConstService
q0	Q_0	$Q_{0s}\gamma_Q$	ConstService
q0gt0	$z_{q0>0}$	$\text{Indicator}(Q_0 > 0)$	ConstService
q0lt0	$z_{q0<0}$	$\text{Indicator}(Q_0 < 0)$	ConstService
Ipcmd0	I_{pcmd0}	$\frac{P_0}{V}$	ConstService
Iqcmd0	I_{qcmd0}	$-\frac{Q_0}{V}$	ConstService
Ipcmd0_LVG	$I_{pcmd0LVG}$	I_{pcmd}	PostInitService
kLVG	k_{LVG}	$\frac{1}{-L_{vpnt0} + L_{vpnt1}}$	ConstService
kLVPL	k_{LVPL}	$\frac{L_{vpl1}z_{Lvplsw}}{Brkpt - Z_{erox}}$	ConstService

Discretes

Name	Symbol	Type	Info
S1_lim	lim_{S_1}	AntiWindupRate	Limiter in Lag
S0_lim	lim_{S_0}	AntiWindupRate	Limiter in Lag
HVG_lim	lim_{HVG}	HardLimiter	
Iqout_lim	lim_{Iqout}	HardLimiter	

Blocks

Name	Symbol	Type	Info
LVG	L_{VG}	Piecewise	Ip gain during low voltage
S1	S_1	LagAntiWindupRate	Iqcmd delay
S2	S_2	Lag	Voltage filter with no anti-windup
LVPL	L_{VPL}	Piecewise	Low voltage Ipcmd upper limit
S0	S_0	LagAntiWindupRate	
HVG	H_{VG}	GainLimiter	High voltage gain block
Iqout	I^{qout}	GainLimiter	Iq output block

Config Fields in [REGCA1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.24.2 REGCP1

Renewable energy generator model (REGC_A) with PLL.

A PLL device can be specified for estimating the phase angle at the coupling bus through the `pll` parameter:

- If `pll` is not given, the accurate bus angle will be used.
- If `pll` is not a valid PLL device, the program will error out.
- The program does not check if the provided `pll` actually measures the bus on which the converter is at.

One needs to carefully tune the PLL parameters to match the desired performance.

All other remarks for REGCA1 apply.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Proper- ties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			manda- tory
gen		static generator index			manda- tory
Sn	S_n	Model MVA base	100	<i>MVA</i>	
Tg	T_g	converter time const.	0.100	<i>s</i>	
Rrpwr	R_{rpwr}	Low voltage power logic (LVPL) ramp limit	10	<i>p.u.</i>	
Brkpt	B_{rkpt}	LVPL characteristic voltage 2	1	<i>p.u.</i>	
Zerox	Z_{erox}	LVPL characteristic voltage 1	0.500	<i>p.u.</i>	
Lv- plsw	z_{Lvplsw}	Low volt. P logic: 1-enable, 0-disable	1	<i>bool</i>	
Lvpl1	L_{vpl1}	LVPL gain at Brkpt	1	<i>p.u.</i>	
Volim	V_{olim}	Voltage lim for high volt. reactive current mgnt.	1.200	<i>p.u.</i>	
Lvpnt1	L_{vpnt1}	High volt. point for low volt. active current mgnt.	0.800	<i>p.u.</i>	
Lvpnt0	L_{vpnt0}	Low volt. point for low volt. active current mgnt.	0.400	<i>p.u.</i>	
Iolim	I_{olim}	lower current limit for high volt. reactive current mgnt.	- 1.500	<i>p.u. (mach base)</i>	current
Tfltr	T_{fltr}	Voltage filter T const for low volt. active current mgnt.	0.100	<i>s</i>	
Khv	K_{hv}	Overvolt. compensation gain in high volt. reactive current mgnt.	0.700		
Iqr- max	I_{qrmax}	Upper limit on the ROC for reactive current	1	<i>p.u.</i>	current
Iqr- min	I_{qrmin}	Lower limit on the ROC for reactive current	-1	<i>p.u.</i>	current
Accel	A_{ccel}	Acceleration factor	0		
gamma _p	γ_P	P ratio of linked static gen	1		
gamma _q	γ_Q	Q ratio of linked static gen	1		
pll		Phase-lock loop device idx			
ra	r_a		0		
xs	x_s		0		

Variables

Name	Symbol	Type	Description	Unit	Properties
S1_y	y_{S_1}	State	State in lag TF		v_str
S2_y	y_{S_2}	State	State in lag transfer function		v_str
S0_y	y_{S_0}	State	State in lag TF		v_str
am	θ_m	ExtState	Measured angle		
LVG_y	y_{LVG}	Algeb	Output of piecewise		v_str
Ipcmd	I_{pcmd}	Algeb	current component for active power		v_str
Iqcmd	I_{qcmd}	Algeb	current component for reactive power		v_str
LVPL_y	y_{LVPL}	Algeb	Output of piecewise		v_str
Ipout	I_{pout}	Algeb	Output Ip current		v_str
HVG_x	x_{HVG}	Algeb	Value before limiter		v_str
HVG_y	y_{HVG}	Algeb	Output after limiter and post gain		v_str
Iqout_x	x_{Iqout}	Algeb	Value before limiter		v_str
Iqout_y	y_{Iqout}	Algeb	Output after limiter and post gain		v_str
Pe	P_e	Algeb	Active power output		v_str
Qe	Q_e	Algeb	Reactive power output		v_str
vd	V_d	Algeb	d-axis voltage		v_str
vq	V_q	Algeb	q-axis voltage		v_str
a	θ	ExtAlgeb	Bus voltage angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Sym- bol	Type	Initial Value
S1_y	y_{S_1}	State	$-I_{qcmd}$
S2_y	y_{S_2}	State	$1.0V$
S0_y	y_{S_0}	State	I_{pcmd}
am	θ_m	ExtStat	
LVG_	y_{LVG}	Al- geb	$\text{FixPiecewise}((0, L_{vpnt0} \geq V), (k_{LVG}(-L_{vpnt0} + V), L_{vpnt1} \geq V), (1, \text{True}))$
Ipcmd	I_{pcmd}	Al- geb	$\frac{I_{pcmd0} \text{Indicator}(y_{LVG} > 0)}{y_{LVG}} + \text{Indicator}(y_{LVG} \leq 0)$
Iqcmd	I_{qcmd}	Al- geb	I_{qcmd0}
LVPL_	y_{LVPL}	Al- geb	$\text{FixPiecewise}((9999 - 9999z_{Lvplsw}, Z_{erox} \geq y_{S_2}), (k_{LVPL}(-Z_{erox} + y_{S_2}) - 9999z_{Lvplsw} + 9999, Z_{erox} < y_{S_2}))$
Ipout	I_{pout}	Al- geb	$I_{pcmd}y_{LVG}$
HVG_	x_{HVG}	Al- geb	$K_{hv}(V - V_{olim})$
HVG_	y_{HVG}	Al- geb	$x_{HVG}z_i^{lim_{HVG}}$
Iqout_	x_{Iqout}	Al- geb	$-y_{HVG} + y_{S_1}$
Iqout_	y_{Iqout}	Al- geb	$I_{olim}z_l^{lim_{Iqout}} + x_{Iqout}z_i^{lim_{Iqout}}$
Pe	P_e	Al- geb	P_0
Qe	Q_e	Al- geb	Q_0
vd	V_d	Al- geb	V
vq	V_q	Al- geb	0
a	θ	Ex- tAl- geb	
v	V	Ex- tAl- geb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
S1_y	y_{S_1}	State	$-I_{qcmd} - y_{S_1}$	T_g
S2_y	y_{S_2}	State	$1.0V - y_{S_2}$	T_{fltr}
S0_y	y_{S_0}	State	$I_{pcmd} - y_{S_0}$	T_g
am	θ_m	ExtState	0	

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
LVG_	y_{LVG}	Al- geb	$-y_{LVG} + \text{FixPiecewise}((0, L_{vpnt0} \geq V), (k_{LVG}(-L_{vpnt0} + V), L_{vpnt1} \geq V), (1, \text{True}))$
Ipcmd	I_{pcmd}	Al- geb	$-I_{pcmd} + I_{pcmd0LVG}$
Iqcmd	I_{qcmd}	Al- geb	$I_{qcmd0} - I_{qcmd}$
LVPL	y_{LVPL}	Al- geb	$-y_{LVPL} + \text{FixPiecewise}((9999 - 9999z_{Lvplsw}, Z_{erox} \geq y_{S2}), (k_{LVPL}(-Z_{erox} + y_{S2}) - 9999z_{Lvplsw}, Z_{erox} < y_{S2}))$
Ipout	I_{pout}	Al- geb	$-I_{pout} + y_{LVG}y_{S0}$
HVG_	x_{HVG}	Al- geb	$K_{hv}(V - V_{olim}) - x_{HVG}$
HVG_	y_{HVG}	Al- geb	$x_{HVG}z_i^{lim_{HVG}} - y_{HVG}$
Iqout_	x_{Iqout}	Al- geb	$-x_{Iqout} - y_{HVG} + y_{S1}$
Iqout_	y_{Iqout}	Al- geb	$I_{olim}z_l^{lim_{Iqout}} + x_{Iqout}z_i^{lim_{Iqout}} - y_{Iqout}$
Pe	P_e	Al- geb	$I_{pout}V_d - P_e + V_qy_{Iqout}$
Qe	Q_e	Al- geb	$-I_{pout}V_q - Q_e + V_dy_{Iqout}$
vd	V_d	Al- geb	$V \cos(z_{hetam}(\theta - \theta_m)) - V_d$
vq	V_q	Al- geb	$-V \sin(z_{hetam}(\theta - \theta_m)) - V_q$
a	θ	Ex- tAl- geb	$-P_e$
v	V	Ex- tAl- geb	$-Q_e$

Services

Name	Symbol	Equation	Type
p0	P_0	$P_{0s}\gamma_P$	ConstService
q0	Q_0	$Q_{0s}\gamma_Q$	ConstService
q0gt0	$z_{q0>0}$	Indicator ($Q_0 > 0$)	ConstService
q0lt0	$z_{q0<0}$	Indicator ($Q_0 < 0$)	ConstService
Ipcmd0	I_{pcmd0}	$\frac{P_0}{V}$	ConstService
Iqcmd0	I_{qcmd0}	$-\frac{Q_0}{V}$	ConstService
Ipcmd0_LVG	$I_{pcmd0_{LVG}}$	I_{pcmd}	PostInitService
kLVG	k_{LVG}	$\frac{1}{-L_{vpnt0} + L_{vpnt1}}$	ConstService
kLVPL	k_{LVPL}	$\frac{L_{vpl1}z_{Lvpls w}}{B_{rkpt} - Z_{erox}}$	ConstService

Discretes

Name	Symbol	Type	Info
S1_lim	lim_{S_1}	AntiWindupRate	Limiter in Lag
S0_lim	lim_{S_0}	AntiWindupRate	Limiter in Lag
HVG_lim	lim_{HVG}	HardLimiter	
Iqout_lim	lim_{Iqout}	HardLimiter	

Blocks

Name	Symbol	Type	Info
LVG	L_{VG}	Piecewise	Ip gain during low voltage
S1	S_1	LagAntiWindupRate	Iqcmd delay
S2	S_2	Lag	Voltage filter with no anti-windup
LVPL	L_{VPL}	Piecewise	Low voltage Ipcmd upper limit
S0	S_0	LagAntiWindupRate	
HVG	H_{VG}	GainLimiter	High voltage gain block
Iqout	I^{qout}	GainLimiter	Iq output block

Config Fields in [REGCP1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.24.3 REGCV1

Voltage-controlled VSC with VSG control.

Includes double-loop PI control and swing equation based VSG control. Voltage measurement delays are ignored.

Notes

- Extreme care needs to be taken when coordinating the PI controller parameters.
- Setting the primary frequency control droop k_w can improve small-signal stability.
- The droop k_v for voltage control (pu voltage / pu Q change), if used, needs to be chosen carefully. In most cases, k_v should be a very small positive value if not zero.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
coi2		center of inertia 2 index			
Sn	S_n	Model MVA base	100	<i>MVA</i>	
fn	f	rated frequency	60		
Tc	T_c	switch time constant	0.010	<i>s</i>	
kw	k_ω	speed droop on active power (reciprocal of droop)	0	<i>p.u.</i>	non_negative,ipower
kv	k_v	reactive power droop on voltage	0	<i>p.u.</i>	non_negative,power
M	M	Emulated startup time constant (M=2H)	10	<i>s</i>	power
D	D	Emulated damping coefficient	0	<i>p.u.</i>	power
ra	r_a	resistance	0		z
xs	x_s	reactance	0.200		z
gammap	γ_P	P ratio of linked static gen	1		
gam- maq	γ_Q	Q ratio of linked static gen	1		
Kpvd	$k_{p_{vd}}$	vd controller proportional gain	0.500	<i>p.u.</i>	power
Kivd	$k_{i_{vd}}$	vd controller integral gain	0.020	<i>p.u.</i>	power
Kpvq	$k_{p_{vq}}$	vq controller proportional gain	0.500	<i>p.u.</i>	power
Kivq	$k_{i_{vq}}$	vq controller integral gain	0.020	<i>p.u.</i>	power
KpId	$k_{p_{di}}$	Id controller proportional gain	0.200	<i>p.u.</i>	power
KiId	$k_{i_{di}}$	Id controller integral gain	0.010	<i>p.u.</i>	power
KpIq	$k_{p_{qi}}$	Iq controller proportional gain	0.200	<i>p.u.</i>	power
KiIq	$k_{i_{qi}}$	Iq controller integral gain	0.010	<i>p.u.</i>	power

Variables

Name	Sym- bol	Type	Description	Unit	Proper- ties
dw	$\Delta\omega$	State	delta virtual rotor speed	<i>pu</i> (Hz)	v_str
delta	δ	State	virtual delta	<i>rad</i>	v_str
PIvd_xi	xi_{PIvd}	State	Integrator output		v_str
PIvq_xi	xi_{PIvq}	State	Integrator output		v_str
PIId_xi	xi_{PIId}	State	Integrator output		v_str
PIIq_xi	xi_{PIIq}	State	Integrator output		v_str
ud- Lag_y	y_{udLag}	State	State in lag transfer function		v_str
uqLag_y	y_{uqLag}	State	State in lag transfer function		v_str
ud	ud	AliasState	Alias of udLag_y		
uq	uq	AliasState	Alias of uqLag_y		
Pref2	P_{ref2}	Algeb	active power reference after adjusting by frequency		v_str
vref2	v_{ref2}	Algeb	voltage reference after adjusted by reactive power		v_str
omega	ω	Algeb	virtual rotor speed	<i>pu</i> (Hz)	v_str
vd	V_d	Algeb	d-axis voltage		v_str
vq	V_q	Algeb	q-axis voltage		v_str
Pe	P_e	Algeb	active power injection from VSC		v_str
Qe	Q_e	Algeb	reactive power injection from VSC		v_str
Id	I_d	Algeb	d-axis current		v_str
Iq	I_q	Algeb	q-axis current		v_str
PIvd_y	y_{PIvd}	Algeb	PI output		v_str
PIvq_y	y_{PIvq}	Algeb	PI output		v_str
PIId_y	y_{PIId}	Algeb	PI output		v_str
PIIq_y	y_{PIIq}	Algeb	PI output		v_str
udref	u_{dref}	Algeb	ud reference		v_str
uqref	u_{qref}	Algeb	uq reference		v_str
a	θ	ExtAlgeb	Bus voltage angle		
v	V	ExtAlgeb	Bus voltage magnitude		
Idref	I_{dref}	AliasAl- geb	Alias of PIvd_y		
Iqref	I_{qref}	AliasAl- geb	Alias of PIvq_y		

Initialization Equations

Name	Symbol	Type	Initial Value
dw	$\Delta\omega$	State	0
delta	δ	State	θ
PIvd_xi	xi_{PIvd}	State	I_{d0}
PIvq_xi	xi_{PIvq}	State	I_{q0}
PIId_xi	xi_{PIId}	State	0.0
PIIq_xi	xi_{PIIq}	State	0.0
udLag_y	y_{udLag}	State	u_{dref}
uqLag_y	y_{uqLag}	State	u_{qref}
ud	ud	AliasState	
uq	uq	AliasState	
Pref2	P_{ref2}	Algeb	$P_{ref}u$
vref2	v_{ref2}	Algeb	$V_{ref}u$
omega	ω	Algeb	u
vd	V_d	Algeb	v_{d0}
vq	V_q	Algeb	v_{q0}
Pe	P_e	Algeb	P_{ref}
Qe	Q_e	Algeb	Q_{ref}
Id	I_d	Algeb	I_{d0}
Iq	I_q	Algeb	I_{q0}
PIvd_y	y_{PIvd}	Algeb	$I_{d0} + kp_{vd}(V_d - v_{ref2})$
PIvq_y	y_{PIvq}	Algeb	$I_{q0} + V_q kp_{vq}$
PIId_y	y_{PIId}	Algeb	$kp_{di}(I_d - y_{PIvd})$
PIIq_y	y_{PIIq}	Algeb	$kp_{qi}(I_q - y_{PIvq})$
udref	u_{dref}	Algeb	u_{dref0}
uqref	u_{qref}	Algeb	u_{qref0}
a	θ	ExtAlgeb	
v	V	ExtAlgeb	
Idref	I_{dref}	AliasAlgeb	
Iqref	I_{qref}	AliasAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
dw	$\Delta\omega$	State	$-D\Delta\omega - P_e + P_{ref2}$	M
delta	δ	State	$2\pi\Delta\omega f$	
PIvd_xi	xi_{PIvd}	State	$ki_{vd}(V_d - v_{ref2})$	
PIvq_xi	xi_{PIvq}	State	$V_q ki_{vq}$	
PIId_xi	xi_{PIId}	State	$ki_{di}(I_d - y_{PIvd})$	
PIIq_xi	xi_{PIIq}	State	$ki_{qi}(I_q - y_{PIvq})$	
udLag_y	y_{udLag}	State	$u_{dref} - y_{udLag}$	T_c
uqLag_y	y_{uqLag}	State	$u_{qref} - y_{uqLag}$	T_c
ud	ud	AliasState	0	
uq	uq	AliasState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Pref2	P_{ref2}	Algeb	$-P_{ref2} + P_{ref}u - \Delta\omega k_\omega$
vref2	v_{ref2}	Algeb	$V_{ref} + k_v(-Q_e + Q_{ref}u) - v_{ref2}$
omega	ω	Algeb	$\Delta\omega - \omega + 1$
vd	V_d	Algeb	$Vu \cos(\delta - \theta) - V_d$
vq	V_q	Algeb	$-Vu \sin(\delta - \theta) - V_q$
Pe	P_e	Algeb	$I_d V_d + I_q V_q - P_e$
Qe	Q_e	Algeb	$I_d V_q - I_q V_d - Q_e$
Id	I_d	Algeb	$I_d r_a - I_q x_s + V_d - y_{udLag}$
Iq	I_q	Algeb	$I_d x_s + I_q r_a + V_q - y_{uqLag}$
PIvd_y	y_{PIvd}	Algeb	$kp_{vd}(V_d - v_{ref2}) + xi_{PIvd} - y_{PIvd}$
PIvq_y	y_{PIvq}	Algeb	$V_q kp_{vq} + xi_{PIvq} - y_{PIvq}$
PIId_y	y_{PIId}	Algeb	$kp_{di}(I_d - y_{PIvd}) + xi_{PIId} - y_{PIId}$
PIIq_y	y_{PIIq}	Algeb	$kp_{qi}(I_q - y_{PIvq}) + xi_{PIIq} - y_{PIIq}$
udref	u_{dref}	Algeb	$-I_{qref}x_s + V_d - u_{dref} + y_{PIId}$
uqref	u_{qref}	Algeb	$I_{dref}x_s + V_q - u_{qref} + y_{PIIq}$
a	θ	ExtAlgeb	$-P_e u$
v	V	ExtAlgeb	$-Q_e u$
Idref	I_{dref}	AliasAlgeb	0
Iqref	I_{qref}	AliasAlgeb	0

Services

Name	Symbol	Equation	Type
Pref	P_{ref}	$P_{0s}\gamma_P$	ConstService
Qref	Q_{ref}	$Q_{0s}\gamma_Q$	ConstService
ixs	$1/x_s$	$\frac{1}{x_s}$	ConstService
Id0	I_{d0}	$\frac{P_{ref}u}{V}$	ConstService
Iq0	I_{q0}	$-\frac{Q_{ref}u}{V}$	ConstService
vd0	v_{d0}	Vu	ConstService
vq0	v_{q0}	0	ConstService
udref0	u_{dref0}	$I_{d0}r_a - I_{q0}x_s + v_{d0}$	ConstService
uqref0	u_{qref0}	$I_{d0}x_s + I_{q0}r_a + v_{q0}$	ConstService

Blocks

Name	Symbol	Type	Info
PIvd	$PIvd$	PIController	
PIvq	$PIvq$	PIController	
PIId	$PIId$	PIController	
PIIq	$PIIq$	PIController	
udLag	$udLag$	Lag	
uqLag	$uqLag$	Lag	

Config Fields in [REGCV1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.24.4 REGCV2

Voltage-controlled VSC with VSG control.

The inner-loop current PI controllers are replaced with lag transfer functions.

Notes

To avoid small-signal stability issues, one take extreme care in setting the PI control gains K_{pvd} , K_{ivd} , K_{pvq} , and K_{ivq} , and the emulated inertia M and damping D .

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
coi2		center of inertia 2 index			
Sn	S_n	Model MVA base	100	<i>MVA</i>	
fn	f	rated frequency	60		
Tc	T_c	switch time constant	0.010	<i>s</i>	
kw	k_ω	speed droop on active power (reciprocal of droop)	0	<i>p.u.</i>	non_negative,ipower
kv	k_v	reactive power droop on voltage	0	<i>p.u.</i>	non_negative,power
M	M	Emulated startup time constant ($M=2H$)	10	<i>s</i>	power
D	D	Emulated damping coefficient	0	<i>p.u.</i>	power
ra	r_a	resistance	0		z
xs	x_s	reactance	0.200		z
gammap	γ_P	P ratio of linked static gen	1		
gam- maq	γ_Q	Q ratio of linked static gen	1		
Kpvd	k_{pvd}	vd controller proportional gain	0.500	<i>p.u.</i>	power
Kivd	k_{ivd}	vd controller integral gain	0.020	<i>p.u.</i>	power
Kpvq	k_{pvq}	vq controller proportional gain	0.500	<i>p.u.</i>	power
Kivq	k_{ivq}	vq controller integral gain	0.020	<i>p.u.</i>	power
Tiq	T_{Iq}		0.010		
Tid	T_{Id}		0.010		

Variables

Name	Sym- bol	Type	Description	Unit	Proper- ties
dw	$\Delta\omega$	State	delta virtual rotor speed	<i>pu</i> (Hz)	v_str
delta	δ	State	virtual delta	<i>rad</i>	v_str
PIvd_xi	xi_{PIvd}	State	Integrator output		v_str
PIvq_xi	xi_{PIvq}	State	Integrator output		v_str
LGId_y	y_{LGId}	State	State in lag transfer function		v_str
LGId_y	y_{LGId}	State	State in lag transfer function		v_str
Pref2	P_{ref2}	Algeb	active power reference after adjusting by frequency		v_str
vref2	v_{ref2}	Algeb	voltage reference after adjusted by reactive power		v_str
omega	ω	Algeb	virtual rotor speed	<i>pu</i> (Hz)	v_str
vd	V_d	Algeb	d-axis voltage		v_str
vq	V_q	Algeb	q-axis voltage		v_str
Pe	P_e	Algeb	active power injection from VSC		v_str
Qe	Q_e	Algeb	reactive power injection from VSC		v_str
Id	I_d	Algeb	d-axis current		v_str
Iq	I_q	Algeb	q-axis current		v_str
PIvd_y	y_{PIvd}	Algeb	PI output		v_str
PIvq_y	y_{PIvq}	Algeb	PI output		v_str
a	θ	ExtAlgeb	Bus voltage angle		
v	V	ExtAlgeb	Bus voltage magnitude		
Idref	Id_{ref}	AliasAl- geb	Alias of PIvd_y		
Iqref	Iq_{ref}	AliasAl- geb	Alias of PIvq_y		

Initialization Equations

Name	Symbol	Type	Initial Value
dw	$\Delta\omega$	State	0
delta	δ	State	θ
PIvd_xi	xi_{PIvd}	State	I_{d0}
PIvq_xi	xi_{PIvq}	State	I_{q0}
LGId_y	y_{LGId}	State	y_{PIvd}
LGIq_y	y_{LGIq}	State	y_{PIvq}
Pref2	P_{ref2}	Algeb	$P_{ref}u$
vref2	v_{ref2}	Algeb	$V_{ref}u$
omega	ω	Algeb	u
vd	V_d	Algeb	v_{d0}
vq	V_q	Algeb	v_{q0}
Pe	P_e	Algeb	P_{ref}
Qe	Q_e	Algeb	Q_{ref}
Id	I_d	Algeb	I_{d0}
Iq	I_q	Algeb	I_{q0}
PIvd_y	y_{PIvd}	Algeb	$I_{d0} + kp_{vd}(V_d - v_{ref2})$
PIvq_y	y_{PIvq}	Algeb	$I_{q0} + V_q kp_{vq}$
a	θ	ExtAlgeb	
v	V	ExtAlgeb	
Idref	$Idref$	AliasAlgeb	
Iqref	$Iqref$	AliasAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
dw	$\Delta\omega$	State	$-D\Delta\omega - P_e + P_{ref2}$	M
delta	δ	State	$2\pi\Delta\omega f$	
PIvd_xi	xi_{PIvd}	State	$ki_{vd}(V_d - v_{ref2})$	
PIvq_xi	xi_{PIvq}	State	$V_q ki_{vq}$	
LGId_y	y_{LGId}	State	$-y_{LGId} + y_{PIvd}$	T_{Id}
LGIq_y	y_{LGIq}	State	$-y_{LGIq} + y_{PIvq}$	T_{Iq}

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Pref2	P_{ref2}	Algeb	$-P_{ref2} + P_{refu} - \Delta\omega k_\omega$
vref2	v_{ref2}	Algeb	$V_{ref} + k_v(-Q_e + Q_{refu}) - v_{ref2}$
omega	ω	Algeb	$\Delta\omega - \omega + 1$
vd	V_d	Algeb	$V_u \cos(\delta - \theta) - V_d$
vq	V_q	Algeb	$-V_u \sin(\delta - \theta) - V_q$
Pe	P_e	Algeb	$I_d V_d + I_q V_q - P_e$
Qe	Q_e	Algeb	$I_d V_q - I_q V_d - Q_e$
Id	I_d	Algeb	$-I_d + y_{LGI} I_d$
Iq	I_q	Algeb	$-I_q + y_{LGI} I_q$
PIvd_y	y_{PIvd}	Algeb	$kp_{vd}(V_d - v_{ref2}) + xi_{PIvd} - y_{PIvd}$
PIvq_y	y_{PIvq}	Algeb	$V_q kp_{vq} + xi_{PIvq} - y_{PIvq}$
a	θ	ExtAlgeb	$-P_e u$
v	V	ExtAlgeb	$-Q_e u$
Idref	Id_{ref}	AliasAlgeb	0
Iqref	Iq_{ref}	AliasAlgeb	0

Services

Name	Symbol	Equation	Type
Pref	P_{ref}	$P_{0s} \gamma_P$	ConstService
Qref	Q_{ref}	$Q_{0s} \gamma_Q$	ConstService
ixs	$1/xs$	$\frac{1}{x_s}$	ConstService
Id0	I_{d0}	$\frac{P_{refu}}{V}$	ConstService
Iq0	I_{q0}	$-\frac{Q_{refu}}{V}$	ConstService
vd0	v_{d0}	V_u	ConstService
vq0	v_{q0}	0	ConstService

Blocks

Name	Symbol	Type	Info
PIvd	$PIvd$	PIController	
PIvq	$PIvq$	PIController	
LGIId	$LGIId$	Lag	
LGIIq	$LGIIq$	Lag	

Config Fields in [REGCV2]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.24.5 REGF1

Grid-forming inverter using droop.

Implementation of EPRI Memorandum

D. Ramasubramanian, "PROPOSAL FOR SUITE OF GENERIC GRID FORMING (GFM) POSITIVE SEQUENCE MODELS"

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
Sn	S_n	Model MVA base	100	<i>MVA</i>	
rf	r_a	resistance	0		<i>z</i>
xf	x_s	reactance	0.200		<i>z</i>
Vdip	V_{dip}	V threshold to freeze states	0.800	<i>p.u.</i>	
Tfrz	T_{frz}	Time to keep state frozen	0		
PQFLAG		P/Q priority flag; 0-Q priority, 1-P priority	1	<i>bool</i>	
fn	f	rated frequency	60		
dwmax	$\Delta\omega_{max}$	maximum value of frequency deviation	75		
dwmin	$\Delta\omega_{min}$	minimum value of frequency deviation	-75		
wdrp	ω_{drp}	frequency droop percentage	0.033		
Qdrp	Q_{drp}	Voltage droop percentage	0.045		
Tr	T_c	transducer time constant	0.005	<i>s</i>	
Te	T_e	output state time constant	0.005	<i>s</i>	
KPi	K_{Pi}	current control proportional gain	0.500		non_negative
KIi	K_{Ii}	current control integral gain	20		non_negative
KPv	K_{Pv}	voltage control proportional gain	3		non_negative
KIv	K_{Iv}	voltage control integral gain	10		non_negative
Pmax	P_{max}	max. active power	1		non_negative,power
Pmin	P_{min}	min. active power	-1		power
KPplim	K_{Pplim}	Kp for P limits	5		non_negative
KIplim	K_{Iplim}	KI for P limits	30		non_negative

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Table 32 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
Qmax	Q_{max}	max. reactive power	1		non_negative,power
Qmin	Q_{min}	min. reactive power	-1		power
KPqlim	K_{Pqlim}	Kp for Q limits	0.100		non_negative
KIqlim	K_{Iqlim}	KI for Q limits	1.500		non_negative
Tpm	T_{pm}	power signal input delay (3 Delta t)	0.025		
gammap	γ_P	P ratio of linked static gen	1		
gammaq	γ_Q	Q ratio of linked static gen	1		

Variables

Name	Symbol	Type	Description	Unit	Properties
Psen_y	y_{Psen}	State	State in lag transfer function		v_str
Qsen_y	y_{Qsen}	State	State in lag transfer function		v_str
Psig_y	y_{Psig}	State	State in lag TF		v_str
Qsig_y	y_{Qsig}	State	State in lag TF		v_str
PIplim_xi	xi_{PIplim}	State	Integrator output		v_str
PIqlim_xi	xi_{PIqlim}	State	Integrator output		v_str
delta	δ	State	virtual delta	rad	v_str
PIvd_xi	xi_{PIvd}	State	Integrator output		v_str
PIvq_xi	xi_{PIvq}	State	Integrator output		v_str
PIId_xi	xi_{PIId}	State	Integrator output		v_str
PIIq_xi	xi_{PIIq}	State	Integrator output		v_str
udLag_y	y_{udLag}	State	State in lag transfer function		v_str
uqLag_y	y_{uqLag}	State	State in lag transfer function		v_str
ud	ud	AliasState	Alias of udLag_y		
uq	uq	AliasState	Alias of uqLag_y		
Paux	P_{aux}	Algeb			v_str
Qaux	Q_{aux}	Algeb			v_str
PIplim_y	y_{PIplim}	Algeb	PI output		v_str
PIqlim_y	y_{PIqlim}	Algeb	PI output		v_str
vd	V_d	Algeb	d-axis voltage		v_str
vq	V_q	Algeb	q-axis voltage		v_str
Pe	P_e	Algeb	active power injection from VSC		v_str
Qe	Q_e	Algeb	reactive power injection from VSC		v_str
Id	I_d	Algeb	d-axis current		v_str
Iq	I_q	Algeb	q-axis current		v_str
dw_x	x_{dw}	Algeb	Value before limiter		v_str
dw_y	y_{dw}	Algeb	Output after limiter and post gain		v_str
vref2	v_{ref2}	Algeb	voltage reference after droop		v_str
PIvd_y	y_{PIvd}	Algeb	PI output		v_str
PIvq_y	y_{PIvq}	Algeb	PI output		v_str

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Table 33 – continued from previous page

Name	Symbol	Type	Description	Unit	Properties
PIId_y	y_{PIId}	Algeb	PI output		v_str
PIIq_y	y_{PIIq}	Algeb	PI output		v_str
udref	u_{dref}	Algeb	ud reference		v_str
uqref	u_{qref}	Algeb	uq reference		v_str
a	θ	ExtAlgeb	Bus voltage angle		
v	V	ExtAlgeb	Bus voltage magnitude		
Idref	$Idref$	AliasAlgeb	Alias of PIvd_y		
Iqref	$Iqref$	AliasAlgeb	Alias of PIIq_y		

Initialization Equations

Name	Symbol	Type	Initial Value
Psen_y	y_{Psen}	State	P_e
Qsen_y	y_{Qsen}	State	Q_e
Psig_y	y_{Psig}	State	$Paux + y_{Psen}$
Qsig_y	y_{Qsig}	State	$Qaux + y_{Qsen}$
PIplim_xi	xi_{PIplim}	State	y_{Psen}
PIqlim_xi	xi_{PIqlim}	State	y_{Qsen}
delta	δ	State	θ
PIvd_xi	xi_{PIvd}	State	I_{d0}
PIvq_xi	xi_{PIvq}	State	I_{q0}
PIId_xi	xi_{PIId}	State	0.0
PIIq_xi	xi_{PIIq}	State	0.0
udLag_y	y_{udLag}	State	u_{dref}
uqLag_y	y_{uqLag}	State	u_{qref}
ud	ud	AliasState	
uq	uq	AliasState	
Paux	$Paux$	Algeb	0
Qaux	$Qaux$	Algeb	0
PIplim_y	y_{PIplim}	Algeb	$K_{Pplim}(-y_{Psen} + y_{Psig}) + y_{Psen}$
PIqlim_y	y_{PIqlim}	Algeb	$K_{Pqlim}(-y_{Qsen} + y_{Qsig}) + y_{Qsen}$
vd	V_d	Algeb	v_{d0}
vq	V_q	Algeb	v_{q0}
Pe	P_e	Algeb	P_{ref}
Qe	Q_e	Algeb	Q_{ref}
Id	I_d	Algeb	I_{d0}
Iq	I_q	Algeb	I_{q0}
dw_x	x_{dw}	Algeb	$\omega_{drp} w_0 (y_{PIplim} - y_{Psen})$
dw_y	y_{dw}	Algeb	$\Delta\omega_{max} z_u^{lim_{dw}} + \Delta\omega_{min} z_l^{lim_{dw}} + x_{dw} z_i^{lim_{dw}}$
vref2	v_{ref2}	Algeb	$V_{ref} u$
PIvd_y	y_{PIvd}	Algeb	$I_{d0} + K_{Pv}(-V_d + v_{ref2})$

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Table 34 – continued from previous page

Name	Symbol	Type	Initial Value
PIvq_y	y_{PIvq}	Algeb	$I_{q0} - K_{Pv}V_q$
PIId_y	y_{PIId}	Algeb	$K_{Pi}(-I_d + y_{PIvd})$
PIIq_y	y_{PIIq}	Algeb	$K_{Pi}(-I_q + y_{PIvq})$
udref	u_{dref}	Algeb	u_{dref0}
uqref	u_{qref}	Algeb	u_{qref0}
a	θ	ExtAlgeb	
v	V	ExtAlgeb	
Idref	$Idref$	AliasAlgeb	
Iqref	$Iqref$	AliasAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
Psen_y	y_{Psen}	State	$P_e - y_{Psen}$	T_c
Qsen_y	y_{Qsen}	State	$Q_e - y_{Qsen}$	T_c
Psig_y	y_{Psig}	State	$Paux + y_{Psen} - y_{Psig}$	T_{pm}
Qsig_y	y_{Qsig}	State	$Qaux + y_{Qsen} - y_{Qsig}$	T_{pm}
PIplim_xi	xi_{PIplim}	State	$K_{Iplim}(-y_{Psen} + y_{Psig})$	
PIqlim_xi	xi_{PIqlim}	State	$K_{Iqlim}(-y_{Qsen} + y_{Qsig})$	
delta	δ	State	y_{dw}	
PIvd_xi	xi_{PIvd}	State	$K_{Iv}(-V_d + v_{ref2})$	
PIvq_xi	xi_{PIvq}	State	$-K_{Iv}V_q$	
PIId_xi	xi_{PIId}	State	$K_{Ii}(-I_d + y_{PIvd})$	
PIIq_xi	xi_{PIIq}	State	$K_{Ii}(-I_q + y_{PIvq})$	
udLag_y	y_{udLag}	State	$u_{dref} - y_{udLag}$	T_e
uqLag_y	y_{uqLag}	State	$u_{qref} - y_{uqLag}$	T_e
ud	ud	AliasState	0	
uq	uq	AliasState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Paux	P_{aux}	Algeb	P_{aux}
Qaux	Q_{aux}	Algeb	Q_{aux}
PIplim_y	y_{PIplim}	Algeb	$K_{Pplim}(-y_{Psen} + y_{Psig}) + x_{iPIplim} - y_{PIplim}$
PIqlim_y	y_{PIqlim}	Algeb	$K_{Pqlim}(-y_{Qsen} + y_{Qsig}) + x_{iPIqlim} - y_{PIqlim}$
vd	V_d	Algeb	$V_u \cos(\delta - \theta) - V_d$
vq	V_q	Algeb	$-V_u \sin(\delta - \theta) - V_q$
Pe	P_e	Algeb	$I_d V_d + I_q V_q - P_e$
Qe	Q_e	Algeb	$I_d V_q - I_q V_d - Q_e$
Id	I_d	Algeb	$I_d r_a - I_q x_s + V_d - y_{udLag}$
Iq	I_q	Algeb	$I_d x_s + I_q r_a + V_q - y_{uqLag}$
dw_x	x_{dw}	Algeb	$\omega_{drp} w_0 (y_{PIplim} - y_{Psen}) - x_{dw}$
dw_y	y_{dw}	Algeb	$\Delta \omega_{max} z_u^{lim_{dw}} + \Delta \omega_{min} z_l^{lim_{dw}} + x_{dw} z_i^{lim_{dw}} - y_{dw}$
vref2	v_{ref2}	Algeb	$Q_{drp} (u y_{PIqlim} - y_{Qsen}) + V_{ref} - v_{ref2}$
PIvd_y	y_{PIvd}	Algeb	$K_{Pv} (-V_d + v_{ref2}) + x_{iPIvd} - y_{PIvd}$
PIvq_y	y_{PIvq}	Algeb	$-K_{Pv} V_q + x_{iPIvq} - y_{PIvq}$
PIId_y	y_{PIId}	Algeb	$K_{Pi} (-I_d + y_{PIvd}) + x_{iPIId} - y_{PIId}$
PIIq_y	y_{PIIq}	Algeb	$K_{Pi} (-I_q + y_{PIvq}) + x_{iPIIq} - y_{PIIq}$
udref	u_{dref}	Algeb	$I_d r_a - I_q x_s + V_d - u_{dref} + y_{PIId}$
uqref	u_{qref}	Algeb	$I_d x_s + I_q r_a + V_q - u_{qref} + y_{PIIq}$
a	θ	ExtAlgeb	$-P_e u$
v	V	ExtAlgeb	$-Q_e u$
Idref	I_{dref}	AliasAlgeb	0
Iqref	I_{qref}	AliasAlgeb	0

Services

Name	Symbol	Equation	Type
Pref	P_{ref}	$P_{0s} \gamma_P$	ConstService
Qref	Q_{ref}	$Q_{0s} \gamma_Q$	ConstService
w0	w_0	$2\pi f$	ConstService
ixf	$1/x_f$	$\frac{1}{x_s}$	ConstService
Id0	I_{d0}	$\frac{\bar{P}_{ref} u}{V}$	ConstService
Iq0	I_{q0}	$-\frac{\bar{Q}_{ref} u}{V}$	ConstService
vd0	v_{d0}	V_u	ConstService
vq0	v_{q0}	0	ConstService
udref0	u_{dref0}	$I_{d0} r_a - I_{q0} x_s + v_{d0}$	ConstService
uqref0	u_{qref0}	$I_{d0} x_s + I_{q0} r_a + v_{q0}$	ConstService

Discretes

Name	Symbol	Type	Info
Psig_lim	lim_{Psig}	AntiWindup	Limiter in Lag
Qsig_lim	lim_{Qsig}	AntiWindup	Limiter in Lag
dw_lim	lim_{dw}	HardLimiter	

Blocks

Name	Symbol	Type	Info
Psen	$Psen$	Lag	
Qsen	$Qsen$	Lag	
Psig	$Psig$	LagAntiWindup	
Qsig	$Qsig$	LagAntiWindup	
PIplim	$PIplim$	PIController	
PIqlim	$PIqlim$	PIController	
dw	dw	GainLimiter	
PIvd	$PIvd$	PIController	
PIvq	$PIvq$	PIController	
PIId	$PIId$	PIController	
PIIq	$PIIq$	PIController	
udLag	$udLag$	Lag	
uqLag	$uqLag$	Lag	

Config Fields in [REGF1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.24.6 REGF2

Grid-forming inverter with VSM control.

