ANDES Manual

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ANDES Manual

ANDES is a Python-based free software package for power system simulation, control and analysis. It establishes a unique **hybrid symbolic-numeric framework** for modeling differential algebraic equations (DAEs) for numerical analysis. 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
- comes with the Newton method for power flow calculation, the implicit trapezoidal method for time-domain simulation, and full eigenvalue calculation
- strictly 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
- an 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

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

CHAPTER 1

Installation

ANDES can be installed in Python 3.6+. Please follow the installation guide carefully.

1.1 Environment

1.1.1 Setting Up Miniconda

We recommend the Miniconda distribution that includes the conda package manager and Python. Downloaded and install the latest Miniconda (x64, with Python 3) from https://conda.io/miniconda.html.

Step 1: Open terminal (on Linux or maxOS) or *Anaconda Prompt* (on Windows, **not the cmd program!!**). Make sure you are in a conda environment - you should see `(base)` prepended to the command-line prompt, such as `(base) C:\Users\user>`.

Create a conda environment for ANDES (recommended)

```
conda create --name andes python=3.7
```

Activate the new environment with

```
conda activate andes
```

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

Step 2: Add the `conda-forge` channel and set it as default

```
conda config --add channels conda-forge
conda config --set channel_priority flexible
```

If these steps complete without an error, continue to *Install Andes*.

1.1.2 Existing Python Environment (Advanced)

This is for advanced user only and is **not recommended on Microsoft Windows**. Please skip it if you have set up a Conda environment.

Instead of using Conda, if you prefer an existing Python environment, you can install ANDES with *pip*:

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

If you see a *Permission denied* error, you will need to install the packages locally with *–user*

1.2 Install ANDES

ANDES can be installed in the user mode and the development mode.

- If you want to use ANDES without modifying the source code, install it in the *User Mode*.
- If you want to develop models or routine, install it in the *Development Mode*.

1.2.1 User Mode

In the Anaconda environment, run

```
conda install andes
```

You will be prompted to confirm the installation,

This command installs ANDES into the active environment, which should be called `andes` if you followed all the above steps.

Note: To use `andes`, you will need to activate the `andes` environment every time in a new Anaconda Prompt or shell.

1.2.2 Development Mode

This is for users who want to hack into the code and, for example, develop new models or routines. The usage of ANDES is the same in development mode as in user mode. In addition, 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:

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

In this way, you can easily update to the latest source code using `git`.

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 this will work, this is not recommended since tracking changes and pushing back code would be painful.

Step 2: Install dependencies

In the Anaconda environment, use `cd` to change directory to the ANDES root folder.

Install dependencies with

```
conda install --file requirements.txt
conda install --file requirements-dev.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.

1.3 Updating ANDES

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 conda (most common for users), run

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

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

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

If you installed ANDES from source code, and the source was cloned using `git`, you can use `git pull` to pull in changes from remote. However, if your source code was downloaded, you will have to download the new source code again and manually overwrite the existing one.

In rare cases, after updating the source code, command-line `andes` will complain about missing dependency. If this ever happens, it means the new ANDES has introduced new dependencies. In such cases, reinstall andes in the development mode to fix. Change directory to the ANDES source code folder that contains `setup.py` and run

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

1.4 Performance Packages

Note: Performance packages can be safely skipped and will not affect the functionality of ANDES.

1.4.1 KVXOPT

KVXOPT is a fork of the CVXOPT with KLU by Uriel Sandoval (@sanurielf). KVXOPT interfaces to KLU, which is roughly 20% faster than UMFPACK for circuit simulations based on our testing.

KVXOPT contains inplace add and set functions for sparse matrix contributed by CURENT. These inplace functions significantly speed up large-scale system simulations.

To install `KVXOPT` run

```
python -m pip install kvxopt
```

CHAPTER 2

Tutorial

ANDES can be used as a command-line tool or a library. The command-line interface (CLI) comes 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 cheat sheet if you are looking for quick help.

2.1 Command Line Usage

2.1.1 Basic Usage

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 and help commands:

```
    _           _         | Version 1.1.2
   /_\  _ _  __| |___ ___ | Python 3.7.6 on Linux, 09/05/2020 12:23:05 PM
  / _ \| ' \/ _` / -_|_-< |
 /_/ \_\_||_\__,_\___/__/ | This program comes with ABSOLUTELY NO WARRANTY.

usage: andes [-h] [-v {1,10,20,30,40,50}]
             {run,plot,doc,misc,prepare,selftest} ...

positional arguments:
  {run,plot,doc,misc,prepare,selftest}
                        [run] run simulation routine; [plot] plot simulation
                        results; [doc] quick documentation; [prepare] run the
                        symbolic-to-numeric preparation; [misc] miscellaneous
                        functions.
```

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```
optional arguments:
  -h, --help            show this help message and exit
  -v {1,10,20,30,40,50}, --verbose {1,10,20,30,40,50}
                        Program logging level in 10-DEBUG, 20-INFO,
                        30-WARNING, 40-ERROR or 50-CRITICAL.
```

Note: If the `andes` command is not found, check if (1) the installation was successful, and (2) you have activated the environment where ANDES is installed.

The first level of commands are chosen from `{run,plot,misc,prepare,selftest}`. Each command contains a group of sub-commands, which can be looked up with `-h`. For example, use `andes run -h` to look up the sub-commands in `run`. The most commonly used commands will be explained in the following.

`andes` has an option for the program verbosity level, controlled by `-v` or `--verbose`. Accepted levels are the same as in the `logging` module: 10 - DEBUG, 20 - INFO, 30 - WARNING, 40 - ERROR, 50 - CRITICAL. To show debugging outputs, use `-v 10`.

2.1.2 andes selftest

After installation, it is encouraged to use `andes selftest` from the command line to test 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
test_alter_param (test_case.Test5Bus) ... ok
...
... (outputs are omitted)
...
test_pflow_mpc (test_pflow_matpower.TestMATPOWER) ... ok

----------------------------------------------------------------------
Ran 23 tests in 13.834s

OK
```

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

Warning: ANDES is getting updates frequently. After updating your copy, please run `andes selftest` 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.

2.1.3 andes prepare

The symbolically defined models in ANDES need to be generated into numerical code for simulation. The code generation can be manually called with `andes prepare`. Generated code are stored in the folder `.andes/calls.pkl` in your home directory. In addition, `andes selftest` implicitly calls the code generation. If you are using ANDES as a package in the user mode, you won't need to call it again.

Option `-q` or `--quick` (enabled by default) can be used to speed up the code generation. It skips the generation of LaTeX-formatted equations, which are only used in documentation and the interactive mode.

For developers, `andes prepare` needs to be called immediately following any model equation modification. Otherwise, simulation results will not reflect the new equations and will likely lead to an error. Option `-i` or `--incremental`, instead of `-q`, can be used to further speed up the code generation during model development. `andes prepare -i` only generates code for models with modified equations.

2.1.4 andes run

`andes run` is the entry point for power system analysis routines. `andes run` takes one positional argument, `filename` , along with other optional keyword arguments. `filename` is the test case path, either relative or absolute. Without other options, ANDES will run power flow calculation for the provided file.

Routine

Option `-r` or `-routine` is used for specifying the analysis routine, followed by the routine name. Available routine names include `pflow, tds, eig`. *pflow* for power flow, *tds* for time domain simulation, and *eig* for eigenvalue analysis. *pflow* is default even if `-r` is not given.

For example, to run time-domain simulation for `kundur_full.xlsx` in the *current directory*, run

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

The file is located at `andes/cases/kundur/kundur_full.xlsx` relative to the source code root folder. Use `cd` to change directory to that folder on your machine.

Two output files, `kundur_full_out.lst` and `kundur_full_out.npy` will be created for variable names and values, respectively.

Likewise, to run eigenvalue analysis for `kundur_full.xlsx`, use

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

The eigenvalue report will be written in a text file named `kundur_full_eig.txt`.

Power flow

To perform a power flow study for test case named `kundur_full.xlsx` in the current directory, run

```
andes run kundur_full.xlsx
```

The full path to the case file is also accepted, for example,

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

Power flow reports will be saved to the current directory in which andes is called. The power flow report contains four sections: a) system statistics, b) ac bus and dc node data, c) ac line data, and d) the initialized values of other algebraic variables and state variables.

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 </Users/user/repos/andes/tests/kundur_full.xlsx>
Input file kundur_full.xlsx parsed in 0.5425 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 0.0080 second.
Report saved to </Users/user/repos/andes/tests/kundur_full_out.txt> in 0.0036␣
↪second.
-> Time Domain Simulation:
Initialization tests passed.
Initialization successful in 0.0152 second.
  0%|                                                      | 0/100 [00:00<?, ?%/
↪s]
  <Toggle 0>: Applying status toggle on Line idx=Line_8
100%|----------------------------| 100/100 [00:03<00:00, 28.99%/s]
Simulation completed in 3.4500 seconds.
TDS outputs saved in 0.0377 second.
-> Single process finished in 4.4310 seconds.
```

This execution first solves the power flow as a starting point. Next, the numerical integration simulates 20 seconds, during which a predefined breaker opens at 2 seconds.

TDS produces two output files by default: a NumPy data file `ieee14_syn_out.npy` and a variable name list file `ieee14_syn_out.lst`. The list file contains 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.

Disable output

The output files can be disabled with option `--no-output` or `-n`. It is useful when only computation is needed without saving the results.

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.

Multiprocessing

ANDES takes multiple files inputs or wildcard. Multiprocessing will be triggered if more than one valid input files are found. For example, to run power flow for files with a prefix of `case5` and a suffix (file extension) of `.m`, run

```
andes run case5*.m
```

Test cases that match the pattern, including `case5.m` and `case57.m`, 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 operation system responsiveness.

Format converter

ANDES recognizes a few input formats and can convert input systems into the `xlsx` format. This function is useful when one wants to use models that are unique in ANDES.

The command for converting is `--convert` (or `-c`), following the output format (only `xlsx` is currently supported). For example, to convert `case5.m` into the `xlsx` format, run

```
andes run case5.m --convert xlsx
```

The output messages will look like

```
Parsing input file </Users/user/repos/andes/cases/matpower/case5.m>
CASE5  Power flow data for modified 5 bus, 5 gen case based on PJM 5-bus␣
↪system
Input file case5.m parsed in 0.0033 second.
xlsx file written to </Users/user/repos/andes/cases/matpower/case5.xlsx>
Converted file /Users/user/repos/andes/cases/matpower/case5.xlsx written in 0.
↪5079 second.
-> Single process finished in 0.8765 second.
```

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

In case one wants to create template sheets to add models later, `--convert-all` can be used instead.

If one wants to add workbooks to an existing xlsx file, one can combine option `--add-book ADD_BOOK` (or `-b ADD_BOOK`), where `ADD_BOOK` can be a single model name or comma-separated model names (without any space). For example,

```
andes run kundur.raw -c -b Toggler
```

will convert file `kundur.raw` into an ANDES xlsx file (kundur.xlsx) and add a template workbook for *Toggler*.

> **Warning:** With `--add-book`, the xlsx file will be overwritten. Any **empty or non-existent models** will be REMOVED.

PSS/E inputs

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

```
andes run wecc.raw
```

and run a no-disturbance time-domain simulation using

```
andes run wecc.raw --addfile wecc_full.dyr -r tds
```

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 and run (see the previous subsection).

The alternative is to edit the dyr file 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 `Toggler`:

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

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

```
Line   'Toggler'  Line_2  1 /
Line   'Toggler'  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‘‘.

Note: When working with PSS/E data, the recommended practice is to edit model dynamic parameters directly in the dyr file so that the data can be easily used by other tools.

2.1.5 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 *out*. 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 example, to plot the generator speed variable of synchronous generator 1 `omega GENROU 0` versus time, read the indices of the variable (2) and time (0), run

```
andes plot kundur_full_out.lst 0 2
```

In this command, `andes plot` is the plotting command for TDS output files. `kundur_full_out.lst` is list file name. `0` is the index of `Time` for the x-axis. `2` is the index of `omega GENROU 0`. Note that for the the file name, either `kundur_full_out.lst` or `kundur_full_out.npy` works, as the program will automatically extract the file name.

The y-axis variabla indices can also be specified in the Python range fashion . For example, `andes plot kundur_full_out.npy 0 2:21:6` will plot the variables at indices 2, 8, 14 and 20.

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

Other optional arguments are listed in the following.

optional arguments:

Argument	Description
optional arguments:	
-h, –help	show this help message and exit
–xmin LEFT	minimum value for X axis
–xmax RIGHT	maximum value for X axis
–ymax YMAX	maximum value for Y axis
–ymin YMIN	minimum value for Y axis
–find FIND	find variable indices that matches the given pattern
–xargs XARGS	find variable indices and return as a list of arguments usable with "| xargs andes plot"
–exclude EXCLUDE	pattern to exclude in find or xargs results
-x XLABEL, –xlabel XLABEL	x-axis label text
-y YLABEL, –ylabel YLABEL	y-axis label text
-s, –savefig	save figure. The default fault is *png*.
-format SAVE_FORMAT	format for savefig. Common formats such as png, pdf, jpg are supported
–dpi DPI	image resolution in dot per inch (DPI)
-g, –grid	grid on
–greyscale	greyscale on
-d, –no-latex	disable LaTeX formatting
-n, –no-show	do not show the plot window
–ytimes YTIMES	scale the y-axis values by YTIMES
-c, –tocsv	convert npy output to csv

2.1.6 andes doc

`andes doc` is a tool for quick lookup of model and routine documentation. It is intended as a quick way for documentation.

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. If you are looking for full documentation, visit andes.readthedocs.io.

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

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

    Time-based connectivity status toggler.

Parameters

 Name  |          Description           | Default | Unit |    Type    |␣
↪Properties
-------+--------------------------------+---------+------+------------+---------
↪--
```

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```
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
 StaticACDC       | VSCShunt
 StaticGen        | PV, Slack
 StaticLoad       | PQ
 StaticShunt      | Shunt
 SynGen           | GENCLS, GENROU
 TimedEvent       | Toggler, 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)
```

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```
           |       | not converged                        |
tstep      | 0.010 | the initial step step size           | float
max_iter   | 15    | maximum number of iterations         | >=10
```

2.1.7 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. `--save-config` saves all configs to a file. By default, it saves to `~/.andes/andes.conf` file, where ~ is the path to your home directory.

With `--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 asn Python automatically 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

`-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).

2.2 Interactive Usage

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

Note: All following blocks starting with >>> are Python code. They should be typed into a Python shell, IPython or Jupyter Notebook, not a Anaconda Prompt or shell.

2.2.1 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 directory to the folder that 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 at the top-right corner.

2.2.2 Import

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

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

2.2.3 Verbosity

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

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

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

Warning: The verbosity level can only be set once. To set a different level, restart the Python kernel.

2.2.4 Making a System

Before running studies, a "System" object needs to be create to hold the system data. The System object can be created by passing the path to the case file the entrypoint function. 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.

Naming convention for the System attributes are as follows

- Model attributes share the same name as class names. For example, ss.Bus is the Bus 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 notebook Example 2.

Output path

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. For example,

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

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

No output

Outputs can be disabled by passing output_path=True to andes.run(). This is useful when one wants to test code without looking at results. For example, do

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

2.2.5 Inspecting Parameter

DataFrame

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

Input parameters for each model instance is returned by the `as_df()` function. For example, to view the input parameters for `Bus`, use

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

A table will be printed with the columns being each parameter and the rows being Bus instances. Parameter in the table is the same as the input file without per-unit conversion.

Parameters have been converted to per unit values under system base. To view the per unit values, use the `as_df_in()` attribute. For example, to view the system-base per unit value of `GENROU`, use

```
>>> ss.GENROU.as_df_in()
```

Dict

In case you need the parameters in `dict`, use `as_dict()`. Values returned by `as_dict()` are system-base per unit values. To retrieve the input data, use `as_dict(vin=True)`.