Implementation of EPRI Memorandum

- D. Ramasubramanian, "PROPOSAL FOR SUITE OF GENERIC GRID FORMING (GFM) POSITIVE SEQUENCE MODELS"

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
Sn	S_n	Model MVA base	100	<i>MVA</i>	
rf	r_a	resistance	0		z
xf	x_s	reactance	0.200		z
Vdip	V_{dip}	V threshold to freeze states	0.800	<i>p.u.</i>	
Tfrz	T_{frz}	Time to keep state frozen	0		
PQFLAG		P/Q priority flag; 0-Q priority, 1-P priority	1	<i>bool</i>	
fn	f	rated frequency	60		
dwmax	$\Delta\omega_{max}$	maximum value of frequency deviation	75		
dwmin	$\Delta\omega_{min}$	minimum value of frequency deviation	-75		
wdrp	ω_{drp}	frequency droop percentage	0.033		
Qdrp	Q_{drp}	Voltage droop percentage	0.045		
Tr	T_c	transducer time constant	0.005	<i>s</i>	
Te	T_e	output state time constant	0.005	<i>s</i>	
KPi	K_{Pi}	current control proportional gain	0.500		non_negative
KIi	K_{Ii}	current control integral gain	20		non_negative
KPv	K_{Pv}	voltage control proportional gain	3		non_negative
KIv	K_{Iv}	voltage control integral gain	10		non_negative
Pmax	P_{max}	max. active power	1		non_negative,power
Pmin	P_{min}	min. active power	-1		power
KPplim	K_{Pplim}	Kp for P limits	5		non_negative
KIplim	K_{Iplim}	KI for P limits	30		non_negative
Qmax	Q_{max}	max. reactive power	1		non_negative,power
Qmin	Q_{min}	min. reactive power	-1		power
KPqlim	K_{Pqlim}	Kp for Q limits	0.100		non_negative
KIqlim	K_{Iqlim}	KI for Q limits	1.500		non_negative
Tpm	T_{pm}	power signal input delay (3 Delta t)	0.025		
gammap	γ_P	P ratio of linked static gen	1		
gammaq	γ_Q	Q ratio of linked static gen	1		
mf	M_f	VSM inertia constant	0.150		
dd	d_d	VSM damping factor	0.110		
pll		PLL device idx (optional)			

Variables

Name	Symbol	Type	Description	Unit	Properties
Psen_y	y_{Psen}	State	State in lag transfer function		v_str
Qsen_y	y_{Qsen}	State	State in lag transfer function		v_str
Psig_y	y_{Psig}	State	State in lag TF		v_str
Qsig_y	y_{Qsig}	State	State in lag TF		v_str
PIplim_xi	xi_{PIplim}	State	Integrator output		v_str
PIqlim_xi	xi_{PIqlim}	State	Integrator output		v_str
delta	δ	State	virtual delta	rad	v_str
INTw_y	y_{INTw}	State	Integrator output		v_str
PIvd_xi	xi_{PIvd}	State	Integrator output		v_str
PIvq_xi	xi_{PIvq}	State	Integrator output		v_str
PIId_xi	xi_{PIId}	State	Integrator output		v_str
PIIq_xi	xi_{PIIq}	State	Integrator output		v_str
udLag_y	y_{udLag}	State	State in lag transfer function		v_str
uqLag_y	y_{uqLag}	State	State in lag transfer function		v_str
ud	ud	AliasState	Alias of udLag_y		
uq	uq	AliasState	Alias of uqLag_y		
Paux	$Paux$	Algeb			v_str
Qaux	$Qaux$	Algeb			v_str
PIplim_y	y_{PIplim}	Algeb	PI output		v_str
PIqlim_y	y_{PIqlim}	Algeb	PI output		v_str
vd	V_d	Algeb	d-axis voltage		v_str
vq	V_q	Algeb	q-axis voltage		v_str
Pe	P_e	Algeb	active power injection from VSC		v_str
Qe	Q_e	Algeb	reactive power injection from VSC		v_str
Id	I_d	Algeb	d-axis current		v_str
Iq	I_q	Algeb	q-axis current		v_str
wref	ω_{ref}	Algeb	speed ref	pu	v_str
dw_x	x_{dw}	Algeb	Value before limiter		v_str
dw_y	y_{dw}	Algeb	Output after limiter and post gain		v_str
vref2	v_{ref2}	Algeb	voltage reference after droop		v_str
PIvd_y	y_{PIvd}	Algeb	PI output		v_str
PIvq_y	y_{PIvq}	Algeb	PI output		v_str
PIId_y	y_{PIId}	Algeb	PI output		v_str
PIIq_y	y_{PIIq}	Algeb	PI output		v_str
udref	u_{dref}	Algeb	ud reference		v_str
uqref	u_{qref}	Algeb	uq reference		v_str
a	θ	ExtAlgeb	Bus voltage angle		
v	V	ExtAlgeb	Bus voltage magnitude		
plldw	$\Delta\omega_{PLL}$	ExtAlgeb	PLL measured freq. deviation		
Idref	I_{dref}	AliasAlgeb	Alias of PIvd_y		
Iqref	I_{qref}	AliasAlgeb	Alias of PIvq_y		

Initialization Equations

Name	Symbol	Type	Initial Value
Psen_y	y_{Psen}	State	P_e
Qsen_y	y_{Qsen}	State	Q_e
Psig_y	y_{Psig}	State	$P_{aux} + y_{Psen}$
Qsig_y	y_{Qsig}	State	$Q_{aux} + y_{Qsen}$
PIplim_xi	xi_{PIplim}	State	y_{Psen}
PIqlim_xi	xi_{PIqlim}	State	y_{Qsen}
delta	δ	State	θ
INTw_y	y_{INTw}	State	ω_{ref}
PIvd_xi	xi_{PIvd}	State	I_{d0}
PIvq_xi	xi_{PIvq}	State	I_{q0}
PIId_xi	xi_{PIId}	State	0.0
PIIq_xi	xi_{PIIq}	State	0.0
udLag_y	y_{udLag}	State	u_{dref}
uqLag_y	y_{uqLag}	State	u_{qref}
ud	ud	AliasState	
uq	uq	AliasState	
Paux	P_{aux}	Algeb	0
Qaux	Q_{aux}	Algeb	0
PIplim_y	y_{PIplim}	Algeb	$K_{Pplim}(-y_{Psen} + y_{Psig}) + y_{Psen}$
PIqlim_y	y_{PIqlim}	Algeb	$K_{Pqlim}(-y_{Qsen} + y_{Qsig}) + y_{Qsen}$
vd	V_d	Algeb	v_{d0}
vq	V_q	Algeb	v_{q0}
Pe	P_e	Algeb	P_{ref}
Qe	Q_e	Algeb	Q_{ref}
Id	I_d	Algeb	I_{d0}
Iq	I_q	Algeb	I_{q0}
wref	ω_{ref}	Algeb	1
dw_x	x_{dw}	Algeb	$w_0(-\omega_{ref} + y_{INTw})$
dw_y	y_{dw}	Algeb	$\Delta\omega_{max}z_u^{lim_{dw}} + \Delta\omega_{min}z_l^{lim_{dw}} + x_{dw}z_i^{lim_{dw}}$
vref2	v_{ref2}	Algeb	$V_{ref}u$
PIvd_y	y_{PIvd}	Algeb	$I_{d0} + K_{Pv}(-V_d + v_{ref2})$
PIvq_y	y_{PIvq}	Algeb	$I_{q0} - K_{Pv}V_q$
PIId_y	y_{PIId}	Algeb	$K_{Pi}(-I_d + y_{PIvd})$
PIIq_y	y_{PIIq}	Algeb	$K_{Pi}(-I_q + y_{PIvq})$
udref	u_{dref}	Algeb	u_{dref0}
uqref	u_{qref}	Algeb	u_{qref0}
a	θ	ExtAlgeb	
v	V	ExtAlgeb	
plldw	$\Delta\omega_{PLL}$	ExtAlgeb	
Idref	I_{dref}	AliasAlgeb	
Iqref	I_{qref}	AliasAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
Psen_y	y_{Psen}	State	$P_e - y_{Psen}$	T_c
Qsen_y	y_{Qsen}	State	$Q_e - y_{Qsen}$	T_c
Psig_y	y_{Psig}	State	$Paux + y_{Psen} - y_{Psig}$	T_{pm}
Qsig_y	y_{Qsig}	State	$Qaux + y_{Qsen} - y_{Qsig}$	T_{pm}
PI- plim_xi	xi_{PIplim}	State	$K_{Iplim}(-y_{Psen} + y_{Psig})$	
PIqlim_xi	xi_{PIqlim}	State	$K_{Iqlim}(-y_{Qsen} + y_{Qsig})$	
delta	δ	State	y_{dw}	
INTw_y	y_{INTw}	State	$\Delta\omega_{PLL}\omega_{drp}d_d + \omega_{drp}(y_{PIplim} - y_{Psen}) + \omega_{ref} - y_{INTw}$	T_{int}
PIvd_xi	xi_{PIvd}	State	$K_{Iv}(-V_d + v_{ref2})$	
PIvq_xi	xi_{PIvq}	State	$-K_{Iv}V_q$	
PIId_xi	xi_{PIId}	State	$K_{Ii}(-I_d + y_{PIvd})$	
PIIq_xi	xi_{PIIq}	State	$K_{Ii}(-I_q + y_{PIvq})$	
udLag_y	y_{udLag}	State	$u_{dref} - y_{udLag}$	T_e
uqLag_y	y_{uqLag}	State	$u_{qref} - y_{uqLag}$	T_e
ud	ud	AliasState	0	
uq	uq	AliasState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Paux	P_{aux}	Algeb	P_{aux}
Qaux	Q_{aux}	Algeb	Q_{aux}
PIplim_y	y_{PIplim}	Algeb	$K_{Pplim}(-y_{Psen} + y_{Psig}) + x i_{PIplim} - y_{PIplim}$
PIqlim_y	y_{PIqlim}	Algeb	$K_{Pqlim}(-y_{Qsen} + y_{Qsig}) + x i_{PIqlim} - y_{PIqlim}$
vd	V_d	Algeb	$V_u \cos(\delta - \theta) - V_d$
vq	V_q	Algeb	$-V_u \sin(\delta - \theta) - V_q$
Pe	P_e	Algeb	$I_d V_d + I_q V_q - P_e$
Qe	Q_e	Algeb	$I_d V_q - I_q V_d - Q_e$
Id	I_d	Algeb	$I_d r_a - I_q x_s + V_d - y_{udLag}$
Iq	I_q	Algeb	$I_d x_s + I_q r_a + V_q - y_{uqLag}$
wref	ω_{ref}	Algeb	$1 - \omega_{ref}$
dw_x	x_{dw}	Algeb	$w_0(-\omega_{ref} + y_{INTw}) - x_{dw}$
dw_y	y_{dw}	Algeb	$\Delta\omega_{max} z_u^{lim_{dw}} + \Delta\omega_{min} z_l^{lim_{dw}} + x_{dw} z_i^{lim_{dw}} - y_{dw}$
vref2	v_{ref2}	Algeb	$Q_{drp}(y_{PIqlim} - y_{Qsen}) + V_{ref} - v_{ref2}$
PIvd_y	y_{PIvd}	Algeb	$K_{Pv}(-V_d + v_{ref2}) + x i_{PIvd} - y_{PIvd}$
PIvq_y	y_{PIvq}	Algeb	$-K_{Pv}V_q + x i_{PIvq} - y_{PIvq}$
PIId_y	y_{PIId}	Algeb	$K_{Pi}(-I_d + y_{PIvd}) + x i_{PIId} - y_{PIId}$
PIIq_y	y_{PIIq}	Algeb	$K_{Pi}(-I_q + y_{PIvq}) + x i_{PIIq} - y_{PIIq}$
udref	u_{dref}	Algeb	$I_d r_a - I_q x_s + V_d - u_{dref} + y_{PIId}$
uqref	u_{qref}	Algeb	$I_d x_s + I_q r_a + V_q - u_{qref} + y_{PIIq}$
a	θ	ExtAlgeb	$-P_e u$
v	V	ExtAlgeb	$-Q_e u$
plldw	$\Delta\omega_{PLL}$	ExtAlgeb	0
Idref	I_{dref}	AliasAlgeb	0
Iqref	I_{qref}	AliasAlgeb	0

Services

Name	Symbol	Equation	Type
Pref	P_{ref}	$P_{0s}\gamma_P$	ConstService
Qref	Q_{ref}	$Q_{0s}\gamma_Q$	ConstService
w0	w_0	$2\pi f$	ConstService
ixf	$1/x_f$	$\frac{1}{x_s}$	ConstService
Id0	I_{d0}	$\frac{P_{ref} u}{V}$	ConstService
Iq0	I_{q0}	$-\frac{Q_{ref} u}{V}$	ConstService
vd0	v_{d0}	V_u	ConstService
vq0	v_{q0}	0	ConstService
Tint	T_{int}	$M_f \omega_{drp}$	ConstService
udref0	u_{dref0}	$I_{d0} r_a - I_{q0} x_s + v_{d0}$	ConstService
uqref0	u_{qref0}	$I_{d0} x_s + I_{q0} r_a + v_{q0}$	ConstService

Discretes

Name	Symbol	Type	Info
Psig_lim	lim_{Psig}	AntiWindup	Limiter in Lag
Qsig_lim	lim_{Qsig}	AntiWindup	Limiter in Lag
dw_lim	lim_{dw}	HardLimiter	

Blocks

Name	Symbol	Type	Info
Psen	$Psen$	Lag	
Qsen	$Qsen$	Lag	
Psig	$Psig$	LagAntiWindup	
Qsig	$Qsig$	LagAntiWindup	
PIplim	$PIplim$	PIController	
PIqlim	$PIqlim$	PIController	
INTw	$INTw$	Integrator	
dw	dw	GainLimiter	
PIvd	$PIvd$	PIController	
PIvq	$PIvq$	PIController	
PIId	$PIId$	PIController	
PIIq	$PIIq$	PIController	
udLag	$udLag$	Lag	
uqLag	$uqLag$	Lag	

Config Fields in [REGF2]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.24.7 REGF3

Grid-forming inverter with dVOC.

Implementation of EPRI Memorandum

- D. Ramasubramanian, "PROPOSAL FOR SUITE OF GENERIC GRID FORMING (GFM) POSITIVE SEQUENCE MODELS"

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
Sn	S_n	Model MVA base	100	<i>MVA</i>	
rf	r_a	resistance	0		z
xf	x_s	reactance	0.200		z
Vdip	V_{dip}	V threshold to freeze states	0.800	<i>p.u.</i>	
Tfrz	T_{frz}	Time to keep state frozen	0		
PQFLAG		P/Q priority flag; 0-Q priority, 1-P priority	1	<i>bool</i>	
fn	f	rated frequency	60		
dwmax	$\Delta\omega_{max}$	maximum value of frequency deviation	75		
dwmin	$\Delta\omega_{min}$	minimum value of frequency deviation	-75		
wdrp	ω_{drp}	frequency droop percentage	0.033		
Qdrp	Q_{drp}	Voltage droop percentage	0.045		
Tr	T_c	transducer time constant	0.005	<i>s</i>	
Te	T_e	output state time constant	0.005	<i>s</i>	
KPi	K_{Pi}	current control proportional gain	0.500		non_negative
KIi	K_{Ii}	current control integral gain	20		non_negative
KPv	K_{Pv}	voltage control proportional gain	3		non_negative
KIv	K_{Iv}	voltage control integral gain	10		non_negative
Pmax	P_{max}	max. active power	1		non_negative,power
Pmin	P_{min}	min. active power	-1		power
KPplim	K_{Pplim}	Kp for P limits	5		non_negative
KIplim	K_{Iplim}	KI for P limits	30		non_negative
Qmax	Q_{max}	max. reactive power	1		non_negative,power
Qmin	Q_{min}	min. reactive power	-1		power
KPqlim	K_{Pqlim}	Kp for Q limits	0.100		non_negative
KIqlim	K_{Iqlim}	KI for Q limits	1.500		non_negative
Tpm	T_{pm}	power signal input delay (3 Delta t)	0.025		
gammap	γ_P	P ratio of linked static gen	1		
gammaq	γ_Q	Q ratio of linked static gen	1		

Variables

Name	Symbol	Type	Description	Unit	Properties
Psen_y	y_{Psen}	State	State in lag transfer function		v_str
Qsen_y	y_{Qsen}	State	State in lag transfer function		v_str
Psig_y	y_{Psig}	State	State in lag TF		v_str
Qsig_y	y_{Qsig}	State	State in lag TF		v_str
PIplim_xi	xi_{PIplim}	State	Integrator output		v_str
PIqlim_xi	xi_{PIqlim}	State	Integrator output		v_str
delta	δ	State	virtual delta	rad	v_str
vref2	$vref_2$	State			v_str
PIvd_xi	xi_{PIvd}	State	Integrator output		v_str
PIvq_xi	xi_{PIvq}	State	Integrator output		v_str
PIId_xi	xi_{PIId}	State	Integrator output		v_str
PIIq_xi	xi_{PIIq}	State	Integrator output		v_str
udLag_y	y_{udLag}	State	State in lag transfer function		v_str
uqLag_y	y_{uqLag}	State	State in lag transfer function		v_str
ud	ud	AliasState	Alias of udLag_y		
uq	uq	AliasState	Alias of uqLag_y		
Paux	$Paux$	Algeb			v_str
Qaux	$Qaux$	Algeb			v_str
PIplim_y	y_{PIplim}	Algeb	PI output		v_str
PIqlim_y	y_{PIqlim}	Algeb	PI output		v_str
vd	V_d	Algeb	d-axis voltage		v_str
vq	V_q	Algeb	q-axis voltage		v_str
Pe	P_e	Algeb	active power injection from VSC		v_str
Qe	Q_e	Algeb	reactive power injection from VSC		v_str
Id	I_d	Algeb	d-axis current		v_str
Iq	I_q	Algeb	q-axis current		v_str
wref	ω_{ref}	Algeb	speed ref	pu	v_str
Vref	V_{ref}	Algeb			v_str
dw_x	x_{dw}	Algeb	Value before limiter		v_str
dw_y	y_{dw}	Algeb	Output after limiter and post gain		v_str
derv	dV	Algeb	input to voltage integrator		v_str
PIvd_y	y_{PIvd}	Algeb	PI output		v_str
PIvq_y	y_{PIvq}	Algeb	PI output		v_str
PIId_y	y_{PIId}	Algeb	PI output		v_str
PIIq_y	y_{PIIq}	Algeb	PI output		v_str
udref	u_{dref}	Algeb	ud reference		v_str
uqref	u_{qref}	Algeb	uq reference		v_str
a	θ	ExtAlgeb	Bus voltage angle		
v	V	ExtAlgeb	Bus voltage magnitude		
Idref	I_{dref}	AliasAlgeb	Alias of PIvd_y		
Iqref	I_{qref}	AliasAlgeb	Alias of PIvq_y		

Initialization Equations

Name	Symbol	Type	Initial Value
Psen_y	y_{Psen}	State	P_e
Qsen_y	y_{Qsen}	State	Q_e
Psig_y	y_{Psig}	State	$P_{aux} + y_{Psen}$
Qsig_y	y_{Qsig}	State	$Q_{aux} + y_{Qsen}$
PIplim_xi	xi_{PIplim}	State	y_{Psen}
PIqlim_xi	xi_{PIqlim}	State	y_{Qsen}
delta	δ	State	θ
vref2	$vref_2$	State	V_d
PIvd_xi	xi_{PIvd}	State	I_{d0}
PIvq_xi	xi_{PIvq}	State	I_{q0}
PIId_xi	xi_{PIId}	State	0.0
PIIq_xi	xi_{PIIq}	State	0.0
udLag_y	y_{udLag}	State	u_{dref}
uqLag_y	y_{uqLag}	State	u_{qref}
ud	ud	AliasState	
uq	uq	AliasState	
Paux	P_{aux}	Algeb	0
Qaux	Q_{aux}	Algeb	0
PIplim_y	y_{PIplim}	Algeb	$K_{Pplim}(-y_{Psen} + y_{Psig}) + y_{Psen}$
PIqlim_y	y_{PIqlim}	Algeb	$K_{Pqlim}(-y_{Qsen} + y_{Qsig}) + y_{Qsen}$
vd	V_d	Algeb	v_{d0}
vq	V_q	Algeb	v_{q0}
Pe	P_e	Algeb	P_{ref}
Qe	Q_e	Algeb	Q_{ref}
Id	I_d	Algeb	I_{d0}
Iq	I_q	Algeb	I_{q0}
wref	ω_{ref}	Algeb	1
Vref	V_{ref}	Algeb	V_{ref}
dw_x	x_{dw}	Algeb	$\frac{\omega_{drp} w_0 (y_{PIplim} - y_{Psen})}{vref_2^2}$
dw_y	y_{dw}	Algeb	$\Delta\omega_{max} z_u^{lim_{dw}} + \Delta\omega_{min} z_l^{lim_{dw}} + x_{dw} z_i^{lim_{dw}}$
derv	dV	Algeb	0
PIvd_y	y_{PIvd}	Algeb	$I_{d0} + K_{Pv}(-V_d + vref_2)$
PIvq_y	y_{PIvq}	Algeb	$I_{q0} - K_{Pv}V_q$
PIId_y	y_{PIId}	Algeb	$K_{Pi}(-I_d + y_{PIvd})$
PIIq_y	y_{PIIq}	Algeb	$K_{Pi}(-I_q + y_{PIvq})$
udref	u_{dref}	Algeb	u_{dref0}
uqref	u_{qref}	Algeb	u_{qref0}
a	θ	ExtAlgeb	
v	V	ExtAlgeb	
Idref	$Idref$	AliasAlgeb	
Iqref	$Iqref$	AliasAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
Psen_y	y_{Psen}	State	$P_e - y_{Psen}$	T_c
Qsen_y	y_{Qsen}	State	$Q_e - y_{Qsen}$	T_c
Psig_y	y_{Psig}	State	$Paux + y_{Psen} - y_{Psig}$	T_{pm}
Qsig_y	y_{Qsig}	State	$Qaux + y_{Qsen} - y_{Qsig}$	T_{pm}
PIplim_xi	xi_{PIplim}	State	$K_{Iplim}(-y_{Psen} + y_{Psig})$	
PIqlim_xi	xi_{PIqlim}	State	$K_{Iqlim}(-y_{Qsen} + y_{Qsig})$	
delta	δ	State	y_{dw}	
vref2	$vref_2$	State	dVw_0	
PIvd_xi	xi_{PIvd}	State	$K_{Iv}(-V_d + vref_2)$	
PIvq_xi	xi_{PIvq}	State	$-K_{Iv}V_q$	
PIId_xi	xi_{PIId}	State	$K_{Ii}(-I_d + y_{PIvd})$	
PIIq_xi	xi_{PIIq}	State	$K_{Ii}(-I_q + y_{PIvq})$	
udLag_y	y_{udLag}	State	$u_{dref} - y_{udLag}$	T_e
uqLag_y	y_{uqLag}	State	$u_{qref} - y_{uqLag}$	T_e
ud	ud	AliasState	0	
uq	uq	AliasState	0	

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
Paux	$Paux$	Algeb	$Paux$
Qaux	$Qaux$	Algeb	$Qaux$
PI- plim_y	y_{PIplim}	Algeb	$K_{Pplim}(-y_{Psen} + y_{Psig}) + xi_{PIplim} - y_{PIplim}$
PIqlim_y	y_{PIqlim}	Algeb	$K_{Pqlim}(-y_{Qsen} + y_{Qsig}) + xi_{PIqlim} - y_{PIqlim}$
vd	V_d	Algeb	$Vu \cos(\delta - \theta) - V_d$
vq	V_q	Algeb	$-Vu \sin(\delta - \theta) - V_q$
Pe	P_e	Algeb	$I_d V_d + I_q V_q - P_e$
Qe	Q_e	Algeb	$I_d V_q - I_q V_d - Q_e$
Id	I_d	Algeb	$I_d r_a - I_q x_s + V_d - y_{udLag}$
Iq	I_q	Algeb	$I_d x_s + I_q r_a + V_q - y_{uqLag}$
wref	ω_{ref}	Algeb	$1 - \omega_{ref}$
Vref	V_{ref}	Algeb	$V_{ref} - V_{ref}$
dw_x	x_{dw}	Algeb	$\frac{\omega_{drp} w_0 (y_{PIplim} - y_{Psen})}{vref_2^2} - x_{dw}$
dw_y	y_{dw}	Algeb	$\Delta \omega_{max} z_u^{lim_{dw}} + \Delta \omega_{min} z_l^{lim_{dw}} + x_{dw} z_i^{lim_{dw}} - y_{dw}$
derv	dV	Algeb	$K_{dvocvref_2} (V_{ref} - vref_2) (V_{ref} + vref_2) + \frac{\omega_{drp} (y_{PIqlim} - y_{Qsen})}{vref_2} - dV$
PIvd_y	y_{PIvd}	Algeb	$K_{Pv}(-V_d + vref_2) + xi_{PIvd} - y_{PIvd}$
PIvq_y	y_{PIvq}	Algeb	$-K_{Pv} V_q + xi_{PIvq} - y_{PIvq}$
PIId_y	y_{PIId}	Algeb	$K_{Pi}(-I_d + y_{PIvd}) + xi_{PIId} - y_{PIId}$
PIIq_y	y_{PIIq}	Algeb	$K_{Pi}(-I_q + y_{PIvq}) + xi_{PIIq} - y_{PIIq}$
udref	u_{dref}	Algeb	$I_d r_a - I_q x_s + V_d - u_{dref} + y_{PIId}$
uqref	u_{qref}	Algeb	$I_d x_s + I_q r_a + V_q - u_{qref} + y_{PIIq}$
a	θ	ExtAlgeb	$-P_e u$
v	V	ExtAlgeb	$-Q_e u$
Idref	$Idref$	AliasAl- geb	0
Iqref	$Iqref$	AliasAl- geb	0

Services

Name	Symbol	Equation	Type
Pref	P_{ref}	$P_{0s}\gamma_P$	ConstService
Qref	Q_{ref}	$Q_{0s}\gamma_Q$	ConstService
w0	w_0	$2\pi f$	ConstService
ixf	$1/xf$	$\frac{1}{x_s}$	ConstService
Id0	I_{d0}	$\frac{P_{ref}u}{V}$	ConstService
Iq0	I_{q0}	$-\frac{Q_{ref}u}{V}$	ConstService
vd0	v_{d0}	Vu	ConstService
vq0	v_{q0}	0	ConstService
Kdvoc	$Kdvoc$	$\frac{400000000\omega_{drp}}{(99990000-2(100-100Q_{drp})^2)^2}$	ConstService
udref0	u_{dref0}	$I_{d0}r_a - I_{q0}x_s + v_{d0}$	ConstService
uqref0	u_{qref0}	$I_{d0}x_s + I_{q0}r_a + v_{q0}$	ConstService

Discretes

Name	Symbol	Type	Info
Psig_lim	lim_{Psig}	AntiWindup	Limiter in Lag
Qsig_lim	lim_{Qsig}	AntiWindup	Limiter in Lag
dw_lim	lim_{dw}	HardLimiter	

Blocks

Name	Symbol	Type	Info
Psen	P_{sen}	Lag	
Qsen	Q_{sen}	Lag	
Psig	P_{sig}	LagAntiWindup	
Qsig	Q_{sig}	LagAntiWindup	
PIplim	PI_{plim}	PIController	
PIqlim	PI_{qlim}	PIController	
dw	dw	GainLimiter	
PIvd	PI_{vd}	PIController	
PIvq	PI_{vq}	PIController	
PIId	PII_d	PIController	
PIIq	PII_q	PIController	
udLag	$udLag$	Lag	
uqLag	$uqLag$	Lag	

Config Fields in [REGF3]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.25 RenGovernor

Renewable turbine governor group.

Common Parameters: `u`, `name`, `ree`, `w0`, `Sn`, `Pe0`

Common Variables: `Pm`, `wr0`, `wt`, `wg`, `s3_y`

Available models: *WTDTA1*, *WTDS*

5.25.1 WTDTA1

WTDTA wind turbine drive-train model.

One can set `Htfrac` to 0 to simulate a single-mass drive train. `Htfrac` has to be within $[0, 1]$

User-provided reference speed should be specified in parameter `w0`. Internally, `w0` is set to the algebraic variable `wr0`.

Note for PSS/E dyr parser:

In PSS/E doc, *Freq1* is said to be Hz, but exported data from PSS/E 34 uses per unit. ANDES requires `Freq1` in per unit frequency.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
ree		Renewable exciter idx			mandatory
H	H_t	Total inertia constant	3	<i>MWs/MVA</i>	non_zero,non_negative,power
DAMP	D_{amp}	Damp coefficient	0	<i>p.u. (gen base)</i>	power
Ht- frac	D_{shaft}	Turbine inertia fraction (Hturb/H)	0.500		power
Freq1	$Freq1$	First shaft torsional resonant frequency, p.u. (Hz)	1	<i>p.u. (Hz)</i>	
Dshaft	D_{shaft}	Shaft damping factor	1	<i>p.u. (gen base)</i>	power
w0	ω_0	Default speed if not using a torque model	1	<i>p.u.</i>	
reg			0		
Sn	S_n		0		

Variables

Name	Symbol	Type	Description	Unit	Properties
s1_y	y_{s1}	State	Integrator output		v_str
s2_y	y_{s2}	State	Integrator output		v_str
s3_y	y_{s3}	State	Integrator output		v_str
wt	ω_t	AliasState	Alias of s1_y		
wg	ω_g	AliasState	Alias of s2_y		
wr0	ω_{r0}	Algeb	speed set point	<i>p.u.</i>	v_str
Pm	P_m	Algeb	Mechanical power		v_str
pd	P_d	Algeb	Output after damping		v_str
wge	wge	ExtAlgeb			
Pe	Pe	ExtAlgeb	Retrieved Pe of RenGen		

Initialization Equations

Name	Symbol	Type	Initial Value
s1_y	y_{s1}	State	ω_{r0}
s2_y	y_{s2}	State	ω_{r0}
s3_y	y_{s3}	State	$\frac{P_{e0}}{\omega_{r0}}$
wt	ω_t	AliasState	
wg	ω_g	AliasState	
wr0	ω_{r0}	Algeb	ω_0
Pm	P_m	Algeb	P_{e0}
pd	P_d	Algeb	0
wge	wge	ExtAlgeb	
Pe	P_e	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
s1_y	y_{s1}	State	$-1.0P_d + \frac{1.0P_m}{y_{s1}} - 1.0y_{s3}$	$2H_t$
s2_y	y_{s2}	State	$-1.0Damp(-\omega_0 + y_{s2}) + 1.0P_d - \frac{1.0P_e}{y_{s2}} + 1.0y_{s3}$	$2H_g$
s3_y	y_{s3}	State	$K_{shaft}(y_{s1} - y_{s2})$	1.0
wt	ω_t	AliasState	0	
wg	ω_g	AliasState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
wr0	ω_{r0}	Algeb	$\omega_0 - \omega_{r0}$
Pm	P_m	Algeb	$-P_m + P_{e0}$
pd	P_d	Algeb	$D_{shaft}(y_{s1} - y_{s2}) - P_d$
wge	wge	ExtAlgeb	$y_{s2} - 1.0$
Pe	P_e	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
Ht2	$2H_t$	$2D_{shaft}H_t$	ConstService
Hg2	$2H_g$	$2H_t(1 - D_{shaft})$	ConstService
Kshaft	K_{shaft}	$\frac{0.5 \cdot 2H_g 2H_t Freq_1^2}{H_t}$	ConstService

Blocks

Name	Symbol	Type	Info
s1	$s1$	Integrator	
s2	$s2$	Integrator	
s3	$s3$	Integrator	

Config Fields in [WTDTA1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.25.2 WTDS

Custom wind turbine model with a single swing-equation.

This model is used to simulate the mechanical swing of the combined machine and turbine mass. The speed output is `s1_y` which will be fed to `RenExciter.wg`.

`PFLAG` needs to be set to 1 in exciter to consider speed for Pref.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
ree		Renewable exciter idx			mandatory
H	H_t	Total inertia	3	<i>MWs/MVA</i>	non_zero,non_negative,power
D	D_{shaft}	Damping coefficient	1	<i>p.u.</i>	power
w0	ω_0	Default speed if not using a torque model	1	<i>p.u.</i>	
reg			0		
Sn	S_n		0		

Variables

Name	Symbol	Type	Description	Unit	Properties
s1_y	y_{s1}	State	Integrator output		v_str
s3_y	y_{s3}	State	Unused state variable		
wt	ω_t	AliasState	Alias of s1_y		
wg	ω_g	AliasState	Alias of s1_y		
Pm	P_m	Algeb	Mechanical power		v_str
wr0	ω_{r0}	Algeb	speed set point	<i>p.u.</i>	v_str
wge	wge	ExtAlgeb			
Pe	Pe	ExtAlgeb	Retrieved Pe of RenGen		

Initialization Equations

Name	Symbol	Type	Initial Value
s1_y	y_{s1}	State	ω_{r0}
s3_y	y_{s3}	State	
wt	ω_t	AliasState	
wg	ω_g	AliasState	
Pm	P_m	Algeb	P_{e0}
wr0	ω_{r0}	Algeb	ω_0
wge	wge	ExtAlgeb	
Pe	Pe	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
s1_y	y_{s1}	State	$-1.0D_{shaft}(-\omega_{r0} + y_{s1}) + \frac{1.0(P_m - Pe)}{wge}$	$2H$
s3_y	y_{s3}	State	0	
wt	ω_t	AliasState	0	
wg	ω_g	AliasState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Pm	P_m	Algeb	$-P_m + P_{e0}$
wr0	ω_{r0}	Algeb	$\omega_0 - \omega_{r0}$
wge	wge	ExtAlgeb	$y_{s1} - 1.0$
Pe	Pe	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
H2	$2H$	$2H_t$	ConstService
Kshaft	K_{shaft}	1.0	ConstService

Blocks

Name	Symbol	Type	Info
s1	$s1$	Integrator	

Config Fields in [WTDS]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.26 RenPitch

Renewable generator pitch controller group.

Common Parameters: u, name, rea

Available models: *WTPTA1*

5.26.1 WTPTA1

Wind turbine pitch control model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
rea		Renewable aerodynamics model idx			mandatory
Kiw	K_{iw}	Pitch-control integral gain	0.100	<i>p.u.</i>	
Kpw	K_{pw}	Pitch-control proportional gain	0	<i>p.u.</i>	
Kic	K_{ic}	Pitch-compensation integral gain	0.100	<i>p.u.</i>	
Kpc	K_{pc}	Pitch-compensation proportional gain	0	<i>p.u.</i>	
Kcc	K_{cc}	Gain for P diff	0	<i>p.u.</i>	
Tp	T_{θ}	Blade response time const.	0.300	<i>s</i>	
thmax	θ_{max}	Max. pitch angle	30	<i>deg.</i>	
thmin	θ_{min}	Min. pitch angle	0	<i>deg.</i>	
dthmax	θ_{max}	Max. pitch angle rate	5	<i>deg.</i>	
dthmin	θ_{min}	Min. pitch angle rate	-5	<i>deg.</i>	
rego			0		
ree			0		

Variables

Name	Symbol	Type	Description	Unit	Properties
Plc_xi	xi_{PI_c}	State	Integrator output		v_str
PIw_xi	xi_{PI_w}	State	Integrator output		v_str
LG_y	y_{LG}	State	State in lag TF		v_str
wt	wt	ExtState			
Pord	$Pord$	ExtState			
Plc_yul	$y_{PI_c}^{ul}$	Algeb			v_str
Plc_y	y_{PI_c}	Algeb	PI output		v_str
wref	ω_{ref}	Algeb	optional speed reference		v_str
PIw_yul	$y_{PI_w}^{ul}$	Algeb			v_str
PIw_y	y_{PI_w}	Algeb	PI output		v_str
theta	θ	ExtAlgeb			
Pref	$Pref$	ExtAlgeb			

Initialization Equations

Name	Symbol	Type	Initial Value
Plc_xi	xi_{PI_c}	State	0.0
PIw_xi	xi_{PI_w}	State	0.0
LG_y	y_{LG}	State	$1.0y_{PI_c} + 1.0y_{PI_w}$
wt	wt	ExtState	
Pord	$Pord$	ExtState	
Plc_yul	$y_{PI_c}^{ul}$	Algeb	$K_{pc}(Pord - Pref)$
Plc_y	y_{PI_c}	Algeb	$\theta_{max}z_u^{hl_{PI_c}} + \theta_{min}z_l^{hl_{PI_c}} + y_{PI_c}^{ul}z_i^{hl_{PI_c}}$
wref	ω_{ref}	Algeb	wt
PIw_yul	$y_{PI_w}^{ul}$	Algeb	$K_{pw}(K_{cc}(Pord - Pref) - \omega_{ref} + wt)$
PIw_y	y_{PI_w}	Algeb	$\theta_{max}z_u^{hl_{PI_w}} + \theta_{min}z_l^{hl_{PI_w}} + y_{PI_w}^{ul}z_i^{hl_{PI_w}}$
theta	θ	ExtAlgeb	
Pref	$Pref$	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
Plc_xi	xi_{PI_c}	State	$K_{ic}(Pord - Pref)$	
PIw_xi	xi_{PI_w}	State	$K_{iw}(K_{cc}(Pord - Pref) - \omega_{ref} + wt)$	
LG_y	y_{LG}	State	$-y_{LG} + 1.0y_{PI_c} + 1.0y_{PI_w}$	T_θ
wt	wt	ExtState	0	
Pord	$Pord$	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
PIc_yul	$y_{PI_c}^{ul}$	Algeb	$K_{pc}(Pord - Pref) + xi_{PI_c} - y_{PI_c}^{ul}$
PIc_y	y_{PI_c}	Algeb	$\theta_{max} z_u^{hl_{PI_c}} + \theta_{min} z_l^{hl_{PI_c}} + y_{PI_c}^{ul} z_i^{hl_{PI_c}} - y_{PI_c}$
wref	ω_{ref}	Algeb	$-\omega_{ref} + wref_0$
PIw_yul	$y_{PI_w}^{ul}$	Algeb	$K_{pw}(K_{cc}(Pord - Pref) - \omega_{ref} + wt) + xi_{PI_w} - y_{PI_w}^{ul}$
PIw_y	y_{PI_w}	Algeb	$\theta_{max} z_u^{hl_{PI_w}} + \theta_{min} z_l^{hl_{PI_w}} + y_{PI_w}^{ul} z_i^{hl_{PI_w}} - y_{PI_w}$
theta	θ	ExtAlgeb	$-\theta_0 + y_{LG}$
Pref	$Pref$	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
wref0	$wref_0$	ω_{ref}	PostInitService

Discretes

Name	Symbol	Type	Info
PIc_aw	aw_{PI_c}	AntiWindup	
PIc_hl	hl_{PI_c}	HardLimiter	
PIw_aw	aw_{PI_w}	AntiWindup	
PIw_hl	hl_{PI_w}	HardLimiter	
LG_lim	lim_{LG}	AntiWindupRate	Limiter in Lag

Blocks

Name	Symbol	Type	Info
PIc	PI_c	PIAWHardLimit	PI for active power diff compensation
PIw	PI_w	PIAWHardLimit	PI for speed and active power deviation
LG	LG	LagAntiWindupRate	Output lag anti-windup rate limiter

Config Fields in [WTPTA1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.27 RenPlant

Renewable plant control group.

Common Parameters: *u*, *name*

Available models: *REPCA1*

5.27.1 REPCA1

REPCA1: renewable energy power plant control model.

The output of the model, *Pext* and *Qext*, are the increment signals of active and reactive power for the electrical control model.

Notes for PSS/E DYN parser:

1. If ICONs M+1 and M+2 are set to 0 when using generator power, an error will be thrown by the parser, saying "<REPCA1> cannot retrieve <bus1> from <ACLine> using <line>: KeyError('Group <ACLine> does not contain device with idx=False')". Manual effort is required to run the converted file. In the REPCA1 sheet, provide the *idx* of a line that connects to the RenGen bus.
2. PSS/E enters ICONs M+3 as a string in single quotes. The pair of single quotes need to be removed, or the conversion will fail.

Parameters

Name	Symbol	Description	Default	Unit	Properties
<i>idx</i>		unique device <i>idx</i>			
<i>u</i>	<i>u</i>	connection status	1	<i>bool</i>	
<i>name</i>		device name			
<i>ree</i>		RenExciter <i>idx</i>			mandatory
<i>line</i>		<i>Idx</i> of line that connect to measured bus			mandatory
<i>busr</i>		Optional remote bus for voltage and freq. measurement			
<i>busf</i>		BusFreq <i>idx</i> for mode 2			
<i>VCFlag</i>		Droop flag; 0-with droop if power factor ctrl, 1-line drop comp.		<i>bool</i>	mandatory
<i>RefFlag</i>		Q/V select; 0-Q control, 1-V control		<i>bool</i>	mandatory
<i>Fflag</i>		Frequency control flag; 0-disable, 1-enable		<i>bool</i>	mandatory

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Table 41 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
PLflag		Pline ctrl. flag; 0-disable, 1-enable	True	<i>bool</i>	
Tfltr	T_{fltr}	V or Q filter time const.	0.020		
Kp	K_p	Q proportional gain	1		
Ki	K_i	Q integral gain	0.100		
Tft	T_{ft}	Lead time constant	1		
Tfv	T_{fv}	Lag time constant	1		
Vfrz	V_{frz}	Voltage below which s2 is frozen	0.800		
Rc	R_c	Line drop compensation R			
Xc	X_c	Line drop compensation R			
Kc	K_c	Reactive power compensation gain	0		
emax	e_{max}	Upper limit on deadband output	999		
emin	e_{min}	Lower limit on deadband output	-999		
dbd1	d_{bd1}	Lower threshold for reactive power control deadband (≤ 0)	-0.100		
dbd2	d_{bd2}	Upper threshold for reactive power control deadband (≥ 0)	0.100		
Qmax	Q_{max}	Upper limit on output of V-Q control	999		
Qmin	Q_{min}	Lower limit on output of V-Q control	-999		
Kpg	K_{pg}	Proportional gain for power control	1		
Kig	K_{ig}	Integral gain for power control	0.100		
Tp	T_p	Time constant for P measurement	0.020		
fdbd1	f_{dbd1}	Lower threshold for freq. error deadband	-0.000	<i>p.u. (Hz)</i>	
fdbd2	f_{dbd2}	Upper threshold for freq. error deadband	0.000	<i>p.u. (Hz)</i>	
femax	f_{emax}	Upper limit for freq. error	0.050		
femin	f_{emin}	Lower limit for freq. error	-0.050		
Pmax	P_{max}	Upper limit on power error (used by PI ctrl.)	999	<i>p.u. (MW)</i>	power
Pmin	P_{min}	Lower limit on power error (used by PI ctrl.)	-999	<i>p.u. (MW)</i>	power
Tg	T_g	Power controller lag time constant	0.020		
Ddn	D_{dn}	Reciprocal of droop for over-freq. conditions	10		
Dup	D_{up}	Reciprocal of droop for under-freq. conditions	10		
reg		Retrieved RenGen idx			
bus		Retrieved bus idx			
bus1		Retrieved Line.bus1 idx			
bus2		Retrieved Line.bus2 idx			
r		Retrieved Line.r			
x		Retrieved Line.x			

Variables

Name	Symbol	Type	Description	Unit	Properties
s0_y	y_{s0}	State	State in lag transfer function		v_str
s1_y	y_{s1}	State	State in lag transfer function		v_str
s2_xi	$x_{i_{s2}}$	State	Integrator output		v_str

continues on next page

Table 42 – continued from previous page

Name	Symbol	Type	Description	Unit	Properties
s3_x	x'_{s3}	State	State in lead-lag		v_str
s4_y	y_{s4}	State	State in lag transfer function		v_str
s5_xi	xi_{s5}	State	Integrator output		v_str
s6_y	y_{s6}	State	State in lag transfer function		v_str
Vref	Q_{ref}	Algeb			v_str
Qlinef	Q_{linef}	Algeb			v_str
Refsel	R_{efsel}	Algeb			v_str
dbd_y	y_{dbd}	Algeb	Deadband type 1 output		v_str
enf	e_{nf}	Algeb	e Hardlimit output before freeze		v_str
s2_ys	ys_{s2}	Algeb	PI summation before limit		v_str
s2_y	y_{s2}	Algeb	PI output		v_str
s3_y	y_{s3}	Algeb	Output of lead-lag		v_str
ferr	f_{err}	Algeb	Frequency deviation	p.u. (Hz)	v_str
fdbd_y	y_{fdbd}	Algeb	Deadband type 1 output		v_str
Plant_pref	P_{ref}	Algeb	Plant P ref		v_str
Plerr	P_{lerr}	Algeb	Pline error		v_str
Perr	P_{err}	Algeb	Power error before fe limits		v_str
s5_ys	ys_{s5}	Algeb	PI summation before limit		v_str
s5_y	y_{s5}	Algeb	PI output		v_str
Pext	P_{ext}	ExtAlgeb	Pref from RenExciter renamed as Pext		
Qext	Q_{ext}	ExtAlgeb	Qref from RenExciter renamed as Qext		
v	V	ExtAlgeb	Bus (or busr, if given) terminal voltage		
a	θ	ExtAlgeb	Bus (or busr, if given) phase angle		
f	f	ExtAlgeb	Bus frequency	p.u.	
v1	V_1	ExtAlgeb	Voltage at Line.bus1		
v2	V_2	ExtAlgeb	Voltage at Line.bus2		
a1	θ_1	ExtAlgeb	Angle at Line.bus1		
a2	θ_2	ExtAlgeb	Angle at Line.bus2		