For example, to retrieve the original input data of GENROU's, use

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

2.2.6 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()
```

2.2.7 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.

2.2.8 Plotting TDS Results

TDS comes with a plotting utility for interactive 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 to 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

2.2.9 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, refer to *andes_doc*.

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.

2.2.10 Pretty Print of Equations

Each ANDES models offers pretty print of LaTeX-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 $T\dot{\mathbf{x}} = \mathbf{f}$

- `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`.

2.2.11 Finding Help

General help

To find help on a Python class, method, or function, use the built-in `help()` 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?`.

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.

2.3 Notebook Examples

Check out more examples in Jupyter Notebook in the *examples* folder of the repository at here. You can run the examples in a live Jupyter Notebook online using Binder.

2.4 I/O Formats

2.4.1 Input Formats

ANDES currently supports the following input formats:

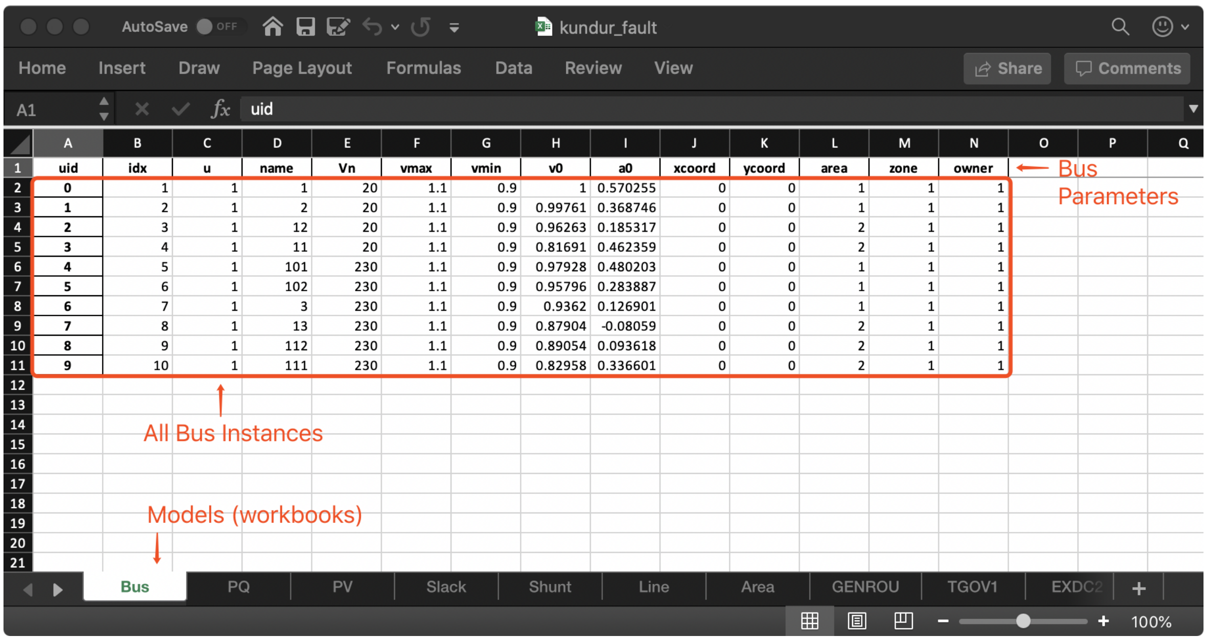
- ANDES Excel (.xlsx)
- PSS/E RAW (.raw) and DYR (.dyr)
- MATPOWER (.m)

2.4.2 ANDES xlsx Format

The ANDES xlsx format is a newly introduced format since v0.8.0. This format uses Microsoft Excel for conveniently viewing and editing model parameters. You can use LibreOffice or WPS Office alternatively to Microsoft Excel.

xlsx Format Definition

The ANDES xlsx format contains multiple workbooks (tabs at the bottom). Each workbook contains the parameters of all instances of the model, whose name is the workbook name. The first row in a worksheet is used for the names of parameters available to the model. Starting from the second row, each row corresponds to an instance with the parameters in the corresponding columns. An example of the Bus workbook is shown in the following.

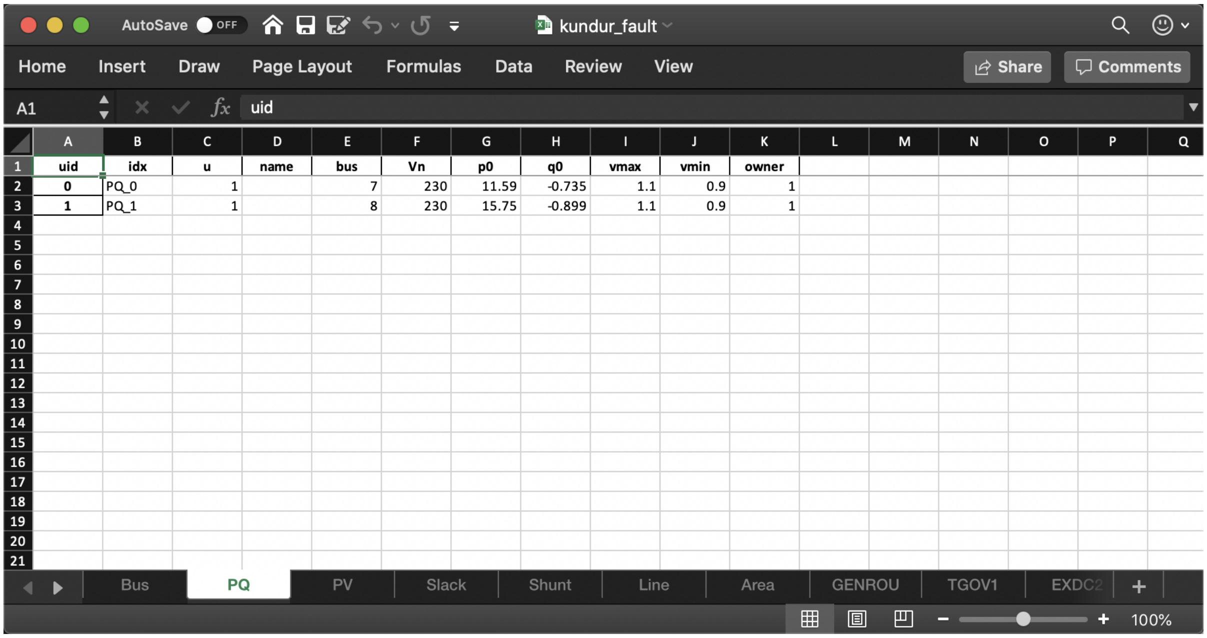


uid	idx	u	name	Vn	vmax	vmin	v0	a0	xcoord	ycoord	area	zone	owner
0	1	1	1	20	1.1	0.9	1	0.570255	0	0	1	1	1
1	2	1	2	20	1.1	0.9	0.99761	0.368746	0	0	1	1	1
2	3	1	12	20	1.1	0.9	0.96263	0.185317	0	0	2	1	1
3	4	1	11	20	1.1	0.9	0.81691	0.462359	0	0	2	1	1
4	5	1	101	230	1.1	0.9	0.97928	0.480203	0	0	1	1	1
5	6	1	102	230	1.1	0.9	0.95796	0.283887	0	0	1	1	1
6	7	1	3	230	1.1	0.9	0.9362	0.126901	0	0	1	1	1
7	8	1	13	230	1.1	0.9	0.87904	-0.08059	0	0	2	1	1
8	9	1	112	230	1.1	0.9	0.89054	0.093618	0	0	2	1	1
9	10	1	111	230	1.1	0.9	0.82958	0.336601	0	0	2	1	1

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

- `uid` is an internally generated unique instance index. This column can be left empty if the xlsx file is being manually created. Exporting the xlsx file with `--convert` will automatically assign the `uid`.
- `idx` is the unique instance index for referencing. An unique `idx` should be provided explicitly for each instance. Accepted types for `idx` include numbers and strings without spaces.
- `name` is the instance name.
- `u` is the connectivity status of the instance. Accepted values are 0 and 1. Unexpected behaviors may occur if other numerical values are assigned.

As mentioned above, `idx` is the unique index for an instance to be referenced. For example, a PQ instance can reference a Bus instance so that the PQ is connected to the Bus. This is done through providing the `idx` of the desired bus as the `bus` parameter of the PQ.



uid	idx	u	name	bus	Vn	p0	q0	vmax	vmin	owner
0	PQ_0	1		7	230	11.59	-0.735	1.1	0.9	1
1	PQ_1	1		8	230	15.75	-0.899	1.1	0.9	1

In the example PQ workbook shown above, there are two PQ instances on buses with `idx` being 7 and 8, respectively.

Convert to xlsx

Please refer to the the `--convert` command for converting a recognized file to xlsx. See *format converter* for more detail.

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.

2.5 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/

2.6 Make Documentation

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

```
make html
```

After a minute, HTML documentation will be saved to `docs/build/html` with the index page being `index.html`.

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)
```

CHAPTER 3

Modeling Cookbook

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.

class andes.system.**System**(*case: Optional[str] = None*, *name: Optional[str] = None*, *config_path: Optional[str] = None*, *default_config: Optional[bool] = False*, *options: Optional[Dict[KT, VT]] = None*, ***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.

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

Note: *andes.System* is an alias of *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 `devices/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 groups will be stored to dictionary `System.groups`.

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 symbolically defined equations need to be generated into anonymous function calls for accelerating numerical simulations. This process is automatically invoked for the first time ANDES is run command line. It takes several seconds up to a minute to finish the generation.

Note: Code generation has been done if one has executed `andes`, `andes selftest`, or `andes prepare`.

Warning: When models are modified (such as adding new models or changing equation strings), code generation needs to be executed again for consistency. It can be more conveniently triggered from command line with `andes prepare -i`.

`andes.system.System.`**`prepare`**(*self*, *quick=False*, *incremental=False*)

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.

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

```python
import andes
sys = andes.System()
sys.prepare()
```

Since the process is slow, generated numerical functions (Python Callable) will be serialized into a file for future speed up. The package used for serializing/de-serializing numerical calls is `dill`. System has a function called `dill` for serializing using the `dill` package.

`andes.system.System.`**`dill`**`(`*self*`)`

Serialize generated numerical functions in `System.calls` with package `dill`.

The serialized file will be stored to `~/.andes/calls.pkl`, where ~ is the home directory path.

Notes

This function sets *dill.settings['recurse'] = True* to serialize the function calls recursively.

`andes.system.System.`**`undill`**`(`*self*`)`

Deserialize the function calls from `~/.andes/calls.pkl` with `dill`.

If no change is made to models, future calls to `prepare()` can be replaced with `undill()` for acceleration.

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
x	Array for state variable values
y	Array for algebraic variable values
z	Array for 0/1 limiter states (if enabled)
f	Array for differential equation derivatives
Tf	Left-hand side time constant array for f
g	Array for algebraic equation mismatches

The defined scalar member attributes to store array sizes are

Scalar	Description
m	The number of algebraic variables/equations
n	The number of algebraic variables/equations
o	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: Union[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: collections.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: collections.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: collections.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: collections.OrderedDict*, *niter=None*, *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: collections.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: collections.OrderedDict*`)`

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: collections.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: collections.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.`**`get_config`**`(`*self*`)`

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.

`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.

`andes.system.System.`**`load_config`**(*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

> **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 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.

3.2.1 Model Data

`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 *GENCLS* should be named *GENCLSData*.

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.

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

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 `Vb = Vn = 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.

3.2.2 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* defines DAE variables, services, and other types of parameters, in the constructor `__init__`.

Notes

To modify parameters or services use `set()`, which writes directly to the given attribute, or `alter()`, which converts parameters to system base like that for input data.

Examples

Take the static PQ as an example, the subclass of *Model*, *PQ*, should looks 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`.

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 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. It 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 variables 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))"

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 implements a piecewise 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

3.2.3 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.

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.

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.

3.2.4 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.model.`**`SymProcessor`**(*parent*)

A helper class for symbolic processing and code generation.

Parameters

parent [Model] The *Model* instance to document

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.

non_vars_dict [OrderedDict] symbols in `input_syms` but not in `var_syms`.

`generate_init`()

Generate lambda functions for initial values.

`generate_jacobians`()

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)

non_vars_dict [OrderedDict] name-symbol pair of all non-variables, namely, (inputs_dict - vars_dict)

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`.

3.2.5 Jacobian Storage

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` an `_vgyc`: `_vgy` is a list of callables, while `_vgyc` is a list of constant numbers.

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 * p0`, and the equation associated with `q` is `u * (v0 - v)`. Therefore, the derivative of equation `v0 - v` over `v` is `-u`. Note that `u` is unknown at generation time, thus the value is NOT a constant and should to go `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]`.

3.2.6 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

3.2.7 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.

3.3 Atom Types

ANDES contains three types of atom classes for building DAE models. These types are parameter, variable and service.

3.3.1 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.

3.3.2 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.a*, and the equation evaluation results will be stored in *self.v.e*

3.4 Parameters

3.4.1 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.

Subclasses	Description
DataParam	An alias of *BaseParam*. Can be used for any non-numerical parameters.
NumParam	The numerical parameter type. Used for all parameters in equations
IdxParam	The parameter type for storing *idx* into other models
ExtParam	Externally defined parameter
TimerParam	Parameter for storing the action time of events

3.4.2 Data Parameters

class andes.core.param.**BaseParam**(*default: Union[float, str, int, None] = None, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, mandatory: bool = False, export: bool = True, iconvert: Optional[Callable] = None, oconvert: Optional[Callable] = 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`.