Initialization Equations

Name	Symbol	Type	Initial Value
s0_y	y_{s0}	State	$V_{comp}s_1^{SW_{VC}} + s_0^{SW_{VC}} (K_c Q_{line} + V)$
s1_y	y_{s1}	State	Q_{line}
s2_xi	xi_{s2}	State	0.0
s3_x	x'_{s3}	State	y_{s2}
s4_y	y_{s4}	State	P_{line}
s5_xi	xi_{s5}	State	0.0
s6_y	y_{s6}	State	y_{s5}
Vref	Q_{ref}	Algeb	V_{ref0}
Qlinef	Q_{linef}	Algeb	Q_{line0}

continues on next page

Table 43 – continued from previous page

Name	Symbol	Type	Initial Value
Refsel	R_{efsel}	Algeb	$s_0^{SW_{Ref}} (Q_{linef} - y_{s1}) + s_1^{SW_{Ref}} (Q_{ref} - y_{s0})$
dbd_y	y_{dbd}	Algeb	$1.0z_l^{db_{dbd}} (R_{efsel} - d_{bd1}) + 1.0z_u^{db_{dbd}} (R_{efsel} - d_{bd2})$
enf	e_{nf}	Algeb	$e_{max}z_u^{e_{HL}} + e_{min}z_l^{e_{HL}} + y_{dbd}z_i^{e_{HL}}$
s2_ys	y_{s2}	Algeb	K_{pehld}
s2_y	y_{s2}	Algeb	$Q_{max}z_u^{lim_{s2}} + Q_{min}z_l^{lim_{s2}} + y_{s2}z_i^{lim_{s2}}$
s3_y	y_{s3}	Algeb	y_{s2}
ferr	f_{err}	Algeb	$-f + f_{ref}$
fdbd_y	y_{fdbd}	Algeb	$1.0z_l^{db_{fdbd}} (-f_{dbd1} + f_{err}) + 1.0z_u^{db_{fdbd}} (-f_{dbd2} + f_{err})$
Plant_pref	P_{ref}	Algeb	P_{line0}
Plerr	P_{lerr}	Algeb	$P_{ref} - y_{s4}$
Perr	P_{err}	Algeb	$D_{dn}y_{fdbd}z_1^{f_{dt0}} + D_{up}y_{fdbd}z_0^{f_{dt0}} + P_{lerr}s_1^{SW_{PL}}$
s5_ys	y_{s5}	Algeb	$K_{pg} \left(P_{err}z_i^{f_{eHL}} + f_{emax}z_u^{f_{eHL}} + f_{emin}z_l^{f_{eHL}} \right)$
s5_y	y_{s5}	Algeb	$P_{max}z_u^{lim_{s5}} + P_{min}z_l^{lim_{s5}} + y_{s5}z_i^{lim_{s5}}$
Pext	P_{ext}	ExtAlgeb	
Qext	Q_{ext}	ExtAlgeb	
v	V	ExtAlgeb	
a	θ	ExtAlgeb	
f	f	ExtAlgeb	
v1	V_1	ExtAlgeb	
v2	V_2	ExtAlgeb	
a1	θ_1	ExtAlgeb	
a2	θ_2	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
s0_y	y_{s0}	State	$V_{comp}s_1^{SW_{VC}} + s_0^{SW_{VC}} (K_c Q_{line} + V) - y_{s0}$	T_{fltr}
s1_y	y_{s1}	State	$Q_{line} - y_{s1}$	T_{fltr}
s2_xi	$x_{i_{s2}}$	State	$K_i (e_{hld} + 2y_{s2} - 2y_{s2})$	
s3_x	x'_{s3}	State	$-x'_{s3} + y_{s2}$	T_{fv}
s4_y	y_{s4}	State	$P_{line} - y_{s4}$	T_p
s5_xi	$x_{i_{s5}}$	State	$K_{ig} \left(P_{err}z_i^{f_{eHL}} + f_{emax}z_u^{f_{eHL}} + f_{emin}z_l^{f_{eHL}} + 2y_{s5} - 2y_{s5} \right)$	
s6_y	y_{s6}	State	$y_{s5} - y_{s6}$	T_g

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Vref	Q_{ref}	Algeb	$-Q_{ref} + V_{ref0}$
Qlinef	Q_{linef}	Algeb	$Q_{line0} - Q_{linef}$
Refsel	R_{efsel}	Algeb	$-R_{efsel} + s_0^{SW_{Ref}} (Q_{linef} - y_{s1}) + s_1^{SW_{Ref}} (Q_{ref} - y_{s0})$
dbd_y	y_{dbd}	Algeb	$-y_{dbd} + 1.0z_l^{db_{dbd}} (R_{efsel} - d_{bd1}) + 1.0z_u^{db_{dbd}} (R_{efsel} - d_{bd2})$
enf	e_{nf}	Algeb	$e_{max}z_u^{e_{HL}} + e_{min}z_l^{e_{HL}} - e_{nf} + y_{dbd}z_i^{e_{HL}}$
s2_ys	y_{s2}	Algeb	$K_{pe}hld + xi_{s2} - y_{s2}$
s2_y	y_{s2}	Algeb	$Q_{max}z_u^{lim_{s2}} + Q_{min}z_l^{lim_{s2}} - y_{s2} + y_{s2}z_i^{lim_{s2}}$
s3_y	y_{s3}	Algeb	$T_{ft}(-x'_{s3} + y_{s2}) + T_{fv}x'_{s3} - T_{fv}y_{s3} + \left(z_1^{LT_{s3}}\right)^2 (-x'_{s3} + y_{s3})$
ferr	f_{err}	Algeb	$-f - f_{err} + f_{ref}$
fdbd_y	y_{fdbd}	Algeb	$-y_{fdbd} + 1.0z_l^{db_{fdbd}} (-f_{dbd1} + f_{err}) + 1.0z_u^{db_{fdbd}} (-f_{dbd2} + f_{err})$
Plant_pref	P_{ref}	Algeb	$P_{line0} - P_{ref}$
Plerr	P_{lerr}	Algeb	$-P_{lerr} + P_{ref} - y_{s4}$
Perr	P_{err}	Algeb	$D_{dn}y_{fdbd}z_1^{f_{dlt0}} + D_{up}y_{fdbd}z_0^{f_{dlt0}} - P_{err} + P_{lerr}s_1^{SW_{PL}}$
s5_ys	y_{s5}	Algeb	$K_{pg} \left(P_{err}z_i^{f_{eHL}} + f_{emax}z_u^{f_{eHL}} + f_{emin}z_l^{f_{eHL}} \right) + xi_{s5} - y_{s5}$
s5_y	y_{s5}	Algeb	$P_{max}z_u^{lim_{s5}} + P_{min}z_l^{lim_{s5}} - y_{s5} + y_{s5}z_i^{lim_{s5}}$
Pext	P_{ext}	ExtAlgeb	$s_1^{SW_F} y_{s6}$
Qext	Q_{ext}	ExtAlgeb	y_{s3}
v	V	ExtAlgeb	0
a	θ	ExtAlgeb	0
f	f	ExtAlgeb	0
v1	V_1	ExtAlgeb	0
v2	V_2	ExtAlgeb	0
a1	θ_1	ExtAlgeb	0
a2	θ_2	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
Isign	I_{sign}	0	CurrentSign
Iline	I_{line}	$\frac{I_{sign}(V_1 e^{i\theta_1} - V_2 e^{i\theta_2})}{r + ix}$	VarService
Iline0	I_{line0}	I_{line}	ConstService
Pline	P_{line}	$\text{re} \left(I_{sign} V_1 \text{conj} \left(\frac{V_1 e^{i\theta_1} - V_2 e^{i\theta_2}}{r + ix} \right) e^{i\theta_1} \right)$	VarService
Pline0	P_{line0}	P_{line}	ConstService
Qline	Q_{line}	$\text{im} \left(I_{sign} V_1 \text{conj} \left(\frac{V_1 e^{i\theta_1} - V_2 e^{i\theta_2}}{r + ix} \right) e^{i\theta_1} \right)$	VarService
Qline0	Q_{line0}	Q_{line}	ConstService
Vcomp	V_{comp}	$ I_{line} (R_{cs} + iX_{cs}) - V e^{i\theta} $	VarService
Vref0	V_{ref0}	$V_{comp} s_1^{SW_{VC}} + s_0^{SW_{VC}} (K_c Q_{line0} + V)$	ConstService
zf	z_f	f_{rz} Indicator ($V < V_{frz}$)	VarService
eHld	e_{hld}	0	VarHold
Freq_ref	f_{ref}	1.0	ConstService

Discretes

Name	Symbol	Type	Info
SWVC	SW_{VC}	Switcher	
SWRef	SW_{Ref}	Switcher	
SWF	SW_F	Switcher	
SWPL	SW_{PL}	Switcher	
dbd_db	db_{dbd}	DeadBand	
eHL	e_{HL}	Limiter	Hardlimit on deadband output
s2_lim	lim_{s2}	HardLimiter	
s3_LT1	LT_{s3}	LessThan	
s3_LT2	LT_{s3}	LessThan	
fdbd_db	db_{fdbd}	DeadBand	
fdlt0	$fdlt0$	LessThan	frequency deadband output less than zero
feHL	f_{eHL}	Limiter	Limiter for power (frequency) error
s5_lim	lim_{s5}	HardLimiter	

Blocks

Name	Symbol	Type	Info
s0	s_0	Lag	V filter
s1	s_1	Lag	
dbd	d^{bd}	DeadBand1	
s2	s_2	PITrackAW	PI controller for eHL output
s3	s_3	LeadLag	
s4	s_4	Lag	Pline filter
fdbd	f^{dbd}	DeadBand1	frequency error deadband
s5	s_5	PITrackAW	PI for fe limiter output
s6	s_6	Lag	Output filter for Pext

Config Fields in [REPCA1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
kqs	K_{qs}	2	Tracking gain for reactive power PI controller	
ksg	K_{sg}	2	Tracking gain for active power PI controller	
freeze	f_{rz}	1	Voltage dip freeze flag; 1-enable, 0-disable	

5.28 RenTorque

Renewable torque (Pref) controller.

Common Parameters: u, name

Available models: *WTTQA1*

5.28.1 WTTQA1

Wind turbine generator torque (Pref) model.

PI state freeze following voltage dip has not been implemented.

Resets wg in *REECA1* model to 1.0 when torque model is connected. This effectively ignores *PFLAG* of *REECA1*.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
rep		RenPitch controller idx			mandatory
Kip	K_{ip}	Pref-control integral gain	0.100	<i>p.u.</i>	
Kpp	K_{pp}	Pref-control proportional gain	0	<i>p.u.</i>	
Tp	T_p	Pe sensing time const.	0.050	<i>s</i>	
Twref	T_{wref}	Speed reference time const.	30	<i>s</i>	
Temax	T_{emax}	Max. electric torque	1.200	<i>p.u.</i>	power
Temin	T_{emin}	Min. electric torque	0	<i>p.u.</i>	power
Tflag		Tflag; 1-power error, 0-speed error		<i>bool</i>	mandatory
p1	p_1	Active power point 1	0.200	<i>p.u.</i>	power
sp1	s_{p1}	Speed power point 1	0.580	<i>p.u.</i>	
p2	p_2	Active power point 2	0.400	<i>p.u.</i>	power
sp2	s_{p2}	Speed power point 2	0.720	<i>p.u.</i>	
p3	p_3	Active power point 3	0.600	<i>p.u.</i>	power
sp3	s_{p3}	Speed power point 3	0.860	<i>p.u.</i>	
p4	p_4	Active power point 4	0.800	<i>p.u.</i>	power
sp4	s_{p4}	Speed power point 4	1	<i>p.u.</i>	
Tn	T_n	Turbine rating. Use Sn from gov if none.	nan	<i>MVA</i>	
rea			0		
rego			0		
ree			0		
reg			0		
Sngo	$S_{n,go}$		0		
w0	ω_0		0		

Variables

Name	Symbol	Type	Description	Unit	Properties
s1_y	y_{s1}	State	State in lag transfer function		v_str
s2_y	y_{s2}	State	State in lag transfer function		v_str
PI_xi	xi_{PI}	State	Integrator output		v_str
wg	ω_g	ExtState			v_str,v_setter
wt	ω_t	ExtState			v_str,v_setter
s3_y	y_{s3}	ExtState			v_str,v_setter
fPe_y	y_{fPe}	Algeb	Output of piecewise		v_str
Tsel	T_{sel}	Algeb	Output after Tflag selector		v_str
PI_yul	y_{PI}^{ul}	Algeb			v_str
PI_y	y_{PI}	Algeb	PI output		v_str
Pe	P_e	ExtAlgeb			
wr0	ω_{r0}	ExtAlgeb	Retrieved initial w0 from RenGovernor		v_str,v_setter
wge	ω_{ge}	ExtAlgeb			v_str,v_setter
Pref	P_{ref}	ExtAlgeb			v_str,v_setter

Initialization Equations

Nam	Sym- bol	Type	Initial Value
s1_y	y_{s1}	State	$1.0P_e$
s2_y	y_{s2}	State	$1.0y_{fPe}$
PI_xi	xi_{PI}	State	$\frac{P_{ref0}}{y_{fPe}}$
wg	ω_g	ExtSta	y_{fPe}
wt	ω_t	ExtSta	y_{fPe}
s3_y	y_{s3}	ExtSta	$\frac{P_{ref0}}{\omega_q}$
fPe_	y_{fPe}	Al- geb	FixPiecewise $((s_{p1}, p_1 \geq y_{s1}), (k_{p1}(-p_1 + y_{s1}) + s_{p1}, p_2 \geq y_{s1}), (k_{p2}(-p_2 + y_{s1}) + s_{p2}, p_3 \geq y_{s1}), (k_{p3}(-p_3 + y_{s1}) + s_{p3}, p_4 \geq y_{s1}))$
Tsel	T_{sel}	Al- geb	$s_0^{SWT}(-\omega_g + y_{s2}) + \frac{s_1^{SWT}(P_e - P_{ref0})}{\omega_g}$
PI_yi	y_{PI}^{ul}	Al- geb	$K_{pp}T_{sel} + \frac{P_{ref0}}{y_{fPe}}$
PI_y	y_{PI}	Al- geb	$T_{emax}z_u^{hlPI} + T_{emin}z_l^{hlPI} + y_{PI}^{ul}z_i^{hlPI}$
Pe	P_e	Ex- tAl- geb	
wr0	ω_{r0}	Ex- tAl- geb	y_{fPe}
wge	ω_{ge}	Ex- tAl- geb	1.0
Pref	P_{ref}	Ex- tAl- geb	$\omega_g y_{PI}$

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
s1_y	y_{s1}	State	$1.0P_e - y_{s1}$	T_p
s2_y	y_{s2}	State	$1.0y_{fPe} - y_{s2}$	T_{wref}
PI_xi	xi_{PI}	State	$K_{ip}T_{sel}$	
wg	ω_g	ExtState	0	
wt	ω_t	ExtState	0	
s3_y	y_{s3}	ExtState	0	

Algebraic Equations

Nam	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
fPe_	y_{fPe}	Al- geb	$-y_{fPe} + \text{FixPiecewise}((s_{p1}, p_1 \geq y_{s1}), (k_{p1}(-p_1 + y_{s1}) + s_{p1}, p_2 \geq y_{s1}), (k_{p2}(-p_2 + y_{s1}) + s_{p2},$
Tsel	T_{sel}	Al- geb	$-T_{sel} + s_0^{SW_T}(-\omega_g + y_{s2}) + \frac{s_1^{SW_T}(P_e - P_{ref0})}{\omega_g}$
PI_y	y_{PI}^{ul}	Al- geb	$K_{pp}T_{sel} + xi_{PI} - y_{PI}^{ul}$
PI_y	y_{PI}	Al- geb	$T_{emax}z_u^{hl_{PI}} + T_{emin}z_l^{hl_{PI}} + y_{PI}^{ul}z_i^{hl_{PI}} - y_{PI}$
Pe	P_e	Ex- tAl- geb	0
wr0	ω_{r0}	Ex- tAl- geb	$-\omega_0 + y_{fPe}$
wge	ω_{ge}	Ex- tAl- geb	$1 - y_{fPe}$
Pref	P_{ref}	Ex- tAl- geb	$-\frac{P_{ref0}}{\omega_{ge}} + \omega_g y_{PI}$

Services

Name	Symbol	Equation	Type
kp1	k_{p1}	$\frac{-s_{p1} + s_{p2}}{-p_1 + p_2}$	ConstService
kp2	k_{p2}	$\frac{-s_{p2} + s_{p3}}{-p_2 + p_3}$	ConstService
kp3	k_{p3}	$\frac{-s_{p3} + s_{p4}}{-p_3 + p_4}$	ConstService

Discretes

Name	Symbol	Type	Info
SWT	SW_T	Switcher	
PI_aw	aw_{PI}	AntiWindup	
PI_hl	hl_{PI}	HardLimiter	

Blocks

Name	Symbol	Type	Info
s1	s_1	Lag	Pe filter
fPe	f_{Pe}	Piecewise	Piecewise Pe to wref mapping
s2	s_2	Lag	speed filter
PI	PI	PIAWHardLimit	PI controller

Config Fields in [WTTQA1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.29 StaticACDC

AC DC device for power flow

Common Parameters: u, name

Available models: *VSCShunt*

5.29.1 VSCShunt

Data for VSC Shunt in power flow

Parameters

Name	Sym- bol	Description	De- fault	Unit	Proper- ties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		idx of connected bus			manda- tory
node1		Node 1 index			manda- tory
node2		Node 2 index			manda- tory
Vn	V_n	AC voltage rating	110		non_zero
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	<i>kV</i>	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	<i>kV</i>	non_zero
Idcn	I_{dcn}	DC current rating	1	<i>kA</i>	non_zero
rsh	r_{sh}	AC interface resistance	0.003	<i>ohm</i>	z
xsh	x_{sh}	AC interface reactance	0.060	<i>ohm</i>	z
con- trol		Control method: 0-PQ, 1-PV, 2-vQ or 3-vV			manda- tory
v0		AC voltage setting (PV or vV) or initial guess (PQ or vQ)	1		
p0		AC active power setting	0	<i>pu</i>	
q0		AC reactive power setting	0	<i>pu</i>	
vdc0	v_{dc0}	DC voltage setting	1	<i>pu</i>	
k0		Loss coefficient - constant	0		
k1		Loss coefficient - linear	0		
k2		Loss coefficient - quadratic	0		
droop		Enable dc voltage droop control	0	<i>boolean</i>	
K		Droop coefficient	0		
vhigh		Upper voltage threshold in droop control	9999	<i>pu</i>	
vlow		Lower voltage threshold in droop control	0	<i>pu</i>	
vsh- max		Maximum ac interface voltage	1.100	<i>pu</i>	
vsh- min		Minimum ac interface voltage	0.900	<i>pu</i>	
Ish- max		Maximum ac current	2	<i>pu</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
ash	θ_{sh}	Algeb	voltage phase behind the transformer	rad	v_str
vsh	V_{sh}	Algeb	voltage magnitude behind transformer	p.u.	v_str
psh	P_{sh}	Algeb	active power injection into VSC	p.u.	v_str
qsh	Q_{sh}	Algeb	reactive power injection into VSC		v_str
pdc	P_{dc}	Algeb	DC power injection		v_str
a	a	ExtAlgeb	AC bus voltage phase		
v	v	ExtAlgeb	AC bus voltage magnitude		
v1	v_1	ExtAlgeb	DC node 1 voltage		
v2	v_2	ExtAlgeb	DC node 2 voltage		

Initialization Equations

Name	Symbol	Type	Initial Value
ash	θ_{sh}	Algeb	a
vsh	V_{sh}	Algeb	v_0
psh	P_{sh}	Algeb	$p_0 (s_0^{mode} + s_1^{mode})$
qsh	Q_{sh}	Algeb	$q_0 (s_0^{mode} + s_2^{mode})$
pdc	P_{dc}	Algeb	0
a	a	ExtAlgeb	
v	v	ExtAlgeb	
v1	v_1	ExtAlgeb	
v2	v_2	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
ash	θ_{sh}	Algeb	$-P_{sh} + u (V_{sh} b_{sh} v \sin(\theta_{sh} - a) - V_{sh} g_{sh} v \cos(\theta_{sh} - a) + g_{sh} v^2)$
vsh	V_{sh}	Algeb	$-Q_{sh} + u (V_{sh} b_{sh} v \cos(\theta_{sh} - a) + V_{sh} g_{sh} v \sin(\theta_{sh} - a) - b_{sh} v^2)$
psh	P_{sh}	Algeb	$u (-P_{sh} + p_0) (s_0^{mode} + s_1^{mode}) + u (s_2^{mode} + s_3^{mode}) (v_1 - v_2 - v_{dc0})$
qsh	Q_{sh}	Algeb	$u (-Q_{sh} + q_0) (s_0^{mode} + s_2^{mode}) + u (s_1^{mode} + s_3^{mode}) (-v + v_0)$
pdc	P_{dc}	Algeb	$P_{dc} + u (V_{sh}^2 g_{sh} - V_{sh} b_{sh} v \sin(\theta_{sh} - a) - V_{sh} g_{sh} v \cos(\theta_{sh} - a))$
a	a	ExtAlgeb	$-P_{sh}$
v	v	ExtAlgeb	$-Q_{sh}$
v1	v_1	ExtAlgeb	$-\frac{P_{dc}}{v_1 - v_2}$
v2	v_2	ExtAlgeb	$\frac{P_{dc}}{v_1 - v_2}$

Services

Name	Symbol	Equation	Type
gsh	g_{sh}	$\frac{\text{re}(r_{sh}) - \text{im}(x_{sh})}{(\text{re}(r_{sh}) - \text{im}(x_{sh}))^2 + (\text{re}(x_{sh}) + \text{im}(r_{sh}))^2}$	ConstService
bsh	b_{sh}	$\frac{-\text{re}(x_{sh}) - \text{im}(r_{sh})}{(\text{re}(r_{sh}) - \text{im}(x_{sh}))^2 + (\text{re}(x_{sh}) + \text{im}(r_{sh}))^2}$	ConstService

Discretes

Name	Symbol	Type	Info
mode	$mode$	Switcher	

Config Fields in [VSCShunt]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.30 StaticGen

Static generator group.

Static generators include PV and Slack, which are used to impose algebraic equations. Static generators are used primarily for power flow.

Static generators do not have the modeling details for stability simulation. Although some of them can stay for time-domain simulation, most of them should be substituted by dynamic generators, including synchronous generators and inverter-based resources upon TDS initialization.

The substitution is done by setting the `gen` field of a dynamic generator to refer to the static generator. To replace one StaticGen by multiple dynamic generators, see the notes in [SynGen](#). Generators connected to the same bus need to have their `gammap` and `gammaq`, respectively, summed up to be exactly 1.0.

TDS initialization will ensure that the dynamic generators impose the same amount of power as the static generator. At the end of initialization, *StaticGen*'s that have been substituted will have their connectivity status `u` changed to 0.

Common Parameters: `u`, `name`, `Sn`, `Vn`, `p0`, `q0`, `ra`, `xs`, `subidx`

Common Variables: `q`, `a`, `v`

Available models: *PV*, *Slack*

5.30.1 PV

Static PV generator with reactive power limit checking and PV-to-PQ conversion.

$pv2pq = 1$ turns on the conversion. It starts from iteration min_iter or when the convergence error drops below err_tol .

The PV-to-PQ conversion first ranks the reactive violations. A maximum number of $npv2pq$ PVs above the upper limit, and a maximum of $npv2pq$ PVs below the lower limit will be converted to PQ, which sets the reactive power to $pmax$ or $pmin$.

If $pv2pq$ is 1 (enabled) and $npv2pq$ is 0, heuristics will be used to determine the number of PVs to be converted for each iteration.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
Sn	S_n	Power rating	100		non_zero
Vn	V_n	AC voltage rating	110		non_zero
subidx		index for generators on the same bus			
bus		idx of the installed bus			mandatory
busr		bus idx for remote voltage control			
p0	p_0	active power set point in system base	0	<i>p.u.</i>	
q0	q_0	reactive power set point in system base	0	<i>p.u.</i>	
pmax	p_{max}	maximum active power in system base	999	<i>p.u.</i>	
pmin	p_{min}	minimum active power in system base	-1	<i>p.u.</i>	
qmax	q_{max}	maximum reactive power in system base	999	<i>p.u.</i>	
qmin	q_{min}	minimum reactive power in system base	-999	<i>p.u.</i>	
v0	v_0	voltage set point	1		
vmax	v_{max}	maximum voltage	1.400		
vmin	v_{min}	minimum allowed voltage	0.600		
ra	r_a	armature resistance	0		
xs	x_s	armature reactance	0.300		
busv0	V_{0bus}		0		

Variables

Name	Symbol	Type	Description	Unit	Properties
q	q	Algeb	actual reactive power generation	$p.u.$	v_str
a	θ	ExtAlgeb			
v	V	ExtAlgeb			v_str, v_setter

Initialization Equations

Name	Symbol	Type	Initial Value
q	q	Algeb	$q_0 u$
a	θ	ExtAlgeb	
v	V	ExtAlgeb	$V_{0bus} (1 - u) + uv_0$

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
q	q	Algeb	$u \left(z_i^{qlim} (-V + v_0) + z_l^{qlim} (-q + q_{min}) + z_u^{qlim} (-q + q_{max}) \right)$
a	θ	ExtAlgeb	$-pu$
v	V	ExtAlgeb	$-qu$

Services

Name	Symbol	Equation	Type
p	p	p_0	ConstService

Discretes

Name	Symbol	Type	Info
qlim	$qlim$	SortedLimiter	

Config Fields in [PV]

Option	Sym- bol	Value	Info	Accepted val- ues
al- low_adjust		1	allow adjusting upper or lower limits	(0, 1)
ad- just_lower		0	adjust lower limit	(0, 1)
ad- just_upper		1	adjust upper limit	(0, 1)
pv2pq	z_{pv2pq}	0	convert PV to PQ in PFlow at Q limits	(0, 1)
npv2pq	n_{pv2pq}	0	max. # of conversion each iteration, 0 - auto	≥ 0
min_iter	sw_{iter}	2	iteration number starting from which to enable switching	int
err_tol	ϵ_{tol}	0.010	iteration error below which to enable switching	float
abs_violation		1	use absolute (1) or relative (0) limit violation	(0, 1)

5.30.2 Slack

Slack generator.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
Sn	S_n	Power rating	100		non_zero
Vn	V_n	AC voltage rating	110		non_zero
subidx		index for generators on the same bus			
bus		idx of the installed bus			mandatory
busr		bus idx for remote voltage control			
p0	p_0	active power set point in system base	0	<i>p.u.</i>	
q0	q_0	reactive power set point in system base	0	<i>p.u.</i>	
pmax	p_{max}	maximum active power in system base	999	<i>p.u.</i>	
pmin	p_{min}	minimum active power in system base	-1	<i>p.u.</i>	
qmax	q_{max}	maximum reactive power in system base	999	<i>p.u.</i>	
qmin	q_{min}	minimum reactive power in system base	-999	<i>p.u.</i>	
v0	v_0	voltage set point	1		
vmax	v_{max}	maximum voltage voltage	1.400		
vmin	v_{min}	minimum allowed voltage	0.600		
ra	r_a	armature resistance	0		
xs	x_s	armature reactance	0.300		
a0	θ_0	reference angle set point	0		
busv0	V_{0bus}		0		
busa0	θ_{0bus}		0		

Variables

Name	Symbol	Type	Description	Unit	Properties
q	q	Algeb	actual reactive power generation	<i>p.u.</i>	v_str
p	p	Algeb	actual active power generation	<i>p.u.</i>	v_str
a	θ	ExtAlgeb			v_str,v_setter
v	V	ExtAlgeb			v_str,v_setter

Initialization Equations

Name	Symbol	Type	Initial Value
q	q	Algeb	$q_0 u$
p	p	Algeb	$p_0 u$
a	θ	ExtAlgeb	$\theta_0 u + \theta_{0bus} (1 - u)$
v	V	ExtAlgeb	$V_{0bus} (1 - u) + uv_0$

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
q	q	Algeb	$u \left(z_i^{qlim} (-V + v_0) + z_l^{qlim} (-q + q_{min}) + z_u^{qlim} (-q + q_{max}) \right)$
p	p	Algeb	$u \left(z_i^{plim} (-\theta + \theta_0) + z_l^{plim} (-p + p_{min}) + z_u^{plim} (-p + p_{max}) \right)$
a	θ	ExtAlgeb	$-pu$
v	V	ExtAlgeb	$-qu$

Discretes

Name	Symbol	Type	Info
qlim	$qlim$	SortedLimiter	
plim	$plim$	SortedLimiter	

Config Fields in [Slack]

Option	Sym- bol	Value	Info	Accepted val- ues
al- low_adjust		1	allow adjusting upper or lower limits	(0, 1)
ad- just_lower		0	adjust lower limit	(0, 1)
ad- just_upper		1	adjust upper limit	(0, 1)
pv2pq	z_{pv2pq}	0	convert PV to PQ in PFlow at Q limits	(0, 1)
npv2pq	n_{pv2pq}	0	max. # of conversion each iteration, 0 - auto	≥ 0
min_iter	sw_{iter}	2	iteration number starting from which to enable switching	int
err_tol	ϵ_{tol}	0.010	iteration error below which to enable switching	float
abs_violation		1	use absolute (1) or relative (0) limit violation	(0, 1)
av2pv	z_{av2pv}	0	convert Slack to PV in PFlow at P limits	(0, 1)

5.31 StaticLoad

Static load group.

Common Parameters: *u*, *name*

Available models: *PQ*

5.31.1 PQ

PQ load model.

Implements an automatic *pq2z* conversion during power flow when the voltage is outside [*vmin*, *vmax*]. The conversion can be turned off by setting *pq2z* to 0 in the Config file.

Before time-domain simulation, PQ load will be converted to impedance, current source, and power source based on the weights in the Config file.

Weights (*p2p*, *p2i*, *p2z*) corresponds to the weights for constant power, constant current and constant impedance. *p2p*, *p2i* and *p2z* must be in decimal numbers and sum up exactly to 1. The same rule applies to (*q2q*, *q2i*, *q2z*).

To alter the PQ load in terms of power during simulation, one needs to set the conversion weights to preserve the constant power portion. For example, the PQ can remain as constant power load by setting

```
ss.PQ.config.p2p = 1.0
ss.PQ.config.p2i = 0
ss.PQ.config.p2z = 0

ss.PQ.config.q2q = 1.0
ss.PQ.config.q2i = 0
ss.PQ.config.q2z = 0
```

Then, the constant power portion can be altered by changing the *Ppf* and *Qpf* constants for active power and reactive power.

The equivalent constant current components are in constants *Ipeq* and *Iqeq* for active and reactive current, and the equivalent impedances are in *Req* and *Xeq*.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		linked bus idx			mandatory
Vn	V_n	AC voltage rating	110	<i>kV</i>	non_zero
p0	p_0	active power load in system base	0	<i>p.u.</i>	
q0	q_0	reactive power load in system base	0	<i>p.u.</i>	
vmax	v_{max}	max voltage before switching to impedance	1.200		
vmin	v_{min}	min voltage before switching to impedance	0.800		
owner		owner idx			

Variables

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Initialization Equations

Name	Symbol	Type	Initial Value
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"	
a	θ	ExtAlgeb	$u \left(I_{peq} V \gamma_{p2i} + P_{pf} \gamma_{p2p} + R_{eq} V^2 \gamma_{p2z} \right) \text{Indicator} (t_{dae} \geq 0)$ $u \left(R_{lb} V^2 z_l^{vcmp} + R_{ub} V^2 z_u^{vcmp} + p_0 z_i^{vcmp} \right) \text{Indicator} (t_{dae} < 0)$	+
v	V	ExtAlgeb	$u \left(I_{peq} V \gamma_{q2i} + Q_{pf} \gamma_{q2q} + V^2 X_{eq} \gamma_{q2z} \right) \text{Indicator} (t_{dae} \geq 0)$ $u \left(V^2 X_{lb} z_l^{vcmp} + V^2 X_{ub} z_u^{vcmp} + q_0 z_i^{vcmp} \right) \text{Indicator} (t_{dae} < 0)$	+

Services

Name	Symbol	Equation	Type
Rub	R_{ub}	$\frac{p_0}{v_{max}^2}$	ConstService
Xub	X_{ub}	$\frac{q_0}{v_{max}^2}$	ConstService
Rlb	R_{lb}	$\frac{p_0}{v_{min}^2}$	ConstService
Xlb	X_{lb}	$\frac{q_0}{v_{min}^2}$	ConstService
Ppf	P_{pf}	$R_{lb}V_0^2z_l^{vcmp} + R_{ub}V_0^2z_u^{vcmp} + p_0z_i^{vcmp}$	ConstService
Qpf	Q_{pf}	$V_0^2X_{lb}z_l^{vcmp} + V_0^2X_{ub}z_u^{vcmp} + q_0z_i^{vcmp}$	ConstService
Req	R_{eq}	$\frac{P_{pf}}{V_0^2}$	ConstService
Xeq	X_{eq}	$\frac{Q_{pf}}{V_0^2}$	ConstService
Ipeq	I_{peq}	$\frac{P_{pf}}{V_0}$	ConstService
Ireq	I_{req}	$\frac{Q_{pf}}{V_0}$	ConstService

Discretes

Name	Symbol	Type	Info
vcmp	$vcmp$	Limiter	

Config Fields in [PQ]

Option	Sym- bol	Value	Info	Accepted val- ues
al- low_adjust		1	allow adjusting upper or lower limits	(0, 1)
ad- just_lower		0	adjust lower limit	(0, 1)
ad- just_upper		1	adjust upper limit	(0, 1)
pq2z	z_{pq2z}	1	pq2z conversion if out of voltage limits	(0, 1)
p2p	γ_{p2p}	0	P constant power percentage for TDS. Must have (p2p+p2i+p2z)=1	float
p2i	γ_{p2i}	0	P constant current percentage	float
p2z	γ_{p2z}	1	P constant impedance percentage	float
q2q	γ_{q2q}	0	Q constant power percentage for TDS. Must have (q2q+q2i+q2z)=1	float
q2i	γ_{q2i}	0	Q constant current percentage	float
q2z	γ_{q2z}	1	Q constant impedance percentage	float

5.32 StaticShunt

Static shunt compensator group.

Common Parameters: u, name

Available models: *Shunt*, *ShuntTD*, *ShuntSw*

5.32.1 Shunt

Phasor-domain shunt compensator Model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		idx of connected bus			mandatory
Sn	S_n	Power rating	100		non_zero
Vn	V_n	AC voltage rating	110		non_zero
g	g	shunt conductance (real part)	0		y
b	b	shunt susceptance (positive as capacitive)	0		y
fn	f_n	rated frequency	60		

Variables

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Initialization Equations

Name	Symbol	Type	Initial Value
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation " $0 = g(x, y)$ "
a	θ	ExtAlgeb	$V^2 g_u$
v	V	ExtAlgeb	$-V^2 b_u$

Config Fields in [Shunt]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.32.2 ShuntTD

Static shunt model with inverse transformation from phasor to time-domain.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		idx of connected bus			mandatory
Sn	S_n	Power rating	100		non_zero
Vn	V_n	AC voltage rating	110		non_zero
g	g	shunt conductance (real part)	0		y
b	b	shunt susceptance (positive as capacitive)	0		y
fn	f_n	rated frequency	60		

Variables

Name	Symbol	Type	Description	Unit	Properties
vta	V_{ta}	Algeb			v_str
vtb	V_{tb}	Algeb			v_str
vtc	V_{tc}	Algeb			v_str
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Initialization Equations

Name	Symbol	Type	Initial Value
vta	V_{ta}	Algeb	$\frac{\sqrt{3}V \cos(\theta + 2\pi f_{sys} t_{dae})}{3}$
vtb	V_{tb}	Algeb	$-\frac{\sqrt{3}V \cos(\theta + 2\pi f_{sys} t_{dae} + \frac{\pi}{3})}{3}$
vtc	V_{tc}	Algeb	$-\frac{\sqrt{3}V \sin(\theta + 2\pi f_{sys} t_{dae} + \frac{\pi}{6})}{3}$
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
vta	V_{ta}	Algeb	$\frac{\sqrt{3}V \cos(\theta + 2\pi f_{sys} t_{dae})}{3} - V_{ta}$
vtb	V_{tb}	Algeb	$-\frac{\sqrt{3}V \cos(\theta + 2\pi f_{sys} t_{dae} + \frac{\pi}{3})}{3} - V_{tb}$
vtc	V_{tc}	Algeb	$-\frac{\sqrt{3}V \sin(\theta + 2\pi f_{sys} t_{dae} + \frac{\pi}{6})}{3} - V_{tc}$
a	θ	ExtAlgeb	$V^2 gu$
v	V	ExtAlgeb	$-V^2 bu$

Config Fields in [ShuntTD]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.32.3 ShuntSw

Switched Shunt Model.

Parameters gs , bs and ns must be entered in string literals, comma-separated. They need to have the same length.

For example, in the excel file, one can put

```
gs = [0, 0]
bs = [0.2, 0.2]
ns = [2, 4]
```

To use individual shunts as fixed shunts, set the corresponding $ns = 0$ or $ns = [0]$.

The effective shunt susceptances and conductances are stored in services $beff$ and $geff$.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		idx of connected bus			mandatory
Sn	S_n	Power rating	100		non_zero
Vn	V_n	AC voltage rating	110		non_zero
g	g	shunt conductance (real part)	0		y
b	b	shunt susceptance (positive as capacitive)	0		y
fn	f_n	rated frequency	60		
gs		a list literal of switched conductances blocks	0	<i>p.u.</i>	y
bs		a list literal of switched susceptances blocks	0	<i>p.u.</i>	y
ns		a list literal of the element numbers in each switched block	[0]		
vref		voltage reference	1	<i>p.u.</i>	non_zero,non_negative
dv		voltage error deadband	0.050	<i>p.u.</i>	non_zero,non_negative
dt		delay before two consecutive switching	30	<i>sec- onds</i>	non_negative

Variables

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Initialization Equations

Name	Symbol	Type	Initial Value
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation " $0 = g(x, y)$ "
a	θ	ExtAlgeb	$V^2 g e f f u$
v	V	ExtAlgeb	$-V^2 b e f f u$

Services

Name	Symbol	Equation	Type
vlo	v_{lo}	$-dv + vref$	ConstService
vup	v_{up}	$dv + vref$	ConstService

Discretes

Name	Symbol	Type	Info
adj	adj	ShuntAdjust	shunt adjuster

Config Fields in [ShuntSw]

Option	Sym- bol	Value	Info	Accepted val- ues
al- low_adjust		1	allow adjusting upper or lower limits	(0, 1)
ad- just_lower		0	adjust lower limit	(0, 1)
ad- just_upper		1	adjust upper limit	(0, 1)
min_iter	sw_{iter}	2	iteration number starting from which to enable switching	int
err_tol	ϵ_{tol}	0.010	iteration error below which to enable switching	float

5.33 SynGen

Synchronous generator group.

SynGen replaces StaticGen upon the initialization of dynamic studies. SynGen and inverter-based resources contain parameters `gammap` and `gammaq` for splitting the initial power of a StaticGen into multiple dynamic ones.

`gammap`, for example, is the active power ratio of the dynamic generator to the static one. If a StaticGen is supposed to be replaced by one SynGen, the `gammap` and `gammaq` should both be 1.

It is critical to ensure that `gammap` and `gammaq`, respectively, of all dynamic power sources sum up to 1.0. Otherwise, the initial power injections imposed by dynamic sources will differ from the static ones. The initialization will then fail with mismatches power injection equations corresponding to bus `a` and `v`.

Common Parameters: `u`, `name`, `Sn`, `Vn`, `fn`, `bus`, `M`, `D`, `subidx`

Common Variables: `omega`, `delta`

Available models: *GENCLS*, *GENROU*, *PLBVFU1*

5.33.1 GENCLS

Classical generator model.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
coi		center of inertia index			
coi2		center of inertia index			
Sn	S_n	Power rating	100	<i>MVA</i>	
Vn	V_n	AC voltage rating	110		
fn	f	rated frequency	60		
D	D	Damping coefficient	0		power
M	M	machine start up time (2H)	6		non_zero,non_negative,power
ra	r_a	armature resistance	0		<i>z</i>
xl	x_l	leakage reactance	0		<i>z</i>
xd1	x'_d	d-axis transient reactance	0.302		<i>z</i>
kp	k_p	active power feedback gain	0		
kw	k_w	speed feedback gain	0		
S10	$S_{1.0}$	first saturation factor	0		
S12	$S_{1.2}$	second saturation factor	1		
gammap	γ_P	P ratio of linked static gen	1		
gam- maq	γ_Q	Q ratio of linked static gen	1		
subidx		Generator idx in plant; only used by PSS/E data	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
delta	δ	State	rotor angle	<i>rad</i>	v_str
omega	ω	State	rotor speed	<i>pu (Hz)</i>	v_str
Id	I_d	Algeb	d-axis current		v_str
Iq	I_q	Algeb	q-axis current		v_str
vd	V_d	Algeb	d-axis voltage		v_str
vq	V_q	Algeb	q-axis voltage		v_str
tm	τ_m	Algeb	mechanical torque		v_str
te	τ_e	Algeb	electric torque		v_str
vf	v_f	Algeb	excitation voltage	<i>pu</i>	v_str
XadIfd	$X_{ad}I_{fd}$	Algeb	d-axis armature excitation current	<i>p.u (kV)</i>	v_str
Pe	P_e	Algeb	active power injection		v_str
Qe	Q_e	Algeb	reactive power injection		v_str
psid	ψ_d	Algeb	d-axis flux		v_str
psiq	ψ_q	Algeb	q-axis flux		v_str
a	θ	ExtAlgeb	Bus voltage phase angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
delta	δ	State	δ_0
omega	ω	State	u
Id	I_d	Algeb	$I_{d0}u$
Iq	I_q	Algeb	$I_{q0}u$
vd	V_d	Algeb	$V_{d0}u$
vq	V_q	Algeb	$V_{q0}u$
tm	τ_m	Algeb	τ_{m0}
te	τ_e	Algeb	$\tau_{e0}u$
vf	v_f	Algeb	uv_{f0}
XadIfd	$X_{ad}I_{fd}$	Algeb	uv_{f0}
Pe	P_e	Algeb	$u(I_{d0}V_{d0} + I_{q0}V_{q0})$
Qe	Q_e	Algeb	$u(I_{d0}V_{q0} - I_{q0}V_{d0})$
psid	ψ_d	Algeb	$\psi_{d0}u$
psiq	ψ_q	Algeb	$\psi_{q0}u$
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
delta	δ	State	$2\pi f u (\omega - 1)$	
omega	ω	State	$u (-D (\omega - 1) - \tau_e + \tau_m)$	M

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Id	I_d	Algeb	$I_d x'_d + \psi_d - v_f$
Iq	I_q	Algeb	$I_q x'_d + \psi_q$
vd	V_d	Algeb	$V u \sin (\delta - \theta) - V_d$
vq	V_q	Algeb	$V u \cos (\delta - \theta) - V_q$
tm	τ_m	Algeb	$-\tau_m + \tau_{m0}$
te	τ_e	Algeb	$-\tau_e + u (-I_d \psi_q + I_q \psi_d)$
vf	v_f	Algeb	$u v_{f0} - v_f$
XadIfd	$X_{ad} I_{fd}$	Algeb	$-X_{ad} I_{fd} + u v_{f0}$
Pe	P_e	Algeb	$-P_e + u (I_d V_d + I_q V_q)$
Qe	Q_e	Algeb	$-Q_e + u (I_d V_q - I_q V_d)$
psid	ψ_d	Algeb	$-\psi_d + u (I_q r_a + V_q)$
psiq	ψ_q	Algeb	$\psi_q + u (I_d r_a + V_d)$
a	θ	ExtAlgeb	$-u (I_d V_d + I_q V_q)$
v	V	ExtAlgeb	$-u (I_d V_q - I_q V_d)$

Services

Name	Symbol	Equation	Type
p0	P_0	$P_{0s}\gamma_P$	ConstService
q0	Q_0	$Q_{0s}\gamma_Q$	ConstService
_V	V_c	$V e^{i\theta}$	ConstService
_S	S	$P_0 - iQ_0$	ConstService
_I	I_c	$\frac{S}{\text{conj}(V_c)}$	ConstService
_E	E	$I_c (r_a + ix'_d) + V_c$	ConstService
_deltac	δ_c	$\log\left(\frac{E}{ E }\right)$	ConstService
delta0	δ_0	$u \text{im}(\delta_c)$	ConstService
vdq	V_{dq}	$V_c u e^{-\delta_c + 0.5i\pi}$	ConstService
Idq	I_{dq}	$I_c u e^{-\delta_c + 0.5i\pi}$	ConstService
Id0	I_{d0}	$\text{re}(I_{dq})$	ConstService
Iq0	I_{q0}	$\text{im}(I_{dq})$	ConstService
vd0	V_{d0}	$\text{re}(V_{dq})$	ConstService
vq0	V_{q0}	$\text{im}(V_{dq})$	ConstService
tm0	τ_{m0}	$u (I_{d0} (I_{d0} r_a + V_{d0}) + I_{q0} (I_{q0} r_a + V_{q0}))$	ConstService
psid0	ψ_{d0}	$I_{q0} r_a u + V_{q0}$	ConstService
psiq0	ψ_{q0}	$-I_{d0} r_a u - V_{d0}$	ConstService
vf0	v_{f0}	$I_{d0} x'_d + I_{q0} r_a + V_{q0}$	ConstService

Config Fields in [GENCLS]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
vf_lower		1	lower limit for vf warning	
vf_upper		5	upper limit for vf warning	

5.33.2 GENROU

Round rotor generator with quadratic saturation.