> **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.

class andes.core.param.**DataParam**(*default: Union[float, str, int, None] = None, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, mandatory: bool = False, export: bool = True, iconvert: Optional[Callable] = None, oconvert: Optional[Callable] = 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

class andes.core.param.**IdxParam**(*default: Union[float, str, int, None] = None, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, mandatory: bool = False, unique: bool = False, export: bool = True, model: Optional[str] = None, iconvert: Optional[Callable] = None, oconvert: Optional[Callable] = 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')
```

3.4.3 Numeric Parameters

class andes.core.param.**NumParam**(*default: Union[float, str, Callable, None] = None, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, vrange: Union[List[T], Tuple, None] = None, vtype: Optional[Type[CT_co]] = <class 'float'>, iconvert: Optional[Callable] = None, oconvert: Optional[Callable] = 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.

3.4.4 External Parameters

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.

Attributes

parent_model [Model] The parent model providing the original parameter.

3.4.5 Timer Parameter

class andes.core.param.**TimerParam**(*callback: Optional[Callable] = None*, *default: Union[float, str, Callable, None] = None*, *name: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = None*, *unit: Optional[str] = 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 toggler class *Toggler* takes a parameter *t* for the toggle time. Inside `Toggler.__init__`, one would have

```
self.t = TimerParam()
```

The *Toggler* class also needs to define a method for togging 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 `Toggler.__init__`, assign the function as the callback for *self.t*

```
self.t.callback = self._u_switch
```

3.5 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.

Class	Description
State	A state variable and associated diff. equation $\mathbf{T}\dot{x} = \mathbf{f}$
Algeb	An algebraic variable and an associated algebraic equation $0 = \mathbf{g}$
ExtState	An external state variable and part of the differential equation (uncommon)
ExtAlgeb	An external algebraic variable and part of the algebraic equation

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.

3.5.1 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])*.

3.5.2 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.

3.5.3 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.

3.5.4 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*.

3.5.5 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*.

class andes.core.var.**BaseVar**(*name: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = None*, *unit: Optional[str] = None*, *v_str: Union[str, float, None] = None*, *v_iter: Optional[str] = None*, *e_str: Optional[str] = None*, *discrete: Optional[andes.core.discrete.Discrete] = None*, *v_setter: Optional[bool] = False*, *e_setter: Optional[bool] = False*, *addressable: Optional[bool] = True*, *export: Optional[bool] = True*, *diag_eps: Optional[float] = 0.0*)

Base variable class.

Derived classes *State* and *Algeb* should be used to build model variables.

Parameters

name [str, optional] Variable name

info [str, optional] Descriptive information

unit [str, optional] Unit

tex_name [str] LaTeX-formatted variable name. If is None, use *name* instead.

discrete [Discrete] Associated discrete component. Will call *check_var* on the discrete component.

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

class andes.core.var.**ExtVar**(*model: str, src: str, indexer: Union[List[T], numpy.ndarray, andes.core.param.BaseParam, andes.core.service.BaseService, None] = None, allow_none: Optional[bool] = False, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, v_str: Union[str, float, None] = None, v_iter: Optional[str] = None, e_str: Optional[str] = None, v_setter: Optional[bool] = False, e_setter: Optional[bool] = False, addressable: Optional[bool] = True, export: Optional[bool] = True, diag_eps: Optional[float] = 0.0*)

Externally defined algebraic variable

This class is used to retrieve the addresses of externally- defined variable. The *e* value of the *ExtVar* will be added to the corresponding address in the DAE equation.

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] True to allow None in indexer

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.

class andes.core.var.**State**(*name: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = None*, *unit: Optional[str] = None*, *v_str: Union[str*, *float*, *None] = None*, *v_iter: Optional[str] = None*, *e_str: Optional[str] = None*, *discrete: Optional[andes.core.discrete.Discrete] = None*, *t_const: Union[andes.core.param.BaseParam*, *andes.core.common.DummyValue*, *andes.core.service.BaseService*, *None] = None*, *v_setter: Optional[bool] = False*, *e_setter: Optional[bool] = False*, *addressable: Optional[bool] = True*, *export: Optional[bool] = True*, *diag_eps: Optional[float] = 0.0*)

Differential variable class, an alias of the *BaseVar*.

Parameters

t_const [BaseParam, DummyValue] Left-hand time constant for the differential equation. Time constants will not be evaluated as part of the differential equation. They will be collected to array *dae.Tf* to multiply to the right-hand side *dae.f*.

Attributes

e_code [str] Equation code string, equals string literal `f`

v_code [str] Variable code string, equals string literal `x`

class andes.core.var.**Algeb**(*name: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = None*, *unit: Optional[str] = None*, *v_str: Union[str*, *float*, *None] = None*, *v_iter: Optional[str] = None*, *e_str: Optional[str] = None*, *discrete: Optional[andes.core.discrete.Discrete] = None*, *v_setter: Optional[bool] = False*, *e_setter: Optional[bool] = False*, *addressable: Optional[bool] = True*, *export: Optional[bool] = True*, *diag_eps: Optional[float] = 0.0*)

Algebraic variable class, an alias of the *BaseVar*.

Attributes

e_code [str] Equation code string, equals string literal `g`

v_code [str] Variable code string, equals string literal `y`

class andes.core.var.**ExtState**(*model: str, src: str, indexer: Union[List[T], numpy.ndarray, andes.core.param.BaseParam, andes.core.service.BaseService, None] = None, allow_none: Optional[bool] = False, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, v_str: Union[str, float, None] = None, v_iter: Optional[str] = None, e_str: Optional[str] = None, v_setter: Optional[bool] = False, e_setter: Optional[bool] = False, addressable: Optional[bool] = True, export: Optional[bool] = True, diag_eps: Optional[float] = 0.0*)

External state variable type.

> **Warning:** `ExtState` is not allowed to set `t_const`, as it will conflict with the source `State` variable. In fact, one should not set `e_str` for `ExtState`.

class andes.core.var.**ExtAlgeb**(*model: str, src: str, indexer: Union[List[T], numpy.ndarray, andes.core.param.BaseParam, andes.core.service.BaseService, None] = None, allow_none: Optional[bool] = False, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, v_str: Union[str, float, None] = None, v_iter: Optional[str] = None, e_str: Optional[str] = None, v_setter: Optional[bool] = False, e_setter: Optional[bool] = False, addressable: Optional[bool] = True, export: Optional[bool] = True, diag_eps: Optional[float] = 0.0*)

External algebraic variable type.

class andes.core.var.**AliasState**(*var*, ***kwargs*)

Alias state variable.

Refer to the docs of `AliasAlgeb`.

class andes.core.var.**AliasAlgeb**(*var*, ***kwargs*)

Alias algebraic variable. Essentially `ExtAlgeb` that links to a 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.

3.6 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 `BaseService`, and the supported services are listed as follows.

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

3.6.1 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: Optional[str] = None*, *v_numeric: Optional[Callable] = None*, *vtype: Optional[type] = None*, *name: Optional[str] = None*, *tex_name=None*, *info=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*'.

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

Attributes

v [array-like or a scalar] ConstService value

class andes.core.service.**VarService**(*v_str: Optional[str] = None*, *v_numeric: Optional[Callable] = None*, *vtype: Optional[type] = None*, *name: Optional[str] = None*, *tex_name=None*, *info=None*)

Variable service that gets updated in each step/loop as variables change.

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.

> **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 (vd + jvq), (Id + jIq) 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: Optional[str] = None*, *v_numeric: Optional[Callable] = None*, *vtype: Optional[type] = None*, *name: Optional[str] = None*, *tex_name=None*, *info=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 *vf* variable is initialized followed by other variables. One can store the initial *vf* into *vf0* so that equation `vf - vf0 = 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 *vf0*, in order to correctly initialize *vf*.

3.6.2 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 *p0*:

```
self.p0 = ExtService(src='p',
                     model='StaticGen',
                     indexer=self.gen,
                     tex_name='P_0')
```

class `andes.core.service.`**`ExtService`**(*model: str, src: str, indexer: Union[andes.core.param.BaseParam, andes.core.service.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 GENCLSModel(Model):
    def __init__(...):
        ...
        self.p0 = ExtService(src='p',
                             model='StaticGen',
                             indexer=self.gen,
                             tex_name='P_0')
```

3.6.3 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: andes.core.service.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 `Vn` in one Area. In the `Area` class, one defines

```
class AreaModel(...):
    def __init__(...):
        ...
        # backward reference from `Bus`
        self.Bus = BackRef()

        # collect the Vn 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	Vn
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,
                  )
```

3.6.4 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.**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).

3.6.5 Idx and References

class andes.core.service.**DeviceFinder**(*u*, *link*, *idx_name*, *name=None*, *tex_name=None*, *info=None*)

Service for finding indices of optionally linked devices.

If not provided, *DeviceFinder* will add devices at the beginning of *System.setup*.

Examples

IEEEST stabilizer takes an optional *busf* (IdxParam) for specifying the connected BusFreq, which is needed for mode 6. To avoid reimplementing *BusFreq* within IEEEST, one can do

```
self.busfreq = DeviceFinder(self.busf, link=self.buss, idx_name='bus')
```

where *self.busf* is the optional input, *self.buss* is the bus indices that *busf* should measure, and *idx_name* is the name of a BusFreq parameter through which the measured bus indices are specified. For each *None* values in *self.busf*, a *BusFreq* is created to measure the corresponding bus in *self.buss*.

That is, `BusFreq.[idx_name].v = [link]`. *DeviceFinder* will find / create *BusFreq* devices so that the returned list of *BusFreq* indices are connected to *self.buss*, respectively.

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,
                  )
```

3.6.6 Events

class andes.core.service.**EventFlag**(*u*, *vtype: Optional[type] = None*, *name: Optional[str] = None*, *tex_name=None*, *info=None*)

Service to flag events.

EventFlag.v stores the values of the input variable from the previous iteration/step.

class andes.core.service.**ExtendedEvent**(*u*, *t_ext: Union[int, float, andes.core.param.BaseParam, andes.core.service.BaseService] = 0.0*, *trig: str = 'rise'*, *enable=True*, *v_disabled=0*, *extend_only=False*, *vtype: Optional[type] = None*, *name: Optional[str] = None*, *tex_name=None*, *info=None*)

Service to flag events that extends for period of time after event disappears.

EventFlag.v stores the flags whether the extended time has completed. Outputs will become 1 once then event starts until the extended time ends.

Parameters

- **trig** [str, rise, fall] Triggering edge for the inception 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.

3.6.7 Data Select

class andes.core.service.**DataSelect**(*optional*, *fallback*, *name: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = None*)

Class for selecting values for optional DataParam or NumParam.

This service is a v-provider that uses optional DataParam if available with a fallback.

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: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = None*)

Class for selecting values for optional NumParam.

NumSelect works with internal and external parameters.

Notes

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)
```

3.6.8 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_icheck*, 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`.

3.7 Discrete

3.7.1 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`.

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) .

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.

3.7.2 Limiters

class andes.core.discrete.**Limiter**(*u*, *lower*, *upper*, *enable=True*, *name=None*, *tex_name=None*, *info=None*, *min_iter: int = 2*, *err_tol: float = 0.01*, *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 (>= or <=).

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 `zu = zl = 0`, `zi = 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*, *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=None*, *tex_name=None*, *info=None*, *min_iter: int = 2*, *err_tol: float = 0.01*, *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.**AntiWindup**(*u*, *lower*, *upper*, *enable=True*, *no_lower=False*, *no_upper=False*, *sign_lower=1*, *sign_upper=1*, *name=None*, *tex_name=None*, *info=None*, *state=None*)

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.

3.7.3 Comparers

class andes.core.discrete.**LessThan**(*u*, *bound*, *equal=False*, *enable=True*, *name=None*, *tex_name=None*, *info=None*, *cache=False*, *z0=0*, *z1=1*)

Less than (<) comparison function.

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.

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.

See also:

`numpy.ufunc.reduce` NumPy reduce function

`andes.core.block.HVGate`

andes.core.block.LVGate

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: Union[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 IEEEST 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.

3.7.4 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'
```

3.8 Blocks

3.8.1 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 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: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = 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
   |
LeadLag A  exports (x, y)
   |
Lag B      exports (x, y)
```

SomeModel instance M contains an instance of LeadLag block named A, which contains an instance of a Lag block named B. Both A and B exports two variables `x` and `y`.

In the code of Model, 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)
        self.vars = {..., 'A': self.A}
```

The `__setattr__` magic of LeadLag takes over the construction and assigns `A_B` to *B.name*, given A's name provided at run time. *self.A* is exported with the internal name `A` at the end.

Again, the LeadLag instance name (*A* in this example) MUST be provided in *SomeModel*'s constructor for the name prepending to work correctly. If there is more than one level of nesting, other than the leaf-level block, all parent blocks' names must be provided at instantiation.

When A is picked up by *SomeModel.__setattr__*, B is captured from A's exports. 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`.

In this way, B's `define()` needs no modification since the naming rule is the same. For example, B's internal y is always `{self.name}_y`, although B has gotten a new name `A_B`.

3.8.2 Transfer Functions

The following transfer function blocks have been implemented. They can be imported to build new models.

Algebraic

class andes.core.block.**Gain**(*u*, *K*, *name=None*, *tex_name=None*, *info=None*)
Gain block.

```
        ┌───┐
u  ->   │ K │  ->  y
        └───┘
```

Exports an algebraic output *y*.

define()
Implemented equation and the initial condition are

$$y = Ku$$
$$y^{(0)} = Ku^{(0)}$$

First Order

class andes.core.block.**Integrator**(*u*, *T*, *K*, *y0*, *name=None*, *tex_name=None*, *info=None*)
Integrator block.

```
        ┌──────┐
u  ->   │ K/sT │  ->  y
        └──────┘
```

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*)

Integrator block with anti-windup limiter.

```
           upper
          /-----
     ______
u -> | K/sT | -> y
     -------
   _____/
   lower
```

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*, *name=None*, *tex_name=None*, *info=None*)

Lag (low pass filter) transfer function.

```
     ________
     |   K    |
u -> | ------ | -> y
     | 1 + sT |
     ----------
```

Exports one state variable *y* as the output.

Parameters

K Gain

T Time constant

u Input variable

define()

Notes

Equations and initial values are

$$T\dot{y} = (Ku - y)$$
$$y^{(0)} = Ku$$

class andes.core.block.**LagAntiWindup**(*u*, *T*, *K*, *lower*, *upper*, *name=None*, *tex_name=None*, *info=None*)

Lag (low pass filter) transfer function block with an anti-windup limiter.

```
              upper
            /------
      __________
     |    K     |
u -> | -------- | -> y
     |  1 + sT  |
     |__________|
    _______/
   lower
```

Exports one state variable *y* as the output and one AntiWindup instance *lim*.

Parameters

K Gain

T Time constant

u Input variable

define()

Notes

Equations and initial values are

$$T \dot{y} = (Ku - y)$$
$$y^{(0)} = Ku$$

class andes.core.block.**Washout**(*u*, *T*, *K*, *name=None*, *tex_name=None*, *info=None*)

Washout filter (high pass) block.

```
      __________
     |    sK    |
u -> | -------- | -> y
     |  1 + sT  |
     |__________|
```

Exports state *x* (symbol *x'*) and output algebraic variable *y*.

define()

Notes

Equations and initial values:

$$
\begin{aligned}
T\dot{x'} &= (u - x') \\
Ty &= K(u - x') \\
x'^{(0)} &= u \\
y^{(0)} &= 0
\end{aligned}
$$

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:

$$
\begin{aligned}
T\dot{x'} &= (u - x') \\
Ty &= z_0 K(u - x') + z_1 T x \\
x'^{(0)} &= u \\
y^{(0)} &= 0
\end{aligned}
$$

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

```
        ┌───────────┐
        │   1 + sT1 │
u ->    │ K ─────── │  -> y
        │   1 + sT2 │
        └───────────┘
```

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

$$T_2 \dot{x'} = (u - x')$$
$$T_2 y = K T_1 (u - x') + K T_2 x' + E_2 \text{ , where}$$
$$E_2 = \begin{cases} (y - Kx') & \text{if } T_1 = T_2 = 0 \& zero\_out = True \\ 0 & \text{otherwise} \end{cases}$$
$$x'^{(0)} = u$$
$$y^{(0)} = Ku$$

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)

```
          ___________          upper
         | 1 + sT1   |          /-----
u ->     | _________ |  -> ynl / -> y
         | 1 + sT2   |   _____/
         |___________|  lower
```

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

$$T_2 \dot{x'} = (u - x')$$
$$T_2 y = T_1 (u - x') + T_2 x'$$
$$x'^{(0)} = y^{(0)} = u$$

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)

```
         ____________________
        |         K          |
u ->    | ------------------ | -> y
        | 1 + sT1 + s^2 T2   |
        |____________________
```

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

$$
\begin{aligned}
T_2 \dot{x} &= Ku - y - T_1 x \\
\dot{y} &= x \\
x^{(0)} &= 0 \\
y^{(0)} &= Ku
\end{aligned}
$$

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

```
         ____________________
        | 1 + sT3 + s^2 T4   |
u ->    | ------------------ | -> y
        | 1 + sT1 + s^2 T2   |
        |____________________
```

Exports two internal states (*x1* and *x2*) and output algebraic variable *y*.

TODO: instead of implementing *zero_out* using *LessThan* and an additional term, consider correcting all parameters to 1 if all are 0.

define()

Notes

Implemented equations and initial values are

$$
\begin{aligned}
T_2 \dot{x}_1 &= u - x_2 - T_1 x_1 \\
\dot{x}_2 &= x_1 \\
T_2 y &= T_2 x_2 + T_2 T_3 x_1 + T_4 (u - x_2 - T_1 x_1) + E_2 \,, \text{ where} \\
E_2 &= \begin{cases} (y - x_2) & \text{if } T_1 = T_2 = T_3 = T_4 = 0 \& zero\_out = True \\ 0 & \text{otherwise} \end{cases} \\
x_1^{(0)} &= 0 \\
x_2^{(0)} &= y^{(0)} = u
\end{aligned}
$$

3.8.3 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

$$E_1 S_{E1} = A e^{E1 \times B} E_2 S_{E2} = A e^{E2 \times B}$$

The solutions are given by

$$E_1 S_{E1} e^{\frac{E_1 \log\left(\frac{E_2 S_{E2}}{E_1 S_{E1}}\right)}{E_1 - E_2}} - \frac{\log\left(\frac{E_2 S_{E2}}{E_1 S_{E1}}\right)}{E_1 - E_2}$$

3.8.4 Others

Value Selector

class andes.core.block.**HVGate**(*u1*, *u2*, *name=None*, *tex_name=None*, *info=None*)

High Value Gate. Outputs the maximum of two inputs.