Notes

Parameters:

- x_{d2} and x_{q2} must be equal to pass initialization.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
coi		center of inertia index			
coi2		center of inertia index			
Sn	S_n	Power rating	100	<i>MVA</i>	
Vn	V_n	AC voltage rating	110		
fn	f	rated frequency	60		
D	D	Damping coefficient	0		power
M	M	machine start up time (2H)	6		non_zero,non_negative,power
ra	r_a	armature resistance	0		z
xl	x_l	leakage reactance	0		z
xd1	x'_d	d-axis transient reactance	0.302		z
kp	k_p	active power feedback gain	0		
kw	k_w	speed feedback gain	0		
S10	$S_{1.0}$	first saturation factor	0		
S12	$S_{1.2}$	second saturation factor	1		
gammap	γ_P	P ratio of linked static gen	1		
gammaq	γ_Q	Q ratio of linked static gen	1		
xd	x_d	d-axis synchronous reactance	1.900		z
xq	x_q	q-axis synchronous reactance	1.700		z
xd2	x''_d	d-axis sub-transient reactance	0.300		z
xq1	x'_q	q-axis transient reactance	0.500		z
xq2	x''_q	q-axis sub-transient reactance	0.300		z
Td10	T'_{d0}	d-axis transient time constant	8		
Td20	T''_{d0}	d-axis sub-transient time constant	0.040		
Tq10	T'_{q0}	q-axis transient time constant	0.800		
Tq20	T''_{q0}	q-axis sub-transient time constant	0.020		
subidx		Generator idx in plant; only used by PSS/E data	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
delta	δ	State	rotor angle	<i>rad</i>	v_str
omega	ω	State	rotor speed	<i>pu (Hz)</i>	v_str
e1q	e'_q	State	q-axis transient voltage		v_str
e1d	e'_d	State	d-axis transient voltage		v_str
e2d	e''_d	State	d-axis sub-transient voltage		v_str
e2q	e''_q	State	q-axis sub-transient voltage		v_str
Id	I_d	Algeb	d-axis current		v_str
Iq	I_q	Algeb	q-axis current		v_str
vd	V_d	Algeb	d-axis voltage		v_str
vq	V_q	Algeb	q-axis voltage		v_str
tm	τ_m	Algeb	mechanical torque		v_str
te	τ_e	Algeb	electric torque		v_str
vf	v_f	Algeb	excitation voltage	<i>pu</i>	v_str
XadIfd	$X_{ad}I_{fd}$	Algeb	d-axis armature excitation current	<i>p.u (kV)</i>	v_str
Pe	P_e	Algeb	active power injection		v_str
Qe	Q_e	Algeb	reactive power injection		v_str
psid	ψ_d	Algeb	d-axis flux		v_str
psiq	ψ_q	Algeb	q-axis flux		v_str
psi2q	ψ_{aq}	Algeb	q-axis air gap flux		v_str
psi2d	ψ_{ad}	Algeb	d-axis air gap flux		v_str
psi2	ψ_a	Algeb	air gap flux magnitude		v_str
Se	$S_e(\psi_a)$	Algeb	saturation output		v_str
XaqI1q	$X_{aq}I_{1q}$	Algeb	q-axis reaction	<i>p.u (kV)</i>	v_str
a	θ	ExtAlgeb	Bus voltage phase angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
delta	δ	State	δ_0
omega	ω	State	u
e1q	e'_q	State	ue'_{q0}
e1d	e'_d	State	ue'_{d0}
e2d	e''_d	State	ue''_{d0}
e2q	e''_q	State	ue''_{q0}
Id	I_d	Algeb	$I_{d0}u$
Iq	I_q	Algeb	$I_{q0}u$
vd	V_d	Algeb	$V_{d0}u$
vq	V_q	Algeb	$V_{q0}u$
tm	τ_m	Algeb	τ_{m0}
te	τ_e	Algeb	$\tau_{m0}u$
vf	v_f	Algeb	uv_{f0}
XadIfd	$X_{ad}I_{fd}$	Algeb	uv_{f0}
Pe	P_e	Algeb	$u(I_{d0}V_{d0} + I_{q0}V_{q0})$
Qe	Q_e	Algeb	$u(I_{d0}V_{q0} - I_{q0}V_{d0})$
psid	ψ_d	Algeb	$\psi_{d0}u$
psiq	ψ_q	Algeb	$\psi_{q0}u$
psi2q	ψ_{aq}	Algeb	$\psi_{aq0}u$
psi2d	ψ_{ad}	Algeb	$\psi_{ad0}u$
psi2	ψ_a	Algeb	$u \left \psi''_{0,dq} \right $
Se	$S_e(\psi_a)$	Algeb	$S_{e0}u$
XaqI1q	$X_{aq}I_{1q}$	Algeb	0
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
delta	δ	State	$2\pi f u (\omega - 1)$	
omega	ω	State	$u (-D (\omega - 1) - \tau_e + \tau_m)$	M
e1q	e'_q	State	$-X_{ad}I_{fd} + v_f$	T'_{d0}
e1d	e'_d	State	$-X_{aq}I_{1q}$	T'_{q0}
e2d	e''_d	State	$-I_d (x'_d - x_l) - e''_d + e'_q$	T''_{d0}
e2q	e''_q	State	$I_q (-x_l + x'_q) - e''_q + e'_d$	T''_{q0}

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Id	I_d	Algeb	$I_d x_d'' + \psi_d - \psi_{ad}$
Iq	I_q	Algeb	$I_q x_q'' + \psi_q + \psi_{aq}$
vd	V_d	Algeb	$V u \sin(\delta - \theta) - V_d$
vq	V_q	Algeb	$V u \cos(\delta - \theta) - V_q$
tm	τ_m	Algeb	$-\tau_m + \tau_{m0}$
te	τ_e	Algeb	$-\tau_e + u(-I_d \psi_q + I_q \psi_d)$
vf	v_f	Algeb	$uv_{f0} - v_f$
XadIfd	$X_{ad} I_{fd}$	Algeb	$-X_{ad} I_{fd} + u(S_e(\psi_a)\psi_{ad} + e'_q + (-x'_d + x_d)(I_d \gamma_{d1} - \gamma_{d2} e''_d + \gamma_{d2} e'_q))$
Pe	P_e	Algeb	$-P_e + u(I_d V_d + I_q V_q)$
Qe	Q_e	Algeb	$-Q_e + u(I_d V_q - I_q V_d)$
psid	ψ_d	Algeb	$-\psi_d + u(I_q r_a + V_q)$
psiq	ψ_q	Algeb	$\psi_q + u(I_d r_a + V_d)$
psi2q	ψ_{aq}	Algeb	$\gamma_{q1} e'_d - \psi_{aq} + e''_q (1 - \gamma_{q1})$
psi2d	ψ_{ad}	Algeb	$\gamma_{d1} e'_q + \gamma_{d2} e''_d (x'_d - x_l) - \psi_{ad}$
psi2	ψ_a	Algeb	$-\psi_a^2 + \psi_{ad}^2 + \psi_{aq}^2$
Se	$S_e(\psi_a)$	Algeb	$B_{SAT}^q z_0^{SL} \left(-A_{SAT}^q + \psi_a \right)^2 - S_e(\psi_a)\psi_a$
XaqI1q	$X_{aq} I_{1q}$	Algeb	$S_e(\psi_a)\gamma_{qd}\psi_{aq} - X_{aq} I_{1q} + e'_d + (x_q - x'_q)(-I_q \gamma_{q1} - \gamma_{q2} e''_q + \gamma_{q2} e'_d)$
a	θ	ExtAl- geb	$-u(I_d V_d + I_q V_q)$
v	V	ExtAl- geb	$-u(I_d V_q - I_q V_d)$

Services

Name	Symbol	Equation	Type
p0	P_0	$P_{0s} \gamma_P$	ConstService
q0	Q_0	$Q_{0s} \gamma_Q$	ConstService
gd1	γ_{d1}	$\frac{-x_l + x'_d}{x'_d - x_l}$	ConstService
gq1	γ_{q1}	$\frac{-x_l + x'_q}{-x_l + x'_q}$	ConstService
gd2	γ_{d2}	$\frac{x'_d - x''_d}{(x'_d - x_l)^2}$	ConstService
gq2	γ_{q2}	$\frac{-x''_q + x'_q}{(-x_l + x'_q)^2}$	ConstService
gqd	γ_{qd}	$\frac{-x_l + x_q}{x_d - x_l}$	ConstService
S12	$S{1.2}$	$S_{1.2} - f S_{12} + 1$	ConstService
SAT_E1	E_{SAT}^{1c}	1.0	ConstService
SAT_E2	E_{SAT}^{2c}	$3.2 - 2z_{SAT}^{SE2}$	ConstService
SAT_SE1	SE_{SAT}^{1c}	$S_{1.0}$	ConstService

continues on next page

Table 45 – continued from previous page

Name	Symbol	Equation	Type
SAT_SE2	SE_{SAT}^{2c}	$S_{1.2} - 2z_{SAT}^{SE2} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E_{SAT}^{1c} SE_{SAT}^{1c}}{E_{SAT}^{2c} SE_{SAT}^{2c}}} \left(\text{Indicator} \left(SE_{SAT}^{2c} > 0 \right) + \text{Indicator} \left(SE_{SAT}^{2c} < 0 \right) \right)$	ConstService
SAT_A	A_{SAT}^q	$E_{SAT}^{2c} - \frac{E_{SAT}^{1c} - E_{SAT}^{2c}}{a_{SAT} - 1}$	ConstService
SAT_B	B_{SAT}^q	$\frac{E_{SAT}^{2c} SE_{SAT}^{2c} (a_{SAT} - 1)^2 (\text{Indicator} (a_{SAT} > 0) + \text{Indicator} (a_{SAT} < 0))}{(E_{SAT}^{1c} - E_{SAT}^{2c})^2}$	ConstService
_V	V_c	$V e^{i\theta}$	ConstService
_S	S	$P_0 - iQ_0$	ConstService
_Zs	Z_s	$r_a + i x_d''$	ConstService
_It	I_t	$\frac{S}{\text{conj}(V_c)}$	ConstService
_Is	I_s	$I_t + \frac{V_c}{Z_s}$	ConstService
psi20	ψ_0''	$I_s Z_s$	ConstService
psi20_arg	$\theta_{\psi''0}$	$\arg(\psi_0'')$	ConstService
psi20_abs	$ \psi_0'' $	$ \psi_0'' $	ConstService
_It_arg	θ_{It0}	$\arg(I_t)$	ConstService
_psi20_It_arg	$\theta_{\psi a I t}$	$-\theta_{It0} + \theta_{\psi''0}$	ConstService
Se0	S_{e0}	$\frac{B_{SAT}^q (-A_{SAT}^q + \psi_0'')^2 \text{Indicator}(\psi_0'' \geq A_{SAT}^q)}{ \psi_0'' }$	ConstService
_a	a'	$ \psi_0'' (S_{e0} \gamma_{qd} + 1)$	ConstService
_b	b'	$(-x_q + x_q'') I_t $	ConstService
delta0	δ_0	$\theta_{\psi''0} + \text{atan} \left(\frac{b' \cos(\theta_{\psi a I t})}{-a' + b' \sin(\theta_{\psi a I t})} \right)$	ConstService
Tdq	T{dq}	$-i \sin(\delta_0) + \cos(\delta_0)$	ConstService
psi20_dq	$\psi_{0,dq}''$	$T_{dq} \psi_0''$	ConstService
It_dq	$I_{t,dq}$	$\text{conj}(I_t T_{dq})$	ConstService
psi2d0	ψ_{ad0}	$\text{re}(\psi_{0,dq}'')$	ConstService
psi2q0	ψ_{aq0}	$-\text{im}(\psi_{0,dq}'')$	ConstService
Id0	I_{d0}	$\text{im}(I_{t,dq})$	ConstService
Iq0	I_{q0}	$\text{re}(I_{t,dq})$	ConstService
vd0	V_{d0}	$-I_{d0} r_a + I_{q0} x_q'' + \psi_{aq0}$	ConstService
vq0	V_{q0}	$-I_{d0} x_d'' - I_{q0} r_a + \psi_{ad0}$	ConstService
tm0	τ_{m0}	$u(I_{d0}(I_{d0} r_a + V_{d0}) + I_{q0}(I_{q0} r_a + V_{q0}))$	ConstService
vf0	v_{f0}	$I_{d0}(x_d - x_d'') + \psi_{ad0}(S_{e0} + 1)$	ConstService
psid0	ψ_{d0}	$I_{q0} r_a u + V_{q0}$	ConstService
psiq0	ψ_{q0}	$-I_{d0} r_a u - V_{d0}$	ConstService
e1q0	e'_{q0}	$I_{d0}(x_d' - x_d) - S_{e0} \psi_{ad0} + v_{f0}$	ConstService
e1d0	e'_{d0}	$I_{q0}(x_q - x_q') - S_{e0} \gamma_{qd} \psi_{aq0}$	ConstService
e2d0	e''_{d0}	$I_{d0}(-x_d + x_l) - S_{e0} \psi_{ad0} + v_{f0}$	ConstService
e2q0	e''_{q0}	$-I_{q0}(x_l - x_q) - S_{e0} \gamma_{qd} \psi_{aq0}$	ConstService

Discretes

Name	Symbol	Type	Info
SL	SL	LessThan	

Blocks

Name	Symbol	Type	Info
SAT	S_{AT}	ExcQuadSat	

Config Fields in [GENROU]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
vf_lower		1	lower limit for vf warning	
vf_upper		5	upper limit for vf warning	

5.33.3 PLBVFU1

PLBVFU1 model: playback of voltage and frequency as a generator.

The internal voltage and frequency are named `Vflt` and `omega`. Rotor angle is named `delta`.

The current implementation relies on a `TimeSeries` device to provide the voltage and frequency signals. See `ieee14_plbvf1.xlsx` and `plbvf.xlsx` in `andes/cases/ieee14` for an example.

Voltage and frequency data needs to be specified in per unit. Nominal values are not yet supported.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
Sn	S_n	Power rating	100	<i>MVA</i>	
Vn	V_n	AC voltage rating	110		
ra	r_a	armature resistance	0		<i>z</i>
xs	x_s	generator transient reactance	0.200		non_zero,z
fn	f_n	rated frequency	60		
Vflag		playback voltage signal	1	<i>bool</i>	
fflag		playback frequency signal	1	<i>bool</i>	
filename		playback file name		<i>string</i>	mandatory
Vscale	V_{scale}	playback voltage scale	1	<i>pu</i>	non_negative
fscale	f_{scale}	playback frequency scale	1	<i>pu</i>	non_negative
Tv	T_v	filtering time constant for voltage	0.200	<i>s</i>	non_negative
Tf	T_f	filtering time constant for frequency	0.200	<i>s</i>	non_negative
subidx		Generator idx in plant; only used by PSS/E data	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
Vflt	V_{flt}	State	filtered voltage	<i>pu</i>	v_str
omega	ω	State	filtered frequency	<i>pu</i>	v_str
delta	δ	State	rotor angle	<i>rad</i>	v_str
a	θ	ExtAlgeb	Bus voltage phase angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Initialization Equations

Name	Symbol	Type	Initial Value
Vflt	V_{flt}	State	$1/V_{scale}V_{ts} - V_{offs}$
omega	ω	State	$1/f_{scale}f_{ts} - f_{offs}$
delta	δ	State	δ_0
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
Vflt	V_{flt}	State	$1/V_{scale}Vts - V_{flt} - V_{offs}$	T_v
omega	ω	State	$1/f_{scale}fts - \omega - f_{offs}$	T_f
delta	δ	State	$2\pi f_n u (\omega - 1)$	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
a	θ	ExtAlgeb	$-\frac{VV_{flt}x_s \sin(\delta-\theta)}{r_a^2+x_s^2} + \frac{Vr_a(V-V_{flt} \cos(\delta-\theta))}{r_a^2+x_s^2}$
v	V	ExtAlgeb	$\frac{VV_{flt}r_a \sin(\delta-\theta)}{r_a^2+x_s^2} + \frac{Vx_s(V-V_{flt} \cos(\delta-\theta))}{r_a^2+x_s^2}$

Services

Name	Symbol	Equation	Type
zs	zs	$r_a + ix_s$	ConstService
zs2n	$zs2n$	$r_a^2 - x_s^2$	ConstService
Ec	E_c	$Ve^{i\theta} + (r_a + ix_s) \text{conj} \left(\frac{(p+iq)e^{-i\theta}}{V} \right)$	ConstService
E0	E_0	$ E_c $	ConstService
delta0	δ_0	$\arg(E_c)$	ConstService
Vts	Vts	0	ConstService
fts	fts	0	ConstService
ifscale	$1/f_{scale}$	$\frac{1}{f_{scale}}$	ConstService
iVscale	$1/V_{scale}$	$\frac{1}{V_{scale}}$	ConstService
foffs	f_{offs}	$1/f_{scale}fts - 1$	ConstService
Voffs	V_{offs}	$1/V_{scale}Vts - E_0$	ConstService

Config Fields in [PLBVFU1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.34 TimedEvent

Timed event group

Common Parameters: *u*, *name*

Available models: *Toggle*, *Fault*, *Alter*

5.34.1 Toggle

Time-based connectivity status toggle.

Toggle is used to toggle the connection status (online/offline) of a device at the predefined time. Both the model name (or group name) and the device *idx* need to be specified. It effectively negates the *u* field of the connected device.

Toggle can be useful to implement disconnection, connection, and reconnection of devices. For example, a line trip can be implemented by setting *Line* to the *model* field and the corresponding line's *idx* to the *dev* field.

Multiple Toggles can be added to the same device at different times. Adding two Toggles for an initially connected line with $t=0.1$ and $t=0.2$, for instance, will disconnect the line at $t=0.1$ sec and reconnect it at $t=0.2$ sec.

Parameters

Name	Symbol	Description	Default	Unit	Properties
<i>idx</i>		unique device <i>idx</i>			
<i>u</i>	<i>u</i>	connection status	1	<i>bool</i>	
<i>name</i>		device name			
<i>model</i>		model or group name of the device			mandatory
<i>dev</i>		<i>idx</i> of the device to control			mandatory
<i>t</i>		switch time for connection status	-1		mandatory

Services

Name	Symbol	Equation	Type
<i>_u</i>	<i>u</i>	1	ConstService

Config Fields in [Toggle]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.34.2 Fault

Three-phase-to-ground fault.

A Fault device is used to apply and clear three-phase-to-ground fault to the given bus. One can set two time parameters, t_f and t_c , for the fault-on and fault-clearance time, respectively, although only t_f is mandatory.

A fault is implemented by a very small internal shunt impedance to be connected at the fault-on time. Its reactance and resistance are specified by the parameters x_f and r_f .

To implement a fault and its clearance by tripping a line, one can combine `Fault` and `Toggle`. That is, clear a fault in concurrence with a `Toggle`. The user needs to ensure data consistency so that the line trip actually clears the fault.

Non-convergence can occur in the proximity of a fault due to various reasons, including network power transfer capability limitation and parameter issues of controllers.

When a fault gets cleared, algebraic variables change drastically. E.g., voltages can go from nearly zero back to 1.0. As we are using Newton's method for solving the DAE, the initial values are crucial for the immediate step after fault clearance.

This Fault model restores the pre-fault values for algebraic variables `Fault.config.scale` is the scaling factor to be multiplied to the pre-fault values for adjusting the initial values. Some trial and error are expected for severe disturbances, combined with increasing the fault reactance x_f .

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
bus		linked bus idx			mandatory
tf		Bus fault start time	-1	<i>second</i>	mandatory
tc		Bus fault end time	-1	<i>second</i>	
xf	x_f	Fault to ground reactance (positive)	0.000	<i>p.u.(sys)</i>	
rf	x_f	Fault to ground resistance (positive)	0	<i>p.u.(sys)</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb	Bus voltage angle	<i>p.u.(kV)</i>	
v	V	ExtAlgeb	Bus voltage magnitude	<i>p.u.(kV)</i>	

Initialization Equations

Name	Symbol	Type	Initial Value
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
a	θ	ExtAlgeb	$V^2 g_f u u_f$
v	V	ExtAlgeb	$-V^2 b_f u u_f$

Services

Name	Symbol	Equation	Type
gf	g_f	$\frac{\operatorname{re}(x_f) - \operatorname{im}(x_f)}{(\operatorname{re}(x_f) - \operatorname{im}(x_f))^2 + (\operatorname{re}(x_f) + \operatorname{im}(x_f))^2}$	ConstService
bf	b_f	$\frac{-\operatorname{re}(x_f) - \operatorname{im}(x_f)}{(\operatorname{re}(x_f) - \operatorname{im}(x_f))^2 + (\operatorname{re}(x_f) + \operatorname{im}(x_f))^2}$	ConstService
uf	u_f	0	ConstService

Config Fields in [Fault]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
restore		1	restore algebraic variables to pre-fault values	(0, 1)
mode		1	1. restore all algeb variables, 2. fault bus only	(1, 2, 3)
scale		1	scaling factor of restored algebraic values	

5.34.3 Alter

Model for altering device internal data at predefined time.

Alter is useful to apply load changing, tap changing, step response, etc. can be applied to parameters and constant services but cannot be used to update variables.

Alter is implemented by applying the given calculation to the v field of the linked parameter or constant. Alter will not affect other parameters or constants that depend on the altered variable.

It is not uncommon for equations to depend on intermediate constants rather than the input parameters. Therefore, one will need to inspect model equations to determine the parameter/service to be altered.

Examples

To apply a PQ load change, according to *PQ*, one needs to set the load model to constant power and alter P_{pf} and Q_{pf} . Altering p_0 and q_0 will have no impact as they are not used in the equations for time-domain simulation.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	<i>u</i>	connection status	1	<i>bool</i>	
name		device name			
t		switch time for connection status	-1		mandatory
model		model or group name of the device			mandatory
dev		idx of the device to alter			mandatory
src		model source field (param or service)			mandatory
attr		attribute (e.g., v) of the source field	v		
method		alteration method in +, -, *, /, =			mandatory
amount		the amount to apply			mandatory
rand		use uniform random sampling	0		
lb		lower bound of random sampling	0		
ub		upper bound of random sampling	0		

Discretes

Name	Symbol	Type	Info
SW	<i>SW</i>	Switcher	Switcher for alteration method

Config Fields in [Alter]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.35 TurbineGov

Turbine governor group for synchronous generator.

Common Parameters: u, name

Common Variables: pout

Available models: *TG2*, *TGOV1*, *TGOV1DB*, *TGOV1N*, *TGOV1NDB*, *IEEEGI*, *IEESGO*, *GAST*, *HYGOV*, *HYGOVDB*, *HYGOV4*

5.35.1 TG2

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory,unique
Tn	T_n	Turbine power rating. Equal to S_n if not provided.	0	<i>MVA</i>	
wref0	ω_{ref0}	Base speed reference	1	<i>p.u.</i>	
R	R	Speed regulation gain (mach. base default)	0.050	<i>p.u.</i>	ipower
pmax	p_{max}	Maximum power output	999	<i>p.u.</i>	power
pmin	p_{min}	Minimum power output	0	<i>p.u.</i>	power
dbl	L_{db}	Deadband lower limit	-0.000	<i>p.u.</i>	
dbu	U_{db}	Deadband upper limit	0.000	<i>p.u.</i>	
dbc	C_{db}	Deadband neutral value	0	<i>p.u.</i>	
T1	T_1	Transient gain time	0.200		
T2	T_2	Governor time constant	10		
Sg	S_n	Rated power from generator	0	<i>MVA</i>	
ug	u_g	Generator connection status	0	<i>bool</i>	
Vn	V_n	Rated voltage from generator	0	<i>kV</i>	

Variables

Name	Sym- bol	Type	Description	Unit	Prop- erties
ll_x	x'_{ll}	State	State in lead-lag		v_str
omega	ω	ExtState	Generator speed	<i>p.u.</i>	
paux	P_{aux}	Algeb	Auxiliary power input		v_str
pout	P_{out}	Algeb	Turbine final output power		v_str
wref	ω_{ref}	Algeb	Speed reference variable		v_str
w_d	ω_{dev}	Algeb	Generator speed deviation before dead band (positive for under speed)		v_str
w_dm	ω_{dm}	Algeb	Measured speed deviation after dead band		v_str
w_dmg	ω_{dmG}	Algeb	Speed deviation after dead band after gain		v_str
ll_y	y_{ll}	Algeb	Output of lead-lag		v_str
pnl	P_{nl}	Algeb	Power output before hard limiter		v_str
tm	τ_m	ExtAl- geb	Mechanical power interface to SynGen		

Initialization Equations

Name	Symbol	Type	Initial Value
ll_x	x'_{ll}	State	ω_{dmG}
omega	ω	ExtState	
paux	P_{aux}	Algeb	P_{aux0}
pout	P_{out}	Algeb	$\tau_{m0}u_e$
wref	ω_{ref}	Algeb	ω_{ref0}
w_d	ω_{dev}	Algeb	0
w_dm	ω_{dm}	Algeb	0
w_dmg	ω_{dmG}	Algeb	0
ll_y	y_{ll}	Algeb	ω_{dmG}
pnl	P_{nl}	Algeb	τ_{m0}
tm	τ_m	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
ll_x	x'_{ll}	State	$\omega_{dmG} - x'_{ll}$	T_2
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
paux	P_{aux}	Algeb	$P_{aux0} - P_{aux}$
pout	P_{out}	Algeb	$P_{nl}z_i^{plim} - P_{out} + p_{max}z_u^{plim} + p_{min}z_l^{plim}$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
w_d	ω_{dev}	Algeb	$-\omega_{dev} + u_e(-\omega + \omega_{ref})$
w_dm	ω_{dm}	Algeb	$L_{db}z_l r^{wab} + U_{db}z_u r^{wab} + \omega_{dev}(1 - z_i^{wab}) - \omega_{dm}$
w_dmg	ω_{dmG}	Algeb	$G\omega_{dm} - \omega_{dmG}$
ll_y	y_{ll}	Algeb	$T_1(\omega_{dmG} - x'_{ll}) + T_2x'_{ll} - T_2y_{ll} + (z_1^{LT_{ll}})^2(-x'_{ll} + y_{ll})$
pnl	P_{nl}	Algeb	$-P_{nl} + P_{ref0} + y_{ll}$
tm	τ_m	ExtAlgeb	$u_e(P_{out} - \tau_{m0})$

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
gain	G	$\frac{u}{R}$	ConstService

Discretes

Name	Symbol	Type	Info
w_db	w_{db}	DeadBandRT	
ll_LT1	LT_{ll}	LessThan	
ll_LT2	LT_{ll}	LessThan	
plim	$plim$	HardLimiter	

Blocks

Name	Symbol	Type	Info
ll	ll	LeadLag	

Config Fields in [TG2]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)
deadband	$z_{deadband}$	0	enable input dead band	(0, 1)
hardlimit	$z_{hardlimit}$	1	enable output hard limit	(0, 1)

5.35.2 TGOV1

TGOV1 turbine governor model.

Implements the PSS/E TGOV1 model without deadband.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory,unique
Tn	T_n	Turbine power rating. Equal to S_n if not provided.	0	<i>MVA</i>	
wref0	ω_{ref0}	Base speed reference	1	<i>p.u.</i>	
R	R	Speed regulation gain (mach. base default)	0.050	<i>p.u.</i>	ipower
VMAX	V_{max}	Maximum valve position	1.200	<i>p.u.</i>	power
VMIN	V_{min}	Minimum valve position	0	<i>p.u.</i>	power
T1	T_1	Valve time constant	0.100		
T2	T_2	Lead-lag lead time constant	0.200		
T3	T_3	Lead-lag lag time constant	10		
Dt	D_t	Turbine damping coefficient	0		power
Sg	S_n	Rated power from generator	0	<i>MVA</i>	
ug	u_g	Generator connection status	0	<i>bool</i>	
Vn	V_n	Rated voltage from generator	0	<i>kV</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
LAG_y	y_{LAG}	State	State in lag TF		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
omega	ω	ExtState	Generator speed	<i>p.u.</i>	
paux	P_{aux}	Algeb	Auxiliary power input		v_str
pout	P_{out}	Algeb	Turbine final output power		v_str
wref	ω_{ref}	Algeb	Speed reference variable		v_str
pref	P_{ref}	Algeb	Reference power input		v_str
wd	ω_{dev}	Algeb	Generator speed deviation	<i>p.u.</i>	v_str
pd	P_d	Algeb	Pref plus speed deviation times gain	<i>p.u.</i>	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
tm	τ_m	ExtAlgeb	Mechanical power interface to SynGen		

Initialization Equations

Name	Symbol	Type	Initial Value
LAG_y	y_{LAG}	State	P_d
LL_x	x'_{LL}	State	y_{LAG}
omega	ω	ExtState	
paux	P_{aux}	Algeb	P_{aux0}
pout	P_{out}	Algeb	$\tau_{m0}u_e$
wref	ω_{ref}	Algeb	ω_{ref0}
pref	P_{ref}	Algeb	$R\tau_{m0}$
wd	ω_{dev}	Algeb	0
pd	P_d	Algeb	$\tau_{m0}u_e$
LL_y	y_{LL}	Algeb	y_{LAG}
tm	τ_m	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LAG_y	y_{LAG}	State	$P_d - y_{LAG}$	T_1
LL_x	x'_{LL}	State	$-x'_{LL} + y_{LAG}$	T_3
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
paux	P_{aux}	Algeb	$P_{aux0} - P_{aux}$
pout	P_{out}	Algeb	$-P_{out} + u_e (-D_t \omega_{dev} + y_{LL})$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
pref	P_{ref}	Algeb	$P_{ref0} R - P_{ref}$
wd	ω_{dev}	Algeb	$-\omega_{dev} + u_e (\omega - \omega_{ref})$
pd	P_d	Algeb	$G u_e (P_{aux} + P_{ref} - \omega_{dev}) - P_d$
LL_y	y_{LL}	Algeb	$T_2 (-x'_{LL} + y_{LAG}) + T_3 x'_{LL} - T_3 y_{LL} + \left(z_1^{LT_{LL}}\right)^2 (-x'_{LL} + y_{LL})$
tm	τ_m	ExtAlgeb	$u_e (P_{out} - \tau_{m0})$

Services

Name	Symbol	Equation	Type
ue	u_e	$u u_g$	ConstService
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
gain	G	$\frac{u_e}{R}$	ConstService

Discretes

Name	Symbol	Type	Info
LAG_lim	lim_{LAG}	AntiWindup	Limiter in Lag
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	

Blocks

Name	Symbol	Type	Info
LAG	LAG	LagAntiWindup	
LL	LL	LeadLag	

Config Fields in [TGOV1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.35.3 TGOV1DB

TGOV1 turbine governor model with speed input deadband.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory,unique
Tn	T_n	Turbine power rating. Equal to S_n if not provided.	0	<i>MVA</i>	
wref0	ω_{ref0}	Base speed reference	1	<i>p.u.</i>	
R	R	Speed regulation gain (mach. base default)	0.050	<i>p.u.</i>	ipower
VMAX	V_{max}	Maximum valve position	1.200	<i>p.u.</i>	power
VMIN	V_{min}	Minimum valve position	0	<i>p.u.</i>	power
T1	T_1	Valve time constant	0.100		
T2	T_2	Lead-lag lead time constant	0.200		
T3	T_3	Lead-lag lag time constant	10		
Dt	D_t	Turbine damping coefficient	0		power
dbL	db_L	Lower bound of deadband	0	<i>p.u.</i>	
dbU	db_U	Upper bound of deadband	0	<i>p.u.</i>	
Sg	S_n	Rated power from generator	0	<i>MVA</i>	
ug	u_g	Generator connection status	0	<i>bool</i>	
Vn	V_n	Rated voltage from generator	0	<i>kV</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
LAG_y	y_{LAG}	State	State in lag TF		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
omega	ω	ExtState	Generator speed	<i>p.u.</i>	
paux	P_{aux}	Algeb	Auxiliary power input		v_str
pout	P_{out}	Algeb	Turbine final output power		v_str
wref	ω_{ref}	Algeb	Speed reference variable		v_str
pref	P_{ref}	Algeb	Reference power input		v_str
wd	ω_{dev}	Algeb	Generator speed deviation	<i>p.u.</i>	v_str
pd	P_d	Algeb	Pref plus speed deviation times gain	<i>p.u.</i>	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
DB_y	y_{DB}	Algeb	Deadband type 1 output		v_str
tm	τ_m	ExtAlgeb	Mechanical power interface to SynGen		

Initialization Equations

Name	Symbol	Type	Initial Value
LAG_y	y_{LAG}	State	P_d
LL_x	x'_{LL}	State	y_{LAG}
omega	ω	ExtState	
paux	P_{aux}	Algeb	P_{aux0}
pout	P_{out}	Algeb	$\tau_{m0}u_e$
wref	ω_{ref}	Algeb	ω_{ref0}
pref	P_{ref}	Algeb	$R\tau_{m0}$
wd	ω_{dev}	Algeb	0
pd	P_d	Algeb	$\tau_{m0}u_e$
LL_y	y_{LL}	Algeb	y_{LAG}
DB_y	y_{DB}	Algeb	$1.0z_l^{db_{DB}}(\omega_{dev} - db_L) + 1.0z_u^{db_{DB}}(\omega_{dev} - db_U)$
tm	τ_m	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LAG_y	y_{LAG}	State	$P_d - y_{LAG}$	T_1
LL_x	x'_{LL}	State	$-x'_{LL} + y_{LAG}$	T_3
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
paux	P_{aux}	Algeb	$P_{aux0} - P_{aux}$
pout	P_{out}	Algeb	$-D_t y_{DB} - P_{out} + y_{LL}$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
pref	P_{ref}	Algeb	$P_{ref0} R - P_{ref}$
wd	ω_{dev}	Algeb	$-\omega_{dev} + u_e (\omega - \omega_{ref})$
pd	P_d	Algeb	$G u_e (P_{aux} + P_{ref} - y_{DB}) - P_d$
LL_y	y_{LL}	Algeb	$T_2 (-x'_{LL} + y_{LAG}) + T_3 x'_{LL} - T_3 y_{LL} + \left(z_1^{LT_{LL}}\right)^2 (-x'_{LL} + y_{LL})$
DB_y	y_{DB}	Algeb	$-y_{DB} + 1.0 z_l^{db_{DB}} (\omega_{dev} - db_L) + 1.0 z_u^{db_{DB}} (\omega_{dev} - db_U)$
tm	τ_m	ExtAlgeb	$u_e (P_{out} - \tau_{m0})$

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
gain	G	$\frac{u_e}{R}$	ConstService

Discretes

Name	Symbol	Type	Info
LAG_lim	lim_{LAG}	AntiWindup	Limiter in Lag
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
DB_db	db_{DB}	DeadBand	

Blocks

Name	Symbol	Type	Info
LAG	LAG	LagAntiWindup	
LL	LL	LeadLag	
DB	DB	DeadBand1	deadband for speed deviation

Config Fields in [TGOV1DB]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.35.4 TGOV1N

New TGOV1 (TGOV1N) turbine governor model.

The TGOV1N model that sums `pref` and `paux` signals after the droop. This model is useful for incorporating AGC and scheduling signals, which will not be multiplied by $1/R$ like in the original TGOV1 model.

Scheduling changes should write to `pref0.v` in place. AGC signal should write to `paux0.v` in place.

Modifying `tm0` is not allowed.

Examples

To update all `paux0` values to `paux_new`, which contains the new values, do

```
ss.TGOV1N.paux0.v[:] = paux_new  # in-place update of the `paux0.v` array
```

instead of

```
ss.TGOV1N.paux0.v = paux_new  # error; changes the reference of `paux0.v`
```

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory,unique
Tn	T_n	Turbine power rating. Equal to S_n if not provided.	0	<i>MVA</i>	
wref0	ω_{ref0}	Base speed reference	1	<i>p.u.</i>	
R	R	Speed regulation gain (mach. base default)	0.050	<i>p.u.</i>	ipower
VMAX	V_{max}	Maximum valve position	1.200	<i>p.u.</i>	power
VMIN	V_{min}	Minimum valve position	0	<i>p.u.</i>	power
T1	T_1	Valve time constant	0.100		
T2	T_2	Lead-lag lead time constant	0.200		
T3	T_3	Lead-lag lag time constant	10		
Dt	D_t	Turbine damping coefficient	0		power
Sg	S_n	Rated power from generator	0	<i>MVA</i>	
ug	u_g	Generator connection status	0	<i>bool</i>	
Vn	V_n	Rated voltage from generator	0	<i>kV</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
LAG_y	y_{LAG}	State	State in lag TF		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
omega	ω	ExtState	Generator speed	<i>p.u.</i>	
paux	P_{aux}	Algeb	Auxiliary power input		v_str
pout	P_{out}	Algeb	Turbine final output power		v_str
wref	ω_{ref}	Algeb	Speed reference variable		v_str
pref	P_{ref}	Algeb	Reference power input		v_str
wd	ω_{dev}	Algeb	Generator speed deviation	<i>p.u.</i>	v_str
pd	P_d	Algeb	Pref plus speed deviation times gain	<i>p.u.</i>	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
tm	τ_m	ExtAlgeb	Mechanical power interface to SynGen		

Initialization Equations

Name	Symbol	Type	Initial Value
LAG_y	y_{LAG}	State	P_d
LL_x	x'_{LL}	State	y_{LAG}
omega	ω	ExtState	
paux	P_{aux}	Algeb	P_{aux0}
pout	P_{out}	Algeb	$\tau_{m0}u_e$
wref	ω_{ref}	Algeb	ω_{ref0}
pref	P_{ref}	Algeb	τ_{m0}
wd	ω_{dev}	Algeb	0
pd	P_d	Algeb	$\tau_{m0}u_e$
LL_y	y_{LL}	Algeb	y_{LAG}
tm	τ_m	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LAG_y	y_{LAG}	State	$P_d - y_{LAG}$	T_1
LL_x	x'_{LL}	State	$-x'_{LL} + y_{LAG}$	T_3
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
paux	P_{aux}	Algeb	$P_{aux0} - P_{aux}$
pout	P_{out}	Algeb	$-P_{out} + u_e(-D_t\omega_{dev} + y_{LL})$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
pref	P_{ref}	Algeb	$P_{ref0} - P_{ref}$
wd	ω_{dev}	Algeb	$-\omega_{dev} + u_e(\omega - \omega_{ref})$
pd	P_d	Algeb	$-P_d + u_e(-G\omega_{dev} + P_{aux} + P_{ref})$
LL_y	y_{LL}	Algeb	$T_2(-x'_{LL} + y_{LAG}) + T_3x'_{LL} - T_3y_{LL} + \left(z_1^{LT_{LL}}\right)^2(-x'_{LL} + y_{LL})$
tm	τ_m	ExtAlgeb	$u_e(P_{out} - \tau_{m0})$

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
gain	G	$\frac{u_e}{R}$	ConstService

Discretes

Name	Symbol	Type	Info
LAG_lim	lim_{LAG}	AntiWindup	Limiter in Lag
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	

Blocks

Name	Symbol	Type	Info
LAG	LAG	LagAntiWindup	
LL	LL	LeadLag	

Config Fields in [TGOV1N]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.35.5 TGOV1NDB

TGOV1N turbine governor model with speed input deadband.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory,unique
Tn	T_n	Turbine power rating. Equal to S_n if not pro- vided.	0	<i>MVA</i>	
wref0	ω_{ref0}	Base speed reference	1	<i>p.u.</i>	
R	R	Speed regulation gain (mach. base default)	0.050	<i>p.u.</i>	ipower
VMAX	V_{max}	Maximum valve position	1.200	<i>p.u.</i>	power
VMIN	V_{min}	Minimum valve position	0	<i>p.u.</i>	power
T1	T_1	Valve time constant	0.100		
T2	T_2	Lead-lag lead time constant	0.200		
T3	T_3	Lead-lag lag time constant	10		
Dt	D_t	Turbine damping coefficient	0		power
dbL	db_L	Lower bound of deadband	0	<i>p.u.</i>	
dbU	db_U	Upper bound of deadband	0	<i>p.u.</i>	
Sg	S_n	Rated power from generator	0	<i>MVA</i>	
ug	u_g	Generator connection status	0	<i>bool</i>	
Vn	V_n	Rated voltage from generator	0	<i>kV</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
LAG_y	y_{LAG}	State	State in lag TF		v_str
LL_x	x'_{LL}	State	State in lead-lag		v_str
omega	ω	ExtState	Generator speed	<i>p.u.</i>	
paux	P_{aux}	Algeb	Auxiliary power input		v_str
pout	P_{out}	Algeb	Turbine final output power		v_str
wref	ω_{ref}	Algeb	Speed reference variable		v_str
pref	P_{ref}	Algeb	Reference power input		v_str
wd	ω_{dev}	Algeb	Generator speed deviation	<i>p.u.</i>	v_str
pd	P_d	Algeb	Pref plus speed deviation times gain	<i>p.u.</i>	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
DB_y	y_{DB}	Algeb	Deadband type 1 output		v_str
tm	τ_m	ExtAlgeb	Mechanical power interface to SynGen		

Initialization Equations

Name	Symbol	Type	Initial Value
LAG_y	y_{LAG}	State	P_d
LL_x	x'_{LL}	State	y_{LAG}
omega	ω	ExtState	
paux	P_{aux}	Algeb	P_{aux0}
pout	P_{out}	Algeb	$\tau_{m0}u_e$
wref	ω_{ref}	Algeb	ω_{ref0}
pref	P_{ref}	Algeb	τ_{m0}
wd	ω_{dev}	Algeb	0
pd	P_d	Algeb	$\tau_{m0}u_e$
LL_y	y_{LL}	Algeb	y_{LAG}
DB_y	y_{DB}	Algeb	$1.0z_l^{db_{DB}}(\omega_{dev} - db_L) + 1.0z_u^{db_{DB}}(\omega_{dev} - db_U)$
tm	τ_m	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LAG_y	y_{LAG}	State	$P_d - y_{LAG}$	T_1
LL_x	x'_{LL}	State	$-x'_{LL} + y_{LAG}$	T_3
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
paux	P_{aux}	Algeb	$P_{aux0} - P_{aux}$
pout	P_{out}	Algeb	$-D_t y_{DB} - P_{out} + y_{LL}$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
pref	P_{ref}	Algeb	$P_{ref0} - P_{ref}$
wd	ω_{dev}	Algeb	$-\omega_{dev} + u_e(\omega - \omega_{ref})$
pd	P_d	Algeb	$-P_d + u_e(Gy_{DB} + P_{aux} + P_{ref})$
LL_y	y_{LL}	Algeb	$T_2(-x'_{LL} + y_{LAG}) + T_3x'_{LL} - T_3y_{LL} + \left(z_1^{LT_{LL}}\right)^2(-x'_{LL} + y_{LL})$
DB_y	y_{DB}	Algeb	$-y_{DB} + 1.0z_l^{db_{DB}}(\omega_{dev} - db_L) + 1.0z_u^{db_{DB}}(\omega_{dev} - db_U)$
tm	τ_m	ExtAlgeb	$u_e(P_{out} - \tau_{m0})$

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
gain	G	$\frac{u_e}{R}$	ConstService

Discretes

Name	Symbol	Type	Info
LAG_lim	lim_{LAG}	AntiWindup	Limiter in Lag
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
DB_db	db_{DB}	DeadBand	

Blocks

Name	Symbol	Type	Info
LAG	LAG	LagAntiWindup	
LL	LL	LeadLag	
DB	DB	DeadBand1	deadband for speed deviation

Config Fields in [TGOV1NDB]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.35.6 IEEEG1

IEEE Type 1 Speed-Governing Model.

If only one generator is connected, its *idx* must be given to *syn*, and *syn2* must be left blank. Each generator must provide data in its *Sn* base.

syn is connected to the high-pressure output (PHP) and the optional *syn2* is connected to the low- pressure output (PLP).

The speed deviation of generator 1 (*syn*) is measured. If the turbine rating *Tn* is not specified, the sum of *Sn* of all connected generators will be used.

Normally, $K1 + K2 + \dots + K8 = 1.0$. If the second generator is not connected, $K1 + K3 + K5 + K7 = 1$, and $K2 + K4 + K6 + K8 = 0$. If *K1* to *K8* do not sum up to 1.0, they will be normalized. The normalized parameters are called *K1n* through *K8n*.