```
         ____________
u1 ->  | HV Gate    |
                      ->  y
u2 ->  |  (MAX)     |
       |____________
```

class andes.core.block.**LVGate**(*u1*, *u2*, *name=None*, *tex_name=None*, *info=None*)

Low Value Gate. Outputs the minimum of the two inputs.

```
         ____________
u1 ->  | LV Gate  |
                  | ->  y
u2 ->  |  (MIN)   |
       |____________
```

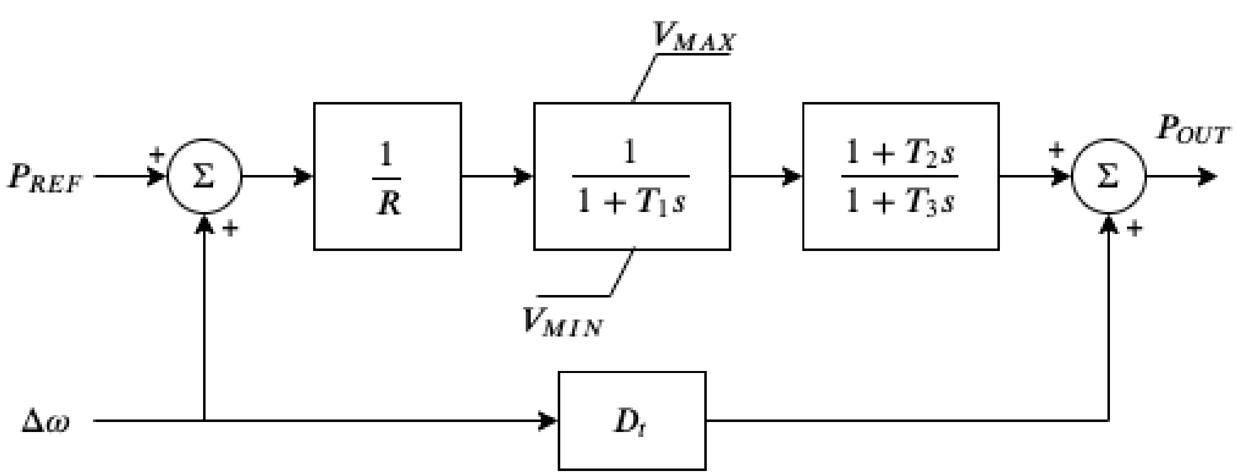
3.9 Examples

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 IEEEST example walks through the source code and explains the complete setup, including optional parameters, input selection, and manual per-unit conversion.

3.9.1 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.

$$\begin{bmatrix} \dot{x}_{LG} \\ \dot{x}_{LL} \end{bmatrix} = \begin{bmatrix} z_{i,lim}^{LG} \left(P_d - x_{LG}\right)/T_1 \\ \left(x_{LG} - x_{LL}\right)/T_3 \end{bmatrix}$$

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} (1-\omega) - \omega_d \\ R \times \tau_{m0} - P_{ref} \\ \left(P_{ref} + \omega_d\right)/R - P_d \\ D_t \omega_d + y_{LL} - P_{OUT} \\ \frac{T_2}{T_3}\left(x_{LG} - x_{LL}\right) + x_{LL} - y_{LL} \\ u\left(P_{OUT} - \tau_{m0}\right) \end{bmatrix}$$

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`.

```python
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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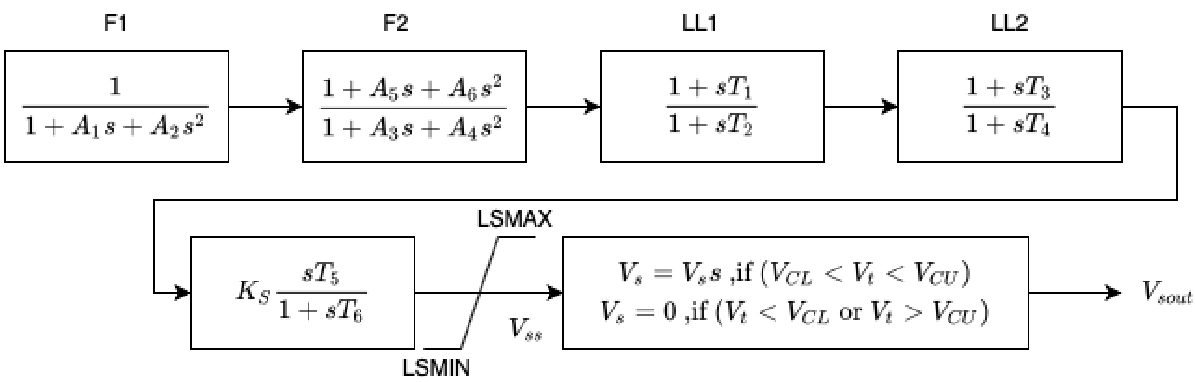
```
    self.pout.e_str = '(LL_y + Dt * wd) - pout'
```

The complete code can be found in class `TGOV1Model` in `andes/models/governor.py`.

3.9.2 IEEEST

In this example, we will explain step-by-step how *IEEEST* is programmed. The block diagram of IEEEST 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, `IEEESTData` defines the input parameters for IEEEST. Use `IdxParam` for fields that store idx-es of devices that IEEEST 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.

```
self.group = 'PSS'
self.flags.update({'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.

IEEESTModel

`IEEESTModel` inherits from `PSSBase` and adds specific model components. After calling `PSSBase`'s constructor, IEEESTModel 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 Sb / Sn. 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 Sb / Sn.

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 = len(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'

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 IEEEST model.

Finalize

Assemble `IEEESTData` and `IEEESTModel` into `IEEEST`:

```
class IEEEST(IEEESTData, IEEESTModel):
    def __init__(self, system, config):
        IEEESTData.__init__(self)
        IEEESTModel.__init__(self, system, config)
```

Locate `andes/models/__init__.py`, in `file_classes`, find the key `pss` and add `IEEEST` to its value list. In `file_classes`, keys are the `.py` file names under the folder `models`, and values are class names to be imported from that file. If the file name does not exist as a key in `file_classes`, add it after all prerequisite models. For example, PSS should be added after exciters (and generators, of course).

Finally, locate `andes/models/group.py`, check if the class with `PSS` exist. It is the name of IEEEST's group name. If not, create one by inheriting from `GroupBase`:

```
class PSS(GroupBase):
    """Power system stabilizer group."""

    def __init__(self):
```

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```
        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 IEEEST model. When developing new models, use `andes prepare` to generate numerical code and start debugging.

CHAPTER 4

Test Cases

4.1 Directory

ANDES comes with several test cases in the `andes/cases/` folder. 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.

The test case library will continue to build as more models get implemented.

A tree view of the test directory is as follows.

```
cases/
├── 5bus/
│   └── pjm5bus.xlsx
├── GBnetwork/
│   ├── GBnetwork.m
│   ├── GBnetwork.xlsx
│   └── README.md
├── ieee14/
│   ├── ieee14.dyr
│   └── ieee14.raw
├── kundur/
│   ├── kundur.raw
│   ├── kundur_aw.xlsx
│   ├── kundur_coi.xlsx
│   ├── kundur_coi_empty.xlsx
│   ├── kundur_esdc2a.xlsx
│   ├── kundur_esst3a.xlsx
│   ├── kundur_exdc2_zero_tb.xlsx
│   ├── kundur_exst1.xlsx
│   ├── kundur_freq.xlsx
```

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```
│      ├── kundur_full.dyr
│      ├── kundur_full.xlsx
│      ├── kundur_gentrip.xlsx
│      ├── kundur_ieeeg1.xlsx
│      ├── kundur_ieeest.xlsx
│      ├── kundur_sexs.xlsx
│      └── kundur_st2cut.xlsx
├── matpower/
│      ├── case118.m
│      ├── case14.m
│      ├── case300.m
│      └── case5.m
├── nordic44/
│      ├── N44_BC.dyr
│      ├── N44_BC.raw
│      └── README.md
├── npcc/
│      ├── npcc.raw
│      └── npcc_full.dyr
├── wecc/
│      ├── wecc.raw
│      ├── wecc.xlsx
│      ├── wecc_full.dyr
│      ├── wecc_gencls.dyr
└── wscc9/
       ├── wscc9.raw
       └── wscc9.xlsx
```

4.2 MATPOWER Cases

MATPOWER cases has 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.

The numerical library used for sparse matrix factorization is KLU. In addition, Jacobians are updated in place `spmatrix.ipadd`. Computations are performed on macOS 10.15.4 with i9-9980H, 16 GB 2400 MHz DDR4, running ANDES 0.9.1, CVXOPT 1.2.4 and NumPy 1.18.1.

The statistics of convergence, number of iterations, and solution time (including equation evaluation, Jacobian, and factorization time) are reported in the following table. The computation time may vary depending on operating system and hardware.

File Name	Converged?	# of Iterations	Time [s]
case30.m	1	3	0.012
case_ACTIVSg500.m	1	3	0.019
case13659pegase.m	1	5	0.531
case9Q.m	1	3	0.011
case_ACTIVSg200.m	1	2	0.013

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Table 1 – continued from previous page

File Name	Converged?	# of Iterations	Time [s]
case24_ieee_rts.m	1	4	0.014
case300.m	1	5	0.026
case6495rte.m	1	5	0.204
case39.m	1	1	0.009
case18.m	1	4	0.013
case_RTS_GMLC.m	1	3	0.014
case1951rte.m	1	3	0.047
case6ww.m	1	3	0.010
case5.m	1	3	0.010
case69.m	1	3	0.014
case6515rte.m	1	4	0.168
case2383wp.m	1	6	0.084
case30Q.m	1	3	0.011
case2868rte.m	1	4	0.074
case1354pegase.m	1	4	0.047
case2848rte.m	1	3	0.063
case4_dist.m	1	3	0.010
case6470rte.m	1	4	0.175
case2746wp.m	1	4	0.074
case_SyntheticUSA.m	1	21	11.120
case118.m	1	3	0.014
case30pwl.m	1	3	0.021
case57.m	1	3	0.017
case89pegase.m	1	5	0.024
case6468rte.m	1	6	0.232
case2746wop.m	1	4	0.075
case85.m	1	3	0.011
case22.m	1	2	0.008
case4gs.m	1	3	0.012
case14.m	1	2	0.010
case_ACTIVSg10k.m	1	4	0.251
case2869pegase.m	1	6	0.136
case_ieee30.m	1	2	0.010
case2737sop.m	1	5	0.087
case9target.m	1	5	0.013
case1888rte.m	1	2	0.037
case145.m	1	3	0.018
case_ACTIVSg2000.m	1	3	0.059
case_ACTIVSg70k.m	1	15	7.043
case9241pegase.m	1	6	0.497
case9.m	1	3	0.010
case141.m	1	3	0.012
case_ACTIVSg25k.m	1	7	1.040

Continued on next page

Table 1 – continued from previous page

File Name	Converged?	# of Iterations	Time [s]
case118.m	1	3	0.015
case1354pegase.m	1	4	0.048
case13659pegase.m	1	5	0.523
case14.m	1	2	0.011
case141.m	1	3	0.013
case145.m	1	3	0.017
case18.m	1	4	0.012
case1888rte.m	1	2	0.037
case1951rte.m	1	3	0.052
case22.m	1	2	0.011
case2383wp.m	1	6	0.086
case24_ieee_rts.m	1	4	0.015
case2736sp.m	1	4	0.074
case2737sop.m	1	5	0.108
case2746wop.m	1	4	0.093
case2746wp.m	1	4	0.089
case2848rte.m	1	3	0.065
case2868rte.m	1	4	0.079
case2869pegase.m	1	6	0.137
case30.m	1	3	0.033
case300.m	1	5	0.102
case30Q.m	1	3	0.013
case30pwl.m	1	3	0.013
case39.m	1	1	0.008
case4_dist.m	1	3	0.010
case4gs.m	1	3	0.010
case5.m	1	3	0.011
case57.m	1	3	0.015
case6468rte.m	1	6	0.229
case6470rte.m	1	4	0.170
case6495rte.m	1	5	0.198
case6515rte.m	1	4	0.169
case69.m	1	3	0.012
case6ww.m	1	3	0.011
case85.m	1	3	0.013
case89pegase.m	1	5	0.020
case9.m	1	3	0.010
case9241pegase.m	1	6	0.487
case9Q.m	1	3	0.013
case9target.m	1	5	0.015
case_ACTIVSg10k.m	1	4	0.257
case_ACTIVSg200.m	1	2	0.014
case_ACTIVSg2000.m	1	3	0.058

Continued on next page

Table 1 – continued from previous page

File Name	Converged?	# of Iterations	Time [s]
case_ACTIVSg25k.m	1	7	1.118
case_ACTIVSg500.m	1	3	0.027
case_ACTIVSg70k.m	1	15	6.931
case_RTS_GMLC.m	1	3	0.014
case_SyntheticUSA.m	1	21	11.103
case_ieee30.m	1	2	0.010
case3375wp.m	0	•	0.061
case33bw.m	0	•	0.007
case3120sp.m	0	•	0.037
case3012wp.m	0	•	0.082
case3120sp.m	0	•	0.039
case3375wp.m	0	•	0.059
case33bw.m	0	•	0.007

CHAPTER 5

Model References

Supported Groups and Models

Group	Models
ACLine	Line
ACTopology	Bus
Calculation	ACE, ACEc, COI
Collection	Area
DCLink	Ground, R, L, C, RCp, RCs, RLs, RLCs, RLCp
DCTopology	Node
DG	PVD1
DynLoad	ZIP, FLoad
Exciter	EXDC2, IEEEX1, ESDC2A, EXST1, ESST3A, SEXS
Experimental	PI2, TestDB1, TestPI, TestLagAWFreeze, FixedGen
FreqMeasurement	BusFreq, BusROCOF
Information	Summary
Motor	Motor3, Motor5
PSS	IEEEST, ST2CUT
PhasorMeasurement	PMU
RenAerodynamics	WTARA1, WTARV1
RenExciter	REECA1
RenGen	REGCA1
RenGovernor	WTDTA1, WTDS
RenPitch	WTPTA1
RenPlant	REPCA1
RenTorque	WTTQA1
StaticACDC	VSCShunt
StaticGen	PV, Slack
StaticLoad	PQ
StaticShunt	Shunt, ShuntSw
SynGen	GENCLS, GENROU
TimedEvent	Toggler, Fault, Alter
TurbineGov	TG2, TGOV1, TGOV1N, TGOV1DB, IEEEG1

5.1 ACLine

Common Parameters: u, name, bus1, bus2, r, x

Common Variables: v1, v2, a1, a2

Available models: *Line*

5.1.1 Line

Group *ACLine*

AC transmission line model.