If initialization error occurs for variable *vs*, it is due to the limits *PMIN* and *PMAX*.

IEEEG1 does not yet support the change of reference (scheduling).

Parameters

Name	Symbol	Description	Default	Unit	Properties
<i>idx</i>		unique device <i>idx</i>			
<i>u</i>	<i>u</i>	connection status	1	<i>bool</i>	
<i>name</i>		device name			
<i>syn</i>		Synchronous generator <i>idx</i>			mandatory,unique
<i>Tn</i>	<i>T_n</i>	Turbine power rating. Equal to <i>Sn</i> if not provided.	0	<i>MVA</i>	
<i>wref0</i>	<i>ω_{ref0}</i>	Base speed reference	1	<i>p.u.</i>	
<i>syn2</i>		Optional SynGen <i>idx</i>			
<i>K</i>	<i>K</i>	Gain (1/R) in mach. base	20	<i>p.u. (power)</i>	power
<i>T1</i>	<i>T₁</i>	Gov. lag time const.	1		
<i>T2</i>	<i>T₂</i>	Gov. lead time const.	1		
<i>T3</i>	<i>T₃</i>	Valve controller time const.	0.100		
<i>UO</i>	<i>U_o</i>	Max. valve opening rate	0.100	<i>p.u./sec</i>	
<i>UC</i>	<i>U_c</i>	Max. valve closing rate	-0.100	<i>p.u./sec</i>	
<i>PMAX</i>	<i>P_{MAX}</i>	Max. turbine power	5		power
<i>PMIN</i>	<i>P_{MIN}</i>	Min. turbine power	0		power
<i>T4</i>	<i>T₄</i>	Inlet piping/steam bowl time constant	0.400		
<i>K1</i>	<i>K₁</i>	Fraction of power from HP	0.500		
<i>K2</i>	<i>K₂</i>	Fraction of power from LP	0		
<i>T5</i>	<i>T₅</i>	Time constant of 2nd boiler pass	8		
<i>K3</i>	<i>K₃</i>	Fraction of HP shaft power after 2nd boiler pass	0.500		
<i>K4</i>	<i>K₄</i>	Fraction of LP shaft power after 2nd boiler pass	0		
<i>T6</i>	<i>T₆</i>	Time constant of 3rd boiler pass	0.500		
<i>K5</i>	<i>K₅</i>	Fraction of HP shaft power after 3rd boiler pass	0		

continues on next page

Table 46 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
K6	K_6	Fraction of LP shaft power after 3rd boiler pass	0		
T7	T_7	Time constant of 4th boiler pass	0.050		
K7	K_7	Fraction of HP shaft power after 4th boiler pass	0		
K8	K_8	Fraction of LP shaft power after 4th boiler pass	0		
Sg	S_n	Rated power from generator	0	MVA	
ug	u_g	Generator connection status	0	bool	
Vn	V_n	Rated voltage from generator	0	kV	
Sg2	S_{n2}	Rated power of Syn2	0	MVA	

Variables

Name	Symbol	Type	Description	Unit	Properties
LL_x	x'_{LL}	State	State in lead-lag		v_str
IAW_y	y_{IAW}	State	AW Integrator output		v_str
L4_y	y_{L4}	State	State in lag transfer function		v_str
L5_y	y_{L5}	State	State in lag transfer function		v_str
L6_y	y_{L6}	State	State in lag transfer function		v_str
L7_y	y_{L7}	State	State in lag transfer function		v_str
omega	ω	ExtState	Generator speed	p.u.	
paux	P_{aux}	Algeb	Auxiliary power input		v_str
pout	P_{out}	Algeb	Turbine final output power		v_str
wref	ω_{ref}	Algeb	Speed reference variable		v_str
wd	ω_{dev}	Algeb	Generator under speed	p.u.	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
vs	V_s	Algeb	Valve speed		v_str
vsl	V_{sl}	Algeb	Valve move speed after limiter		v_str
PHP	P_{HP}	Algeb	HP output		v_str
PLP	P_{LP}	Algeb	LP output		v_str
tm	τ_m	ExtAlgeb	Mechanical power interface to SynGen		
tm2	τ_{m2}	ExtAlgeb	Mechanical power to syn2		

Initialization Equations

Name	Symbol	Type	Initial Value
LL_x	x'_{LL}	State	ω_{dev}
IAW_y	y_{IAW}	State	tm_{012}
L4_y	y_{L4}	State	y_{IAW}
L5_y	y_{L5}	State	y_{L4}
L6_y	y_{L6}	State	y_{L5}
L7_y	y_{L7}	State	y_{L6}
omega	ω	ExtState	
paux	P_{aux}	Algeb	P_{aux0}
pout	P_{out}	Algeb	$\tau_{m0}u_e$
wref	ω_{ref}	Algeb	ω_{ref0}
wd	ω_{dev}	Algeb	0
LL_y	y_{LL}	Algeb	ω_{dev}
vs	V_s	Algeb	0
vsl	V_{sl}	Algeb	$U_c z_l^{HL} + U_o z_u^{HL} + V_s z_i^{HL}$
PHP	P_{HP}	Algeb	$u_e (K_{1n}y_{L4} + K_{3n}y_{L5} + K_{5n}y_{L6} + K_{7n}y_{L7})$
PLP	P_{LP}	Algeb	$u_e (K_{2n}y_{L4} + K_{4n}y_{L5} + K_{6n}y_{L6} + K_{8n}y_{L7})$
tm	τ_m	ExtAlgeb	
tm2	τ_{m2}	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LL_x	x'_{LL}	State	$\omega_{dev} - x'_{LL}$	T_1
IAW_y	y_{IAW}	State	V_{sl}	1
L4_y	y_{L4}	State	$y_{IAW} - y_{L4}$	T_4
L5_y	y_{L5}	State	$y_{L4} - y_{L5}$	T_5
L6_y	y_{L6}	State	$y_{L5} - y_{L6}$	T_6
L7_y	y_{L7}	State	$y_{L6} - y_{L7}$	T_7
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
paux	P_{aux}	Algeb	$P_{aux0} - P_{aux}$
pout	P_{out}	Algeb	$P_{HP}u_e - P_{out}$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
wd	ω_{dev}	Algeb	$-\omega_{dev} + u_e(-\omega + \omega_{ref})$
LL_y	y_{LL}	Algeb	$KT_1x'_{LL} + KT_2(\omega_{dev} - x'_{LL}) - T_1y_{LL} + \left(z_1^{LT_{LL}}\right)^2(-Kx'_{LL} + y_{LL})$
vs	V_s	Algeb	$-V_s + \frac{u_e(P_{aux} + tm_{012} - y_{IAW} + y_{LL})}{T_3}$
vsl	V_{sl}	Algeb	$U_c z_l^{HL} + U_o z_u^{HL} + V_s z_i^{HL} - V_{sl}$
PHP	P_{HP}	Algeb	$-P_{HP} + u_e(K_{1n}y_{L4} + K_{3n}y_{L5} + K_{5n}y_{L6} + K_{7n}y_{L7})$
PLP	P_{LP}	Algeb	$-P_{LP} + u_e(K_{2n}y_{L4} + K_{4n}y_{L5} + K_{6n}y_{L6} + K_{8n}y_{L7})$
tm	τ_m	ExtAlgeb	$u_e(P_{out} - \tau_{m0})$
tm2	τ_{m2}	ExtAlgeb	$u_e z_{syn2}(P_{LP} - \tau_{m02})$

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
sumK18	$\sum{i=1}^8 K_i$	$K_1 + K_2 + K_3 + K_4 + K_5 + K_6 + K_7 + K_8$	ConstService
Kcoeff	K{coeff}	$\frac{1}{\sum_{i=1}^8 K_i}$	ConstService
K1n	K_{1n}	$K_1 K_{coeff}$	ConstService
K2n	K_{2n}	$K_2 K_{coeff}$	ConstService
K3n	K_{3n}	$K_3 K_{coeff}$	ConstService
K4n	K_{4n}	$K_4 K_{coeff}$	ConstService
K5n	K_{5n}	$K_5 K_{coeff}$	ConstService
K6n	K_{6n}	$K_6 K_{coeff}$	ConstService
K7n	K_{7n}	$K_7 K_{coeff}$	ConstService
K8n	K_{8n}	$K_8 K_{coeff}$	ConstService
tm0K2	tm{0K2}	$\tau_{m0} z_{syn2}(K_{2n} + K_{4n} + K_{6n} + K_{8n})$	PostInitService
tm02K1	tm{02K1}	$\tau_{m02}(K_{1n} + K_{3n} + K_{5n} + K_{7n})$	PostInitService
tm012	tm_{012}	$\tau_{m02} + \tau_{m0}$	ConstService

Discretes

Name	Symbol	Type	Info
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
HL	HL	HardLimiter	Limiter on valve speed
IAW_lim	lim_{IAW}	AntiWindup	Limiter in integrator

Blocks

Name	Symbol	Type	Info
LL	LL	LeadLag	Signal conditioning for wd
IAW	IAW	IntegratorAntiWindup	Valve position integrator
L4	$L4$	Lag	first process
L5	$L5$	Lag	second (reheat) process
L6	$L6$	Lag	third process
L7	$L7$	Lag	fourth (second reheat) process

Config Fields in [IEEEG1]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.35.7 IEESGO

IEEE Standard Governor (IEESGO).

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory,unique
Tn	T_n	Turbine power rating. Equal to S_n if not pro- vided.	0	<i>MVA</i>	
wref0	ω_{ref0}	Base speed reference	1	<i>p.u.</i>	
T1	T_1	Controller lag	0.020		
T2	T_2	Lead compensation	1		
T3	T_3	Governor lag	1		
T4	T_4	Steam inlet delay	0.500		
T5	T_5	Reheater delay	10		
T6	T_6	Crossover delay	0.500		
K1	K_1	1/pu regulation	0.020		
K2	K_2	fraction K2	1		
K3	K_3	fraction K3	1		
PMAX	P_{MAX}	Max. turbine power	5		power
PMIN	P_{MIN}	Min. turbine power	0		power
Sg	S_n	Rated power from generator	0	<i>MVA</i>	
ug	u_g	Generator connection status	0	<i>bool</i>	
Vn	V_n	Rated voltage from generator	0	<i>kV</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
F1_y	y_{F1}	State	State in lag transfer function		v_str
F2_x	x'_{F2}	State	State in lead-lag		v_str
F3_y	y_{F3}	State	State in lag transfer function		v_str
F4_y	y_{F4}	State	State in lag transfer function		v_str
F5_y	y_{F5}	State	State in lag transfer function		v_str
omega	ω	ExtState	Generator speed	<i>p.u.</i>	
paux	P_{aux}	Algeb	Auxiliary power input		v_str
pout	P_{out}	Algeb	Turbine final output power		v_str
wref	ω_{ref}	Algeb	Speed reference variable		v_str
F2_y	y_{F2}	Algeb	Output of lead-lag		v_str
HL_x	x_{HL}	Algeb	Value before limiter		v_str
HL_y	y_{HL}	Algeb	Output after limiter and post gain		v_str
tm	τ_m	ExtAlgeb	Mechanical power interface to SynGen		

Initialization Equations

Name	Symbol	Type	Initial Value
F1_y	y_{F1}	State	$K_1 u_e (\omega - \omega_{ref})$
F2_x	x'_{F2}	State	y_{F1}
F3_y	y_{F3}	State	$1.0 y_{HL}$
F4_y	y_{F4}	State	$K_2 y_{F3}$
F5_y	y_{F5}	State	$K_3 y_{F4}$
omega	ω	ExtState	
paux	P_{aux}	Algeb	P_{aux0}
pout	P_{out}	Algeb	$\tau_{m0} u_e$
wref	ω_{ref}	Algeb	ω_{ref0}
F2_y	y_{F2}	Algeb	y_{F1}
HL_x	x_{HL}	Algeb	$1.0 u_e (P_{aux} + P_{ref0} - y_{F2})$
HL_y	y_{HL}	Algeb	$1.0 P_{MAX} z_u^{lim_{HL}} + 1.0 P_{MIN} z_l^{lim_{HL}} + 1.0 x_{HL} z_i^{lim_{HL}}$
tm	τ_m	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
F1_y	y_{F1}	State	$K_1 u_e (\omega - \omega_{ref}) - y_{F1}$	T_1
F2_x	x'_{F2}	State	$-x'_{F2} + y_{F1}$	T_3
F3_y	y_{F3}	State	$-y_{F3} + 1.0 y_{HL}$	T_4
F4_y	y_{F4}	State	$K_2 y_{F3} - y_{F4}$	T_5
F5_y	y_{F5}	State	$K_3 y_{F4} - y_{F5}$	T_6
omega	ω	ExtState	0	

Algebraic Equations

Name	Sym- bol	Type	RHS of Equation "0 = g(x, y)"
paux	P_{aux}	Algeb	$P_{aux0} - P_{aux}$
pout	P_{out}	Algeb	$-P_{out} + u_e (y_{F3} \cdot (1 - K_2) + y_{F4} \cdot (1 - K_3) + y_{F5})$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
F2_y	y_{F2}	Algeb	$1.0 T_2 (-x'_{F2} + y_{F1}) + 1.0 T_3 x'_{F2} - T_3 y_{F2} + \left(z_1^{LT_{F2}}\right)^2 (-1.0 x'_{F2} + y_{F2})$
HL_x	x_{HL}	Algeb	$1.0 u_e (P_{aux} + P_{ref0} - y_{F2}) - x_{HL}$
HL_y	y_{HL}	Algeb	$1.0 P_{MAX} z_u^{lim_{HL}} + 1.0 P_{MIN} z_l^{lim_{HL}} + 1.0 x_{HL} z_i^{lim_{HL}} - y_{HL}$
tm	τ_m	ExtAl- geb	$u_e (P_{out} - \tau_{m0})$

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService

Discretes

Name	Symbol	Type	Info
F2_LT1	LT_{F2}	LessThan	
F2_LT2	LT_{F2}	LessThan	
HL_lim	lim_{HL}	HardLimiter	

Blocks

Name	Symbol	Type	Info
F1	$F1$	Lag	
F2	$F2$	LeadLag	
HL	HL	GainLimiter	
F3	$F3$	Lag	
F4	$F4$	Lag	
F5	$F5$	Lag	

Config Fields in [IEESGO]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.35.8 GAST

GAST turbine governor model.

Reference:

[1] Neplan, TURBINE-GOVERNOR GAST, [Online],

Available:

https://www.neplan.ch/wp-content/uploads/2015/08/Nep_TURBINES_GOV.pdf

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory,unique
Tn	T_n	Turbine power rating. Equal to S_n if not provided.	0	MVA	
wref0	ω_{ref0}	Base speed reference	1	<i>p.u.</i>	
R	R	Speed regulation gain (mach. base default)	0.050	<i>p.u.</i>	ipower
VMAX	V_{max}	Maximum valve position	1.200	<i>p.u.</i>	power
VMIN	V_{min}	Minimum valve position	0	<i>p.u.</i>	power
KT	K_T	Temperature limiter gain	5		
AT	A_T	Ambient temperature load limit	1		power
T1	T_1	Valve time constant	0.100		
T2	T_2	Lead-lag lead time constant	0.200		
T3	T_3	Lead-lag lag time constant	10		
Dt	D_t	Turbine damping coefficient	0		power
Sg	S_n	Rated power from generator	0	MVA	
ug	u_g	Generator connection status	0	<i>bool</i>	
Vn	V_n	Rated voltage from generator	0	kV	

Variables

Name	Symbol	Type	Description	Unit	Properties
LAG_y	y_{LAG}	State	State in lag TF		v_str
LG2_y	y_{LG2}	State	State in lag transfer function		v_str
LG3_y	y_{LG3}	State	State in lag transfer function		v_str
omega	ω	ExtState	Generator speed	<i>p.u.</i>	
paux	P_{aux}	Algeb	Auxiliary power input		v_str
pout	P_{out}	Algeb	Turbine final output power		v_str
wref	ω_{ref}	Algeb	Speed reference variable		v_str
pref	P_{ref}	Algeb	Reference power input		v_str
wd	ω_{dev}	Algeb	Generator under speed	<i>p.u.</i>	v_str
pd	P_d	Algeb	Pref plus under speed times gain	<i>p.u.</i>	v_str
v9	V_9	Algeb	V_9 for LVGate input		v_str
LVG_y	y_{LVG}	Algeb	LVGate output		v_str
tm	τ_m	ExtAlgeb	Mechanical power interface to SynGen		

Initialization Equations

Name	Symbol	Type	Initial Value
LAG_y	y_{LAG}	State	y_{LVG}
LG2_y	y_{LG2}	State	y_{LAG}
LG3_y	y_{LG3}	State	y_{LG2}
omega	ω	ExtState	
paux	P_{aux}	Algeb	P_{aux0}
pout	P_{out}	Algeb	$\tau_{m0}u_e$
wref	ω_{ref}	Algeb	ω_{ref0}
pref	P_{ref}	Algeb	$R\tau_{m0}$
wd	ω_{dev}	Algeb	0
pd	P_d	Algeb	$\tau_{m0}u_e$
v9	V_9	Algeb	$u_e(A_T + K_T(A_T - \tau_{m0}))$
LVG_y	y_{LVG}	Algeb	$P_d z_1^{None_{LVG}} + V_9 z_0^{None_{LVG}}$
tm	τ_m	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LAG_y	y_{LAG}	State	$-y_{LAG} + y_{LVG}$	T_1
LG2_y	y_{LG2}	State	$y_{LAG} - y_{LG2}$	T_2
LG3_y	y_{LG3}	State	$y_{LG2} - y_{LG3}$	T_3
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
paux	P_{aux}	Algeb	$P_{aux0} - P_{aux}$
pout	P_{out}	Algeb	$-P_{out} + u_e (-D_t \omega_{dev} + y_{LG2})$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
pref	P_{ref}	Algeb	$P_{ref0} R - P_{ref}$
wd	ω_{dev}	Algeb	$-\omega_{dev} + u_e (\omega - \omega_{ref})$
pd	P_d	Algeb	$G u_e (P_{aux} + P_{ref} - \omega_{dev}) - P_d$
v9	V_9	Algeb	$-V_9 + u_e (A_T + K_T (A_T - y_{LG3}))$
LVG_y	y_{LVG}	Algeb	$P_d z_1^{None_{LVG}} + V_9 z_0^{None_{LVG}} - y_{LVG}$
tm	τ_m	ExtAlgeb	$u_e (P_{out} - \tau_{m0})$

Services

Name	Symbol	Equation	Type
ue	u_e	$u u_g$	ConstService
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
gain	G	$\frac{u_e}{R}$	ConstService

Discretes

Name	Symbol	Type	Info
LVG_lt	$None_{LVG}$	LessThan	
LAG_lim	lim_{LAG}	AntiWindup	Limiter in Lag

Blocks

Name	Symbol	Type	Info
LVG	<i>LVG</i>	LVGate	LVGate
LAG	<i>LAG</i>	LagAntiWindup	
LG2	<i>LG2</i>	Lag	Lag T2
LG3	<i>LG3</i>	Lag	Lag T3

Config Fields in [GAST]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.35.9 HYGOV

HYGOV turbine governor model.

Implements the PSS/E HYGOV model without deadband.

Reference:

[1] PSSE, Model Library, HYGOV

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory,unique
Tn	T_n	Turbine power rating. Equal to S_n if not provided.	0	<i>MVA</i>	
wref0	ω_{ref0}	Base speed reference	1	<i>p.u.</i>	
R	R	Speed regulation gain (mach. base default)	0.050	<i>p.u.</i>	ipower
r	r	Temporary droop ($R < r$)	1	<i>p.u.</i>	ipower
GMAX	G_{max}	Maximum governor response	1	<i>p.u.</i>	power
GMIN	G_{min}	Minimum governor response	0	<i>p.u.</i>	power
VELM	$VELM$	Gate velocity limit	0.300	<i>p.u.</i>	power
Tf	T_f	Filter time constant	0.050		
Tr	T_r	Governor time constant	1		
Tg	T_g	Servo time constant	0.050		
Dt	D_t	Turbine damping coefficient	0		power
qNL	q_{NL}	No-load flow at nominal head	0.100		power
Tw	T_w	Water inertia time constant constant	1		
At	A_t	Turbine gain	1		
Sg	S_n	Rated power from generator	0	<i>MVA</i>	
ug	u_g	Generator connection status	0	<i>bool</i>	
Vn	V_n	Rated voltage from generator	0	<i>kV</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
gtpos	δ	State	State in gate position (c)	rad	v_str
LAG_y	y_{LAG}	State	State in lag transfer function		v_str
q_y	y_q	State	Integrator output		v_str
omega	ω	ExtState	Generator speed	p.u.	
paux	P_{aux}	Algeb	Auxiliary power input		v_str
pout	P_{out}	Algeb	Turbine final output power		v_str
wref	ω_{ref}	Algeb	Speed reference variable		v_str
pref	P_{ref}	Algeb	Reference power input		v_str
wd	ω_{dev}	Algeb	Generator speed deviation	p.u.	v_str
pd	P_d	Algeb	Pref plus speed deviation times gain	p.u.	v_str
dg	dg	Algeb	desired gate (c)	p.u.	v_str
h	h	Algeb	turbine head	p.u.	v_str
tm	τ_m	ExtAlgeb	Mechanical power interface to SynGen		

Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	P_d
gtpos	δ	State	q_0
LAG_y	y_{LAG}	State	dg
q_y	y_q	State	q_0
omega	ω	ExtState	
paux	P_{aux}	Algeb	P_{aux0}
pout	P_{out}	Algeb	$\tau_{m0}u_e$
wref	ω_{ref}	Algeb	ω_{ref0}
pref	P_{ref}	Algeb	Rq_0
wd	ω_{dev}	Algeb	0
pd	P_d	Algeb	0
dg	dg	Algeb	q_0
h	h	Algeb	1
tm	τ_m	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$P_d - y_{LG}$	T_f
gtpos	δ	State	y_{LG}	
LAG_y	y_{LAG}	State	$dg - y_{LAG}$	T_g
q_y	y_q	State	$1 - \frac{y_q^2}{y_{LAG}^2}$	T_w
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
paux	P_{aux}	Algeb	$P_{aux0} - P_{aux}$
pout	P_{out}	Algeb	$-P_{out} + u_e (A_t h (-q_{NL} + y_q) - D_t \omega_{dev} y_{LAG})$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
pref	P_{ref}	Algeb	$-P_{ref} + Rq_0$
wd	ω_{dev}	Algeb	$-\omega_{dev} + u_e (\omega - \omega_{ref})$
pd	P_d	Algeb	$-P_d + u_e (P_{aux} + P_{ref} - Rdg - \omega_{dev})$
dg	dg	Algeb	$1/ry_{LG} + \delta - dg$
h	h	Algeb	$-h + \frac{y_q^2}{y_{LAG}^2}$
tm	τ_m	ExtAlgeb	$u_e (P_{out} - \tau_{m0})$

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
VELMn	$-VELM$	$-VELM$	ConstService
tr	$r * Tr$	$T_r r$	ConstService
gr	$1/r$	$\frac{1}{r}$	ConstService
ratel	$rate_l$	$-1/r - VELM$	ConstService
rateu	$rate_u$	$-1/r + VELM$	ConstService
q0	q_0	$q_{NL} + \frac{\tau_{m0}}{A_t}$	ConstService
dgl	dg_{lower}	$-1/ry_{LG} - VELM$	VarService
dgu	dg_{upper}	$-1/ry_{LG} + VELM$	VarService

Discretes

Name	Symbol	Type	Info
dg_lim	lim_{dg}	AntiWindupRate	gate velocity and position limiter

Blocks

Name	Symbol	Type	Info
LG	LG	Lag	filter after speed deviation (e)
LAG	LAG	Lag	gate opening (g)
q	q	Integrator	turbine flow (q)

Config Fields in [HYGOV]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.35.10 HYGOVDB

HYGOV turbine governor model with speed input deadband.

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory,unique
Tn	T_n	Turbine power rating. Equal to S_n if not provided.	0	<i>MVA</i>	
wref0	ω_{ref0}	Base speed reference	1	<i>p.u.</i>	
R	R	Speed regulation gain (mach. base default)	0.050	<i>p.u.</i>	ipower
r	r	Temporary droop ($R < r$)	1	<i>p.u.</i>	ipower
GMAX	G_{max}	Maximum governor response	1	<i>p.u.</i>	power
GMIN	G_{min}	Minimum governor response	0	<i>p.u.</i>	power
VELM	$VELM$	Gate velocity limit	0.300	<i>p.u.</i>	power
Tf	T_f	Filter time constant	0.050		
Tr	T_r	Governor time constant	1		
Tg	T_g	Servo time constant	0.050		
Dt	D_t	Turbine damping coefficient	0		power
qNL	q_{NL}	No-load flow at nominal head	0.100		power
Tw	T_w	Water inertia time constant constant	1		
At	A_t	Turbine gain	1		
dbL	db_L	Lower bound of deadband	0	<i>p.u.</i>	
dbU	db_U	Upper bound of deadband	0	<i>p.u.</i>	
Sg	S_n	Rated power from generator	0	<i>MVA</i>	
ug	u_g	Generator connection status	0	<i>bool</i>	
Vn	V_n	Rated voltage from generator	0	<i>kV</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
LG_y	y_{LG}	State	State in lag transfer function		v_str
gtpos	δ	State	State in gate position (c)	rad	v_str
LAG_y	y_{LAG}	State	State in lag transfer function		v_str
q_y	y_q	State	Integrator output		v_str
omega	ω	ExtState	Generator speed	p.u.	
paux	P_{aux}	Algeb	Auxiliary power input		v_str
pout	P_{out}	Algeb	Turbine final output power		v_str
wref	ω_{ref}	Algeb	Speed reference variable		v_str
pref	P_{ref}	Algeb	Reference power input		v_str
wd	ω_{dev}	Algeb	Generator speed deviation	p.u.	v_str
pd	P_d	Algeb	Pref plus speed deviation times gain	p.u.	v_str
dg	dg	Algeb	desired gate (c)	p.u.	v_str
h	h	Algeb	turbine head	p.u.	v_str
DB_y	y_{DB}	Algeb	Deadband type 1 output		v_str
tm	τ_m	ExtAlgeb	Mechanical power interface to SynGen		

Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	P_d
gtpos	δ	State	q_0
LAG_y	y_{LAG}	State	dg
q_y	y_q	State	q_0
omega	ω	ExtState	
paux	P_{aux}	Algeb	P_{aux0}
pout	P_{out}	Algeb	$\tau_{m0}u_e$
wref	ω_{ref}	Algeb	ω_{ref0}
pref	P_{ref}	Algeb	Rq_0
wd	ω_{dev}	Algeb	0
pd	P_d	Algeb	0
dg	dg	Algeb	q_0
h	h	Algeb	1
DB_y	y_{DB}	Algeb	$1.0z_l^{db_{DB}} (\omega_{dev} - db_L) + 1.0z_u^{db_{DB}} (\omega_{dev} - db_U)$
tm	τ_m	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$P_d - y_{LG}$	T_f
gtpos	δ	State	y_{LG}	
LAG_y	y_{LAG}	State	$dg - y_{LAG}$	T_g
q_y	y_q	State	$1 - \frac{y_q^2}{y_{LAG}^2}$	T_w
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
paux	P_{aux}	Algeb	$P_{aux0} - P_{aux}$
pout	P_{out}	Algeb	$-P_{out} + u_e (A_t h (-q_{NL} + y_q) - D_t \omega_{dev} y_{LAG})$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
pref	P_{ref}	Algeb	$-P_{ref} + Rq_0$
wd	ω_{dev}	Algeb	$-\omega_{dev} + u_e (\omega - \omega_{ref})$
pd	P_d	Algeb	$-P_d + u_e (P_{aux} + P_{ref} - Rdg - y_{DB})$
dg	dg	Algeb	$1/ry_{LG} + \delta - dg$
h	h	Algeb	$-h + \frac{y_q^2}{y_{LAG}^2}$
DB_y	y_{DB}	Algeb	$-y_{DB} + 1.0z_l^{db_{DB}} (\omega_{dev} - db_L) + 1.0z_u^{db_{DB}} (\omega_{dev} - db_U)$
tm	τ_m	ExtAlgeb	$u_e (P_{out} - \tau_{m0})$

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
VELMn	$-VELM$	$-VELM$	ConstService
tr	$r * Tr$	$T_r r$	ConstService
gr	$1/r$	$\frac{1}{r}$	ConstService
ratel	$rate_l$	$-1/r - VELM$	ConstService
rateu	$rate_u$	$-1/r + VELM$	ConstService
q0	q_0	$q_{NL} + \frac{\tau_{m0}}{A_t}$	ConstService
dgl	dg_{lower}	$-1/ry_{LG} - VELM$	VarService
dgu	dg_{upper}	$-1/ry_{LG} + VELM$	VarService

Discretes

Name	Symbol	Type	Info
dg_lim	lim_{dg}	AntiWindupRate	gate velocity and position limiter
DB_db	db_{DB}	DeadBand	

Blocks

Name	Symbol	Type	Info
LG	LG	Lag	filter after speed deviation (e)
LAG	LAG	Lag	gate opening (g)
q	q	Integrator	turbine flow (q)
DB	DB	DeadBand1	deadband for speed deviation

Config Fields in [HYGOVDB]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.35.11 HYGOV4

HYGOV4 turbine governor model.

Implements the PSS/E HYGOV4 model with the following ignored:

- input deadband DB1
- valve position deadband DB2
- nonlinear function bewteen GV and P_{GV}

Parameters

Name	Sym- bol	Description	De- fault	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
syn		Synchronous generator idx			manda- tory,unique
Tn	T_n	Turbine power rating. Equal to S_n if not pro- vided.	0	<i>MVA</i>	
wref0	ω_{ref0}	Base speed reference	1	<i>p.u.</i>	
Rperm	R_{perm}	Speed Regulation Gain (mach. base default)	0.500	<i>p.u.</i>	ipower
Rtemp	R_{temp}	Temporary Droop (Rtemp < Rperm)	1	<i>p.u.</i>	ipower
UO	U_O	Maximum Gate opening velocity	1	<i>p.u.</i>	power
UC	U_C	Maximum Gate closing velocity	0	<i>p.u.</i>	power
PMAX	P_{MAX}	Maximum Gate opening	1	<i>p.u.</i>	power
PMIN	P_{MIN}	Minimum Gate opening	0	<i>p.u.</i>	power
Tp	T_p	Pilot servo time constant	0.050		
Tg	T_g	Gate servo time constant	0.050		
Tr	T_r	Dashpot time constant	0.050		
Tw	T_w	Water inertia time constant	1		
At	A_t	Turbine gain	1		
Dturb	D_{turb}	Turbine Damping Factor	0		power
Hdam	H_{dam}	Head available at dam	1		power
qNL	q_{NL}	No-Load flow at nominal head	0.100		power
Sg	S_n	Rated power from generator	0	<i>MVA</i>	
ug	u_g	Generator connection status	0	<i>bool</i>	
Vn	V_n	Rated voltage from generator	0	<i>kV</i>	

Variables

Name	Symbol	Type	Description	Unit	Properties
GATE_y	y_{GATE}	State	AW Integrator output		v_str
WO_x	x'_{WO}	State	State in washout filter		v_str
LAG_y	y_{LAG}	State	State in lag transfer function		v_str
q_y	y_q	State	Integrator output		v_str
omega	ω	ExtState	Generator speed	<i>p.u.</i>	
paux	P_{aux}	Algeb	Auxiliary power input		v_str
pout	P_{out}	Algeb	Turbine final output power		v_str
wref	ω_{ref}	Algeb	Speed reference variable		v_str
pref	P_{ref}	Algeb	Reference power input		v_str
wd	ω_{dev}	Algeb	Generator speed deviation	<i>p.u.</i>	v_str
SV_x	x_{SV}	Algeb	Value before limiter		v_str
SV_y	y_{SV}	Algeb	Output after limiter and post gain		v_str
WO_y	y_{WO}	Algeb	Output of washout filter		v_str
Psum	P_{sum}	Algeb	summation of power input to servo	<i>p.u.</i>	v_str
trhead	$trhead$	Algeb	turbine head	<i>p.u.</i>	v_str
tm	τ_m	ExtAlgeb	Mechanical power interface to SynGen		

Initialization Equations

Name	Symbol	Type	Initial Value
GATE_y	y_{GATE}	State	$\frac{q_0}{H_{dam}^{0.5}}$
WO_x	x'_{WO}	State	y_{GATE}
LAG_y	y_{LAG}	State	P_{sum}
q_y	y_q	State	q_0
omega	ω	ExtState	
paux	P_{aux}	Algeb	P_{aux0}
pout	P_{out}	Algeb	$\tau_m 0 u_e$
wref	ω_{ref}	Algeb	ω_{ref0}
pref	P_{ref}	Algeb	$\frac{R_{perm} q_0}{H_{dam}^{0.5}}$
wd	ω_{dev}	Algeb	0
SV_x	x_{SV}	Algeb	$1/T_g y_{LAG}$
SV_y	y_{SV}	Algeb	$U_C z_l^{lim_{SV}} + U_O z_u^{lim_{SV}} + x_{SV} z_i^{lim_{SV}}$
WO_y	y_{WO}	Algeb	0
Psum	P_{sum}	Algeb	0
trhead	$trhead$	Algeb	H_{dam}
tm	τ_m	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
GATE_y	y_{GATE}	State	y_{SV}	1
WO_x	x'_{WO}	State	$-x'_{WO} + y_{GATE}$	T_r
LAG_y	y_{LAG}	State	$P_{sum} - y_{LAG}$	T_p
q_y	y_q	State	$H_{dam} - trhead$	T_w
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
paux	P_{aux}	Algeb	$P_{aux0} - P_{aux}$
pout	P_{out}	Algeb	$-P_{out} + u_e (A_t trhead (-q_{NL} + y_q) - D_{turb} \omega_{dev} y_{GATE})$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
pref	P_{ref}	Algeb	$\frac{R_{perm} q_0}{H_{dam}^{0.5}} - P_{ref}$
wd	ω_{dev}	Algeb	$-\omega_{dev} + u_e (\omega - \omega_{ref})$
SV_x	x_{SV}	Algeb	$1/T_g y_{LAG} - x_{SV}$
SV_y	y_{SV}	Algeb	$U_C z_l^{lim_{SV}} + U_O z_u^{lim_{SV}} + x_{SV} z_i^{lim_{SV}} - y_{SV}$
WO_y	y_{WO}	Algeb	$R_{temp} * T_r (-x'_{WO} + y_{GATE}) - T_r y_{WO}$
Psum	P_{sum}	Algeb	$-P_{sum} + u_e (P_{aux} + P_{ref} - R_{perm} y_{GATE} - \omega_{dev} - y_{WO})$
trhead	$trhead$	Algeb	$-trhead + \frac{y_q^2}{y_{GATE}^2}$
tm	τ_m	ExtAlgeb	$u_e (P_{out} - \tau_{m0})$

Services

Name	Symbol	Equation	Type
ue	u_e	uu_g	ConstService
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
iTg	$1/T_g$	$\frac{u}{T_g}$	ConstService
R	$R_{temp} + R_{perm}$	$R_{perm} + R_{temp}$	ConstService
TrRtemp	$R_{temp} * T_r$	$R_{temp} T_r$	ConstService
q0	q_0	$q_{NL} + \frac{\tau_{m0}}{A_t H_{dam}}$	ConstService

Discretes

Name	Symbol	Type	Info
SV_lim	lim_{SV}	HardLimiter	
GATE_lim	lim_{GATE}	AntiWindup	Limiter in integrator

Blocks

Name	Symbol	Type	Info
SV	SV	GainLimiter	servo gain and limiters
GATE	$GATE$	IntegratorAntiWindup	Gate position
WO	WO	Washout	Washout feedback with T_r
LAG	LAG	Lag	lag block with T_p, outputs velocity
q	q	Integrator	turbine flow (q)

Config Fields in [HYGOV4]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

5.36 Undefined

The undefined group. Holds models with no group.

Common Parameters: u, name

5.37 VoltComp

Voltage compensator group for synchronous generators.

Common Parameters: u, name, rc, xc

Common Variables: vcomp

Available models: *IEEEVC*

5.37.1 IEEEVC

Voltage compensator IEEEVC model.

Reference:

[1] PowerWorld, Voltage Compensator, IEEEVC, [Online],

[2] NEPLAN, Exciters Models, [Online],

Available:

https://www.powerworld.com/WebHelp/Content/TransientModels_HTML/Voltage%20Compensator%20IEEEVC.htm?TocPath=%7C%7C%7CIEEEVC%7C____0

https://www.neplan.ch/wp-content/uploads/2015/08/Nep_EXCITERS1.pdf

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	<i>bool</i>	
name		device name			
avr		Exciter idx			mandatory
rc	r_c	Active compensation degree.	0		z
xc	x_c	Reactive compensation degree.	0		z
syn		Retrieved generator idx	0		

Variables

Name	Symbol	Type	Description	Unit	Properties
vcomp	v_{comp}	Algeb	Compensator output voltage to exciter		v_str
v	V	ExtAlgeb	Retrieved bus terminal voltage		
vd	V_d	ExtAlgeb	d-axis machine voltage		
vq	V_q	ExtAlgeb	q-axis machine voltage		
Id	I_d	ExtAlgeb	d-axis machine current		
Iq	I_q	ExtAlgeb	q-axis machine current		
Eterm	E_{term}	ExtAlgeb			v_str

Initialization Equations

Name	Symbol	Type	Initial Value
vcomp	v_{comp}	Algeb	$-Vu + V_{CT}$
v	V	ExtAlgeb	
vd	V_d	ExtAlgeb	
vq	V_q	ExtAlgeb	
Id	I_d	ExtAlgeb	
Iq	I_q	ExtAlgeb	
Eterm	$Eterm$	ExtAlgeb	v_{comp}

Algebraic Equations

Name	Symbol	Type	RHS of Equation " $0 = g(x, y)$ "
vcomp	v_{comp}	Algeb	$-Vu + V_{CT} - v_{comp}$
v	V	ExtAlgeb	0
vd	V_d	ExtAlgeb	0
vq	V_q	ExtAlgeb	0
Id	I_d	ExtAlgeb	0
Iq	I_q	ExtAlgeb	0
Eterm	$Eterm$	ExtAlgeb	v_{comp}

Services

Name	Symbol	Equation	Type
vct	V_{CT}	$u V_d + iV_q + (I_d + iI_q)(r_c + ix_c) $	VarService

Config Fields in [IEEEVC]

Option	Symbol	Value	Info	Accepted values
allow_adjust		1	allow adjusting upper or lower limits	(0, 1)
adjust_lower		0	adjust lower limit	(0, 1)
adjust_upper		1	adjust upper limit	(0, 1)

API REFERENCE

6.1 System

<code>andes.system</code>	System class for power system data and methods
<code>andes.variables</code>	Variable package with classes for numerical DAE.

6.1.1 andes.system

System class for power system data and methods

Functions

<code>example([setup, no_output])</code>	Return an <code>andes.system.System</code> object for the <code>ieee14_linetrip.xlsx</code> as an example.
<code>fix_view_arrays(system)</code>	Point NumPy arrays without OWNDATA (termed "view arrays" here) to the source array.
<code>import_pycode([user_pycode_path])</code>	Helper function to import generated pycode in the following priority:
<code>load_config_rc([conf_path])</code>	Load config from an rc-formatted file.
<code>reload_submodules(module_name)</code>	Helper function for reloading an existing module and its submodules.

example

`andes.system.example (setup=True, no_output=True, **kwargs)`

Return an `andes.system.System` object for the `ieee14_linetrip.xlsx` as an example.

This function is useful when a user wants to quickly get a System object for testing.

Returns

System

An example `andes.system.System` object.

fix_view_arrays

`andes.system.fix_view_arrays(system)`

Point NumPy arrays without OWNDATA (termed "view arrays" here) to the source array.

This function properly sets `v` and `e` arrays of internal variables as views of the corresponding DAE arrays.

Inputs will be refreshed for each model.

Parameters**system**

[`andes.system.System`] System object to be fixed

import_pycode

`andes.system.import_pycode(user_pycode_path=None)`

Helper function to import generated pycode in the following priority:

1. a user-provided path from CLI. Currently, this is only for specifying the path to store the generated pycode via `andes prepare`.
2. `~/ .andes/pycode`. This is where pycode is stored by default.
3. `<andes_package_root>/pycode`. One can store pycode in the ANDES package folder and ship a full package, which does not require code generation.

load_config_rc

`andes.system.load_config_rc(conf_path=None)`

Load config from an rc-formatted file.

Parameters**conf_path**

[None or str] Path to the config file. If is *None*, the function body will not run.

Returns

`configparse.ConfigParser`

reload_submodules

`andes.system.reload_submodules (module_name)`

Helper function for reloading an existing module and its submodules.

It is used to reload the `pycode` module after regenerating code.

Classes

<code>ExistingModels()</code>	Storage class for existing models
<code>System([case, name, config, config_path, ...])</code>	System contains models and routines for modeling and simulation.

andes.system.ExistingModels

class `andes.system.ExistingModels`

Storage class for existing models

`__init__()`

Methods

andes.system.System

class `andes.system.System` (*case: str | None = None, name: str | None = None, config: Dict | None = None, config_path: str | None = None, default_config: bool | None = False, options: Dict | None = None, no_undill: bool | None = False, autogen_stale: bool | None = True, **kwargs*)

System contains models and routines for modeling and simulation.

System contains a several special *OrderedDict* member attributes for housekeeping. These attributes include *models*, *groups*, *routines* and *calls* for loaded models, groups, analysis routines, and generated numerical function calls, respectively.

Parameters

no_undill

[bool, optional, default=False] True to disable the call to `System.undill()` at the end of object creation. False by default.

autogen_stale

[bool, optional, default=True] True to automatically generate code for stale models.

Notes

System stores model and routine instances as attributes. Model and routine attribute names are the same as their class names. For example, *Bus* is stored at `system.Bus`, the power flow calculation routine is at `system.PFlow`, and the numerical DAE instance is at `system.dae`. See attributes for the list of attributes.

Attributes

dae

[andes.variables.dae.DAE] Numerical DAE storage

files

[andes.variables.fileman.FileMan] File path storage

config

[andes.core.Config] System config storage

models

[OrderedDict] model name and instance pairs

groups

[OrderedDict] group name and instance pairs

routines

[OrderedDict] routine name and instance pairs

__init__ (*case: str | None = None, name: str | None = None, config: Dict | None = None, config_path: str | None = None, default_config: bool | None = False, options: Dict | None = None, no_undill: bool | None = False, autogen_stale: bool | None = True, **kwargs*)

Methods

<code>add(model[, param_dict])</code>	Add a device instance for an existing model.
<code>as_dict([vin, skip_empty])</code>	Return system data as a dict where the keys are model names and values are dicts.
<code>calc_pu_coeff()</code>	Perform per unit value conversion.
<code>call_models(method, models, *args, **kwargs)</code>	Call methods on the given models.
<code>collect_config()</code>	Collect config data from models.
<code>collect_ref()</code>	Collect indices into <i>BackRef</i> for all models.
<code>connectivity([info])</code>	Perform connectivity check for system.
<code>e_clear(models)</code>	Clear equation arrays in DAE and model variables.
<code>f_update(models)</code>	Call the differential equation update method for models in sequence.
<code>fg_to_dae()</code>	Collect equation values into the DAE arrays.
<code>find_devices()</code>	Add dependent devices for all model based on <i>DeviceFinder</i> .