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	*bool*	
name		device name			
bus1		idx of from bus			
bus2		idx of to bus			
Sn	S_n	Power rating	100		non_zero
fn	f	rated frequency	60		
Vn1	V_{n1}	AC voltage rating	110		non_zero
Vn2	V_{n2}	rated voltage of bus2	110		non_zero
r	r	line resistance	0.000		z
x	x	line reactance	0.000		z
b		shared shunt susceptance	0		y
g		shared shunt conductance	0		y
b1	b_1	from-side susceptance	0		
g1	g_1	from-side conductance	0		
b2	b_2	to-side susceptance	0		
g2	g_2	to-side conductance	0		
trans		transformer branch flag	0		
tap	t_{ap}	transformer branch tap ratio	1		
phi	ϕ	transformer branch phase shift in rad	0		
owner		owner code			
xcoord		x coordinates			
ycoord		y coordinates			

Variables (States + Algebraics)

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		

Variable 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	Symbol	Type	RHS of Equation "0 = g(x, y)"
a1	a_1	ExtAlgeb	$u\left(-1/t_{ap}v_1v_2\left(-b_{hk}\sin\left(\phi-a_1+a_2\right)+g_{hk}\cos\left(\phi-a_1+a_2\right)\right)+1/t_{ap}^2v_1^2\left(g_h+g_{hk}\right)\right)$
a2	a_2	ExtAlgeb	$u\left(-1/t_{ap}v_1v_2\left(b_{hk}\sin\left(\phi-a_1+a_2\right)+g_{hk}\cos\left(\phi-a_1+a_2\right)\right)+v_2^2\left(g_h+g_{hk}\right)\right)$
v1	v_1	ExtAlgeb	$u\left(-1/t_{ap}v_1v_2\left(-b_{hk}\cos\left(\phi-a_1+a_2\right)-g_{hk}\sin\left(\phi-a_1+a_2\right)\right)-1/t_{ap}^2v_1^2\left(b_h+b_{hk}\right)\right)$
v2	v_2	ExtAlgeb	$u\left(1/t_{ap}v_1v_2\left(b_{hk}\cos\left(\phi-a_1+a_2\right)-g_{hk}\sin\left(\phi-a_1+a_2\right)\right)-v_2^2\left(b_h+b_{hk}\right)\right)$

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	$u\left(ib_h+g_h\right)$	ConstService
yk	y_k	$u\left(ib_k+g_k\right)$	ConstService
yhk	y_{hk}	$\frac{u}{r+i\left(x+1.0\cdot10^{-8}\right)+1.0\cdot10^{-8}}$	ConstService
ghk	g_{hk}	$\operatorname{re}\left(y_{hk}\right)$	ConstService
bhk	b_{hk}	$\operatorname{im}\left(y_{hk}\right)$	ConstService
itap	$1/t_{ap}$	$\frac{1}{t_{ap}}$	ConstService
itap2	$1/t_{ap}^2$	$\frac{1}{t_{ap}^2}$	ConstService

5.2 ACTopology

Common Parameters: u, name

Common Variables: a, v

Available models: *Bus*

5.2.1 Bus

Group *ACTopology*

AC Bus model.

Power balance equation have the form of `load - 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	*bool*	
name		device name			
Vn	V_n	AC voltage rating	110	*kV*	non_zero
vmax	V_{max}	Voltage upper limit	1.100	*p.u.*	
vmin	V_{min}	Voltage lower limit	0.900	*p.u.*	
v0	V_0	initial voltage magnitude	1	*p.u.*	non_zero
a0	θ_0	initial voltage phase angle	0	*rad*	
xcoord		x coordinate (longitude)	0		
ycoord		y coordinate (latitude)	0		
area		Area code			
zone		Zone code			
owner		Owner code			

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
a	θ	Algeb	voltage angle	*rad*	v_str
v	V	Algeb	voltage magnitude	*p.u.*	v_str

Variable Initialization Equations

Name	Symbol	Type	Initial Value
a	θ	Algeb	$\theta_0 \left(1 - z_{flat}\right) + 1.0 \cdot 10^{-8} z_{flat}$
v	V	Algeb	$V_0 \left(1 - z_{flat}\right) + z_{flat}$

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
flat_start	z_{flat}	0	flat start for voltages	(0, 1)

5.3 Calculation

Group of classes that calculates based on other models.

Common Parameters: u, name

Available models: *ACE*, *ACEc*, *COI*

5.3.1 ACE

Group *Calculation*

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	*bool*	
name		device name			
bus		bus idx for freq. measurement			mandatory
bias	β	bias parameter	1	*MW/0.1Hz*	power
busf		Optional BusFreq device idx			
area			0		

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
ace	ace	Algeb	area control error	*p.u. (MW)*	
f	f	ExtAlgeb	Bus frequency	*p.u. (Hz)*	

Variable 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	$10 \cdot 1/S_{b,sys} \beta f_{sys} \left(v^{f_s} - 1\right) - ace$
f	f	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
imva	$1/S_{b,sys}$	$\frac{1}{S_{b,sys}}$	ConstService

Discrete

Name	Symbol	Type	Info
fs	f_s	Sampling	Sampled freq.

Config Fields in [ACE]

Option	Symbol	Value	Info	Accepted values
freq_model		BusFreq	default freq. measurement model	('BusFreq',)
interval		4	sampling time interval	
offset		0	sampling time offset	

5.3.2 ACEc

Group *Calculation*

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	*bool*	
name		device name			
bus		bus idx for freq. measurement			mandatory
bias	β	bias parameter	1	*MW/0.1Hz*	power
busf		Optional BusFreq device idx			
area			0		

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
ace	ace	Algeb	area control error	*p.u. (MW)*	
f	f	ExtAlgeb	Bus frequency	*p.u. (Hz)*	

Variable 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
freq_model		BusFreq	default freq. measurement model	('BusFreq',)

5.3.3 COI

Group *Calculation*

Center of inertia calculation class.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
M		Linearly stored SynGen.M	0		

Variables (States + Algebraics)

Name	Symbol	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}	ExtAlgeb	COI frequency contribution of each generator		
delta_sub	δ_{sub}	ExtAlgeb	COI angle contribution of each generator		

Variable 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

5.4 Collection

Collection of topology models

Common Parameters: u, name

Available models: *Area*

5.4.1 Area

Group *Collection*

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	u	connection status	1	*bool*	
name		device name			

5.5 DCLink

Basic DC links

Common Parameters: u, name

Available models: *Ground*, *R*, *L*, *C*, *RCp*, *RCs*, *RLs*, *RLCs*, *RLCp*

5.5.1 Ground

Group *DCLink*

Ground model that sets the voltage of the connected DC node.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
node		Node index			mandatory
voltage	V_0	Ground voltage (typically 0)	0	*p.u.*	

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
Idc	I_{dc}	Algeb	Ficticious current injection from ground		v_str
v	v	ExtAlgeb			

Variable 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	$u\left(-V_{0}+v\right)$
v	v	ExtAlgeb	$-I_{dc}$

5.5.2 R

Group *DCLink*

Resistive dc line

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	*kV*	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	*kV*	non_zero
Idcn	I_{dcn}	DC current rating	1	*kA*	non_zero
R		DC line resistance	0.010	*p.u.*	non_zero,r

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
Idc	I_{dc}	Algeb	Current from node 2 to 1	*p.u.*	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Variable 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}

5.5.3 L

Group *DCLink*

Inductive dc line

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	*kV*	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	*kV*	non_zero
Idcn	I_{dcn}	DC current rating	1	*kA*	non_zero
L		DC line inductance	0.001	*p.u.*	non_zero,r

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
IL	I_L	State	Inductance current	*p.u.*	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Variable 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

5.5.4 C

Group *DCLink*

Capacitive dc branch

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	*kV*	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	*kV*	non_zero
Idcn	I_{dcn}	DC current rating	1	*kA*	non_zero
C		DC capacitance	0.001	*p.u.*	non_zero,g

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
vC	v_C	State	Capacitor current	*p.u.*	v_str
Idc	I_{dc}	Algeb	Current from node 2 to 1	*p.u.*	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Variable 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}

5.5.5 RCp

Group *DCLink*

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	*kV*	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	*kV*	non_zero
Idcn	I_{dcn}	DC current rating	1	*kA*	non_zero
R	R	DC line resistance	0.010	*p.u.*	non_zero,r
C	C	DC capacitance	0.001	*p.u.*	non_zero,g

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
vC	v_C	State	Capacitor current	*p.u.*	v_str
Idc	I_{dc}	Algeb	Current from node 2 to 1	*p.u.*	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Variable 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	$I_{dc}\left(1-u\right) + u\left(-v_1 + v_2 + v_C\right)$
v1	v_1	ExtAlgeb	$-I_{dc}$
v2	v_2	ExtAlgeb	I_{dc}

5.5.6 RCs

Group *DCLink*

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	*kV*	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	*kV*	non_zero
Idcn	I_{dcn}	DC current rating	1	*kA*	non_zero
R	R	DC line resistance	0.010	*p.u.*	non_zero,r
C	C	DC capacitance	0.001	*p.u.*	non_zero,g

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
vC	v_C	State	Capacitor current	*p.u.*	v_str
Idc	I_{dc}	Algeb	Current from node 2 to 1	*p.u.*	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Variable 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}

5.5.7 RLs

Group *DCLink*

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	*kV*	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	*kV*	non_zero
Idcn	I_{dcn}	DC current rating	1	*kA*	non_zero
R	R	DC line resistance	0.010	*p.u.*	non_zero,r
L	L	DC line inductance	0.001	*p.u.*	non_zero,r

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
IL	I_L	State	Inductance current	*p.u.*	v_str
Idc	I_{dc}	Algeb	Current from node 2 to 1	*p.u.*	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Variable 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}

5.5.8 RLCs

Group *DCLink*

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	*kV*	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	*kV*	non_zero
Idcn	I_{dcn}	DC current rating	1	*kA*	non_zero
R	R	DC line resistance	0.010	*p.u.*	non_zero,r
L	L	DC line inductance	0.001	*p.u.*	non_zero,r
C	C	DC capacitance	0.001	*p.u.*	non_zero,g

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
IL	I_L	State	Inductance current	*p.u.*	v_str
vC	v_C	State	Capacitor current	*p.u.*	v_str
Idc	I_{dc}	Algeb	Current from node 2 to 1	*p.u.*	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Variable 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 x' = f(x, y)"	T (LHS)
IL	I_L	State	$u\left(-I_L R + v_1 - v_2 - v_C\right)$	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}

5.5.9 RLCp

Group *DCLink*

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	*kV*	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	*kV*	non_zero
Idcn	I_{dcn}	DC current rating	1	*kA*	non_zero
R	R	DC line resistance	0.010	*p.u.*	non_zero,r
L	L	DC line inductance	0.001	*p.u.*	non_zero,r
C	C	DC capacitance	0.001	*p.u.*	non_zero,g

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
IL	I_L	State	Inductance current	*p.u.*	v_str
vC	v_C	State	Capacitor current	*p.u.*	v_str
Idc	I_{dc}	Algeb	Current from node 2 to 1	*p.u.*	v_str
v1	v_1	ExtAlgeb	DC voltage on node 1		
v2	v_2	ExtAlgeb	DC voltage on node 2		

Variable 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	$I_{dc}\left(1 - u\right) + u\left(-v_1 + v_2 + v_C\right)$
v1	v_1	ExtAlgeb	$-I_{dc}$
v2	v_2	ExtAlgeb	I_{dc}

5.6 DCTopology

Common Parameters: u, name

Common Variables: v

Available models: *Node*

5.6.1 Node

Group *DCTopology*

DC Node model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
Vdcn	V_{dcn}	DC voltage rating	100	*kV*	non_zero
Idcn	I_{dcn}	DC current rating	1	*kA*	non_zero
v0	V_{dc0}	initial voltage magnitude	1	*p.u.*	
xcoord		x coordinate (longitude)	0		
ycoord		y coordinate (latitude)	0		
area		Area code			
zone		Zone code			
owner		Owner code			

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
v	V_{dc}	Algeb	voltage magnitude	*p.u.*	v_str

Variable Initialization Equations

Name	Symbol	Type	Initial Value
v	V_{dc}	Algeb	$V_{dc0} (1 - z_{flat}) + z_{flat}$

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
flat_start	z_{flat}	0	flat start for voltages	(0, 1)

5.7 DG

Distributed generation (small-scale).

Common Parameters: u, name

Available models: *PVD1*

5.7.1 PVD1

Group *DG*

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 `Pe = Ipout_y * v` and `Qe = Iqout_y * v`.

Frequency tripping response points *ft0*, *ft1*, *ft2*, and *ft3* must be monotinically 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.

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
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
Sn	S_n	device MVA rating	100	*MVA*	
fn	f_n	nominal frequency	60	*Hz*	
busf		Optional BusFreq measurement device idx			
xc	x_c	coupling reactance	0	*p.u.*	z
pqflag		P/Q priority for I limit; 0-Q priority, 1-P priority		*bool*	mandatory
igreg		Remote bus idx for droop response, None for local			
qmx	q_{mx}	Max. reactive power command	0.330		power
qmn	q_{mn}	Min. reactive power command	-0.330		power
pmx	p_{mx}	maximum power limit	999		power
v0	v_0	Lower limit of deadband for Vdroop response	0.800	*pu*	non_zero
v1	v_1	Upper limit of deadband for Vdroop response	1.100	*pu*	non_zero
dqdv	dq/dv	Q-V droop characteristics (negative)	-1		non_zero,power
fdbd	f_{dbd}	frequency deviation deadband	-0.017	*Hz*	non_positive
ddn	D_{dn}	Gain after f deadband	0	*pu (MW)/Hz*	non_negative,power
ialim	I_{alim}	Apparent power limit	1.300		non_zero,non_negat
vt0	V_{t0}	Voltage tripping response curve point 0	0.880	*p.u.*	non_zero,non_negat
vt1	V_{t1}	Voltage tripping response curve point 1	0.900	*p.u.*	non_zero,non_negat
vt2	V_{t2}	Voltage tripping response curve point 2	1.100	*p.u.*	non_zero,non_negat
vt3	V_{t3}	Voltage tripping response curve point 3	1.200	*p.u.*	non_zero,non_negat
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	*Hz*	non_zero,non_negat

Continued on

Table 1 – continued from previous page

Name	Symbol	Description	Default	Unit	Properties
ft1	f_{t1}	Frequency tripping response curve point 1	59.700	Hz	non_zero,non_negat
ft2	f_{t2}	Frequency tripping response curve point 2	60.300	Hz	non_zero,non_negat
ft3	f_{t3}	Frequency tripping response curve point 3	60.500	Hz	non_zero,non_negat
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	s	non_negative
tiq	T_{iq}	Inverter reactive current lag time constant	0.020	s	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		

Variables (States + Algebraics)

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
Qsum	Q_{sum}	Algeb	Total Q (droop + initial)		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			v_str
Iqmax	I_{qmax}	Algeb			v_str
Ipcmd_y	y_{Ipcmd}	Algeb	Gain output after limiter		v_str
Iqcmd_y	y_{Iqcmd}	Algeb	Gain output after limiter		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	$p.u.$	