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Table 1 – continued from previous page

<code>find_models(flag[, skip_zero])</code>	Find models with at least one of the flags as True.
<code>from_ipysheet(model, sheet[, vin])</code>	Set an ipysheet object back to model.
<code>g_islands()</code>	Reset algebraic mismatches for islanded buses.
<code>g_update(models)</code>	Call the algebraic equation update method for models in sequence.
<code>get_z(models)</code>	Get all discrete status flags in a numpy array.
<code>import_groups()</code>	Import all groups classes defined in <code>models/group.py</code> .
<code>import_models()</code>	Import and instantiate models as System member attributes.
<code>import_routines()</code>	Import routines as defined in <code>routines/__init__.py</code> .
<code>init(models, routine)</code>	Initialize the variables for each of the specified models.
<code>j_islands()</code>	Set gy diagonals to eps for <i>a</i> and <i>v</i> variables of islanded buses.
<code>j_update(models[, info])</code>	Call the Jacobian update method for models in sequence.
<code>l_update_eq(models[, init, niter])</code>	Update equation-dependent limiter discrete components by calling <code>l_check_eq</code> of models.
<code>l_update_var(models[, niter, err])</code>	Update variable-based limiter discrete states by calling <code>l_update_var</code> of models.
<code>link_ext_param([model])</code>	Retrieve values for <code>ExtParam</code> for the given models.
<code>precompile([models, nomp, ncpu])</code>	Trigger precompilation for the given models.
<code>prepare([quick, incremental, models, nomp, ncpu])</code>	Generate numerical functions from symbolically defined models.
<code>reload(case, **kwargs)</code>	Reload a new case in the same System object.
<code>remove_pycapsule()</code>	Remove PyCapsule objects in solvers.
<code>reset([force])</code>	Reset to the state after reading data and setup (before power flow).
<code>s_update_post(models)</code>	Update variable services by calling <code>s_update_post</code> of models.
<code>s_update_var(models)</code>	Update variable services by calling <code>s_update_var</code> of models.
<code>save_config([file_path, overwrite])</code>	Save all system, model, and routine configurations to an rc-formatted file.
<code>set_address(models)</code>	Set addresses for differential and algebraic variables.
<code>set_config([config])</code>	Set configuration for the System object.
<code>set_dae_names(models)</code>	Set variable names for differential and algebraic variables, right-hand side of external equations, and discrete flags.
<code>set_output_subidx(models)</code>	Process <code>andes.models.misc.Output</code> data and store the sub-indices into <code>dae.xy</code> .

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Table 1 – continued from previous page

<code>set_var_arrays(models[, inplace, alloc])</code>	Set arrays (v and e) for internal variables to access dae arrays in place.
<code>setup()</code>	Set up system for studies.
<code>store_adder_setter(models)</code>	Store non-inplace adders and setters for variables and equations.
<code>store_existing()</code>	Store existing models in <i>System.existing</i> .
<code>store_no_check_init(models)</code>	Store differential variables with <code>check_init == False</code> .
<code>store_sparse_pattern(models)</code>	Collect and store the sparsity pattern of Jacobian matrices.
<code>store_switch_times(models[, eps])</code>	Store event switching time in a sorted Numpy array in <i>System.switch_times</i> and an <i>OrderedDict</i> <i>System.switch_dict</i> .
<code>summary()</code>	Print out system summary.
<code>supported_models([export])</code>	Return the support group names and model names in a table.
<code>switch_action(models)</code>	Invoke the actions associated with switch times.
<code>to_ipysheet(model[, vin])</code>	Return an ipysheet object for editing in Jupyter Notebook.
<code>undill([autogen_stale])</code>	Reload generated function functions, from either the <code>\$HOME/.andes/pycode</code> folder.
<code>vars_to_dae(model)</code>	Copy variables values from models to <i>System.dae</i> .
<code>vars_to_models()</code>	Copy variable values from <i>System.dae</i> to models.

System.add

`System.add(model, param_dict=None, **kwargs)`

Add a device instance for an existing model.

This methods calls the `add` method of *model* and registers the device *idx* to group.

System.as_dict

`System.as_dict(vin=False, skip_empty=True)`

Return system data as a dict where the keys are model names and values are dicts. Each dict has parameter names as keys and corresponding data in an array as values.

Returns

OrderedDict

System.calc_pu_coeff

`System.calc_pu_coeff()`

Perform per unit value conversion.

This function calculates the per unit conversion factors, stores input parameters to *vin*, and perform the conversion.

System.call_models

`System.call_models (method: str, models: OrderedDict, *args, **kwargs)`

Call methods on the given models.

Parameters

method

[str] Name of the model method to be called

models

[OrderedDict, list, str] Models on which the method will be called

args

Positional arguments to be passed to the model method

kwargs

Keyword arguments to be passed to the model method

Returns

The return value of the models in an *OrderedDict*

System.collect_config

`System.collect_config()`

Collect config data from models.

Returns

dict

a dict containing the config from devices; class names are keys and configs in a dict are values.

System.collect_ref

`System.collect_ref()`

Collect indices into *BackRef* for all models.

System.connectivity

`System.connectivity (info=True)`

Perform connectivity check for system.

Parameters

info

[bool] True to log connectivity summary.

System.e_clear

`System.e_clear (models: OrderedDict)`

Clear equation arrays in DAE and model variables.

This step must be called before calling *f_update* or *g_update* to flush existing values.

System.f_update

`System.f_update (models: OrderedDict)`

Call the differential equation update method for models in sequence.

Notes

Updated equation values remain in models and have not been collected into DAE at the end of this step.

System.fg_to_dae

`System.fg_to_dae()`

Collect equation values into the DAE arrays.

Additionally, the function resets the differential equations associated with variables pegged by anti-windup limiters.

System.find_devices

`System.find_devices()`

Add dependent devices for all model based on *DeviceFinder*.

System.find_models

`System.find_models(flag: str | Tuple | None, skip_zero: bool = True)`

Find models with at least one of the flags as True.

Parameters

flag

[list, str] Flags to find

skip_zero

[bool] Skip models with zero devices

Returns

OrderedDict

model name : model instance

Warning: Checking the number of devices has been centralized into this function. `models` passed to most `System` calls must be retrieved from here.

System.from_ipysheet

`System.from_ipysheet(model: str, sheet, vin: bool = False)`

Set an ipysheet object back to model.

System.g_islands

`System.g_islands()`

Reset algebraic mismatches for islanded buses.

System.g_update

`System.g_update` (*models*: *OrderedDict*)

Call the algebraic equation update method for models in sequence.

Notes

Like *f_update*, updated values have not collected into DAE at the end of the step.

System.get_z

`System.get_z` (*models*: *OrderedDict*)

Get all discrete status flags in a numpy array. Values are written to `dae.z` in place.

Returns

numpy.array

System.import_groups

`System.import_groups` ()

Import all groups classes defined in `models/group.py`.

Groups will be stored as instances with the name as class names. All groups will be stored to dictionary `System.groups`.

System.import_models

`System.import_models` ()

Import and instantiate models as System member attributes.

Models defined in `models/__init__.py` will be instantiated *sequentially* as attributes with the same name as the class name. In addition, all models will be stored in dictionary `System.models` with model names as keys and the corresponding instances as values.

Examples

`system.Bus` stores the *Bus* object, and `system.GENCLS` stores the classical generator object, `system.models['Bus ']` points the same instance as `system.Bus`.

System.import_routines

`System.import_routines()`

Import routines as defined in `routines/__init__.py`.

Routines will be stored as instances with the name as class names. All routines will be stored to dictionary `System.routines`.

Examples

`System.PFlow` is the power flow routine instance, and `System.TDS` and `System.EIG` are time-domain analysis and eigenvalue analysis routines, respectively.

System.init

`System.init(models: OrderedDict, routine: str)`

Initialize the variables for each of the specified models.

For each model, the initialization procedure is:

- Get values for all *ExtService*.
- Call the model *init()* method, which initializes internal variables.
- Copy variables to DAE and then back to the model.

System.j_islands

`System.j_islands()`

Set gy diagonals to eps for *a* and *v* variables of islanded buses.

System.j_update

`System.j_update(models: OrderedDict, info=None)`

Call the Jacobian update method for models in sequence.

The procedure is - Restore the sparsity pattern with `andes.variables.dae.DAE.restore_sparse()` - For each sparse matrix in (fx, fy, gx, gy), evaluate the Jacobian function calls and add values.

Notes

Updated Jacobians are immediately reflected in the DAE sparse matrices (fx, fy, gx, gy).

System.l_update_eq

`System.l_update_eq` (*models: OrderedDict, init=False, niter=0*)

Update equation-dependent limiter discrete components by calling `l_check_eq` of models. Force set equations after evaluating equations.

This function is must be called after differential equation updates.

System.l_update_var

`System.l_update_var` (*models: OrderedDict, niter=0, err=None*)

Update variable-based limiter discrete states by calling `l_update_var` of models.

This function is must be called before any equation evaluation.

System.link_ext_param

`System.link_ext_param` (*model=None*)

Retrieve values for `ExtParam` for the given models.

System.precompile

`System.precompile` (*models: OrderedDict | None = None, nomp: bool = False, ncpu: int = 1*)

Trigger precompilation for the given models.

Arguments are the same as `prepare`.

System.prepare

`System.prepare` (*quick=False, incremental=False, models=None, nomp=False, ncpu=1*)

Generate numerical functions from symbolically defined models.

All procedures in this function must be independent of test case.

Parameters

quick

[bool, optional] True to skip pretty-print generation to reduce code generation time.

incremental

[bool, optional] True to generate only for modified models, incrementally.

models

[list, OrderedDict, None] List or OrderedDict of models to prepare

nomp

[bool] True to disable multiprocessing

Warning: Generated lambda functions will be serialized to file, but pretty prints (SymPy objects) can only exist in the System instance on which prepare is called.

Notes

Option `incremental` compares the md5 checksum of all var and service strings, and only re-generate for updated models.

Examples

If one needs to print out LaTeX-formatted equations in a Jupyter Notebook, one need to generate such equations with

```
import andes
sys = andes.prepare()
```

Alternatively, one can explicitly create a System and generate the code

```
import andes
sys = andes.System()
sys.prepare()
```

System.reload

`System.reload(case, **kwargs)`

Reload a new case in the same System object.

System.remove_pycapsule

`System.remove_pycapsule()`

Remove PyCapsule objects in solvers.

System.reset

`System.reset` (*force=False*)

Reset to the state after reading data and setup (before power flow).

Warning: If TDS is initialized, reset will lead to unpredictable state.

System.s_update_post

`System.s_update_post` (*models: OrderedDict*)

Update variable services by calling `s_update_post` of models.

This function is called at the end of `System.init()`.

System.s_update_var

`System.s_update_var` (*models: OrderedDict*)

Update variable services by calling `s_update_var` of models.

This function is must be called before any equation evaluation after limiter update function `l_update_var`.

System.save_config

`System.save_config` (*file_path=None, overwrite=False*)

Save all system, model, and routine configurations to an rc-formatted file.

Parameters

file_path

[str, optional] path to the configuration file default to `~/andes/andes.rc`.

overwrite

[bool, optional] If file exists, True to overwrite without confirmation. Otherwise prompt for confirmation.

Warning: Saved config is loaded back and populated *at system instance creation time*. Configs from the config file takes precedence over default config values.

System.set_address

`System.set_address (models)`

Set addresses for differential and algebraic variables.

System.set_config

`System.set_config (config=None)`

Set configuration for the System object.

Config for models are routines are passed directly to their constructors.

System.set_dae_names

`System.set_dae_names (models)`

Set variable names for differential and algebraic variables, right-hand side of external equations, and discrete flags.

System.set_output_subidx

`System.set_output_subidx (models)`

Process `andes.models.misc.Output` data and store the sub-indices into `dae.xy`.

Parameters

models

[OrderedDict] Models currently in use for the routine

System.set_var_arrays

`System.set_var_arrays (models, inplace=True, alloc=True)`

Set arrays (*v* and *e*) for internal variables to access dae arrays in place.

This function needs to be called after de-serializing a System object, where the internal variables are incorrectly assigned new memory.

Parameters

models

[OrderedDict, list, Model, optional] Models to execute.

inplace

[bool] True to retrieve arrays that share memory with dae

alloc

[bool] True to allocate for arrays internally

System.setup

`System.setup()`

Set up system for studies.

This function is to be called after adding all device data.

System.store_adder_setter

`System.store_adder_setter(models)`

Store non-inplace adders and setters for variables and equations.

System.store_existing

`System.store_existing()`

Store existing models in *System.existing*.

TODO: Models with *TimerParam* will need to be stored anyway. This will allow adding switches on the fly.

System.store_no_check_init

`System.store_no_check_init(models)`

Store differential variables with `check_init == False`.

System.store_sparse_pattern

`System.store_sparse_pattern(models: OrderedDict)`

Collect and store the sparsity pattern of Jacobian matrices.

This is a runtime function specific to cases.

Notes

For gy matrix, always make sure the diagonal is reserved. It is a safeguard if the modeling user omitted the diagonal term in the equations.

System.store_switch_times

`System.store_switch_times (models, eps=0.0001)`

Store event switching time in a sorted Numpy array in `System.switch_times` and an `OrderedDict` `System.switch_dict`.

`System.switch_dict` has keys as event times and values as the `OrderedDict` of model names and instances associated with the event.

Parameters

models

[`OrderedDict`] model name : model instance

eps

[float] The small time step size to use immediately before and after the event

Returns

array-like

`self.switch_times`

System.summary

`System.summary ()`

Print out system summary.

System.supported_models

`System.supported_models (export='plain')`

Return the support group names and model names in a table.

Returns

str

A table-formatted string for the groups and models

System.switch_action

`System.switch_action (models: OrderedDict)`

Invoke the actions associated with switch times.

This function will not be called if `flat=True` is passed to system.

System.to_ipysheet

`System.to_ipysheet` (*model: str, vin: bool = False*)

Return an ipysheet object for editing in Jupyter Notebook.

System.undill

`System.undill` (*autogen_stale=True*)

Reload generated function functions, from either the `$HOME/.andes/pycode` folder.

If no change is made to models, future calls to `prepare()` can be replaced with `undill()` for acceleration.

Parameters

autogen_stale: bool

True to automatically call code generation if stale code is detected. Regardless of this option, codegen is trigger if importing existing code fails.

System.vars_to_dae

`System.vars_to_dae` (*model*)

Copy variables values from models to *System.dae*.

This function clears *DAE.x* and *DAE.y* and collects values from models.

System.vars_to_models

`System.vars_to_models` ()

Copy variable values from *System.dae* to models.

6.1.2 andes.variables

Variable package with classes for numerical DAE.

Modules

```
andes.variables.dae
```

```
andes.variables.fileman
```

```
andes.variables.report
```

andes.variables.dae**Classes**

<code>DAE(system)</code>	Class for storing numerical values of the DAE system, including variables, equations and first order derivatives (Jacobian matrices).
<code>DAETimeSeries([dae])</code>	DAE time series data.

andes.variables.dae.DAE

class `andes.variables.dae.DAE` (*system*)

Class for storing numerical values of the DAE system, including variables, equations and first order derivatives (Jacobian matrices).

Variable values and equation values are stored as `numpy.ndarray`, while Jacobians are stored as `kvxopt.spmatrix`. The defined arrays and descriptions are as follows:

DAE Array	Description
<code>x</code>	Array for state variable values
<code>y</code>	Array for algebraic variable values
<code>z</code>	Array for 0/1 limiter states (if enabled)
<code>f</code>	Array for differential equation derivatives
<code>Tf</code>	Left-hand side time constant array for <code>f</code>
<code>g</code>	Array for algebraic equation mismatches

The defined scalar member attributes to store array sizes are

Scalar	Description
<code>m</code>	The number of algebraic variables/equations
<code>n</code>	The number of algebraic variables/equations
<code>o</code>	The number of limiter state flags

The derivatives of f and g with respect to x and y are stored in four `kvxopt.spmatrix` sparse matrices: **fx**, **fy**, **gx**, and **gy**, where the first letter is the equation name, and the second letter is the variable name.

Notes

DAE in ANDES is defined in the form of

$$\begin{aligned}T\dot{x} &= f(x, y) \\ 0 &= g(x, y)\end{aligned}$$

DAE does not keep track of the association of variable and address. Only a variable instance keeps track of its addresses.

`__init__` (*system*)

Methods

<code>alloc_or_extend_names()</code>	Allocate empty lists for names for the given size.
<code>build_pattern(name)</code>	Build sparse matrices with stored patterns.
<code>clear_arrays()</code>	Reset equation and variable arrays to empty.
<code>clear_fg()</code>	Resets equation arrays to empty.
<code>clear_ijv()</code>	Clear stored triplets.
<code>clear_ts()</code>	Drop the TimeSeries data and create a new one.
<code>clear_xy()</code>	Reset variable arrays to empty.
<code>clear_z()</code>	Reset status arrays to empty
<code>get_name(arr)</code>	Helper function for getting the list of variable names based on the array name.
<code>get_size(name)</code>	Get the size of an array or sparse matrix based on name.
<code>print_array(name[, values, tol])</code>	Debug helper to print array values and names.
<code>request_address(array_name, ndevice, nvar[, ...])</code>	Interface for requesting addresses for a model.
<code>reset()</code>	Reset array sizes to zero and clear all arrays.
<code>resize_arrays()</code>	Resize arrays to the new sizes <i>m</i> and <i>n</i> , and <i>o</i> .
<code>restore_sparse([names])</code>	Restore all sparse matrices to the sparsity pattern filled with zeros (for variable Jacobian elements) and non-zero constants.
<code>set_t(t)</code>	Helper function for setting time in-place.
<code>store()</code>	Store values for the current time step to the Time-Series storage.
<code>store_sparse_ijv(name, row, col, val)</code>	Store the sparse pattern triplets.
<code>write_lst(lst_path)</code>	Dump the variable name lst file.
<code>write_npy(file_path)</code>	Write TDS data into NumPy uncompressed format.
<code>write_npz(file_path)</code>	Write TDS data into NumPy compressed format.

DAE.alloc_or_extend_names

DAE.alloc_or_extend_names()

Allocate empty lists for names for the given size.

DAE.build_pattern

DAE.build_pattern(*name*)

Build sparse matrices with stored patterns.

Call to *store_row_col_idx* should be made before this function.

Parameters

name

[name] jac name

DAE.clear_arrays

DAE.clear_arrays()

Reset equation and variable arrays to empty.

DAE.clear_fg

DAE.clear_fg()

Resets equation arrays to empty.

DAE.clear_ijv

DAE.clear_ijv()

Clear stored triplets.

DAE.clear_ts

DAE.clear_ts()

Drop the TimeSeries data and create a new one.

DAE.clear_xy**DAE.clear_xy()**

Reset variable arrays to empty.

DAE.clear_z**DAE.clear_z()**

Reset status arrays to empty

DAE.get_name**DAE.get_name(arr)**

Helper function for getting the list of variable names based on the array name.

Parameters**arr**

[str] Array name in 'f', 'g', 'x', 'y', 'z'.

DAE.get_size**DAE.get_size(name)**

Get the size of an array or sparse matrix based on name.

Parameters**name**

[str (f, g, fx, gy, etc.)] array/sparse name

Returns**tuple**

sizes of each element in a tuple

DAE.print_array**DAE.print_array(name, values=None, tol=None)**

Debug helper to print array values and names.

Parameters**name**

[str] array name in 'f', 'g', 'x', 'y'

values

[array-like, optional] substitute array values to use

tol[float, optional] tolerance value to use. Values below *tol* will not be displayed**DAE.request_address****DAE.request_address** (*array_name: str, ndevice, nvar, collate=False*)

Interface for requesting addresses for a model.

Parameters**array_name**

[str] array name in 'x' and 'y'

ndevice

[int] number of devices

nvar

[int] number of variables

collate[bool, optional] False if the same variable for different devices are contiguous. True if variables for the same devices should collate. Note: setting *collate* to True will degrade the performance.**Returns****list**

A list of arrays for each variable.

DAE.reset**DAE.reset** ()

Reset array sizes to zero and clear all arrays.

DAE.resize_arrays**DAE.resize_arrays** ()Resize arrays to the new sizes *m* and *n*, and *o*.If `m > len(self.y)` or `n > len(self.x)`, arrays will be extended. Otherwise, new empty arrays will be sliced, starting from 0 to the given size.

Warning: This function should not be called directly. Instead, it is called in `System.set_address` which re-points variables used in power flow to the new array for dynamic analyses.

DAE.restore_sparse

DAE.**restore_sparse** (*names=None*)

Restore all sparse matrices to the sparsity pattern filled with zeros (for variable Jacobian elements) and non-zero constants.

Parameters

names

[None or list] List of Jacobian names to restore sparsity pattern

DAE.set_t

DAE.**set_t** (*t*)

Helper function for setting time in-place.

DAE.store

DAE.**store** ()

Store values for the current time step to the TimeSeries storage. Values include variables, equation RHS and discrete states.

DAE.store_sparse_ijv

DAE.**store_sparse_ijv** (*name, row, col, val*)

Store the sparse pattern triplets.

This function is to be called by System after building the complete sparsity pattern for each Jacobian matrix.

Parameters

name

[str] sparse Jacobian matrix name

row

[np.ndarray] all row indices

col

[np.ndarray] all col indices

val

[np.ndarray] all values

DAE.write_lst

`DAE.write_lst` (*lst_path*)

Dump the variable name lst file.

Parameters

lst_path

Path to the lst file.

Returns

bool

succeed flag

DAE.write_npy

`DAE.write_npy` (*file_path*)

Write TDS data into NumPy uncompressed format.

DAE.write_npz

`DAE.write_npz` (*file_path*)

Write TDS data into NumPy compressed format.

The function supports writing out all values at once or writing them out incrementally.

Attributes

<i>fg</i>	Return a concatenated array of [f, g].
<i>x_name_output</i>	Return a list of state var names selected by Output.
<i>x_tex_name_output</i>	Return a list of state var LaTeX names selected by Output.
<i>xy</i>	Return a concatenated array of [x, y].
<i>xy_name</i>	Return a concatenated list of all variable names without format.
<i>xy_tex_name</i>	Return a concatenated list of all variable names in LaTeX format.
<i>xyz</i>	Return a concatenated array of [x, y].
<i>xyz_name</i>	Return a concatenated list of all variable names without format.
<i>xyz_tex_name</i>	Return a concatenated list of all variable names in LaTeX format.
<i>y_name_output</i>	Return a list of algeb var names selected by Output.
<i>y_tex_name_output</i>	Return a list of algeb var LaTeX names selected by Output.

DAE.fg

property `DAE.fg`

Return a concatenated array of [f, g].

DAE.x_name_output

property `DAE.x_name_output`

Return a list of state var names selected by Output.

DAE.x_tex_name_output

property `DAE.x_tex_name_output`

Return a list of state var LaTeX names selected by Output.

DAE.xy

property DAE.**xy**

Return a concatenated array of [x, y].

DAE.xy_name

property DAE.**xy_name**

Return a concatenated list of all variable names without format.

DAE.xy_tex_name

property DAE.**xy_tex_name**

Return a concatenated list of all variable names in LaTeX format.

DAE.xyz

property DAE.**xyz**

Return a concatenated array of [x, y].

DAE.xyz_name

property DAE.**xyz_name**

Return a concatenated list of all variable names without format.

DAE.xyz_tex_name

property DAE.**xyz_tex_name**

Return a concatenated list of all variable names in LaTeX format.

DAE.y_name_output

property DAE.**y_name_output**

Return a list of algeb var names selected by Output.

DAE.y_tex_name_output

property DAE.y_tex_name_output

Return a list of algeb var LaTeX names selected by Output.

andes.variables.dae.DAETimeSeries

class andes.variables.dae.DAETimeSeries (*dae=None*)

DAE time series data.

__init__ (*dae=None*)

Methods

<code>get_data</code> (base_vars, *[a, rhs])	Get time-series data, either for a variable or for the equation associated with the variable.
<code>reset</code> ()	Reset the internal storage and erase all data.
<code>unpack</code> ([df, attr, warn_empty])	Unpack dict-stored data into arrays and/or dataframes.
<code>unpack_df</code> (attr)	Construct pandas dataframes.
<code>unpack_np</code> (attr[, warn_empty])	Unpack dict data into numpy arrays.

DAETimeSeries.get_data

DAETimeSeries.**get_data** (*base_vars: BaseVar | List[BaseVar], *, a=None, rhs: bool = False*)

Get time-series data, either for a variable or for the equation associated with the variable.

Parameters

base_var

[BaseVar or a sequence of BaseVar(s)] The variable types and internal addresses are used for looking up the data.

a

[an array/list of int or None] Sub-indices into the address of *base_var*. Applied to each variable.

Returns

np.ndarray

A two-dimensional array. Each row corresponds to one time step. Each column corresponds to a different different variable.

DAETimeSeries.reset`DAETimeSeries.reset()`

Reset the internal storage and erase all data.

DAETimeSeries.unpack`DAETimeSeries.unpack(df=False, attr=None, warn_empty=True)`

Unpack dict-stored data into arrays and/or dataframes.

Parameters**df**

[bool] True to construct DataFrames *self.df* and *self.df_z* (time-consuming).

attr

[str, optional] Attribute name to unpack. If None, unpack all.

Returns

True when done.

DAETimeSeries.unpack_df`DAETimeSeries.unpack_df(attr)`

Construct pandas dataframes.

DAETimeSeries.unpack_np`DAETimeSeries.unpack_np(attr, warn_empty=True)`

Unpack dict data into numpy arrays.

Attributes*df*

Short-hand for the xy dataframe.

DAETimeTypeSeries.df

property DAETimeTypeSeries.df

Short-hand for the xy dataframe.

andes.variables.fileman

Functions

<code>add_suffix(fullname, suffix)</code>	Add suffix to a full file name.
---	---------------------------------

add_suffix

andes.variables.fileman.add_suffix(*fullname, suffix*)

Add suffix to a full file name.

Classes

<code>FileMan([case])</code>	Define a File Manager class for System
------------------------------	--

andes.variables.fileman.FileMan

class andes.variables.fileman.FileMan(*case=None, **kwargs*)

Define a File Manager class for System

__init__(*case=None, **kwargs*)

Initialize the output file names. For inputs, all absolute paths will be respected. All relative paths are relative to *input_path*.

case: must be full path to case

output: desired name for format conversion output

input_path: default path for input files that only contains file name. If *input_path* is not provided,

it will be derived from the path of *case*.

output_path: path for output files. Default to current working directory where *andes* is invoked.

Methods

<code>get_fullpath([fullname])</code>	Return the original full path if full path is specified, otherwise search in the case file path.
<code>set([case])</code>	Perform the input and output set up.

FileMan.get_fullpath

`FileMan.get_fullpath (fullname=None)`

Return the original full path if full path is specified, otherwise search in the case file path.

Parameters

fullname

[str, optional] Full name of the file. If relative, prepend *input_path*. Otherwise, leave it as is.

FileMan.set

`FileMan.set (case=None, **kwargs)`

Perform the input and output set up.

andes.variables.report

Functions

```
report_info(system)
```

report_info

`andes.variables.report.report_info (system)`

Classes

<code>Report(system)</code>	Report class to store system static analysis reports
-----------------------------	--

`andes.variables.report.Report`

class `andes.variables.report.Report` (*system*)

Report class to store system static analysis reports

`__init__` (*system*)

Methods

<code>update()</code>	Update values based on the requested content
<code>write()</code>	Write report to file.

`Report.update`

`Report.update()`

Update values based on the requested content

`Report.write`

`Report.write()`

Write report to file.

Attributes

<code>info</code>

Report.info

property `Report.info`

6.2 Routines

andes.routines

Package for ANDES analysis routines.

6.2.1 andes.routines

Package for ANDES analysis routines.

Modules

andes.routines.base

Base class for ANDES calculation routines.

andes.routines.criteria

Stability criteria module.

andes.routines.daeint

Integration methods for DAE.

andes.routines.eig

Module for eigenvalue analysis.

andes.routines.pflow

Module for power flow calculation.

andes.routines.tds

ANDES module for time-domain simulation.

andes.routines.base

Base class for ANDES calculation routines.

Classes

BaseRoutine([system, config])

Base routine class.

andes.routines.base.BaseRoutine

class `andes.routines.base.BaseRoutine` (*system=None, config=None*)

Base routine class.

Provides references to system, config, and solver.

__init__ (*system=None, config=None*)

Methods

<code>doc([max_width, export])</code>	Routine documentation interface.
<code>init()</code>	Routine initialization interface.
<code>report(**kwargs)</code>	Report interface.
<code>run(**kwargs)</code>	Routine main entry point.
<code>summary(**kwargs)</code>	Summary interface

BaseRoutine.doc

`BaseRoutine.doc (max_width=78, export='plain')`
Routine documentation interface.

BaseRoutine.init

`BaseRoutine.init()`
Routine initialization interface.

BaseRoutine.report

`BaseRoutine.report (**kwargs)`
Report interface.

BaseRoutine.run

`BaseRoutine.run (**kwargs)`
Routine main entry point.

BaseRoutine.summary

`BaseRoutine.summary (**kwargs)`
Summary interface

Attributes

<i>class_name</i>

BaseRoutine.class_name

property BaseRoutine.class_name

andes.routines.criteria

Stability criteria module.

Functions

<i>deltadelta</i> (delta, diff_limit)	Test if a system is stable by comparing the maximum rotor angle difference with a threshold.
---------------------------------------	--

deltadelta

andes.routines.criteria.**deltadelta** (*delta*, *diff_limit*)

Test if a system is stable by comparing the maximum rotor angle difference with a threshold.

Returns

bool

True if the system is stable, False otherwise.

andes.routines.daeint

Integration methods for DAE.

Classes

<i>BackEuler</i> ()	Backward Euler's integration method.
<i>ImplicitIter</i> ()	Base class for implicit iterative methods.
<i>Trapezoid</i> ()	Trapezoidal methods.

andes.routines.daeint.BackEuler**class** andes.routines.daeint.**BackEuler**

Backward Euler's integration method.

__init__ (*args, **kwargs)**Methods**

<code>calc_jac(tds, gxs, gys)</code>	Build full Jacobian matrix A_C for Trapezoid method.
<code>calc_q(x, f, Tf, h, x0, f0)</code>	Calculate the residual of algebraized differential equations.
<code>step(tds)</code>	Integrate with Implicit Trapezoidal Method (ITM) to the current time.

BackEuler.calc_jac**static** BackEuler.**calc_jac** (tds, gxs, gys)Build full Jacobian matrix A_C for Trapezoid method.**BackEuler.calc_q****static** BackEuler.**calc_q** (x, f, Tf, h, x0, f0)

Calculate the residual of algebraized differential equations.

Notes

Numba jit somehow slows down this function for the 14-bus and the 2k-bus systems.

BackEuler.step**static** BackEuler.**step** (tds)

Integrate with Implicit Trapezoidal Method (ITM) to the current time.

This function has an internal Newton-Raphson loop for algebraized semi-explicit DAE. The function returns the convergence status when done but does NOT progress simulation time.

Returns**bool**Convergence status in `tds.converged`.

andes.routines.daeint.ImplicitIter**class** andes.routines.daeint.**ImplicitIter**

Base class for implicit iterative methods.

__init__ (*args, **kwargs)**Methods***calc_jac*(tds, gxs, gys)*calc_q*(x, f, Tf, h, x0, f0)*step*(tds)

Integrate with Implicit Trapezoidal Method (ITM) to the current time.

ImplicitIter.calc_jac**static** ImplicitIter.**calc_jac** (tds, gxs, gys)**ImplicitIter.calc_q****static** ImplicitIter.**calc_q** (x, f, Tf, h, x0, f0)**ImplicitIter.step****static** ImplicitIter.**step** (tds)

Integrate with Implicit Trapezoidal Method (ITM) to the current time.

This function has an internal Newton-Raphson loop for algebraized semi-explicit DAE. The function returns the convergence status when done but does NOT progress simulation time.

Returns**bool**

Convergence status in tds.converged.

andes.routines.daeint.Trapezoid**class** andes.routines.daeint.Trapezoid

Trapezoidal methods.

__init__ (*args, **kwargs)**Methods**

<code>calc_jac(tds, gxs, gys)</code>	Build full Jacobian matrix A_C for Trapezoid method.
<code>calc_q(x, f, Tf, h, x0, f0)</code>	Calculate the residual of algebraized differential equations.
<code>step(tds)</code>	Integrate with Implicit Trapezoidal Method (ITM) to the current time.

Trapezoid.calc_jac**static** Trapezoid.**calc_jac** (tds, gxs, gys)Build full Jacobian matrix A_C for Trapezoid method.**Trapezoid.calc_q****static** Trapezoid.**calc_q** (x, f, Tf, h, x0, f0)

Calculate the residual of algebraized differential equations.

Notes

Numba jit somehow slows down this function for the 14-bus and the 2k-bus systems.

Trapezoid.step**static** Trapezoid.**step** (tds)

Integrate with Implicit Trapezoidal Method (ITM) to the current time.

This function has an internal Newton-Raphson loop for algebraized semi-explicit DAE. The function returns the convergence status when done but does NOT progress simulation time.

Returns**bool**Convergence status in `tds.converged`.

andes.routines.eig

Module for eigenvalue analysis.

Classes

<i>EIG</i> (system, config)	Eigenvalue analysis routine
-----------------------------	-----------------------------

andes.routines.eig.EIG

class andes.routines.eig.**EIG**(system, config)

Eigenvalue analysis routine

__init__(system, config)

Methods

<i>calc_As</i> ([dense])	Return state matrix and store to <code>self.As</code> .
<i>calc_eig</i> ([As])	Calculate eigenvalues and right eigen vectors.
<i>calc_pfactor</i> ([As])	Compute participation factor of states in eigenvalues.
<i>doc</i> ([max_width, export])	Routine documentation interface.
<i>export_mat</i> ()	Export state matrix to a <CaseName>_As.mat file with the variable name As, where <CaseName> is the test case name.
<i>find_zero_states</i> ()	Find the indices of states associated with zero time constants in x.
<i>init</i> ()	Routine initialization interface.
<i>plot</i> ([mu, fig, ax, left, right, ymin, ymax, ...])	Plot utility for eigenvalues in the S domain.
<i>plot_root_loci</i> (results, eig_indices[, ax, ...])	Plot the root loci.
<i>post_process</i> ()	Post processing of eigenvalues.
<i>report</i> ([x_name])	Save eigenvalue analysis reports.
<i>run</i> (**kwargs)	Run small-signal stability analysis.
<i>stats</i> ()	Return statistics of results in a string.
<i>summary</i> ()	Print out a summary to <code>logger.info</code> .
<i>sweep</i> (params, idxes, values)	Parameter sweep for root loci plot.

EIG.calc_As

EIG.calc_As (*dense=True*)

Return state matrix and store to `self.As`.

Returns

kvxopt.matrix
state matrix

Notes

For systems in the mass-matrix formulation,

$$\begin{aligned}T\dot{x} &= f(x, y) \\ 0 &= g(x, y)\end{aligned}$$

Assume T is non-singular, the state matrix is calculated from

$$A_s = T^{-1}(f_x - f_y * g_y^{-1} * g_x)$$

EIG.calc_eig

EIG.calc_eig (*As=None*)

Calculate eigenvalues and right eigen vectors.

This function is a wrapper to `np.linalg.eig`. Results are returned but not stored to `EIG`.

Returns

np.array(dtype=complex)
eigenvalues

np.array()
right eigenvectors

EIG.calc_pfactor

EIG.calc_pfactor (*As=None*)

Compute participation factor of states in eigenvalues.

Each row in the participation factor correspond to one state, and each column correspond to one mode.

Parameters

As
[np.array or None] State matrix to process. If None, use `self.As`.

Returns

np.array(dtype=complex)
eigenvalues

np.array
participation factor matrix

EIG.doc

EIG.doc (*max_width=78, export='plain'*)

Routine documentation interface.

EIG.export_mat

EIG.export_mat ()

Export state matrix to a <CaseName>_As.mat file with the variable name As, where <CaseName> is the test case name.

State variable names are stored in variables x_name and x_tex_name.

Returns

bool
True if successful

EIG.find_zero_states

EIG.find_zero_states ()

Find the indices of states associated with zero time constants in x.

EIG.init

EIG.init ()

Routine initialization interface.

EIG.plot

EIG.plot (*mu=None, fig=None, ax=None, left=-6, right=0.5, ymin=-8, ymax=8, damping=0.05, line_width=0.5, s=40, dpi=None, figsize=None, base_color='black', show=True, latex=True, style='default'*)

Plot utility for eigenvalues in the S domain.

Parameters

mu
[array, optional] an array of complex eigenvalues

fig

[figure handl, optional] existing matplotlib figure handle

ax

[axis handle, optional] existing axis handle

left

[int, optional] left tick for the x-axis, by default -6

right

[float, optional] right tick, by default 0.5

ymin

[int, optional] bottom tick, by default -8

ymax

[int, optional] top tick, by default 8

damping

[float, optional] damping value for which the dash plots are drawn

line_width

[float, optional] default line width, by default 0.5

s

[float or array-like, shape (n,), optional] The marker size in points**2

dpi

[int, optional] figure dpi

figsize

[[type], optional] default figure size, by default None

base_color

[str, optional] base color for negative eigenvalues

show

[bool, optional] True to show figure after plot, by default True

latex

[bool, optional] True to use latex, by default True

Returns**figure**

matplotlib figure object

axis

matplotlib axis object

EIG.plot_root_loci

EIG.plot_root_loci (*results, eig_indices, ax=None, dpi=None, figsize=None, draw_line=False, arrow_threshold=0.2, **kwargs*)

Plot the root loci.

Markers increase in size for the first parameter through the last.

Parameters

results

[dict] Eigenvalue results from parameter sweeping

eig_indices

[Iterable] A list of eigenvalue indices to plot. The indices are 0-based, whereas the indices in the eigenvalue analysis report are 1-based.

ax

[matplotlib.axes.Axes or None] Axes to plot on. If None, create a new figure.

dpi

[int or None] DPI of the figure. If None, use the default DPI.

figsize

[tuple or None] Figure size. If None, use the default size.

draw_line

[bool, optional, False by default] If True, draw lines to connect the roots. Note that due to the non-fixed ordering of eigenvalues, lines will largely connect different modes!

arrow_threshold

[float] Threshold for plotting arrows. If the begin and end points of a locus is shorter than this threshold, no arrow is plotted.

Returns

matplotlib.figure.Figure

Figure containing the plot.

matplotlib.axes.Axes

Axes of the plot.

Examples

To plot the root loci of the first two eigenvalues, do

```
fig, ax = ss.EIG.plot_root_loci(ret, [0, 1])
```

where `ret` is the return of `andes.routines.eig.EIG.sweep()`.

EIG.post_process

EIG.post_process()

Post processing of eigenvalues.

EIG.report

EIG.report (*x_name=None*, ***kwargs*)

Save eigenvalue analysis reports.

Returns

None

EIG.run

EIG.run (***kwargs*)

Run small-signal stability analysis.

EIG.stats

EIG.stats()

Return statistics of results in a string.

EIG.summary

EIG.summary()

Print out a summary to `logger.info`.

EIG.sweep

EIG.sweep (*params*, *idxes*, *values*)

Parameter sweep for root loci plot.

Parameters

params

[list of NumParam or ConstService] list of parameters indices to sweep. For example, `[ss.GENCLS.M]` for GENCLS.M. To update `ss.GENCLS.M` for two generators, `params` should be set to `[ss.GENCLS.M, ss.GENCLS.M]`.

idxes

[list of int or str] list of indices to sweep. For example, ["GENCLS_1", "GENCLS_2"] for the indices of GENCLS whose corresponding parameter will be updated. The length of `idxes` must match that of `params` and `values`.

values: list of lists

New values of the parameters. Each element in `values` is a list for the corresponding element in `params` and `idxes`.

Returns**dict**

A dictionary of the results where the keys are 0-indexed count of parameter set, and the values are dictionaries. Each value dictionary contains a `mu` field for the eigenvalues.

Examples

To apply 10 parameters evenly spaced between 1 and 10 to `ss.GENCLS.M` of `GENCLS_1`, do

```
ret = ss.EIG.sweep(ss.GENCLS.M, "GENCLS_1", np.linspace(1, 2, 10))
```

This is equivalent to the following just for convenience.

```
ret = ss.EIG.sweep([ss.GENCLS.M],
                  ["GENCLS_1"],
                  [np.linspace(1, 2, 10)])
```

Attributes

```
class_name
```

EIG.class_name

property `EIG.class_name`

andes.routines.pflow

Module for power flow calculation.

Classes

<code>PFlow([system, config])</code>	Power flow calculation routine.
--------------------------------------	---------------------------------

andes.routines.pflow.PFlow

class `andes.routines.pflow.PFlow` (*system=None, config=None*)

Power flow calculation routine.

`__init__` (*system=None, config=None*)

Methods

<code>doc([max_width, export])</code>	Routine documentation interface.
<code>fg_update()</code>	Evaluate the limiters and residual equations.
<code>init()</code>	Initialize variables for power flow.
<code>newton_krylov([verbose])</code>	Full Newton-Krylov method from SciPy.
<code>nr_solve()</code>	Solve the power flow problem using iterative Newton's method.
<code>nr_step()</code>	Solve a single iteration step using the Newton-Raphson method.
<code>report()</code>	Write power flow report to a plain-text file.
<code>run(**kwargs)</code>	Solve the power flow using the selected method.
<code>summary()</code>	Output a summary for the PFlow routine.

PFlow.doc

`PFlow.doc` (*max_width=78, export='plain'*)

Routine documentation interface.

PFlow.fg_update`PFlow.fg_update()`

Evaluate the limiters and residual equations.

PFlow.init`PFlow.init()`

Initialize variables for power flow.

PFlow.newton_krylov`PFlow.newton_krylov(verbose=True)`

Full Newton-Krylov method from SciPy.

Parameters**verbose**

True if verbose.

Returns**bool**

Convergence status

Warning: The result might be wrong if discrete are in use!

PFlow.nr_solve`PFlow.nr_solve()`

Solve the power flow problem using iterative Newton's method.

PFlow.nr_step`PFlow.nr_step()`

Solve a single iteration step using the Newton-Raphson method.

Returns**float**

maximum absolute mismatch

PFlow.report

`PFlow.report()`

Write power flow report to a plain-text file.

Returns

bool

True if report was written, False otherwise.

PFlow.run

`PFlow.run(**kwargs)`

Solve the power flow using the selected method.

Returns

bool

convergence status

PFlow.summary

`PFlow.summary()`

Output a summary for the PFlow routine.

Attributes

```
class_name
```

PFlow.class_name

property `PFlow.class_name`

andes.routines.tds

ANDES module for time-domain simulation.

Classes

<code>TDS([system, config])</code>	Time-domain simulation routine.
------------------------------------	---------------------------------

andes.routines.tds.TDS

class `andes.routines.tds.TDS` (*system=None, config=None*)

Time-domain simulation routine.

Some cases may be sensitive to large convergence tolerance `config.tol`. If numerical oscillation happens, try reducing `config.tol` to $1e-6$.

__init__ (*system=None, config=None*)

Methods

<code>calc_h([resume])</code>	Calculate the time step size during the TDS.
<code>check_criteria()</code>	Check stability criteria.
<code>do_switch()</code>	Checks if is an event time and perform switch if true.
<code>doc([max_width, export])</code>	Routine documentation interface.
<code>fg_update(models[, init])</code>	Perform one round of evaluation for one iteration step.
<code>init()</code>	Initialize the status, storage and values for TDS.
<code>init_resume()</code>	Initialize a resumed simulation.
<code>itm_step()</code>	Integrate for the step size of <code>self.h</code> using implicit trapezoid method.
<code>load_plotter()</code>	Manually load a plotter into <code>TDS.plotter</code> .
<code>report(**kwargs)</code>	Report interface.
<code>reset()</code>	Reset internal states to pre-init condition.
<code>rewind(t)</code>	TODO: rewind to a past time.
<code>run([no_summary])</code>	Run time-domain simulation using numerical integration.
<code>save_output([npz])</code>	Save the simulation data into two files: a <code>.lst</code> file and a <code>.npz</code> file.
<code>set_method([name])</code>	Set DAE solution method.
<code>streaming_init()</code>	Send out initialization variables and process init from modules.
<code>streaming_step()</code>	Sync, handle and streaming for each integration step.
<code>summary()</code>	Print out a summary of TDS options to logger.info.
<code>test_init()</code>	Test if the TDS initialization is successful.

TDS.calc_h

`TDS.calc_h(resume=False)`

Calculate the time step size during the TDS.

Parameters

resume

[bool] If True, calculate the initial step size.

Returns

float

computed time step size stored in `self.h`

Notes

A heuristic function is used for variable time step size

```
h = min(0.50 * h, hmin), if niter >= 15
    max(1.10 * h, hmax), if niter <= 6
    min(0.95 * h, hmin), otherwise
```

TDS.check_criteria

`TDS.check_criteria()`

Check stability criteria.

TDS.do_switch

`TDS.do_switch()`

Checks if is an event time and perform switch if true.

TDS.doc

`TDS.doc(max_width=78, export='plain')`

Routine documentation interface.

TDS.fg_update

TDS.fg_update (*models*, *init=False*)

Perform one round of evaluation for one iteration step. The following operations are performed in order:

- variable service updating through `s_update_var`
- discrete flags updating through `l_update_var`
- evaluation of the right-hand-side of `f`
- equation-dependent discrete flags updating through `l_update_eq`
- evaluation of the right-hand-side of `g`
- collection of residuals into `dae` through `fg_to_dae`.

TDS.init

TDS.init ()

Initialize the status, storage and values for TDS.

Returns

array-like

The initial values of `xy`.

TDS.init_resume

TDS.init_resume ()

Initialize a resumed simulation.

TDS.itm_step

TDS.itm_step ()

Integrate for the step size of `self.h` using implicit trapezoid method.

Returns

bool

Convergence status in `self.converged`.

TDS.load_plotter

TDS.load_plotter ()

Manually load a plotter into `TDS.plotter`.

TDS.report

TDS.report (**kwargs)

Report interface.

TDS.reset

TDS.reset ()

Reset internal states to pre-init condition.

TDS.rewind

TDS.rewind (t)

TODO: rewind to a past time.

TDS.run

TDS.run (no_summary=False, **kwargs)

Run time-domain simulation using numerical integration.

The default method is the Implicit Trapezoidal Method (ITM).

TDS.save_output

TDS.save_output (npz=True)

Save the simulation data into two files: a *.lst* file and a *.npz* file.

This function saves the output regardless of the *files.no_output* flag.

Parameters

npz

[bool] True to save in npz format; False to save in npy format.

Returns

bool

True if files are written. False otherwise.

TDS.set_method

`TDS.set_method (name: str = 'trapezoid')`

Set DAE solution method.

Parameters

name

[str, optional, default: 'trapezoid'] DAE solver name

TDS.streaming_init

`TDS.streaming_init ()`

Send out initialization variables and process init from modules.

Returns

None

TDS.streaming_step

`TDS.streaming_step ()`

Sync, handle and streaming for each integration step.

Returns

None

TDS.summary

`TDS.summary ()`

Print out a summary of TDS options to logger.info.

Returns

None

TDS.test_init

`TDS.test_init ()`

Test if the TDS initialization is successful.

This function update `dae.f` and `dae.g` and checks if the residuals are zeros.

Attributes

<code>class_name</code>

TDS.class_name

property TDS.class_name

6.3 Plot

<code>andes.plot</code>

The ANDES plotting tool.

6.3.1 andes.plot

The ANDES plotting tool.

Functions

<code>eig_plot(name, args)</code>

<code>parse_y(y, upper[, lower])</code>

Parse command-line input for Y indices and return a list of indices

<code>set_font([family, size, style, weight])</code>
--

Sets the font for matplotlib.

<code>set_latex()</code>

Enables LaTeX for matplotlib based on the <i>with_latex</i> option and <i>dvipng</i> availability.
--

<code>set_style([style])</code>

Set matplotlib style.

<code>tdsplot(filename, y[, x, to_csv, find, ...])</code>

TDS plot main function based on the new TDSDData class.

eig_plot

`andes.plot.eig_plot` (*name, args*)

parse_y

`andes.plot.parse_y(y, upper, lower=0)`

Parse command-line input for Y indices and return a list of indices

Parameters

y

[Union[List, Set, Tuple]]

Input for Y indices. Could be single item (with or without colon), or multiple items

upper

[int] Upper limit. In the return list y, $y[i] \leq \text{upper}$.

lower

[int] Lower limit. In the return list y, $y[i] \geq \text{lower}$.

Returns

set_font

`andes.plot.set_font(family='serif', size=12, style='normal', weight='normal')`

Sets the font for matplotlib.

Parameters

family

[str] Font family.

size

[int] Font size.

style

[str] Font style.

weight

[str] Font weight.

set_latex

`andes.plot.set_latex()`

Enables LaTeX for matplotlib based on the *with_latex* option and *dvipng* availability.

Returns

bool

True for LaTeX on, False for off

set_style

```
andes.plot.set_style(style='default')
```

Set matplotlib style.

Parameters

style

[str] *default*, *ieee* (require *scienceplots*), or other available styles (see *matplotlib.pyplot.style.available*).

tdsplot

```
andes.plot.tdsplot(filename, y, x=(0,), to_csv=False, find=None, xargs=None, exclude=None,
                  **kwargs)
```

TDS plot main function based on the new TDSData class.

Parameters

filename

[str] Path to the ANDES TDS output data file. Works without extension.

x

[list or int, optional] The index for the x-axis variable. x=0 by default for time

y

[list or int] The indices for the y-axis variable

to_csv

[bool] True if need to export to a csv file

find

[str, optional] if not none, specify the variable name to find

xargs

[str, optional] similar to find, but return the result indices with file name, x idx name for xargs

exclude

[str, optional] variable name pattern to exclude

Returns

TDSData object

Classes

<code>TDSData([full_name, mode, dae, path])</code>	A data container for loading and plotting results from Andes time-domain simulation.
--	--

andes.plot.TDSData

class `andes.plot.TDSData` (*full_name=None, mode='file', dae=None, path=None*)

A data container for loading and plotting results from Andes time-domain simulation.

__init__ (*full_name=None, mode='file', dae=None, path=None*)

Methods

<code>bqplot_data(xdata, ydata, *[xheader, ...])</code>	Plot with bqplot.
<code>data_to_df()</code>	Convert to pandas.DataFrame
<code>export_csv([path, idx, header, formatted, ...])</code>	Export to a csv file.
<code>find(query[, exclude, formatted, idx_only])</code>	Return variable names and indices matching <i>query</i> .
<code>get_call([backend])</code>	Get the internal <i>plot_data</i> function for the specified backend.
<code>get_header(idx[, formatted])</code>	Return a list of the variable names at the given indices.
<code>get_values(idx)</code>	Return the variable values at the given indices.
<code>guess_event_time()</code>	Guess the event starting time from the input data by checking when the values start to change
<code>load_dae()</code>	Load from DAE time series.
<code>load_lst()</code>	Load the lst file into internal data structures <i>_idx</i> , <i>_fname</i> , <i>_uname</i> , and counts the number of variables to <i>nvars</i> .
<code>load_npy_or_csv([delimiter])</code>	Load the npy, zpy or (the legacy) csv file into the internal data structure <i>self._xy</i> .
<code>panoview mdl, vars, *[ncols, idx, a, figsize])</code>	Panoramic view of variables of a given model instance.
<code>plot(yidx[, xidx, a, ytimes, ycalc, left, ...])</code>	Entry function for plotting.
<code>plot_data(xdata, ydata, *[xheader, ...])</code>	Plot lines for the supplied data and options.
<code>plotn(nrows, ncols, yidxes[, xidxes, dpi, ...])</code>	Plot multiple subfigures in one figure.

TDSData.bqplot_data

`TDSData.bqplot_data` (*xdata*, *ydata*, *, *xheader=None*, *yheader=None*, *xlabel=None*, *ylabel=None*, *left=None*, *right=None*, *ymin=None*, *ymax=None*, *legend=True*, *grid=False*, *fig=None*, *dpi=None*, *line_width=1.0*, *greyscale=False*, *savefig=None*, *save_format=None*, *title=None*, ***kwargs*)

Plot with `bqplot`. Experimental and incomplete.

TDSData.data_to_df

`TDSData.data_to_df()`

Convert to `pandas.DataFrame`

TDSData.export_csv

`TDSData.export_csv` (*path=None*, *idx=None*, *header=None*, *formatted=False*, *sort_idx=True*, *fmt='%18e'*)

Export to a csv file.

Parameters

path

[str] path of the csv file to save

idx

[None or array-like, optional] the indices of the variables to export. Export all by default

header

[None or array-like, optional] customized header if not *None*. Use the names from the 1st file by default

formatted

[bool, optional] Use LaTeX-formatted header. Does not apply when using customized header

sort_idx

[bool, optional] Sort by idx or not, # TODO: implement sort

fmt

[str] cell formatter

Returns

str

The path of the exported csv file

TDSDData.find

`TDSDData.find(query, exclude=None, formatted=False, idx_only=False)`

Return variable names and indices matching *query*.

Parameters**query**

[str] The string for querying variables. Multiple conditions can be separated by comma without space.

exclude

[str, optional] A string pattern to be excluded

formatted

[bool, optional] True to return formatted names, False otherwise

idx_only

[bool, optional] True if only return indices

Returns**(list, list)**

(List of found indices, list of found names)

TDSDData.get_call

`TDSDData.get_call(backend=None)`

Get the internal *plot_data* function for the specified backend.

TDSDData.get_header

`TDSDData.get_header(idx, formatted=False)`

Return a list of the variable names at the given indices.

Parameters**idx**

[list or int] The indices of the variables to retrieve

formatted

[bool] True to retrieve latex-formatted names, False for unformatted names

Returns**list**

A list of variable names (headers)

TDSDData.get_values

`TDSDData.get_values (idx)`

Return the variable values at the given indices.

Parameters

idx

[list] The index of the variables to retrieve. *idx=0* is for Time. Variable indices start at 1.

Returns

np.ndarray

Variable data

TDSDData.guess_event_time

`TDSDData.guess_event_time ()`

Guess the event starting time from the input data by checking when the values start to change

TDSDData.load_dae

`TDSDData.load_dae ()`

Load from DAE time series.

TDSDData.load_lst

`TDSDData.load_lst ()`

Load the lst file into internal data structures *_idx*, *_fname*, *_uname*, and counts the number of variables to *nvars*.

Returns

None

TDSDData.load_npy_or_csv

`TDSDData.load_npy_or_csv (delimiter=',')`

Load the npy, zpy or (the legacy) csv file into the internal data structure *self._xy*.

Parameters

delimiter

[str, optional] The delimiter for the case file. Default to comma.

Returns

None

TDSData.panoview

`TDSData.panoview (mdl, vars, *, ncols=3, idx=None, a=None, figsize=None, **kwargs)`

Panoramic view of variables of a given model instance.

Select variables through `vars`. Select devices through `idx` or `a`, which has a higher priority.

This function also takes other arguments recognizable by `self.plot`.

Parameters

mdl

[ModelBase] Model instance

var

[list of str] A list of variable names to display

ncol

[int] Number of columns

idx

[list] A list of device idx-es for showing

a

[list of int] A list of device 0-based positions for showing

figsize

[tuple] Figure size for plotting

Examples

To plot omega and delta of GENROUs GENROU_1 and GENROU_2:

```
system.TDS.plt.plot(system.GENROU,
                    vars=['omega', 'delta'],
                    idx=['GENROU_1', 'GENROU_2'])
```

TDSData.plot

`TDSData.plot (yidx, xidx=(0,), *, a=None, ytimes=None, ycalc=None, left=None, right=None, ymin=None, ymax=None, xlabel=None, ylabel=None, xheader=None, yheader=None, legend=None, grid=False, greyscale=False, latex=True, dpi=None, line_width=1.0, font_size=12, savefig=None, save_format=None, show=True, title=None, linestyle=None, use_bqplot=False, hline1=None, hline2=None, vline1=None, vline2=None, hline=None, vline=None, fig=None, ax=None, backend=None, set_xlim=True, set_ylim=True, autoscale=False, legend_bbox=None, legend_loc=None, legend_ncol=1, figsize=None, color=None, **kwargs)`

Entry function for plotting.

This function retrieves the x and y values based on the *xidx* and *yidx* inputs, applies scaling functions *ytimes* and *ycalc* sequentially, and delegates the plotting to the backend.

Parameters

yidx

[list or int] The indices for the y-axis variables

xidx

[tuple or int, optional] The index for the x-axis variable

a

[tuple or list, optional] The 0-indexed sub-indices into *yidx* to plot.

ytimes

[float, optional] A scaling factor to apply to all y values.

left

[float] The starting value of the x axis

right

[float] The ending value of the x axis

ymin

[float] The minimum value of the y axis

ymax

[float] The maximum value of the y axis

ylabel

[str] Text label for the y axis

yheader

[list] A list containing the variable names for the y-axis variable

title

[str] Title string to be shown at the top

fig

Existing figure object to draw the axis on.

ax

Existing axis object to draw the lines on.

Returns

(fig, ax)

Figure and axis handles for matplotlib backend.

fig

Figure object for bqplot backend.

Other Parameters

ycalc: callable, optional

A callable to apply to all y values after scaling with *ytimes*.

xlabel

[str] Text label for the x axis

xheader

[list] A list containing the variable names for the x-axis variable

legend

[bool] True to show legend and False otherwise

legend_ncol

[int] Number of columns in legend

legend_bbox

[tuple of two floats] legend box to anchor

grid

[bool] True to show grid and False otherwise

latex

[bool] True to enable latex and False to disable

greyscale

[bool] True to use greyscale, False otherwise

savefig

[bool or str] True to save to png figure file. str is treated as the output file name.

save_format

[str] File extension string (pdf, png or jpg) for the savefig format

dpi

[int] Dots per inch for screen print or save. *savefig* uses a minimum of 200 dpi

line_width

[float] Plot line width

font_size

[float] Text font size (labels and legends)

figsize

[tuple] Figure size passed when creating new figure

show

[bool] True to show the image

backend

[str or None] *bqplot* to use the bqplot backend in notebook. None for matplotlib.

hline1: float, optional

Dashed horizontal line 1

hline2: float, optional

Dashed horizontal line 2

vline1: float, optional

Dashed horizontal line 1

vline2: float, optional

Dashed vertical line 2

hline: float or Iterable

y-axis location of horizontal line(s)

vline: float or Iterable

x-axis location of vertical line(s)

TDSData.plot_data

`TDSData.plot_data` (*xdata*, *ydata*, *, *xheader=None*, *yheader=None*, *xlabel=None*, *ylabel=None*, *linestyle=None*, *left=None*, *right=None*, *ymin=None*, *ymax=None*, *legend=None*, *grid=False*, *fig=None*, *ax=None*, *latex=True*, *dpi=None*, *line_width=1.0*, *font_size=12*, *greyscale=False*, *savefig=None*, *save_format=None*, *show=True*, *title=None*, *hline1=None*, *hline2=None*, *vline1=None*, *hline=None*, *vline=None*, *vline2=None*, *set_xlim=True*, *set_ylim=True*, *autoscale=False*, *figsize=None*, *legend_bbox=None*, *legend_loc=None*, *legend_ncol=1*, *mask=True*, *color=None*, *style='default'*, ***kwargs*)

Plot lines for the supplied data and options.

This functions takes *xdata* and *ydata* values. If you provide variable indices instead of values, use *plot()*.

See the argument lists of *plot()* for more.

Parameters

xdata

[array-like] An array-like object containing the values for the x-axis variable

ydata

[array] An array containing the values of each variables for the y-axis variable. The row of *ydata* must match the row of *xdata*. Each column correspondings to a variable.

mask

[bool] If enabled (1), when specifying axis limits, only data in the limits will be used for plotting to optimize for autoscaling. It is done through an index mask.

Returns

(fig, ax)

The figure and axis handles

Examples

To plot the results of arithmetic calculation of variables, retrieve the values, do the calculation, and plot with *plot_data*.

```
>>> v = ss.dae.ts.y[:, ss.PVD1.v.a]
>>> Ipcmd = ss.dae.ts.y[:, ss.PVD1.Ipcmd_y.a]
>>> t = ss.dae.ts.t
```

```
>>> ss.TDS.plt.plot_data(t, v * Ipcmd,
>>>                        xlabel='Time [s]',
>>>                        ylabel='Ipcmd [pu]')
```

TDSData.plotn

`TDSData.plotn` (*nrows*: *int*, *ncols*: *int*, *yidxes*, *xidxes*=*None*, *, *dpi*=*None*, *titles*=*None*, *a*=*None*, *figsize*=*None*, *xlabel*=*None*, *ylabel*=*None*, *sharex*=*None*, *sharey*=*None*, *show*=*True*, *xlabel_offs*=(0.5, 0.01), *ylabel_offs*=(0.05, 0.5), *hspace*=0.2, *wspace*=0.2, ***kwargs*)

Plot multiple subfigures in one figure.

Parameters *xidxes*, *a*, *xlabels* and *ylabels*, if provided, must have the same length as *yidxes*.

Parameters

nrows

[int] number of rows

ncols

[int] number of cols

yidx

A list of *BaseVar* or index lists.

6.4 I/O

andes.io

ANDES input parsers and output formatters.

6.4.1 andes.io

ANDES input parsers and output formatters.

Functions

<code>dump(system, output_format[, full_path, ...])</code>	Dump the System data into the requested output format.
<code>get_output_ext(out_format)</code>	Helper function to get the output extension for the given output format.
<code>guess(system)</code>	Guess the input format based on extension and content.
<code>parse(system)</code>	Parse input file with the given format in <code>system.files.input_format</code> .
<code>read_file_like(infile)</code>	Read a file-like object and return a list of splitted lines.

dump

`andes.io.dump(system, output_format, full_path=None, overwrite=False, **kwargs)`

Dump the System data into the requested output format.

Parameters

system

System object

output_format

[str] Output format name. 'xlsx' will be used if is not an instance of *str*.

Returns

bool

True if successful; False otherwise.

get_output_ext

`andes.io.get_output_ext(out_format)`

Helper function to get the output extension for the given output format.

Parameters

out_format

[str] Output format name.

Returns

str

[file extension without dot or empty if not supported]

guess

`andes.io.guess (system)`

Guess the input format based on extension and content.

Also stores the format name to *system.files.input_format*.

Parameters

system[System] System instance with the file name set to *system.files*

Returns

str

format name

parse

`andes.io.parse (system)`Parse input file with the given format in *system.files.input_format*.

Returns

bool

True if successful; False otherwise.

read_file_like

`andes.io.read_file_like (infile: str | IOBase)`

Read a file-like object and return a list of splitted lines.

Modules

<code>andes.io.json</code>	JSON reader and writer for ANDES.
<code>andes.io.matpower</code>	Simple MATPOWER format parser
<code>andes.io.psse</code>	PSS/E file parser.
<code>andes.io.streaming</code>	Simulation data streaming interface for CURENT DiME2.
<code>andes.io.txt</code>	Output TXT file formatter.
<code>andes.io.xlsx</code>	Excel reader and writer for ANDES power system parameters

andes.io.json

JSON reader and writer for ANDES.

Functions

<code>read(system, infile)</code>	Read JSON file with ANDES model data into an empty system.
<code>testlines(infile)</code>	
<code>write(system, outfile[, skip_empty, overwrite])</code>	Write loaded ANDES system data into a JSON file.

read

`andes.io.json.read(system, infile: str | IOBase)`

Read JSON file with ANDES model data into an empty system.

Parameters

system

[System] Empty System instance

infile

[str or io.BaseIO] str: path to the input file; or io.BaseIO: a stream to read from

Returns

System

System instance after succeeded

testlines

`andes.io.json.testlines(infile)`

write

`andes.io.json.write(system, outfile, skip_empty=True, overwrite=None, **kwargs)`

Write loaded ANDES system data into a JSON file.

Parameters

system

[System] A loaded system with parameters

outfile

[str] Path to the output file

skip_empty

[bool] Skip output of empty models (n = 0)

overwrite

[bool] None to prompt for overwrite selection; True to overwrite; False to not overwrite

Returns**bool**

True if file written; False otherwise

andes.io.matpower

Simple MATPOWER format parser

Functions

<i>m2mpc</i> (infile)	Parse MATPOWER file and return a dictionary with the data.
<i>mpc2system</i> (mpc, system)	Load an mpc dict into an empty ANDES system.
<i>read</i> (system, file)	Read a MATPOWER data file into mpc, and build andes device elements.
<i>system2mpc</i> (system)	Convert data from an ANDES system to an mpc dict.
<i>testlines</i> (infile)	Test if this file is in the MATPOWER format.

m2mpc`andes.io.matpower.m2mpc (infile: str) → dict`

Parse MATPOWER file and return a dictionary with the data.

Supported fields include

- baseMVA
- bus
- bus_names
- gen
- branch
- gencost (parsed but not used)
- areas (parsed but not used)

Parameters

infile

[str] Path to the MATPOWER file.

Returns

dict

mpc struct names : numpy arrays

mpc2system

`andes.io.matpower.mpc2system(mpc: dict, system) → bool`

Load an mpc dict into an empty ANDES system.

Parameters

system

[andes.system.System] Empty system to load the data into.

mpc

[dict] mpc struct names : numpy arrays

Returns

bool

True if successful, False otherwise.

read

`andes.io.matpower.read(system, file)`

Read a MATPOWER data file into mpc, and build andes device elements.

system2mpc

`andes.io.matpower.system2mpc(system) → dict`

Convert data from an ANDES system to an mpc dict.

In the gen section, slack generators precedes PV generators.

testlines

`andes.io.matpower.testlines(infile)`

Test if this file is in the MATPOWER format.

NOT YET IMPLEMENTED.

andes.io.psse

PSS/E file parser.

Include a RAW parser and a DYR parser.

Functions

<code>get_block_lines(b, mdata)</code>	Return the number of lines based on the block index in the RAW file.
<code>read(system, file)</code>	Read PSS/E RAW file v32/v33 formats.
<code>read_add(system, file)</code>	Read an addition PSS/E dyr file.
<code>sort_psse_models(dyr_yaml, system)</code>	Sort supported models so that model names are ordered by dependency.
<code>testlines(infile)</code>	Check the raw file for frequency base.

get_block_lines

`andes.io.psse.get_block_lines(b, mdata)`

Return the number of lines based on the block index in the RAW file.

read

`andes.io.psse.read(system, file)`

Read PSS/E RAW file v32/v33 formats.

read_add

`andes.io.psse.read_add(system, file)`

Read an addition PSS/E dyr file.

Parameters

system

[System] System instance to which data will be loaded

file

[str] Path to the additional *dyr* file

Returns

bool

data parsing status

sort_psse_models

`andes.io.psse.sort_psse_models(dyr_yaml, system)`

Sort supported models so that model names are ordered by dependency.

Dependency is determined by checking the `find` key in `psse-dyr.yaml` for each model.

Returns

list

The sequence of model names for loading parameters.

testlines

`andes.io.psse.testlines(infile)`

Check the raw file for frequency base.

andes.io.streaming

Simulation data streaming interface for CURENT DiME2.

Classes

<code>Streaming(system)</code>

ANDES data streaming class to interface with CURENT LTB.
--

andes.io.streaming.Streaming

class `andes.io.streaming.Streaming(system)`

ANDES data streaming class to interface with CURENT LTB.

`__init__(system)`

Methods

<code>build_init()</code>	Build <i>Varheader</i> , <i>Idxvgs</i> and <i>SysParam</i> after power flow routine
<code>connect()</code>	Connect to DiME 2 server.
<code>finalize()</code>	Send DONE signal when simulation completes
<code>handle_alter(Alter)</code>	Handle parameter altering
<code>handle_event(Event)</code>	Handle Fault, Breaker, Syn and Load Events
<code>record_module_init(name, init_var)</code>	Record the variable requests from modules
<code>send_init([recepient])</code>	Broadcast <i>Varheader</i> , <i>Idxvgs</i> and <i>SysParam</i> to all DiME clients after power flow routine
<code>sync_and_handle()</code>	Sync until the queue is empty.
<code>transpose_matlab_row(a)</code>	
<code>vars_to_modules()</code>	Stream the results from the last step to modules
<code>vars_to_pmu()</code>	Broadcast all PMU measurements and BusFreq measurements in the variable <i>pmudata</i>

Streaming.build_init

Streaming.**build_init** ()

Build *Varheader*, *Idxvgs* and *SysParam* after power flow routine

Streaming.connect

Streaming.**connect** ()

Connect to DiME 2 server.

If *dime_address* is specified from the command-line, streaming will be automatically enabled. Otherwise, settings from the Config file will be used.

Streaming.finalize

Streaming.**finalize** ()

Send DONE signal when simulation completes

Returns

None

Streaming.handle_alter

Streaming.**handle_alter** (*Alter*)

Handle parameter altering

Streaming.handle_event

Streaming.**handle_event** (*Event*)

Handle Fault, Breaker, Syn and Load Events

Streaming.record_module_init

Streaming.**record_module_init** (*name, init_var*)

Record the variable requests from modules

Streaming.send_init

Streaming.**send_init** (*recepient='all'*)

Broadcast *Varheader*, *Idxvgs* and *SysParam* to all DiME clients after power flow routine

Streaming.sync_and_handle

Streaming.**sync_and_handle** ()

Sync until the queue is empty. Handle sync'ed commands.

Streaming.transpose_matlab_row

static Streaming.**transpose_matlab_row** (*a*)

Streaming.vars_to_modules

Streaming.**vars_to_modules** ()

Stream the results from the last step to modules

Returns

None

Streaming.vars_to_pmu

Streaming.**vars_to_pmu**()

Broadcast all PMU measurements and BusFreq measurements in the variable *pmudata*

andes.io.txt

Output TXT file formatter.

Functions

```
dump_data(text, header, rowname, data, file)
```

dump_data

`andes.io.txt.dump_data` (*text, header, rowname, data, file, width=18, precision=5*)

andes.io.xlsx

Excel reader and writer for ANDES power system parameters

This module utilizes openpyxl, xlswriter and pandas.DataFrame.

While I like the simplicity of the dome format, spreadsheets are easier to view and edit.

Functions

<code>read</code> (system, infile)	Read an xlsx file with ANDES model data into an empty system
<code>testlines</code> (infile)	
<code>write</code> (system, outfile[, skip_empty, ...])	Write loaded ANDES system data into an xlsx file

read

`andes.io.xlsx.read(system, infile)`

Read an xlsx file with ANDES model data into an empty system

Parameters

system

[System] Empty System instance

infile

[str or file-like] Path to the input file, or a file-like object

Returns

System

System instance after succeeded

testlines

`andes.io.xlsx.testlines(infile)`

write

`andes.io.xlsx.write(system, outfile, skip_empty=True, overwrite=None, add_book=None, **kwargs)`

Write loaded ANDES system data into an xlsx file

Parameters

system

[System] A loaded system with parameters

outfile

[str] Path to the output file

skip_empty

[bool] Skip output of empty models (n = 0)

overwrite

[bool, optional] None to prompt for overwrite selection; True to overwrite; False to not overwrite

add_book

[str, optional] An optional model to be added to the output spreadsheet

Returns

bool

True if file written; False otherwise

6.5 Interoperability

andes.interop

Interopability package between Andes and other software.

6.5.1 andes.interop

Interopability package between Andes and other software.

To install dependencies, do:

```
pip install andes[interop]
```

To install dependencies for *development*, in the ANDES source code folder, do:

```
pip install -e .[interop]
```

Modules

andes.interop.gridcal

Basic GridCal (4.6.1) interface, based on the pandapower interface written by Jinning Wang

andes.interop.matpower

Interoperability with MATPOWER through matpower-pip.

andes.interop.pandapower

Simple pandapower (2.7.0) interface

andes.interop.pypowsybl

Interoperability with pypowsybl.

andes.interop.gridcal

Basic GridCal (4.6.1) interface, based on the pandapower interface written by Jinning Wang

Author: Josep Fanals (@JosepFanals)

Functions

require_gridcal(f)

Decorator for functions that require GridCal.

to_gridcal(ssa[, verify, tol])

Convert an ANDES system to a GridCal grid.

require_gridcal

`andes.interop.gridcal.require_gridcal(f)`

Decorator for functions that require GridCal.

to_gridcal

`andes.interop.gridcal.to_gridcal(ssa, verify=True, tol=1e-06)`

Convert an ANDES system to a GridCal grid.

Parameters

ssa

[`andes.system.System`] The ANDES system to be converted

verify

[bool] If True, the converted network will be verified with the source ANDES system using AC power flow.

tol

[float] The tolerance of error when comparing power flow solutions.

Returns

GridCal.Engine.Core.multi_circuit.MultiCircuit

A GridCal net with the same bus, branch, gen, and load data as the ANDES system

Notes

Handling of the following parameters:

- By default, all generators in `ssp` are controllable unless user-defined controllability is given
- The online status of generators are determined by the online status of `StaticGen` that connected to the `SynGen` or `DG`
- `ssp.gen.name` is from `ssa.StaticGen.idx`, which should be unique

andes.interop.matpower

Interoperability with MATPOWER through `matpower-pip`.

Please install the Python package `matpower` and configure MATLAB or Octave, following the instructions at `matpower-pip`.

To create a MATLAB/Octave instance, do:

```
from andes.interop.matpower import start_instance  
  
m = start_instance()
```

Functions

<code>from_matpower(m, varname[, system])</code>	Retrieve a MATPOWER mpc case from a MATLAB/Octave instance.
<code>require_matpower(f)</code>	Decorator for functions that require matpower.
<code>to_matpower(m, varname, system)</code>	Send an ANDES case to a running MATLAB instance.

from_matpower

`andes.interop.matpower.from_matpower(m, varname, system=None)`

Retrieve a MATPOWER mpc case from a MATLAB/Octave instance.

Parameters

m

[MATLAB/Octave instance] Instance from which to retrieve the MATPOWER case.

varname

[str] Name of the variable in the MATPOWER MPC format to retrieve.

Returns

System

System from the mpc case. The system will not have been set up.

Examples

To retrieve a case from MATPOWER from instance `m`, do the following:

```
from andes.interop.matpower import start_instance, to_matpower, from_
    ↪matpower

system = from_matpower(m, 'mpc')
```

One can create an Excel file with dynamic data only and use the `xlsx` parser to load data into `system`:

```
from andes.io import xlsx

xlsx.read(system, andes.get_case('ieee14/ieee14_dyn_only.xlsx'))
```

The `ieee14_dyn_only.xlsx` is an example spreadsheet that only contains dynamic components. One will need to create the `idx` correctly for dynamic components to match these from the MATPOWER case. If not sure about the indices, one can save the ANDES system to an Excel file, using:

```
xlsx.write(system, 'system_static.xlsx')
```

require_matpower

`andes.interop.matpower.require_matpower(f)`

Decorator for functions that require matpower.

to_matpower

`andes.interop.matpower.to_matpower(m, varname, system)`

Send an ANDES case to a running MATLAB instance.

Parameters

m

[MATLAB/Octave instance] Instance to which to send the MATPOWER case.

varname

[str] Name of the variable to store the mpc case in MATLAB/Octave.

system

[*System*] System whose power flow data to send to MATPOWER.

Examples

The code below will create an IEEE 14-bus example system in ANDES, convert it to MATPOWER's case, and send to the MATLAB/Octave instance.

```
import andes

from andes.interop.matpower import (start_instance,
                                     to_matpower, from_matpower)

m = start_instance()

ss = andes.system.example()
mpc = to_matpower(m, 'mpc', ss)

m.eval("runpf(mpc)")

mpc_out = m.pull("mpc")  # retrieve the mpc case from MATLAB/Octave
```


andes.interop.pandapower

Simple pandapower (2.7.0) interface

Functions

<code>add_gencost(ssp, gen_cost)</code>	Add cost function to converted pandapower net <i>ssp</i> .
<code>build_group_table(ssa, group, columns[, ...])</code>	Build the table for devices in a group in an ANDES System.
<code>make_GSF(ppn[, verify, using_sparse_solver])</code>	Build the Generation Shift Factor matrix of a pandapower net.
<code>make_link_table(ssa)</code>	Build the link table for generators and generator controllers in an ANDES System, including SynGen and DG for now.
<code>require_pandapower(f)</code>	Decorator for functions that require pandapower.
<code>runopp_map(ssp, link_table, **kwargs)</code>	Run OPF in pandapower using <code>pp.runopp()</code> and map results back to ANDES based on the link table.
<code>to_pandapower(ssa[, ctrl, verify, tol])</code>	Convert an ANDES system to a pandapower network for power flow studies.

add_gencost

`andes.interop.pandapower.add_gencost(ssp, gen_cost)`

Add cost function to converted pandapower net *ssp*.

The cost data follows the same format of pypower and matpower.

Now only poly_cost is supported.

Parameters

ssp

The pandapower net

gen_cost

[array] generator cost data

build_group_table

`andes.interop.pandapower.build_group_table(ssa, group, columns, mdl_name=[])`

Build the table for devices in a group in an ANDES System.

Parameters

ssa

[andes.system.System] The ANDES system to build the table

group

[string] The ANDES group

columns

[list of string] The common columns of a group that to be included in the table.

mdl_name

[list of string] The list of models that to be included in the table. Default as all models.

Returns**DataFrame**

The output Dataframe contains the columns from the device

make_GSF

```
andes.interop.pandapower.make_GSF (ppn, verify=True, using_sparse_solver=False)
```

Build the Generation Shift Factor matrix of a pandapower net.

Parameters**ppn**

[pandapower.network.Network] Pandapower network

verify

[bool] True to verify the GSF with that from DC power flow

using_sparse_solver

[bool] True to use a sparse solver for pandapower maktPTDF

Returns**np.ndarray**

The GSF array

make_link_table

```
andes.interop.pandapower.make_link_table (ssa)
```

Build the link table for generators and generator controllers in an ANDES System, including SynGen and DG for now.

Parameters**ssa**

[andes.system.System] The ANDES system to link

Returns**DataFrame**

Each column in the output Dataframe contains the `idx` of linked `StaticGen`,

Bus, DG, RenGen, RenExciter, SynGen, Exciter, and TurbineGov,
gammap, gammaq.

require_pandapower

`andes.interop.pandapower.require_pandapower(f)`

Decorator for functions that require pandapower.

runopp_map

`andes.interop.pandapower.runopp_map(ssp, link_table, **kwargs)`

Run OPF in pandapower using `pp.runopp()` and map results back to ANDES based on the link table.

Parameters

ssp

[pandapower network] The pandapower network

link_table

[DataFrame] The link table of ANDES system

Returns

DataFrame

The DataFrame contains the OPF results with columns `p_mw`, `q_mvar`, `vm_pu` in p.u., and the corresponding `idx` of `StaticGen`, `Exciter`, `TurbineGov` in ANDES.

Notes

- The pandapower net and the ANDES system must have same base MVA.
- Multiple DG connected to the same `StaticGen` will be converted to one generator. The power is dispatched to each DG by the power ratio `gammap`

to_pandapower

`andes.interop.pandapower.to_pandapower(ssa, ctrl=[], verify=True, tol=1e-06)`

Convert an ANDES system to a pandapower network for power flow studies.

Parameters

ssa

[andes.system.System] The ANDES system to be converted

ctrl

[list] The controllability of generators. The length should be the same with the number of `StaticGen`. If not given, controllability of generators will be assigned by default. Example input: `[1, 0, 1, ...]`; PV first, then `Slack`.

verify

[bool] If True, the converted network will be verified with the source ANDES system using AC power flow.

tol

[float] The tolerance of error.

Returns**pandapower.auxiliary.pandapowerNet**

A pandapower net with the same bus, branch, gen, and load data as the ANDES system

Notes**Handling of the following parameters:**

- This interface tracks static power flow model in ANDES: *Bus*, *Line*, *PQ*, *Shunt*, *PV*, and *Slack*. However, it does not track the dynamic models in ANDES, including but not limited to *TurbineGov*, *SynGen*, and *Exciter*.
- The interface converts the `Slack` in ANDES to `gen` in pandapower rather than `ext_gen`.
- MUST NOT verify power flow after initializing TDS in ANDES. ANDES does not allow running `PFlow` for systems with initialized TDS as it will break variable addressing.
- If you want to track dynamic model outputs in ANDES and feedback into pandapower, you might need to manually transfer the results from ANDES to pandapower.
- Generator cost is not included in the conversion. Use `add_gencost()` to add cost data.
- By default, all generators in `ssp` are controllable unless user-defined controllability is given
- The online status of generators are determined by the online status of `StaticGen` that connected to the `SynGen` or `DG`
- `ssp.gen.name` is from `ssa.StaticGen.idx`, which should be unique

andes.interop.pypowsybl

Interoperability with pypowsybl.

Functions

<code>require_pypowsybl(f)</code>	Decorator for functions that require pypowsybl.
<code>to_pypowsybl(ss)</code>	Convert an ANDES system to a pypowsybl network.

require_pypowsybl

`andes.interop.pypowsybl.require_pypowsybl(f)`

Decorator for functions that require pypowsybl.

to_pypowsybl

`andes.interop.pypowsybl.to_pypowsybl(ss)`

Convert an ANDES system to a pypowsybl network.

Parameters

ss

[`andes.system.System`] The ANDES system to be converted.

Returns

`pypowsybl.network.Network`

Warning:

- Power flow results are not verified.

Notes

- Only the BUS_BREAKER topology is supported.
- Each bus has a voltage level named "VL" followed by the bus idx.
- Buses connected by transformers are in the same substation.

Examples

One can utilize pypowsybl to draw network topology. For example,

```
ss = andes.system.example()
n = to_pypowsybl(ss)
results = pp.loadflow.run_ac(n)
```

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```
n.get_network_area_diagram() # show diagram for system
n.get_single_line_diagram("VL6") # show single-line diagram for bus 6
```

6.6 Others

<code>andes.cli</code>	ANDES command-line interface and argument parsers.
<code>andes.main</code>	Main entry point for the ANDES CLI and scripting interfaces.
<code>andes.utils.paths</code>	Utility functions for loading andes stock test cases
<code>andes.utils.snapshot</code>	Utility functions for saving and loading snapshots.
<code>andes.utils.widgets</code>	Support for Jupyter widgets.

6.6.1 andes.cli

ANDES command-line interface and argument parsers.

Functions

<code>create_parser()</code>	Create a parser for the command-line interface.
<code>main()</code>	Entry point of the ANDES command-line interface.
<code>preamble()</code>	Log the ANDES command-line preamble at the <i>logging.INFO</i> level

create_parser

`andes.cli.create_parser()`

Create a parser for the command-line interface.

Returns

argparse.ArgumentParser

Parser with all ANDES options

main

`andes.cli.main()`

Entry point of the ANDES command-line interface.

preamble

`andes.cli.preamble()`

Log the ANDES command-line preamble at the *logging.INFO* level

6.6.2 andes.main

Main entry point for the ANDES CLI and scripting interfaces.

Functions

<code>config_logger([stream_level, stream, file, ...])</code>	Configure an ANDES logger with a <i>FileHandler</i> and a <i>StreamHandler</i> .
<code>demo(**kwargs)</code>	TODO: show some demonstrations from CLI.
<code>doc([attribute, list_supported, config])</code>	Quick documentation from command-line.
<code>edit_conf([edit_config])</code>	Edit the Andes config file which occurs first in the search path.
<code>find_log_path(lg)</code>	Find the file paths of the FileHandlers.
<code>load(case[, codegen, setup, use_input_path])</code>	Load a case and set up a system without running routine.
<code>misc([edit_config, save_config, ...])</code>	Miscellaneous commands.
<code>plot(*args, **kwargs)</code>	Wrapper for the plot tool.
<code>prepare([quick, incremental, models, ...])</code>	Run code generation.
<code>print_license()</code>	Print out Andes license to stdout.
<code>remove_output([recursive])</code>	Remove the outputs generated by Andes, including power flow reports <code>_out.txt</code> , time-domain list <code>_out.lst</code> and data <code>_out.dat</code> , eigenvalue analysis report <code>_eig.txt</code> .
<code>run(filename[, input_path, verbose, ...])</code>	Entry point to run ANDES routines.
<code>run_case(case, *[, routine, profile, ...])</code>	Run single simulation case for the given full path.
<code>save_conf([config_path, overwrite])</code>	Save the Andes config to a file at the path specified by <code>save_config</code> .
<code>selftest([quick, extra])</code>	Run unit tests.
<code>set_logger_level(lg, type_to_set, level)</code>	Set logging level for the given type of handler.
<code>versioninfo()</code>	Print version info for ANDES and dependencies.

config_logger

```
andes.main.config_logger (stream_level=20, *, stream=True, file=True, log_file='andes.log',
                           log_path=None, file_level=10)
```

Configure an ANDES logger with a *FileHandler* and a *StreamHandler*.

This function is called at the beginning of `andes.main.main()`. Updating `stream_level` and `file_level` is now supported.

Parameters

stream

[bool, optional] Create a *StreamHandler* for *stdout* if True. If False, the handler will not be created.

file

[bool, optional] True if logging to `log_file`.

log_file

[str, optional] Log file name for *FileHandler*, 'andes.log' by default. If None, the *FileHandler* will not be created.

log_path

[str, optional] Path to store the log file. By default, the path is generated by `get_log_dir()` in `utils.misc`.

stream_level

[{10, 20, 30, 40, 50}, optional] *StreamHandler* verbosity level.

file_level

[{10, 20, 30, 40, 50}, optional] *FileHandler* verbosity level.

Returns

None

demo

```
andes.main.demo (**kwargs)
```

TODO: show some demonstrations from CLI.

doc

```
andes.main.doc (attribute=None, list_supported=False, config=False, **kwargs)
```

Quick documentation from command-line.

edit_conf

`andes.main.edit_conf(edit_config: str | bool | None = "")`

Edit the Andes config file which occurs first in the search path.

Parameters

edit_config

[bool] If True, try to open up an editor and edit the config file. Otherwise returns.

Returns

bool

True is a config file is found and an editor is opened. False if edit_config is False.

find_log_path

`andes.main.find_log_path(lg)`

Find the file paths of the FileHandlers.

load

`andes.main.load(case, codegen=False, setup=True, use_input_path=True, **kwargs)`

Load a case and set up a system without running routine. Return a system.

Takes other kwargs recognizable by `System`, such as `addfile`, `input_path`, and `no_output`.

Parameters

case: str

Path to the test case

codegen

[bool, optional] Call full `System.prepare` on the returned system. Set to True if one need to inspect pretty-print equations and run simulations.

setup

[bool, optional] Call `System.setup` after loading

use_input_path

[bool, optional] True to use the `input_path` argument to behave the same as `andes.main.run`.

Warning: If one need to add devices in addition to these from the case file, do `setup=False` and call `System.add()` to add devices. When done, manually invoke `setup()` to set up the system.

misc

```
andes.main.misc(edit_config="", save_config="", show_license=False, clean=True, recursive=False,
               overwrite=None, version=False, **kwargs)
```

Miscellaneous commands.

plot

```
andes.main.plot(*args, **kwargs)
```

Wrapper for the plot tool.

prepare

```
andes.main.prepare(quick=False, incremental=False, models=None, precompile=False, nomp=False,
                  **kwargs)
```

Run code generation.

Parameters

full

[bool] True to run full prep with formatted equations. Useful in interactive mode and during document generation.

ncpu

[int] Number of cores to be used for parallel processing.

cli

[bool] True to indicate running from CLI. It will set *quick* to True if not *full*.

precompile

[bool] True to compile model function calls after code generation.

Returns

System object if *cli* is *False*; *exit_code* 0 otherwise.

Warning: The default behavior has changed since v1.0.8: when *cli* is *True* and *full* is not *True*, quick code generation will be used.

print_license

```
andes.main.print_license()
```

Print out Andes license to stdout.

remove_output

```
andes.main.remove_output (recursive=False)
```

Remove the outputs generated by Andes, including power flow reports `_out.txt`, time-domain list `_out.lst` and data `_out.dat`, eigenvalue analysis report `_eig.txt`.

Parameters

recursive

[bool] Recursively clean all subfolders

Returns

bool

`True` is the function body executes with success. `False` otherwise.

run

```
andes.main.run (filename, input_path="", verbose=20, mp_verbose=30, ncpu=1, pool=False, cli=False,
               codegen=False, shell=False, **kwargs)
```

Entry point to run ANDES routines.

Parameters

filename

[str] file name (or pattern)

input_path

[str, optional] input search path

verbose

[int, 10 (DEBUG), 20 (INFO), 30 (WARNING), 40 (ERROR), 50 (CRITICAL)]
Verbosity level. If `config_logger` is called prior to `run`, this option will be ignored.

mp_verbose

[int] Verbosity level for multiprocessing tasks

ncpu

[int, optional] Number of cpu cores to use in parallel

pool: bool, optional

Use Pool for multiprocessing to return a list of created Systems.

kwargs

Other supported keyword arguments

cli

[bool, optional] If is running from command-line. If True, returns exit code instead of System

codegen

[bool, optional] Run full code generation for System before loading case. Only used for single test case.

shell

[bool, optional] If True, enter IPython shell after routine.

Returns**System or exit_code**

An instance of system (if *cli == False*) or an exit code otherwise..

run_case