Variable Initialization Equations

Name	Symbol	Type	Initial Value
Ipout_y	y_{Ipout}	State	$1.0y_{Ipcmd}$
Iqout_y	y_{Iqout}	State	$1.0y_{Iqcmd}$
fHz	f_{Hz}	Algeb	ff_n
Ffl	F_{fl}	Algeb	$K_{ft01}z_i^{FL_1}(f_{Hz} - f_{t0}) + z_u^{FL_1}$
Ffh	F_{fh}	Algeb	$z_i^{FL_2}(K_{ft23}(-f_{Hz} + f_{t2}) + 1) + z_l^{FL_2}$
Fdev	f_{dev}	Algeb	$f_n - f_{Hz}$
DB_y	y_{DB}	Algeb	$D_{dn}(DB_{dbzl}(-f_{dbd} + f_{dev}) + DB_{dbzu}f_{dev})$
Fvl	F_{vl}	Algeb	$K_{vt01}z_i^{VL_1}(V - V_{t0}) + z_u^{VL_1}$
Fvh	F_{vh}	Algeb	$z_i^{VL_2}(K_{vt23}(-V + V_{t2}) + 1) + z_l^{VL_2}$
vp	V_p	Algeb	$Vz_i^{VLo} + 0.01z_l^{VLo}$
Pext	P_{ext}	Algeb	P_{ext0}
Pref	P_{ref}	Algeb	P_{ref0}
Psum	P_{tot}	Algeb	$P_{ext} + P_{ref} + y_{DB}$
Qsum	Q_{sum}	Algeb	$Q_{ref0} + dq/dvz_i^{VQ_2}(-V_{comp} + v_1) + q_{mn}z_u^{VQ_2} + q_{mx}z_l^{VQ_1} + z_i^{VQ_1}(dq/dv(-V_{comp} + V_{qu}) + q_{mx})$
Ipul	$I_{p,ul}$	Algeb	$\frac{P_{tot}z_i^{PHL} + p_{mx}z_u^{PHL}}{V_p}$
Iqul	$I_{q,ul}$	Algeb	$\frac{Q_{sum}}{V_p}$
Ipmax	I_{pmax}	Algeb	$I_{alim}SWPQ_{s1} + \sqrt{I_{pmax0}^2}SWPQ_{s0}$
Iqmax	I_{qmax}	Algeb	$I_{alim}SWPQ_{s0} + \sqrt{I_{qmax0}^2}SWPQ_{s1}$
Ipcmd_y	y_{Ipcmd}	Algeb	$F_{fh}F_{fl}F_{vh}F_{vl}I_{p,ul}Ipcmd_{limzi} + F_{fh}F_{fl}F_{vh}F_{vl}I_{pmax}Ipcmd_{limzu}$
Iqcmd_y	y_{Iqcmd}	Algeb	$F_{fh}F_{fl}F_{vh}F_{vl}I_{q,ul}Iqcmd_{limzi} - F_{fh}F_{fl}F_{vh}F_{vl}I_{qmax}Iqcmd_{limzl} + F_{fh}F_{fl}F_{vh}F_{vl}I_{qmax}Iqcmd_{limzu}$
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}

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	$-F_{fl} + K_{ft01} z_i^{FL_1} (f_{Hz} - f_{t0}) + z_u^{FL_1}$
Ffh	F_{fh}	Algeb	$-F_{fh} + z_i^{FL_2} (K_{ft23} (-f_{Hz} + f_{t2}) + 1) + z_l^{FL_2}$
Fdev	f_{dev}	Algeb	$f_n - f_{Hz} - f_{dev}$
DB_y	y_{DB}	Algeb	$D_{dn} (DB_{dbzl} (-f_{dbd} + f_{dev}) + DB_{dbzu} f_{dev}) - y_{DB}$
Fvl	F_{vl}	Algeb	$-F_{vl} + K_{vt01} z_i^{VL_1} (V - V_{t0}) + z_u^{VL_1}$
Fvh	F_{vh}	Algeb	$-F_{vh} + z_i^{VL_2} (K_{vt23} (-V + V_{t2}) + 1) + z_l^{VL_2}$
vp	V_p	Algeb	$V z_i^{VLo} - V_p + 0.01 z_l^{VLo}$
Pext	P_{ext}	Algeb	$P_{ext0} - P_{ext}$
Pref	P_{ref}	Algeb	$P_{ref0} - P_{ref}$
Psum	P_{tot}	Algeb	$P_{ext} + P_{ref} - P_{tot} + y_{DB}$
Qsum	Q_{sum}	Algeb	$Q_{ref0} - Q_{sum} + dq/dv z_i^{VQ_2} (-V_{comp} + v_1) + q_{mn} z_u^{VQ_2} + q_{mx} z_l^{VQ_1} + z_i^{VQ_1} (dq/dv (-V_{comp} + V_{qu}) + q_{mx})$
Ipul	$I_{p,ul}$	Algeb	$-I_{p,ul} + \frac{P_{tot} z_i^{PHL} + p_{mx} z_u^{PHL}}{V_p}$
Iqul	$I_{q,ul}$	Algeb	$-I_{q,ul} + \frac{Q_{sum}}{V_p}$
Ipmax	I_{pmax}	Algeb	$I_{alim} SWPQ_{s1} - I_{pmax} + \sqrt{I_{pmax}^2} SWPQ_{s0}$
Iqmax	I_{qmax}	Algeb	$I_{alim} SWPQ_{s0} - I_{qmax} + \sqrt{I_{qmax}^2} SWPQ_{s1}$
Ipcmd_y	y_{Ipcmd}	Algeb	$F_{fh} F_{fl} F_{vh} F_{vl} I_{p,ul} Ipcmd_{limzi} + F_{fh} F_{fl} F_{vh} F_{vl} I_{pmax} Ipcmd_{limzu} - y_{Ipcmd}$
Iqcmd_y	y_{Iqcmd}	Algeb	$F_{fh} F_{fl} F_{vh} F_{vl} I_{q,ul} Iqcmd_{limzi} - F_{fh} F_{fl} F_{vh} F_{vl} I_{qmax} Iqcmd_{limzl} + F_{fh} F_{fl} F_{vh} F_{vl} I_{qmax} Iqcmd_{limzu} - y_{Iqcmd}$
a	θ	ExtAlgeb	$-V u y_{Ipout}$
v	V	ExtAlgeb	$-V u y_{Iqout}$
f	f	ExtAlgeb	0

Services

Name	Symbol	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}	$\operatorname{abs}\left(Ve^{i\theta} + ix_c\left(y_{Ipout} + iy_{Iqout}\right)\right)$	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
Ipmaxsq	I^2_{pmax}	$\begin{cases} 0 & \text{for}\: I^2_{alim} - \left(y_{I^{qcmd}}\right)^2 \leq 0 \\ I^2_{alim} - \left(y_{I^{qcmd}}\right)^2 & \text{otherwise} \end{cases}$	VarService
Ipmaxsq0	I^2_{pmax0}	$\begin{cases} 0 & \text{for}\: I^2_{alim} - \frac{Q^2_{ref0}}{V^2} \leq 0 \\ I^2_{alim} - \frac{Q^2_{ref0}}{V^2} & \text{otherwise} \end{cases}$	ConstService
Iqmaxsq	I^2_{qmax}	$\begin{cases} 0 & \text{for}\: I^2_{alim} - \left(y_{I^{pcmd}}\right)^2 \leq 0 \\ I^2_{alim} - \left(y_{I^{pcmd}}\right)^2 & \text{otherwise} \end{cases}$	VarService
Iqmaxsq0	I^2_{qmax0}	$\begin{cases} 0 & \text{for}\: I^2_{alim} - \frac{P^2_{ref0}}{V^2} \leq 0 \\ I^2_{alim} - \frac{P^2_{ref0}}{V^2} & \text{otherwise} \end{cases}$	ConstService

Discrete

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}	LimiterGain	Ip with limiter and coeff.
Iqcmd	I^{qcmd}	LimiterGain	Iq with limiter and coeff.
Ipout	$Ipout$	Lag	Output Ip filter
Iqout	$Iqout$	Lag	Output Iq filter

Config Fields in [PVD1]

Option	Symbol	Value	Info	Accepted values
plim	P_{lim}	0	enable input power limit check bound by [0, pmx]	(0, 1)

5.8 DynLoad

Dynamic load group.

Common Parameters: u, name

Available models: *ZIP*, *FLoad*

5.8.1 ZIP

Group *DynLoad*

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	*bool*	
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 bux idx	0		

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Variable 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

5.8.2 FLoad

Group *DynLoad*

Voltage and frequency dependent load.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
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 (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
f	f	ExtAlgeb			
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Variable 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	$pv0$	$\frac{P_0 V_0^{-ap} kpu}{100}$	ConstService
qv0	$qv0$	$\frac{Q_0 V_0^{-aq} kqu}{100}$	ConstService

5.9 Exciter

Exciter group for synchronous generators.

Common Parameters: u, name, syn

Common Variables: vout, vi

Available models: *EXDC2*, *IEEEX1*, *ESDC2A*, *EXST1*, *ESST3A*, *SEXS*

5.9.1 EXDC2

Group *Exciter*

EXDC2 model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.010	*p.u.*	
TA	T_A	Lag time constant in anti-windup lag	0.040	*p.u.*	
TC	T_C	Lead time constant in lead-lag	1	*p.u.*	
TB	T_B	Lag time constant in lead-lag	1	*p.u.*	
TE	T_E	Exciter integrator time constant	0.800	*p.u.*	
TF1	T_{F1}	Feedback washout time constant	1	*p.u.*	non_zero
KF1	K_{F1}	Feedback washout gain	0.030	*p.u.*	
KA	K_A	Gain in anti-windup lag TF	40	*p.u.*	
KE	K_E	Gain added to saturation	1	*p.u.*	
VRMAX	V_{RMAX}	Maximum excitation limit	7.300	*p.u.*	
VRMIN	V_{RMIN}	Minimum excitation limit	-7.300	*p.u.*	
E1	E_1	First saturation point	0	*p.u.*	
SE1	S_{E1}	Value at first saturation point	0	*p.u.*	
E2	E_2	Second saturation point	1	*p.u.*	
SE2	S_{E2}	Value at second saturation point	1	*p.u.*	
Sn	S_m	Rated power from generator	0	*MVA*	
Vn	V_m	Rated voltage from generator	0	*kV*	
bus	bus	Bus idx of the generators	0		

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
vp	V_p	State	Voltage after saturation feedback, before speed term	*p.u.*	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		
vout	v_{out}	Algeb	Exciter final output voltage		v_str
vref	V_{ref}	Algeb	Reference voltage input	*p.u.*	v_str
Se	$S_e(\|V_{out}\|)$	Algeb	saturation output		v_str
vi	V_i	Algeb	Total input voltages	*p.u.*	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	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Variable Initialization Equations

Name	Symbol	Type	Initial Value
vp	V_p	State	v_{f0}
LS_y	y_{LS}	State	$1.0V$
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	
vout	v_{out}	Algeb	v_{f0}
vref	V_{ref}	Algeb	V_{ref0}
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	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
vp	V_p	State	$-K_E V_p - S_e(\|V_{out}\|) V_p + y_{LA}$	T_E
LS_y	y_{LS}	State	$1.0V - y_{LS}$	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)"
vout	v_{out}	Algeb	$V_p \omega - v_{out}$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
Se	$S_e(\|V_{out}\|)$	Algeb	$\frac{B^q_{SAT} z_0^{SL} \left(-A^q_{SAT} + V_p\right)^2}{V_p} - S_e(\|V_{out}\|)$
vi	V_i	Algeb	$-V_i + V_{ref} - y_{LS} - y_W$
LL_y	y_{LL}	Algeb	$LL_{LT1z1} LL_{LT2z1} \left(-x'_{LL} + y_{LL}\right) + T_B x'_{LL} - T_B y_{LL} + T_C \left(V_i - x'_{LL}\right)$
W_y	y_W	Algeb	$K_{F1} \left(V_p - x'_W\right) - T_{F1} y_W$
vf	v_f	ExtAlgeb	$u \left(-v_{f0} + v_{out}\right)$
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	0
a	θ	ExtAlgeb	0
v	V	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
SAT_E1	E^{1c}_{SAT}	E_1	ConstService
SAT_E2	E^{2c}_{SAT}	E_2	ConstService
SAT_SE1	SE^{1c}_{SAT}	S_{E1}	ConstService
SAT_SE2	SE^{2c}_{SAT}	$S_{E2} - 2 z^{SE2}_{SAT} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E^{1c}_{SAT} SE^{1c}_{SAT}}{E^{2c}_{SAT} SE^{2c}_{SAT}}} \left(\left(SE^{2c}_{SAT} > 0\right) + \left(SE^{2c}_{SAT} < 0\right)\right)$	ConstService
SAT_A	A^q_{SAT}	$E^{2c}_{SAT} - \frac{E^{1c}_{SAT} - E^{2c}_{SAT}}{a_{SAT} - 1}$	ConstService
SAT_B	B^q_{SAT}	$\frac{E^{2c}_{SAT} SE^{2c}_{SAT} \left(a_{SAT} - 1\right)^2 \left(\left(a_{SAT} > 0\right) + \left(a_{SAT} < 0\right)\right)}{\left(E^{1c}_{SAT} - E^{2c}_{SAT}\right)^2}$	ConstService
Se0	S_{e0}	$\frac{B^q_{SAT} \left(A^q_{SAT} - v_{f0}\right)^2 \left(v_{f0} > A^q_{SAT}\right)}{v_{f0}}$	ConstService
vr0	V_{r0}	$v_{f0} \left(K_E + S_{e0}\right)$	ConstService
vb0	V_{b0}	$\frac{V_{r0}}{K_A}$	ConstService
vref0	V_{ref0}	$V + V_{b0}$	ConstService

Discrete

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

5.9.2 IEEEX1

Group *Exciter*

IEEEX1 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	*bool*	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.010	*p.u.*	
TA	T_A	Lag time constant in anti-windup lag	0.040	*p.u.*	
TC	T_C	Lead time constant in lead-lag	1	*p.u.*	
TB	T_B	Lag time constant in lead-lag	1	*p.u.*	
TE	T_E	Exciter integrator time constant	0.800	*p.u.*	
TF1	T_{F1}	Feedback washout time constant	1	*p.u.*	non_zero
KF1	K_{F1}	Feedback washout gain	0.030	*p.u.*	
KA	K_A	Gain in anti-windup lag TF	40	*p.u.*	
KE	K_E	Gain added to saturation	1	*p.u.*	
VRMAX	V_{RMAX}	Maximum excitation limit	7.300	*p.u.*	
VRMIN	V_{RMIN}	Minimum excitation limit	-7.300	*p.u.*	
E1	E_1	First saturation point	0	*p.u.*	
SE1	S_{E1}	Value at first saturation point	0	*p.u.*	
E2	E_2	Second saturation point	1	*p.u.*	
SE2	S_{E2}	Value at second saturation point	1	*p.u.*	
Sn	S_m	Rated power from generator	0	*MVA*	
Vn	V_m	Rated voltage from generator	0	*kV*	
bus	bus	Bus idx of the generators	0		

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
vp	V_p	State	Voltage after saturation feedback, before speed term	*p.u.*	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		
vout	v_{out}	Algeb	Exciter final output voltage		v_str
vref	V_{ref}	Algeb	Reference voltage input	*p.u.*	v_str
Se	$S_e(\|V_{out}\|)$	Algeb	saturation output		v_str
vi	V_i	Algeb	Total input voltages	*p.u.*	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	ExtAlgeb	Excitation field voltage to generator		
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	Armature excitation current		
a	θ	ExtAlgeb	Bus voltage phase angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Variable Initialization Equations

Name	Symbol	Type	Initial Value
vp	V_p	State	v_{f0}
LS_y	y_{LS}	State	$1.0V$
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	
vout	v_{out}	Algeb	v_{f0}
vref	V_{ref}	Algeb	V_{ref0}
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	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
vp	V_p	State	$-K_E V_p - S_e(\|V_{out}\|)V_p + y_{LA}$	T_E
LS_y	y_{LS}	State	$1.0V - y_{LS}$	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)"
vout	v_{out}	Algeb	$V_p - v_{out}$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
Se	$S_e(\|V_{out}\|)$	Algeb	$\frac{B^q_{SAT} z^{SL}_0 \left(-A^q_{SAT} + V_p\right)^2}{V_p} - S_e(\|V_{out}\|)$
vi	V_i	Algeb	$-V_i + V_{ref} - y_{LS} - y_W$
LL_y	y_{LL}	Algeb	$LL_{LT1z1} LL_{LT2z1} \left(-x'_{LL} + y_{LL}\right) + T_B x'_{LL} - T_B y_{LL} + T_C \left(V_i - x'_{LL}\right)$
W_y	y_W	Algeb	$K_{F1} \left(V_p - x'_W\right) - T_{F1} y_W$
vf	v_f	ExtAlgeb	$u \left(-v_{f0} + v_{out}\right)$
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	0
a	θ	ExtAlgeb	0
v	V	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
SAT_E1	E^{1c}_{SAT}	E_1	ConstService
SAT_E2	E^{2c}_{SAT}	E_2	ConstService
SAT_SE1	SE^{1c}_{SAT}	S_{E1}	ConstService
SAT_SE2	SE^{2c}_{SAT}	$S_{E2} - 2z^{SE2}_{SAT} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E^{1c}_{SAT} SE^{1c}_{SAT}}{E^{2c}_{SAT} SE^{2c}_{SAT}}} \left(\left(SE^{2c}_{SAT} > 0\right) + \left(SE^{2c}_{SAT} < 0\right)\right)$	ConstService
SAT_A	A^q_{SAT}	$E^{2c}_{SAT} - \frac{E^{1c}_{SAT} - E^{2c}_{SAT}}{a_{SAT} - 1}$	ConstService
SAT_B	B^q_{SAT}	$\frac{E^{2c}_{SAT} SE^{2c}_{SAT} (a_{SAT} - 1)^2 ((a_{SAT} > 0) + (a_{SAT} < 0))}{\left(E^{1c}_{SAT} - E^{2c}_{SAT}\right)^2}$	ConstService
Se0	S_{e0}	$\frac{B^q_{SAT} \left(A^q_{SAT} - v_{f0}\right)^2 \left(v_{f0} > A^q_{SAT}\right)}{v_{f0}}$	ConstService
vr0	V_{r0}	$v_{f0} \left(K_E + S_{e0}\right)$	ConstService
vb0	V_{b0}	$\frac{V_{r0}}{K_A}$	ConstService
vref0	V_{ref0}	$V + V_{b0}$	ConstService
VRTMAX	$V_{RMAX} V_T$	$V V_{RMAX}$	VarService
VRTMIN	$V_{RMIN} V_T$	$V V_{RMIN}$	VarService

Discrete

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

5.9.3 ESDC2A

Group *Exciter*

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	*bool*	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.010	*p.u.*	
KA	K_A	Regulator gain	80		
TA	T_A	Lag time constant in regulator	0.040	*p.u.*	
TB	T_B	Lag time constant in lead-lag	1	*p.u.*	
TC	T_C	Lead time constant in lead-lag	1	*p.u.*	
VRMAX	V_{RMAX}	Max. exc. limit (0-unlimited)	7.300	*p.u.*	
VRMIN	V_{RMIN}	Min. excitation limit	-7.300	*p.u.*	
KE	K_E	Saturation feedback gain	1	*p.u.*	
TE	T_E	Integrator time constant	0.800	*p.u.*	
KF	K_F	Feedback gain	0.100		
TF1	T_{F1}	Feedback washout time constant	1	*p.u.*	non_zero,non_negative
Switch	S_w	Switch that PSS/E did not implement	0	*bool*	
E1	E_1	First saturation point	0	*p.u.*	
SE1	S_{E1}	Value at first saturation point	0	*p.u.*	
E2	E_2	Second saturation point	0	*p.u.*	
SE2	S_{E2}	Value at second saturation point	0	*p.u.*	
Sn	S_m	Rated power from generator	0	*MVA*	
Vn	V_m	Rated voltage from generator	0	*kV*	
bus	bus	Bus idx of the generators	0		

Variables (States + Algebraics)

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		
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	$S_e(\|V_{out}\|)$	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		
v	V	ExtAlgeb	Bus voltage magnitude		

Variable Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	V
LL_x	x'_{LL}	State	V_i
LA_y	y_{LA}	State	$K_A y_{LL}$
INT_y	y_{INT}	State	v_{f0}
WF_x	x'_{WF}	State	y_{INT}
omega	ω	ExtState	
vout	v_{out}	Algeb	v_{f0}
vref	V_{ref}	Algeb	V_{ref0}
vi	V_i	Algeb	$-V + V_{ref0}$
LL_y	y_{LL}	Algeb	V_i
UEL	U_{EL}	Algeb	0
HG_y	y_{HG}	Algeb	$HG_{sls0}U_{EL} + HG_{sls1}y_{LL}$
Se	$S_e(\|V_{out}\|)$	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	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$V - y_{LG}$	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
INT_y	y_{INT}	State	$-V_{FE} + y_{LA}$	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)"
vout	v_{out}	Algeb	$-v_{out} + y_{INT}$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
vi	V_i	Algeb	$-V - V_i + V_{ref} - y_{WF}$
LL_y	y_{LL}	Algeb	$LL_{LT1z1} LL_{LT2z1} \left(-x'_{LL} + y_{LL}\right) + T_B x'_{LL} - T_B y_{LL} + T_C \left(V_i - x'_{LL}\right)$
UEL	U_{EL}	Algeb	$-U_{EL}$
HG_y	y_{HG}	Algeb	$HG_{sls0} U_{EL} + HG_{sls1} y_{LL} - y_{HG}$
Se	$S_e(\|V_{out}\|)$	Algeb	$\frac{B^q_{SAT} z_0^{SL} \left(-A^q_{SAT} + y_{INT}\right)^2}{y_{INT}} - S_e(\|V_{out}\|)$
VFE	V_{FE}	Algeb	$-V_{FE} + y_{INT} \left(K_E + S_e(\|V_{out}\|)\right)$
WF_y	y_{WF}	Algeb	$K_F \left(-x'_{WF} + y_{INT}\right) - T_{F1} y_{WF}$
vf	v_f	ExtAlgeb	$u \left(-v_{f0} + v_{out}\right)$
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	0
a	θ	ExtAlgeb	0
v	V	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
VRMAXc	$VRMAXc$	$V_{RMAX} - 999z_{VRMAX} + 999$	ConstService
SAT_E1	E^{1c}_{SAT}	E_1	ConstService
SAT_E2	E^{2c}_{SAT}	E_2	ConstService
SAT_SE1	SE^{1c}_{SAT}	S_{E1}	ConstService
SAT_SE2	SE^{2c}_{SAT}	$S_{E2} - 2z^{SE2}_{SAT} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E^{1c}_{SAT}SE^{1c}_{SAT}}{E^{2c}_{SAT}SE^{2c}_{SAT}}}\left(\left(SE^{2c}_{SAT} > 0\right) + \left(SE^{2c}_{SAT} < 0\right)\right)$	ConstService
SAT_A	A^q_{SAT}	$E^{2c}_{SAT} - \frac{E^{1c}_{SAT} - E^{2c}_{SAT}}{a_{SAT} - 1}$	ConstService
SAT_B	B^q_{SAT}	$\frac{E^{2c}_{SAT}SE^{2c}_{SAT}\left(a_{SAT}-1\right)^2\left(\left(a_{SAT}>0\right)+\left(a_{SAT}<0\right)\right)}{\left(E^{1c}_{SAT}-E^{2c}_{SAT}\right)^2}$	ConstService
Se0	S_{e0}	$\frac{B^q_{SAT}\left(A^q_{SAT}-v_{f0}\right)^2\left(v_{f0}>A^q_{SAT}\right)}{v_{f0}}$	ConstService
vfe0	V_{FE0}	$v_{f0}\left(K_E + S_{e0}\right)$	ConstService
vref0	V_{ref0}	$V + \frac{V_{FE0}}{K_A}$	ConstService
VRU	$V_T V_{RMAX}$	$VVRMAXc$	VarService
VRL	$V_T V_{RMIN}$	VV_{RMIN}	VarService

Discrete

Name	Symbol	Type	Info
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
HG_sl	$None_{HG}$	Selector	HVGate Selector
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

5.9.4 EXST1

Group *Exciter*

EXST1-type static excitation system.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
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
Sn	S_m	Rated power from generator	0	*MVA*	
Vn	V_m	Rated voltage from generator	0	*kV*	
bus	bus	Bus idx of the generators	0		

Variables (States + Algebraics)

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		
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		
v	V	ExtAlgeb	Bus voltage magnitude		

Variable Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	V
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	
vout	v_{out}	Algeb	v_{f0}
vref	V_{ref}	Algeb	V_{ref0}
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	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LG_y	y_{LG}	State	$V - y_{LG}$	T_R
LL_x	x'_{LL}	State	$V_l - x'_{LL}$	T_B
LR_y	y_{LR}	State	$K_A y_{LL} - y_{LR}$	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)"
vout	v_{out}	Algeb	$V_{fmax} z_u^{HLR} + V_{fmin} z_l^{HLR} - v_{out} + y_{LR} z_i^{HLR}$
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	$LL_{LT1z1} LL_{LT2z1} \left(-x'_{LL} + y_{LL}\right) + T_B x'_{LL} - T_B y_{LL} + T_C \left(V_l - x'_{LL}\right)$
WF_y	y_{WF}	Algeb	$K_F \left(-x'_{WF} + y_{LR}\right) - T_F y_{WF}$
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	$u \left(-v_{f0} + v_{out}\right)$
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	0
a	θ	ExtAlgeb	0
v	V	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
vref0	V_{ref0}	$V + \frac{v_{f0}}{K_A}$	ConstService

Discrete

Name	Symbol	Type	Info
HLI	HLI	HardLimiter	Hard limiter on input
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
HLR	HLR	HardLimiter	Hard limiter on regulator output

Blocks

Name	Symbol	Type	Info
LG	LG	Lag	Sensing delay
LL	LL	LeadLag	Lead-lag compensator
LR	LR	Lag	Regulator
WF	WF	Washout	Stablizing circuit feedback

5.9.5 ESST3A

Group *Exciter*

Static exciter type 3A model

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
syn		Synchronous generator idx			mandatory
TR	T_R	Sensing time constant	0.010	*p.u.*	
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		
VRMAX	V_{RMAX}	Maximum excitation limit	8	*p.u.*	
VRMIN	V_{RMIN}	Minimum excitation limit	0	*p.u.*	
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		
VBMAX	V_{BMAX}	VB upper limit	18	*p.u.*	
KC	K_C	Rectifier loading factor proportional to commutating reactance	0.100		
XL	X_L	Potential source reactance	0.010		
VGMAX	V_{GMAX}	VG upper limit	4	*p.u.*	
THETAP	θ_P	Rectifier firing angle	0	*degree*	
TM	K_C	Inner field regulator forward time constant	0.100		
VMMAX	V_{MMAX}	Maximum VM limit	1	*p.u.*	
VMMIN	V_{RMIN}	Minimum VM limit	0.100	*p.u.*	
Sn	S_m	Rated power from generator	0	*MVA*	
Vn	V_m	Rated voltage from generator	0	*kV*	
bus	bus	Bus idx of the generators	0		

Variables (States + Algebraics)

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		
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	Gain output before limiter		v_str
VB_y	y_{VB}	Algeb	Gain output after limiter		v_str
VG_x	x_{VG}	Algeb	Gain output before limiter		v_str
VG_y	y_{VG}	Algeb	Gain output after limiter		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		
v	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		

Variable Initialization Equations

Name	Symbol	Type	Initial Value
LG_y	y_{LG}	State	V
LL_x	x'_{LL}	State	y_{HG}
LAW1_y	y_{LAW1}	State	$K_A y_{LL}$
LAW2_y	y_{LAW2}	State	$K_M V_{RS}$
omega	ω	ExtState	
vout	v_{out}	Algeb	v_{f0}
UEL	U_{EL}	Algeb	0
IN	I_N	Algeb	$\frac{K_C X_{ad} I_{fd}}{V_E}$
FEX_y	y_{FEX}	Algeb	$\begin{cases} 1 & \text{for } I_N \leq 0 \\ 1 - 0.577 I_N & \text{for } I_N \leq 0.433 \\ \sqrt{0.75 - I_N^2} & \text{for } I_N \leq 0.75 \\ 1.732 - 1.732 I_N & \text{for } I_N \leq 1 \\ 0 & \text{otherwise} \end{cases}$
VB_x	x_{VB}	Algeb	$V_E y_{FEX}$
VB_y	y_{VB}	Algeb	$VB_{limzi} x_{VB} + VB_{limzu} V_{BMAX}$
VG_x	x_{VG}	Algeb	$K_G v_{out}$
VG_y	y_{VG}	Algeb	$VG_{limzi} x_{VG} + VG_{limzu} V_{GMAX}$
vrs	V_{RS}	Algeb	$\frac{v_{f0}}{K_M y_{VB}}$
vref	V_{ref}	Algeb	$V + \frac{V_{RS} + y_{VG}}{K_A}$
vi	V_i	Algeb	$-V + V_{ref}$
vil	V_{il}	Algeb	$V_i z_i^{HLI} + V_{IMAX} z_u^{HLI} + V_{IMIN} z_l^{HLI}$
HG_y	y_{HG}	Algeb	$HG_{sls0} U_{EL} + HG_{sls1} V_{il}$
LL_y	y_{LL}	Algeb	y_{HG}
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
v	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	$V - y_{LG}$	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)"
vout	v_{out}	Algeb	$-v_{out} + y_{LAW2} y_{VB}$
UEL	U_{EL}	Algeb	$-U_{EL}$
IN	I_N	Algeb	$-I_N + \frac{K_C X_{ad} I_{fd}}{V_E}$
FEX_y	y_{FEX}	Algeb	$-y_{FEX} + \begin{cases} 1 & \text{for}\: I_N \leq 0 \\ 1 - 0.577 I_N & \text{for}\: I_N \leq 0.433 \\ \sqrt{0.75 - I_N^2} & \text{for}\: I_N \leq 0.75 \\ 1.732 - 1.732 I_N & \text{for}\: I_N \leq 1 \\ 0 & \text{otherwise} \end{cases}$
VB_x	x_{VB}	Algeb	$V_E y_{FEX} - x_{VB}$
VB_y	y_{VB}	Algeb	$VB_{limzi} x_{VB} + VB_{limzu} V_{BMAX} - y_{VB}$
VG_x	x_{VG}	Algeb	$K_G v_{out} - x_{VG}$
VG_y	y_{VG}	Algeb	$VG_{limzi} x_{VG} + VG_{limzu} V_{GMAX} - y_{VG}$
vrs	V_{RS}	Algeb	$-V_{RS} + y_{LAW1} - y_{VG}$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
vi	V_i	Algeb	$-V_i + V_{ref} - y_{LG}$
vil	V_{il}	Algeb	$V_i z_i^{HLI} + V_{IMAX} z_u^{HLI} + V_{IMIN} z_l^{HLI} - V_{il}$
HG_y	y_{HG}	Algeb	$HG_{sls0} U_{EL} + HG_{sls1} V_{il} - y_{HG}$
LL_y	y_{LL}	Algeb	$LL_{LT1z1} LL_{LT2z1} \left(-x'_{LL} + y_{LL}\right) + T_B x'_{LL} - T_B y_{LL} + T_C \left(-x'_{LL} + y_{HG}\right)$
vf	v_f	ExtAlgeb	$u \left(-v_{f0} + v_{out}\right)$
XadIfd	$X_{ad} I_{fd}$	ExtAlgeb	0
a	θ	ExtAlgeb	0
v	V	ExtAlgeb	0
vd	V_d	ExtAlgeb	0
vq	V_q	ExtAlgeb	0
Id	I_d	ExtAlgeb	0
Iq	I_q	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
KPC	K_{PC}	$K_P e^{i \operatorname{radians}{\left(\theta_P \right)}}$	ConstService
VE	V_E	$\left\|K_{PC} \left(V_d + i V_q\right) + i \left(I_d + i I_q\right) \left(K_I + K_{PC} X_L\right)\right\|$	VarService
vref0	V_{ref0}	V_{ref}	PostInitService