```
andes.main.run_case(case, *, routine='pflow', profile=False, convert="", convert_all="",
                    add_book=None, codegen=False, autogen_stale=True,
                    remove_pycapsule=False, **kwargs)
```

Run single simulation case for the given full path. Use `run` instead of `run_case` whenever possible.

Argument `input_path` will not be prepended to `case`.

Arguments recognizable by `load` can be passed to `run_case`.

Parameters**case**

[str] Full path to the test case

routine

[str, ('pflow', 'tds', 'eig')] Computation routine to run

profile

[bool, optional] True to enable profiler

convert

[str, optional] Format name for case file conversion.

convert_all

[str, optional] Format name for case file conversion, output sheets for all available devices.

add_book

[str, optional] Name of the device to be added to an excel case as a new sheet.

codegen

[bool, optional] True to run codegen

autogen_stale

[bool, optional] True to automatically generate code for stale models

remove_pycapsule

[bool, optional] True to remove pycapsule from C libraries. Useful when dill serialization is needed.

save_conf

`andes.main.save_conf (config_path=None, overwrite=None, **kwargs)`

Save the Andes config to a file at the path specified by `save_config`. The save action will not run if `save_config = ''`.

Parameters**config_path**

[None or str, optional, (" by default)] Path to the file to save the config file. If the path is an empty string, the save action will not run. Save to `~/.andes/andes.conf` if None.

Returns**bool**

True is the save action is run. False otherwise.

selftest

`andes.main.selftest (quick=False, extra=False, **kwargs)`

Run unit tests.

set_logger_level

`andes.main.set_logger_level (lg, type_to_set, level)`

Set logging level for the given type of handler.

versioninfo

`andes.main.versioninfo ()`

Print version info for ANDES and dependencies.

6.6.3 andes.utils.paths

Utility functions for loading andes stock test cases

Functions

<code>andes_root()</code>	Return the path to the folder of the ANDES package.
<code>cases_root()</code>	Return the root path to the stock cases
<code>confirm_overwrite(outfile[, overwrite])</code>	Confirm overwriting a file.
<code>get_case(rpath[, check])</code>	Return the path to a stock case for a given path relative to <code>andes/cases</code> .
<code>get_config_path([file_name])</code>	Return the path of the config file to be loaded.
<code>get_dot_andes_path()</code>	Return the path to <code>\$HOME/.andes</code>
<code>get_log_dir()</code>	Get the directory for log file.
<code>get_pycode_path([pycode_path, mkdir])</code>	Get the path to the pycode folder.
<code>list_cases([rpath, no_print])</code>	List stock cases under a given folder relative to <code>andes/cases</code>
<code>tests_root()</code>	Return the root path to the stock cases

andes_root

`andes.utils.paths.andes_root()`
Return the path to the folder of the ANDES package.

cases_root

`andes.utils.paths.cases_root()`
Return the root path to the stock cases

confirm_overwrite

`andes.utils.paths.confirm_overwrite(outfile, overwrite=None)`
Confirm overwriting a file.

get_case

`andes.utils.paths.get_case(rpath, check=True)`

Return the path to a stock case for a given path relative to `andes/cases`.

To list all cases, use `andes.list_cases()`.

Parameters

check

[bool] True to check if file exists

Examples

To get the path to the case *kundur_full.xlsx* under folder *kundur*, do

```
andes.get_case('kundur/kundur_full.xlsx')
```

get_config_path

`andes.utils.paths.get_config_path(file_name='andes.rc')`

Return the path of the config file to be loaded.

Search Priority: 1. current directory; 2. home directory.

Parameters

file_name

[str, optional] Config file name with the default as `andes.rc`.

Returns

Config path in string if found; None otherwise.

get_dot_andes_path

`andes.utils.paths.get_dot_andes_path()`

Return the path to `$HOME/.andes`

get_log_dir

`andes.utils.paths.get_log_dir()`

Get the directory for log file.

The default is `<tempdir>/andes`, where `<tempdir>` is provided by `tempfile.gettempdir()`.

Returns

str

The path to the temporary logging directory

get_pycode_path

`andes.utils.paths.get_pycode_path (pycode_path=None, mkdir=False)`

Get the path to the pycode folder.

list_cases

`andes.utils.paths.list_cases (rpath='.', no_print=False)`

List stock cases under a given folder relative to `andes/cases`

tests_root

`andes.utils.paths.tests_root ()`

Return the root path to the stock cases

Classes

```
DisplayablePath(path, parent_path, is_last)
```

andes.utils.paths.DisplayablePath

class `andes.utils.paths.DisplayablePath (path, parent_path, is_last)`

`__init__ (path, parent_path, is_last)`

Methods

```
displayable()
```

```
make_tree(root[, parent, is_last, criteria])
```

DisplayablePath.displayable

`DisplayablePath.displayable()`

DisplayablePath.make_tree

classmethod `DisplayablePath.make_tree` (*root*, *parent=None*, *is_last=False*,
criteria=None)

Attributes

display_filename_prefix_last

display_filename_prefix_middle

display_parent_prefix_last

display_parent_prefix_middle

displayname

DisplayablePath.display_filename_prefix_last

`DisplayablePath.display_filename_prefix_last = '└─'`

DisplayablePath.display_filename_prefix_middle

`DisplayablePath.display_filename_prefix_middle = '├─'`

DisplayablePath.display_parent_prefix_last

`DisplayablePath.display_parent_prefix_last = '| '`

DisplayablePath.display_parent_prefix_middle

```
DisplayablePath.display_parent_prefix_middle = ' '
```

DisplayablePath.displayname

```
property DisplayablePath.displayname
```

6.6.4 andes.utils.snapshot

Utility functions for saving and loading snapshots.

Code Examples:

1. Setup base case and save the snapshot for once:

```
import andes

ss = andes.run(andes.get_case("ieee14/ieee14_linetrip.xlsx"))
ss.Toggle.u.v[:] = 0 # turn off line trips for the base case
xy = ss.TDS.init()

andes.utils.snapshot.save_ss("ieee14_snapshot.pkl", ss)
```

2. For every scenario afterwards, load the snapshot and apply disturbances:

```
import andes

ss = andes.utils.snapshot.load_ss("ieee14_snapshot.pkl")

# apply specific disturbances
ss.GENROU.omega.v[0] = 1.02

ss.TDS.run()
```

Functions

<code>load_ss(path)</code>	Load an ANDES snapshot and return a System object.
<code>save_ss(path, system)</code>	Save a system with all internal states as a snapshot.

load_ss

`andes.utils.snapshot.load_ss(path)`

Load an ANDES snapshot and return a System object.

Parameters

path

[str] Path to the snapshot file.

Returns

`andes.system.System`

The loaded system object

save_ss

`andes.utils.snapshot.save_ss(path, system)`

Save a system with all internal states as a snapshot.

Returns

Path to the saved snapshot.

Warning: One limitation of the current implementation is version dependency. The snapshots only work with the specific ANDES version that created it.

6.6.5 andes.utils.widgets

Support for Jupyter widgets.

Please manually install the following dependencies:

- `ipywidgets`
- `ipysheet`

If you are using JupyterLab, do

```
jupyter labextension install @jupyter-widgets/jupyterlab-manager
```

Functions

<code>edit_sheet(system, model)</code>	Use ipysheet to edit parameters of one model.
<code>edit_system(system)</code>	Edit a loaded ANDES System with ipywidgets.
<code>on_close(b)</code>	Callback for the Close button.
<code>on_update(b)</code>	Callback for the Update button.

edit_sheet

`andes.utils.widgets.edit_sheet(system, model: str)`

Use ipysheet to edit parameters of one model.

edit_system

`andes.utils.widgets.edit_system(system)`

Edit a loaded ANDES System with ipywidgets.

on_close

`andes.utils.widgets.on_close(b)`

Callback for the Close button. Closes ipywidget objects.

on_update

`andes.utils.widgets.on_update(b)`

Callback for the Update button. Sets new parameters back to System.

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PYTHON MODULE INDEX

a

- `andes.cli`, 882
- `andes.interop`, 873
 - `andes.interop.gridcal`, 873
 - `andes.interop.matpower`, 874
 - `andes.interop.pandapower`, 877
 - `andes.interop.pypowsybl`, 880
- `andes.io`, 862
 - `andes.io.json`, 864
 - `andes.io.matpower`, 865
 - `andes.io.psse`, 867
 - `andes.io.streaming`, 868
 - `andes.io.txt`, 871
 - `andes.io.xlsx`, 871
- `andes.main`, 883
- `andes.plot`, 850
- `andes.routines`, 829
 - `andes.routines.base`, 829
 - `andes.routines.criteria`, 831
 - `andes.routines.daeint`, 831
 - `andes.routines.eig`, 835
 - `andes.routines.pflow`, 842
 - `andes.routines.tds`, 844
- `andes.system`, 797
- `andes.utils.paths`, 890
- `andes.utils.snapshot`, 894
- `andes.utils.widgets`, 895
- `andes.variables`, 814
 - `andes.variables.dae`, 815
 - `andes.variables.fileman`, 826
 - `andes.variables.report`, 827

Symbols

- `__init__()` (*andes.core.discrete.Discrete method*), 368
- `__init__()` (*andes.core.model.Model method*), 279
- `__init__()` (*andes.core.model.ModelCache method*), 290
- `__init__()` (*andes.core.model.ModelCall method*), 291
- `__init__()` (*andes.core.model.ModelData method*), 275
- `__init__()` (*andes.core.param.BaseParam method*), 302
- `__init__()` (*andes.core.param.DataParam method*), 305
- `__init__()` (*andes.core.param.ExtParam method*), 317
- `__init__()` (*andes.core.param.IdxParam method*), 308
- `__init__()` (*andes.core.param.NumParam method*), 313
- `__init__()` (*andes.core.param.TimerParam method*), 320
- `__init__()` (*andes.core.service.BaseService method*), 348
- `__init__()` (*andes.core.service.OperationService method*), 350
- `__init__()` (*andes.core.var.Algeb method*), 333
- `__init__()` (*andes.core.var.AliasAlgeb method*), 343
- `__init__()` (*andes.core.var.AliasState method*), 340
- `__init__()` (*andes.core.var.BaseVar method*), 326
- `__init__()` (*andes.core.var.ExtAlgeb method*), 338
- `__init__()` (*andes.core.var.ExtState method*), 335
- `__init__()` (*andes.core.var.ExtVar method*), 328
- `__init__()` (*andes.core.var.State method*), 331
- `__init__()` (*andes.io.streaming.Streaming method*), 868
- `__init__()` (*andes.models.group.GroupBase method*), 268
- `__init__()` (*andes.plot.TDSDData method*), 853
- `__init__()` (*andes.routines.base.BaseRoutine method*), 829
- `__init__()` (*andes.routines.daeint.BackEuler method*), 832
- `__init__()` (*andes.routines.daeint.ImplicitIter method*), 833
- `__init__()` (*andes.routines.daeint.Trapezoid method*), 834
- `__init__()` (*andes.routines.eig.EIG method*), 835
- `__init__()` (*andes.routines.pflow.PFlow method*), 842
- `__init__()` (*andes.routines.tds.TDS method*), 845
- `__init__()` (*andes.system.ExistingModels method*), 799
- `__init__()` (*andes.system.System method*), 800
- `__init__()` (*andes.utils.paths.DisplayablePath method*), 892
- `__init__()` (*andes.variables.dae.DAE method*), 816
- `__init__()` (*andes.variables.dae.DAETimeSeries method*), 824
- `__init__()` (*andes.variables.fileman.FileMan method*), 826
- `__init__()` (*andes.variables.report.Report method*), 828

A

- `a_reset()` (*andes.core.model.Model method*), 281
- `add()` (*andes.core.model.ModelData method*), 275
- `add()` (*andes.core.param.BaseParam method*), 303

`add()` (*andes.core.param.DataParam method*), 306
`add()` (*andes.core.param.ExtParam method*), 317
`add()` (*andes.core.param.IdxParam method*), 309
`add()` (*andes.core.param.NumParam method*), 314
`add()` (*andes.core.param.TimerParam method*), 321
`add()` (*andes.models.group.GroupBase method*), 269
`add()` (*andes.system.System method*), 802
`add_callback()` (*andes.core.model.ModelCache method*), 291
`add_gencost()` (in module *andes.interop.pandapower*), 877
`add_model()` (*andes.models.group.GroupBase method*), 269
`add_suffix()` (in module *andes.variables.fileman*), 826
`Algeb` (class in *andes.core.var*), 332
`AliasAlgeb` (class in *andes.core.var*), 343
`AliasState` (class in *andes.core.var*), 340
`alloc_or_extend_names()` (*andes.variables.dae.DAE method*), 817
`alter()` (*andes.core.model.Model method*), 281
`andes.cli`
 module, 882
`andes.interop`
 module, 873
`andes.interop.gridcal`
 module, 873
`andes.interop.matpower`
 module, 874
`andes.interop.pandapower`
 module, 877
`andes.interop.pypowsybl`
 module, 880
`andes.io`
 module, 862
`andes.io.json`
 module, 864
`andes.io.matpower`
 module, 865
`andes.io.psse`
 module, 867
`andes.io.streaming`
 module, 868
`andes.io.txt`
 module, 871
`andes.io.xlsx`
 module, 871
`andes.main`
 module, 883
`andes.plot`
 module, 850
`andes.routines`
 module, 829
`andes.routines.base`
 module, 829
`andes.routines.criteria`
 module, 831
`andes.routines.daeint`
 module, 831
`andes.routines.eig`
 module, 835
`andes.routines.pflow`
 module, 842
`andes.routines.tds`
 module, 844
`andes.system`
 module, 797
`andes.utils.paths`
 module, 890
`andes.utils.snapshot`
 module, 894
`andes.utils.widgets`
 module, 895
`andes.variables`
 module, 814
`andes.variables.dae`
 module, 815
`andes.variables.fileman`
 module, 826
`andes.variables.report`
 module, 827
`andes_root()` (in module *andes.utils.paths*), 890
`append_ijv()` (*andes.core.model.ModelCall method*), 292
`as_df()` (*andes.core.model.ModelData method*), 276
`as_df_local()` (*andes.core.model.ModelData method*), 276
`as_dict()` (*andes.core.model.ModelData method*), 276
`as_dict()` (*andes.system.System method*), 802
`assign_memory()` (*andes.core.service.BaseService method*), 348

- `assign_memory()` (*andes.core.service.OperationService* method), 350
- ## B
- `BackEuler` (class in *andes.routines.daeint*), 832
- `BaseParam` (class in *andes.core.param*), 301
- `BaseRoutine` (class in *andes.routines.base*), 829
- `BaseService` (class in *andes.core.service*), 348
- `BaseVar` (class in *andes.core.var*), 325
- `bqplot_data()` (*andes.plot.TDSData* method), 854
- `build_group_table()` (in module *andes.interop.pandapower*), 877
- `build_init()` (*andes.io.streaming.Streaming* method), 869
- `build_pattern()` (*andes.variables.dae.DAE* method), 817
- ## C
- `calc_As()` (*andes.routines.eig.EIG* method), 836
- `calc_eig()` (*andes.routines.eig.EIG* method), 836
- `calc_h()` (*andes.routines.tds.TDS* method), 846
- `calc_jac()` (*andes.routines.daeint.BackEuler* static method), 832
- `calc_jac()` (*andes.routines.daeint.ImplicitIter* static method), 833
- `calc_jac()` (*andes.routines.daeint.Trapezoid* static method), 834
- `calc_pfactor()` (*andes.routines.eig.EIG* method), 836
- `calc_pu_coeff()` (*andes.system.System* method), 803
- `calc_q()` (*andes.routines.daeint.BackEuler* static method), 832
- `calc_q()` (*andes.routines.daeint.ImplicitIter* static method), 833
- `calc_q()` (*andes.routines.daeint.Trapezoid* static method), 834
- `call_models()` (*andes.system.System* method), 803
- `cases_root()` (in module *andes.utils.paths*), 890
- `check_criteria()` (*andes.routines.tds.TDS* method), 846
- `check_eq()` (*andes.core.discrete.Discrete* method), 368
- `check_iter_err()` (*andes.core.discrete.Discrete* method), 368
- `check_var()` (*andes.core.discrete.Discrete* method), 369
- `class_name` (*andes.core.discrete.Discrete* property), 370
- `class_name` (*andes.core.model.Model* property), 290
- `class_name` (*andes.core.param.BaseParam* property), 305
- `class_name` (*andes.core.param.DataParam* property), 308
- `class_name` (*andes.core.param.ExtParam* property), 319
- `class_name` (*andes.core.param.IdxParam* property), 311
- `class_name` (*andes.core.param.NumParam* property), 316
- `class_name` (*andes.core.param.TimerParam* property), 324
- `class_name` (*andes.core.service.BaseService* property), 349
- `class_name` (*andes.core.service.OperationService* property), 351
- `class_name` (*andes.core.var.Algeb* property), 334
- `class_name` (*andes.core.var.AliasAlgeb* property), 345
- `class_name` (*andes.core.var.AliasState* property), 342
- `class_name` (*andes.core.var.BaseVar* property), 327
- `class_name` (*andes.core.var.ExtAlgeb* property), 340
- `class_name` (*andes.core.var.ExtState* property), 337
- `class_name` (*andes.core.var.ExtVar* property), 330
- `class_name` (*andes.core.var.State* property), 332
- `class_name` (*andes.models.group.GroupBase* property), 273
- `class_name` (*andes.routines.base.BaseRoutine* property), 831
- `class_name` (*andes.routines.eig.EIG* property), 841
- `class_name` (*andes.routines.pflow.PFlow* property), 844
- `class_name` (*andes.routines.tds.TDS* property), 850
- `clear_arrays()` (*andes.variables.dae.DAE* method), 817
- `clear_fg()` (*andes.variables.dae.DAE* method), 817
- `clear_ijv()` (*andes.core.model.ModelCall*

method), 292
clear_ijv() (andes.variables.dae.DAE method), 817
clear_ts() (andes.variables.dae.DAE method), 817
clear_xy() (andes.variables.dae.DAE method), 818
clear_z() (andes.variables.dae.DAE method), 818
collect_config() (andes.system.System method), 803
collect_ref() (andes.system.System method), 804
config_logger() (in module andes.main), 884
confirm_overwrite() (in module andes.utils.paths), 890
connect() (andes.io.streaming.Streaming method), 869
connectivity() (andes.system.System method), 804
create_parser() (in module andes.cli), 882

D

DAE (class in andes.variables.dae), 815
DAETimeSeries (class in andes.variables.dae), 824
data_to_df() (andes.plot.TDSData method), 854
DataParam (class in andes.core.param), 305
deltadelta() (in module andes.routines.criteria), 831
demo() (in module andes.main), 884
df (andes.variables.dae.DAETimeSeries property), 826
Discrete (class in andes.core.discrete), 368
display_filename_prefix_last (andes.utils.paths.DisplayablePath attribute), 893
display_filename_prefix_middle (andes.utils.paths.DisplayablePath attribute), 893
display_parent_prefix_last (andes.utils.paths.DisplayablePath attribute), 893
display_parent_prefix_middle (andes.utils.paths.DisplayablePath attribute), 894
displayable() (andes.utils.paths.DisplayablePath method),

893
DisplayablePath (class in andes.utils.paths), 892
displayname (andes.utils.paths.DisplayablePath property), 894
do_switch() (andes.routines.tds.TDS method), 846
doc() (andes.core.model.Model method), 281
doc() (andes.models.group.GroupBase method), 270
doc() (andes.routines.base.BaseRoutine method), 830
doc() (andes.routines.eig.EIG method), 837
doc() (andes.routines.pflow.PFlow method), 842
doc() (andes.routines.tds.TDS method), 846
doc() (in module andes.main), 884
doc_all() (andes.models.group.GroupBase method), 270
dump() (in module andes.io), 862
dump_data() (in module andes.io.txt), 871

E

e_clear() (andes.core.model.Model method), 281
e_clear() (andes.system.System method), 804
e_code (andes.core.var.Algeb attribute), 334
e_code (andes.core.var.AliasAlgeb attribute), 345
e_code (andes.core.var.AliasState attribute), 342
e_code (andes.core.var.ExtAlgeb attribute), 340
e_code (andes.core.var.ExtState attribute), 337
e_code (andes.core.var.State attribute), 332
edit_conf() (in module andes.main), 885
edit_sheet() (in module andes.utils.widgets), 896
edit_system() (in module andes.utils.widgets), 896
EIG (class in andes.routines.eig), 835
eig_plot() (in module andes.plot), 850
example() (in module andes.system), 797
ExistingModels (class in andes.system), 799
export_csv() (andes.plot.TDSData method), 854
export_mat() (andes.routines.eig.EIG method), 837
ExtAlgeb (class in andes.core.var), 338
externalize() (andes.core.model.Model method), 282
ExtParam (class in andes.core.param), 316
ExtState (class in andes.core.var), 335
ExtVar (class in andes.core.var), 327

F

`f_numeric()` (*andes.core.model.Model* method), 282
`f_update()` (*andes.core.model.Model* method), 282
`f_update()` (*andes.system.System* method), 804
`fg` (*andes.variables.dae.DAE* property), 822
`fg_to_dae()` (*andes.system.System* method), 804
`fg_update()` (*andes.routines.pflow.PFlow* method), 843
`fg_update()` (*andes.routines.tds.TDS* method), 847
`FileMan` (class in *andes.variables.fileman*), 826
`finalize()` (*andes.io.streaming.Streaming* method), 869
`find()` (*andes.plot.TDSData* method), 855
`find_devices()` (*andes.system.System* method), 805
`find_idx()` (*andes.core.model.ModelData* method), 276
`find_idx()` (*andes.models.group.GroupBase* method), 270
`find_log_path()` (in module *andes.main*), 885
`find_models()` (*andes.system.System* method), 805
`find_param()` (*andes.core.model.ModelData* method), 277
`find_zero_states()` (*andes.routines.eig.EIG* method), 837
`fix_view_arrays()` (in module *andes.system*), 798
`from_ipysheet()` (*andes.system.System* method), 805
`from_matpower()` (in module *andes.interop.matpower*), 875

G

`g_islands()` (*andes.system.System* method), 805
`g_numeric()` (*andes.core.model.Model* method), 282
`g_update()` (*andes.core.model.Model* method), 282
`g_update()` (*andes.system.System* method), 806
`get()` (*andes.core.model.Model* method), 282
`get()` (*andes.models.group.GroupBase* method), 270
`get_block_lines()` (in module *andes.io.psse*), 867

`get_call()` (*andes.plot.TDSData* method), 855
`get_case()` (in module *andes.utils.paths*), 891
`get_config_path()` (in module *andes.utils.paths*), 891
`get_data()` (*andes.variables.dae.DAETimeSeries* method), 824
`get_dot_andes_path()` (in module *andes.utils.paths*), 891
`get_field()` (*andes.models.group.GroupBase* method), 271
`get_fullpath()` (*andes.variables.fileman.FileMan* method), 827
`get_header()` (*andes.plot.TDSData* method), 855
`get_init_order()` (*andes.core.model.Model* method), 283
`get_inputs()` (*andes.core.model.Model* method), 283
`get_log_dir()` (in module *andes.utils.paths*), 891
`get_md5()` (*andes.core.model.Model* method), 284
`get_name()` (*andes.variables.dae.DAE* method), 818
`get_names()` (*andes.core.discrete.Discrete* method), 369
`get_names()` (*andes.core.param.BaseParam* method), 303
`get_names()` (*andes.core.param.DataParam* method), 306
`get_names()` (*andes.core.param.ExtParam* method), 317
`get_names()` (*andes.core.param.IdxParam* method), 309
`get_names()` (*andes.core.param.NumParam* method), 314
`get_names()` (*andes.core.param.TimerParam* method), 321
`get_names()` (*andes.core.service.BaseService* method), 349
`get_names()` (*andes.core.service.OperationService* method), 350
`get_names()` (*andes.core.var.Algeb* method), 333
`get_names()` (*andes.core.var.AliasAlgeb* method), 343
`get_names()` (*andes.core.var.AliasState* method), 341
`get_names()` (*andes.core.var.BaseVar* method), 326
`get_names()` (*andes.core.var.ExtAlgeb* method),

- 339
get_names() (*andes.core.var.ExtState* method), 336
get_names() (*andes.core.var.ExtVar* method), 329
get_names() (*andes.core.var.State* method), 331
get_next_idx() (*andes.models.group.GroupBase* method), 271
get_output_ext() (*in module andes.io*), 862
get_property() (*andes.core.param.BaseParam* method), 304
get_property() (*andes.core.param.DataParam* method), 307
get_property() (*andes.core.param.ExtParam* method), 318
get_property() (*andes.core.param.IdxParam* method), 310
get_property() (*andes.core.param.NumParam* method), 314
get_property() (*andes.core.param.TimerParam* method), 322
get_pycode_path() (*in module andes.utils.paths*), 892
get_size() (*andes.variables.dae.DAE* method), 818
get_tex_names() (*andes.core.discrete.Discrete* method), 369
get_times() (*andes.core.model.Model* method), 284
get_values() (*andes.core.discrete.Discrete* method), 370
get_values() (*andes.plot.TDSData* method), 856
get_z() (*andes.system.System* method), 806
GroupBase (*class in andes.models.group*), 268
guess() (*in module andes.io*), 863
guess_event_time() (*andes.plot.TDSData* method), 856
- ## H
- handle_alter() (*andes.io.streaming.Streaming* method), 870
handle_event() (*andes.io.streaming.Streaming* method), 870
- ## I
- idx2model() (*andes.models.group.GroupBase* method), 271
idx2uid() (*andes.core.model.Model* method), 284
idx2uid() (*andes.models.group.GroupBase* method), 272
IdxParam (*class in andes.core.param*), 308
ImplicitIter (*class in andes.routines.daeint*), 833
import_groups() (*andes.system.System* method), 806
import_models() (*andes.system.System* method), 806
import_pycode() (*in module andes.system*), 798
import_routines() (*andes.system.System* method), 807
info (*andes.variables.report.Report* property), 829
init() (*andes.core.model.Model* method), 284
init() (*andes.routines.base.BaseRoutine* method), 830
init() (*andes.routines.eig.EIG* method), 837
init() (*andes.routines.pflow.PFlow* method), 843
init() (*andes.routines.tds.TDS* method), 847
init() (*andes.system.System* method), 807
init_resume() (*andes.routines.tds.TDS* method), 847
internalize() (*andes.core.model.Model* method), 284
is_time() (*andes.core.param.TimerParam* method), 322
itm_step() (*andes.routines.tds.TDS* method), 847
- ## J
- j_islands() (*andes.system.System* method), 807
j_numeric() (*andes.core.model.Model* method), 285
j_update() (*andes.core.model.Model* method), 285
j_update() (*andes.system.System* method), 807
- ## L
- l_check_eq() (*andes.core.model.Model* method), 285
l_update_eq() (*andes.system.System* method), 808
l_update_var() (*andes.core.model.Model* method), 285
l_update_var() (*andes.system.System* method), 808
link_ext_param() (*andes.system.System* method), 808

- `link_external()` (*andes.core.param.ExtParam method*), 318
`link_external()` (*andes.core.var.AliasAlgeb method*), 344
`link_external()` (*andes.core.var.AliasState method*), 341
`link_external()` (*andes.core.var.ExtAlgeb method*), 339
`link_external()` (*andes.core.var.ExtState method*), 336
`link_external()` (*andes.core.var.ExtVar method*), 329
`list2array()` (*andes.core.discrete.Discrete method*), 370
`list2array()` (*andes.core.model.Model method*), 286
`list_cases()` (*in module andes.utils.paths*), 892
`load()` (*in module andes.main*), 885
`load_config_rc()` (*in module andes.system*), 798
`load_dae()` (*andes.plot.TDSData method*), 856
`load_lst()` (*andes.plot.TDSData method*), 856
`load_npy_or_csv()` (*andes.plot.TDSData method*), 856
`load_plotter()` (*andes.routines.tds.TDS method*), 848
`load_ss()` (*in module andes.utils.snapshot*), 895
- ## M
- `m2mpc()` (*in module andes.io.matpower*), 865
`main()` (*in module andes.cli*), 883
`make_GSF()` (*in module andes.interop.pandapower*), 878
`make_link_table()` (*in module andes.interop.pandapower*), 878
`make_tree()` (*andes.utils.paths.DisplayablePath class method*), 893
`misc()` (*in module andes.main*), 886
`mock_refresh_inputs()` (*andes.core.model.Model method*), 286
`Model` (*class in andes.core.model*), 277
`ModelCache` (*class in andes.core.model*), 290
`ModelCall` (*class in andes.core.model*), 291
`ModelData` (*class in andes.core.model*), 274
`module`
 `andes.cli`, 882
 `andes.interop`, 873
 `andes.interop.gridcal`, 873
 `andes.interop.matpower`, 874
 `andes.interop.pandapower`, 877
 `andes.interop.pypowsybl`, 880
 `andes.io`, 862
 `andes.io.json`, 864
 `andes.io.matpower`, 865
 `andes.io.psse`, 867
 `andes.io.streaming`, 868
 `andes.io.txt`, 871
 `andes.io.xlsx`, 871
 `andes.main`, 883
 `andes.plot`, 850
 `andes.routines`, 829
 `andes.routines.base`, 829
 `andes.routines.criteria`, 831
 `andes.routines.daeint`, 831
 `andes.routines.eig`, 835
 `andes.routines.pflow`, 842
 `andes.routines.tds`, 844
 `andes.system`, 797
 `andes.utils.paths`, 890
 `andes.utils.snapshot`, 894
 `andes.utils.widgets`, 895
 `andes.variables`, 814
 `andes.variables.dae`, 815
 `andes.variables.fileman`, 826
 `andes.variables.report`, 827
`mpc2system()` (*in module andes.io.matpower*), 866
- ## N
- `n` (*andes.core.param.BaseParam property*), 305
`n` (*andes.core.param.DataParam property*), 308
`n` (*andes.core.param.ExtParam property*), 320
`n` (*andes.core.param.IdxParam property*), 311
`n` (*andes.core.param.NumParam property*), 316
`n` (*andes.core.param.TimerParam property*), 324
`n` (*andes.core.service.BaseService property*), 349
`n` (*andes.core.service.OperationService property*), 351
`n` (*andes.models.group.GroupBase property*), 273
`newton_krylov()` (*andes.routines.pflow.PFlow method*), 843
`nr_solve()` (*andes.routines.pflow.PFlow method*), 843
`nr_step()` (*andes.routines.pflow.PFlow method*), 843
`numba_jitify()` (*andes.core.model.Model method*), 286

NumParam (class in *andes.core.param*), 311

O

on_close() (in module *andes.utils.widgets*), 896
on_update() (in module *andes.utils.widgets*), 896
OperationService (class in *andes.core.service*), 349

P

panoview() (*andes.plot.TDSData* method), 857
parse() (in module *andes.io*), 863
parse_y() (in module *andes.plot*), 851
PFlow (class in *andes.routines.pflow*), 842
plot() (*andes.plot.TDSData* method), 857
plot() (*andes.routines.eig.EIG* method), 837
plot() (in module *andes.main*), 886
plot_data() (*andes.plot.TDSData* method), 860
plot_root_loci() (*andes.routines.eig.EIG* method), 839
plotn() (*andes.plot.TDSData* method), 861
post_init_check() (*andes.core.model.Model* method), 286
post_process() (*andes.routines.eig.EIG* method), 840
preamble() (in module *andes.cli*), 883
precompile() (*andes.core.model.Model* method), 286
precompile() (*andes.system.System* method), 808
prepare() (*andes.core.model.Model* method), 286
prepare() (*andes.system.System* method), 808
prepare() (in module *andes.main*), 886
print_array() (*andes.variables.dae.DAE* method), 818
print_license() (in module *andes.main*), 887

R

r_code (*andes.core.var.AliasAlgeb* attribute), 345
r_code (*andes.core.var.AliasState* attribute), 342
r_code (*andes.core.var.ExtAlgeb* attribute), 340
r_code (*andes.core.var.ExtState* attribute), 337
read() (in module *andes.io.json*), 864
read() (in module *andes.io.matpower*), 866
read() (in module *andes.io.psse*), 867
read() (in module *andes.io.xlsx*), 872
read_add() (in module *andes.io.psse*), 867
read_file_like() (in module *andes.io*), 863
record_module_init() (*andes.io.streaming.Streaming* method), 870

refresh() (*andes.core.model.ModelCache* method), 291
refresh_inputs() (*andes.core.model.Model* method), 287
refresh_inputs_arg() (*andes.core.model.Model* method), 287
register_debug_equation() (*andes.core.model.Model* method), 287
reload() (*andes.system.System* method), 809
reload_submodules() (in module *andes.system*), 799
remove_output() (in module *andes.main*), 887
remove_pycapsule() (*andes.system.System* method), 809
Report (class in *andes.variables.report*), 828
report() (*andes.routines.base.BaseRoutine* method), 830
report() (*andes.routines.eig.EIG* method), 840
report() (*andes.routines.pflow.PFlow* method), 844
report() (*andes.routines.tds.TDS* method), 848
report_info() (in module *andes.variables.report*), 827
request_address() (*andes.variables.dae.DAE* method), 819
require_gridcal() (in module *andes.interop.gridcal*), 874
require_matpower() (in module *andes.interop.matpower*), 876
require_pandapower() (in module *andes.interop.pandapower*), 879
require_pypowsybl() (in module *andes.interop.pypowsybl*), 881
reset() (*andes.core.var.Algeb* method), 333
reset() (*andes.core.var.AliasAlgeb* method), 344
reset() (*andes.core.var.AliasState* method), 341
reset() (*andes.core.var.BaseVar* method), 326
reset() (*andes.core.var.ExtAlgeb* method), 339
reset() (*andes.core.var.ExtState* method), 336
reset() (*andes.core.var.ExtVar* method), 329
reset() (*andes.core.var.State* method), 331
reset() (*andes.routines.tds.TDS* method), 848
reset() (*andes.system.System* method), 810
reset() (*andes.variables.dae.DAE* method), 819
reset() (*andes.variables.dae.DAETimeSeries* method), 825
resize_arrays() (*andes.variables.dae.DAE* method), 819

- `restore()` (*andes.core.param.ExtParam* method), 318
`restore()` (*andes.core.param.NumParam* method), 315
`restore()` (*andes.core.param.TimerParam* method), 322
`restore_sparse()` (*andes.variables.dae.DAE* method), 820
`rewind()` (*andes.routines.tds.TDS* method), 848
`run()` (*andes.routines.base.BaseRoutine* method), 830
`run()` (*andes.routines.eig.EIG* method), 840
`run()` (*andes.routines.pflow.PFlow* method), 844
`run()` (*andes.routines.tds.TDS* method), 848
`run()` (in module *andes.main*), 887
`run_case()` (in module *andes.main*), 888
`runopp_map()` (in module *andes.interop.pandapower*), 879
- ## S
- `s_numeric()` (*andes.core.model.Model* method), 287
`s_numeric_var()` (*andes.core.model.Model* method), 287
`s_update()` (*andes.core.model.Model* method), 287
`s_update_post()` (*andes.core.model.Model* method), 288
`s_update_post()` (*andes.system.System* method), 810
`s_update_var()` (*andes.core.model.Model* method), 288
`s_update_var()` (*andes.system.System* method), 810
`save_conf()` (in module *andes.main*), 889
`save_config()` (*andes.system.System* method), 810
`save_output()` (*andes.routines.tds.TDS* method), 848
`save_ss()` (in module *andes.utils.snapshot*), 895
`selftest()` (in module *andes.main*), 889
`send_init()` (*andes.io.streaming.Streaming* method), 870
`set()` (*andes.core.model.Model* method), 288
`set()` (*andes.core.param.BaseParam* method), 304
`set()` (*andes.core.param.DataParam* method), 307
`set()` (*andes.core.param.ExtParam* method), 318
`set()` (*andes.core.param.IdxParam* method), 310
`set()` (*andes.core.param.NumParam* method), 315
`set()` (*andes.core.param.TimerParam* method), 323
`set()` (*andes.models.group.GroupBase* method), 272
`set()` (*andes.variables.fileman.FileMan* method), 827
`set_address()` (*andes.core.var.Algeb* method), 334
`set_address()` (*andes.core.var.AliasAlgeb* method), 344
`set_address()` (*andes.core.var.AliasState* method), 342
`set_address()` (*andes.core.var.BaseVar* method), 326
`set_address()` (*andes.core.var.ExtAlgeb* method), 339
`set_address()` (*andes.core.var.ExtState* method), 336
`set_address()` (*andes.core.var.ExtVar* method), 329
`set_address()` (*andes.core.var.State* method), 331
`set_address()` (*andes.system.System* method), 811
`set_all()` (*andes.core.param.BaseParam* method), 304
`set_all()` (*andes.core.param.DataParam* method), 307
`set_all()` (*andes.core.param.ExtParam* method), 319
`set_all()` (*andes.core.param.IdxParam* method), 310
`set_all()` (*andes.core.param.NumParam* method), 315
`set_all()` (*andes.core.param.TimerParam* method), 323
`set_arrays()` (*andes.core.var.Algeb* method), 334
`set_arrays()` (*andes.core.var.AliasAlgeb* method), 344
`set_arrays()` (*andes.core.var.AliasState* method), 342
`set_arrays()` (*andes.core.var.BaseVar* method), 327
`set_arrays()` (*andes.core.var.ExtAlgeb* method), 339
`set_arrays()` (*andes.core.var.ExtState* method), 336

- `set_arrays()` (*andes.core.var.ExtVar* method), 329
- `set_arrays()` (*andes.core.var.State* method), 332
- `set_backref()` (*andes.core.model.Model* method), 288
- `set_backref()` (*andes.models.group.GroupBase* method), 273
- `set_config()` (*andes.system.System* method), 811
- `set_dae_names()` (*andes.system.System* method), 811
- `set_font()` (in module *andes.plot*), 851
- `set_in_use()` (*andes.core.model.Model* method), 289
- `set_latex()` (in module *andes.plot*), 851
- `set_logger_level()` (in module *andes.main*), 889
- `set_method()` (*andes.routines.tds.TDS* method), 849
- `set_output_subidx()` (*andes.system.System* method), 811
- `set_pu_coeff()` (*andes.core.param.ExtParam* method), 319
- `set_pu_coeff()` (*andes.core.param.NumParam* method), 315
- `set_pu_coeff()` (*andes.core.param.TimerParam* method), 323
- `set_style()` (in module *andes.plot*), 852
- `set_t()` (*andes.variables.dae.DAE* method), 820
- `set_var_arrays()` (*andes.system.System* method), 811
- `setup()` (*andes.system.System* method), 812
- `solve_iter()` (*andes.core.model.Model* method), 289
- `solve_iter_single()` (*andes.core.model.Model* method), 289
- `sort_psse_models()` (in module *andes.io.psse*), 868
- State* (class in *andes.core.var*), 330
- `stats()` (*andes.routines.eig.EIG* method), 840
- `step()` (*andes.routines.daeint.BackEuler* static method), 832
- `step()` (*andes.routines.daeint.ImplicitIter* static method), 833
- `step()` (*andes.routines.daeint.Trapezoid* static method), 834
- `store()` (*andes.variables.dae.DAE* method), 820
- `store_adder_setter()` (*andes.system.System* method), 812
- `store_existing()` (*andes.system.System* method), 812
- `store_no_check_init()` (*andes.system.System* method), 812
- `store_sparse_ijv()` (*andes.variables.dae.DAE* method), 820
- `store_sparse_pattern()` (*andes.core.model.Model* method), 289
- `store_sparse_pattern()` (*andes.system.System* method), 812
- `store_switch_times()` (*andes.system.System* method), 813
- Streaming* (class in *andes.io.streaming*), 868
- `streaming_init()` (*andes.routines.tds.TDS* method), 849
- `streaming_step()` (*andes.routines.tds.TDS* method), 849
- `summary()` (*andes.routines.base.BaseRoutine* method), 830
- `summary()` (*andes.routines.eig.EIG* method), 840
- `summary()` (*andes.routines.pflow.PFlow* method), 844
- `summary()` (*andes.routines.tds.TDS* method), 849
- `summary()` (*andes.system.System* method), 813
- `supported_models()` (*andes.system.System* method), 813
- `sweep()` (*andes.routines.eig.EIG* method), 840
- `switch_action()` (*andes.core.model.Model* method), 290
- `switch_action()` (*andes.system.System* method), 813
- `sync_and_handle()` (*andes.io.streaming.Streaming* method), 870
- System* (class in *andes.system*), 799
- `system2mpc()` (in module *andes.io.matpower*), 866
- ## T
- `t_const` (*andes.core.var.AliasState* attribute), 343
- `t_const` (*andes.core.var.ExtState* attribute), 337
- TDS* (class in *andes.routines.tds*), 845
- TDSData* (class in *andes.plot*), 853
- `tdsplot()` (in module *andes.plot*), 852
- `test_init()` (*andes.routines.tds.TDS* method), 849
- `testlines()` (in module *andes.io.json*), 864
- `testlines()` (in module *andes.io.matpower*), 866
- `testlines()` (in module *andes.io.psse*), 868

- `testlines()` (in module `andes.io.xlsx`), 872
`tests_root()` (in module `andes.utils.paths`), 892
`TimerParam` (class in `andes.core.param`), 320
`to_array()` (`andes.core.param.ExtParam` method), 319
`to_array()` (`andes.core.param.NumParam` method), 316
`to_array()` (`andes.core.param.TimerParam` method), 324
`to_gridcal()` (in module `andes.interop.gridcal`), 874
`to_ipysheet()` (`andes.system.System` method), 814
`to_matpower()` (in module `andes.interop.matpower`), 876
`to_pandapower()` (in module `andes.interop.pandapower`), 879
`to_pypowsybl()` (in module `andes.interop.pypowsybl`), 881
`transpose_matlab_row()` (`andes.io.streaming.Streaming` static method), 870
`Trapezoid` (class in `andes.routines.daeint`), 834
- ## U
- `undill()` (`andes.system.System` method), 814
`unpack()` (`andes.variables.dae.DAETimeSeries` method), 825
`unpack_df()` (`andes.variables.dae.DAETimeSeries` method), 825
`unpack_np()` (`andes.variables.dae.DAETimeSeries` method), 825
`update()` (`andes.variables.report.Report` method), 828
`update_from_df()` (`andes.core.model.ModelData` method), 277
- ## V
- `v` (`andes.core.service.OperationService` property), 351
`v_code` (`andes.core.var.Algeb` attribute), 335
`v_code` (`andes.core.var.AliasAlgeb` attribute), 345
`v_code` (`andes.core.var.AliasState` attribute), 343
`v_code` (`andes.core.var.ExtAlgeb` attribute), 340
`v_code` (`andes.core.var.ExtState` attribute), 337
`v_code` (`andes.core.var.State` attribute), 332
`v_numeric()` (`andes.core.model.Model` method), 290
`vars_to_dae()` (`andes.system.System` method), 814
`vars_to_models()` (`andes.system.System` method), 814
`vars_to_modules()` (`andes.io.streaming.Streaming` method), 870
`vars_to_pmu()` (`andes.io.streaming.Streaming` method), 871
`versioninfo()` (in module `andes.main`), 889
- ## W
- `warn_init_limit()` (`andes.core.discrete.Discrete` method), 370
`write()` (`andes.variables.report.Report` method), 828
`write()` (in module `andes.io.json`), 864
`write()` (in module `andes.io.xlsx`), 872
`write_lst()` (`andes.variables.dae.DAE` method), 821
`write_npz()` (`andes.variables.dae.DAE` method), 821
`write_npz()` (`andes.variables.dae.DAE` method), 821
- ## X
- `x_name_output` (`andes.variables.dae.DAE` property), 822
`x_tex_name_output` (`andes.variables.dae.DAE` property), 822
`xy` (`andes.variables.dae.DAE` property), 823
`xy_name` (`andes.variables.dae.DAE` property), 823
`xy_tex_name` (`andes.variables.dae.DAE` property), 823
`xyz` (`andes.variables.dae.DAE` property), 823
`xyz_name` (`andes.variables.dae.DAE` property), 823
`xyz_tex_name` (`andes.variables.dae.DAE` property), 823
- ## Y
- `y_name_output` (`andes.variables.dae.DAE` property), 823
`y_tex_name_output` (`andes.variables.dae.DAE` property), 824
- ## Z
- `zip_ijv()` (`andes.core.model.ModelCall` method), 292