Discrete

Name	Symbol	Type	Info
VB_lim	lim_{VB}	HardLimiter	
VG_lim	lim_{VG}	HardLimiter	
HG_sl	$None_{HG}$	Selector	HVGate Selector
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

5.9.6 SEXS

Group *Exciter*

Simplified Excitation System Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
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		
Sn	S_m	Rated power from generator	0	*MVA*	
Vn	V_m	Rated voltage from generator	0	*kV*	
bus	bus	Bus idx of the generators	0		

Variables (States + Algebraics)

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		
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
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		
v	V	ExtAlgeb	Bus voltage magnitude		

Variable Initialization Equations

Name	Symbol	Type	Initial Value
LL_x	x'_{LL}	State	V_i
LAW_y	y_{LAW}	State	Ky_{LL}
omega	ω	ExtState	
vout	v_{out}	Algeb	v_{f0}
vref	V_{ref}	Algeb	V_{ref0}
vi	V_i	Algeb	$-V + V_{ref0}$
LL_y	y_{LL}	Algeb	V_i
vf	v_f	ExtAlgeb	
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	
a	θ	ExtAlgeb	
v	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	$Ky_{LL} - y_{LAW}$	T_E
omega	ω	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
vout	v_{out}	Algeb	$-v_{out} + y_{LAW}$
vref	V_{ref}	Algeb	$V_{ref0} - V_{ref}$
vi	V_i	Algeb	$-V - V_i + V_{ref}$
LL_y	y_{LL}	Algeb	$LL_{LT1z1}LL_{LT2z1}\left(-x'_{LL} + y_{LL}\right) + TA\left(V_i - x'_{LL}\right) + T_B x'_{LL} - T_B y_{LL}$
vf	v_f	ExtAlgeb	$u\left(-v_{f0} + v_{out}\right)$
XadIfd	$X_{ad}I_{fd}$	ExtAlgeb	0
a	θ	ExtAlgeb	0
v	V	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
TA	TA	$T_{A/TB}T_B$	ConstService
vref0	V_{ref0}	$V + \frac{v_{f0}}{K}$	ConstService

Discrete

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	

5.10 Experimental

Experimental group

Common Parameters: u, name

Available models: *PI2*, *TestDB1*, *TestPI*, *TestLagAWFreeze*, *FixedGen*

5.10.1 PI2

Group *Experimental*

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
Kp					
Ki					
Wmax					
Wmin					

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
uin	u_{in}	State			v_str
x	x	State			v_str
y	y	Algeb			v_str
w	w	Algeb			v_str

Variable Initialization Equations

Name	Symbol	Type	Initial Value
uin	u_{in}	State	0
x	x	State	0.05
y	y	Algeb	0.05
w	w	Algeb	0.05

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
uin	u_{in}	State	$\begin{cases} 0 & \text{for}\: t_{dae} \leq 0 \\ 1 & \text{for}\: t_{dae} \leq 2 \\ -1 & \text{for}\: t_{dae} < 6 \\ 1 & \text{otherwise} \end{cases}$	
x	x	State	$Kiu_{in}z_i^{HL}$	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
y	y	Algeb	$Kpu_{in} + x - y$
w	w	Algeb	$Wmaxz_u^{HL} + Wminz_l^{HL} - w + yz_i^{HL}$

Discrete

Name	Symbol	Type	Info
HL	HL	HardLimiter	

5.10.2 TestDB1

Group *Experimental*

Test model for *DeadBand1*.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
uin	u_{in}	Algeb			v_str
DB_y	y_{DB}	Algeb	Deadband type 1 output		v_str

Variable Initialization Equations

Name	Symbol	Type	Initial Value
uin	u_{in}	Algeb	-10
DB_y	y_{DB}	Algeb	$1.0DB_{dbzl}\left(u_{in}+5\right)+1.0DB_{dbzu}\left(u_{in}-5\right)$

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
uin	u_{in}	Algeb	$t_{dae}-u_{in}-10$
DB_y	y_{DB}	Algeb	$1.0DB_{dbzl}\left(u_{in}+5\right)+1.0DB_{dbzu}\left(u_{in}-5\right)-y_{DB}$

Discrete

Name	Symbol	Type	Info
DB_db	db_{DB}	DeadBand	

Blocks

Name	Symbol	Type	Info
DB	DB	DeadBand1	

5.10.3 TestPI

Group *Experimental*

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
Text		Extended event time	1	*s*	

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
PI_xi	xi_{PI}	State	Integrator output		v_str
PIF_xi	xi_{PIF}	State	Integrator output		v_str
PIAW_xi	xi_{PIAW}	State	Integrator output		v_str
PIAWF_xi	xi_{PIAWF}	State	Integrator output		v_str
uin	u_{in}	Algeb			v_str
zf	z_f	Algeb			v_str
PI_y	y_{PI}	Algeb	PI output		v_str
PIF_y	y_{PIF}	Algeb	PI output		v_str
PIAW_ys	ys_{PIAW}	Algeb	PI summation before limit		v_str
PIAW_y	y_{PIAW}	Algeb	PI output		v_str
PIAWF_ys	ys_{PIAWF}	Algeb	PI summation before limit		v_str
PIAWF_y	y_{PIAWF}	Algeb	PI output		v_str
ze	ze	Algeb			v_str

Variable Initialization Equations

Name	Symbol	Type	Initial Value
PI_xi	xi_{PI}	State	0.0
PIF_xi	xi_{PIF}	State	0
PIAW_xi	xi_{PIAW}	State	0.0
PIAWF_xi	xi_{PIAWF}	State	0
uin	u_{in}	Algeb	0
zf	z_f	Algeb	0
PI_y	y_{PI}	Algeb	u_{in}
PIF_y	y_{PIF}	Algeb	$0.5u_{in}$
PIAW_ys	ys_{PIAW}	Algeb	$0.5u_{in}$
PIAW_y	y_{PIAW}	Algeb	$PIAW_{limzi}ys_{PIAW} - 0.5PIAW_{limzl} + 0.5PIAW_{limzu}$
PIAWF_ys	ys_{PIAWF}	Algeb	$0.5u_{in}$
PIAWF_y	y_{PIAWF}	Algeb	$PIAWF_{limzi}ys_{PIAWF} - 0.5PIAWF_{limzl} + 0.5PIAWF_{limzu}$
ze	ze	Algeb	$ExtEvent$

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
PI_xi	xi_{PI}	State	$0.1u_{in}$	
PIF_xi	xi_{PIF}	State	$u_{in}(0.5 - 0.5z_f)$	
PIAW_xi	xi_{PIAW}	State	$0.5u_{in} + 1.0y_{PIAW} - 1.0ys_{PIAW}$	
PIAWF_xi	xi_{PIAWF}	State	$(0.5 - 0.5z_f)(u_{in} + 2y_{PIAWF} - 2ys_{PIAWF})$	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
uin	u_{in}	Algeb	$-u_{in} + \sin(t_{dae})$
zf	z_f	Algeb	$-z_f + \begin{cases} 0 & \text{for}\ t_{dae} \leq 2 \\ 1 & \text{for}\ t_{dae} \leq 6 \\ 0 & \text{for}\ t_{dae} \leq 12 \\ 1 & \text{for}\ t_{dae} \leq 15 \\ 0 & \text{otherwise} \end{cases}$
PI_y	y_{PI}	Algeb	$u_{in} + xi_{PI} - y_{PI}$
PIF_y	y_{PIF}	Algeb	$(1 - z_f)(0.5u_{in} + xi_{PIF} - y_{PIF})$
PIAW_ys	ys_{PIAW}	Algeb	$0.5u_{in} + xi_{PIAW} - ys_{PIAW}$
PIAW_y	y_{PIAW}	Algeb	$PIAW_{limzi}ys_{PIAW} - 0.5PIAW_{limzl} + 0.5PIAW_{limzu} - y_{PIAW}$
PIAWF_ys	ys_{PIAWF}	Algeb	$(1 - z_f)(0.5u_{in} + xi_{PIAWF} - ys_{PIAWF})$
PIAWF_y	y_{PIAWF}	Algeb	$(1 - z_f)(PIAWF_{limzi}ys_{PIAWF} - 0.5PIAWF_{limzl} + 0.5PIAWF_{limzu} - y_{PIAWF})$
ze	ze	Algeb	$ExtEvent - ze$

Services

Name	Symbol	Equation	Type
PIF_flag	z^{flag}_{PIF}	0	EventFlag
PIAWF_flag	z^{flag}_{PIAWF}	0	EventFlag
ExtEvent	$ExtEvent$	0	ExtendedEvent

Discrete

Name	Symbol	Type	Info
PIAW_lim	lim_{PIAW}	HardLimiter	
PIAWF_lim	lim_{PIAWF}	HardLimiter	

Blocks

Name	Symbol	Type	Info
PI	PI	PIController	
PIF	PIF	PIFreeze	
PIAW	$PIAW$	PITrackAW	
PIAWF	$PIAWF$	PITrackAWFreeze	

5.10.4 TestLagAWFreeze

Group *Experimental*

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
LGF_y	y_{LGF}	State	State in lag transfer function		v_str
LGAWF_y	y_{LGAWF}	State	State in lag TF		v_str
uin	u_{in}	Algeb			v_str
zf	z_f	Algeb			v_str

Variable Initialization Equations

Name	Symbol	Type	Initial Value
LGF_y	y_{LGF}	State	$1.0u_{in}$
LGAWF_y	y_{LGAWF}	State	$1.0u_{in}$
uin	u_{in}	Algeb	0
zf	z_f	Algeb	0

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
LGF_y	y_{LGF}	State	$(1 - z_f)(1.0u_{in} - y_{LGF})$	1.0
LGAWF_y	y_{LGAWF}	State	$(1 - z_f)(1.0u_{in} - y_{LGAWF})$	1.0

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
uin	u_{in}	Algeb	$-u_{in} + \sin(t_{dae})$
zf	z_f	Algeb	$-z_f + \begin{cases} 0 & \text{for } t_{dae} \leq 2 \\ 1 & \text{for } t_{dae} \leq 6 \\ 0 & \text{otherwise} \end{cases}$

Services

Name	Symbol	Equation	Type
LGF_flag	z_{LGF}^{flag}	0	EventFlag
LGAWF_flag	z_{LGAWF}^{flag}	0	EventFlag

Discrete

Name	Symbol	Type	Info
LGAWF_lim	lim_{LGAWF}	AntiWindup	Limiter in Lag

Blocks

Name	Symbol	Type	Info
LGF	LGF	LagFreeze	
LGAWF	$LGAWF$	LagAWFreeze	

5.10.5 FixedGen

Group *Experimental*

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb	Bus voltage angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Variable 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	$-P_0$
v	V	ExtAlgeb	$-Q_0$

5.11 FreqMeasurement

Frequency measurements.

Common Parameters: u, name

Common Variables: f

Available models: *BusFreq*, *BusROCOF*

5.11.1 BusFreq

Group *FreqMeasurement*

Bus frequency measurement.

Bus frequency output variable is *f*.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
bus		bus idx			mandatory
Tf	T_f	input digital filter time const	0.020	*sec*	
Tw	T_w	washout time const	0.020	*sec*	
fn	f_n	nominal frequency	60	*Hz*	

Variables (States + Algebraics)

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	*p.u. (Hz)*	v_str
f	f	Algeb	frequency output	*p.u. (Hz)*	v_str
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Variable 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	$1/\omega_n \left(-x'_{WO} + y_L\right) - T_w y_{WO}$
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

5.11.2 BusROCOF

Group *FreqMeasurement*

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	*bool*	
name		device name			
bus		bus idx			mandatory
Tf	T_f	input digital filter time const	0.020	*sec*	
Tw	T_w	washout time const	0.020	*sec*	
fn	f_n	nominal frequency	60	*Hz*	
Tr	T_r	frequency washout time constant	0.100		

Variables (States + Algebraics)

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	*p.u. (Hz)*	v_str
f	f	Algeb	frequency output	*p.u. (Hz)*	v_str
Wf_y	y_{Wf}	Algeb	Output of washout filter		v_str
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Variable 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	$1/\omega_n \left(-x'_{WO} + y_L\right) - T_w y_{WO}$
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

5.12 Information

Group for information container models.

Available models: *Summary*

5.12.1 Summary

Group *Information*

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			

5.13 Motor

Induction Motor group

Common Parameters: u, name

Available models: *Motor3*, *Motor5*

5.13.1 Motor3

Group *Motor*

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 `Toggler` to control the model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
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	*kWs/KVA*	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 (States + Algebraics)

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		

Variable 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	$u\left(I_d V_d + I_q V_q\right)$
q	Q	Algeb	$u\left(I_d V_q - I_q V_d\right)$
Id	I_d	Algeb	1
Iq	I_q	Algeb	
te	τ_e	Algeb	$u\left(I_d e'_d + I_q e'_q\right)$
tm	τ_m	Algeb	$u\left(\alpha + \beta\sigma + \sigma^2 c_2\right)$
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
slip	σ	State	$u\left(-\tau_e + \tau_m\right)$	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	$-V u \sin(\theta) - V_d$
vq	V_q	Algeb	$V u \cos(\theta) - V_q$
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	$u \left(-I_d x' - I_q r_s + V_q - e'_q\right)$
te	τ_e	Algeb	$-\tau_e + u \left(I_d e'_d + I_q e'_q\right)$
tm	τ_m	Algeb	$-\tau_m + u \left(\alpha + \beta\sigma + \sigma^2 c_2\right)$
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

5.13.2 Motor5

Group *Motor*

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 `Toggler` to control the model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
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	*kWs/KVA*	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 (States + Algebraics)

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		

Variable 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	$u\left(I_d V_d + I_q V_q\right)$
q	Q	Algeb	$u\left(I_d V_q - I_q V_d\right)$
Id	I_d	Algeb	$0.9u$
Iq	I_q	Algeb	$0.1u$
te	τ_e	Algeb	$u\left(I_d e''_d + I_q e''_q\right)$
tm	τ_m	Algeb	$u\left(\alpha + \beta\sigma + \sigma^2 c_2\right)$
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
slip	σ	State	$u\left(-\tau_e + \tau_m\right)$	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	$u\left(\omega_b \sigma e'_q - \omega_b \sigma\left(-e''_q + e'_q\right) - \frac{I_q(-x'+x_0)+e'_d}{T'_0} + \frac{-I_q(x'-x'')-e''_d+e'_d}{T''_0}\right)$	
e2q	e''_q	State	$u\left(-\omega_b \sigma e'_d + \omega_b \sigma\left(-e''_d + e'_d\right) - \frac{-I_d(-x'+x_0)+e'_q}{T'_0} + \frac{I_d(x'-x'')-e''_q+e'_q}{T''_0}\right)$	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
vd	V_d	Algeb	$-Vu\sin\left(\theta\right) - V_d$
vq	V_q	Algeb	$Vu\cos\left(\theta\right) - V_q$
p	P	Algeb	$-P + u\left(I_d V_d + I_q V_q\right)$
q	Q	Algeb	$-Q + u\left(I_d V_q - I_q V_d\right)$
Id	I_d	Algeb	$u\left(-I_d r_s + I_q x'' + V_d - e''_d\right)$
Iq	I_q	Algeb	$u\left(-I_d x'' - I_q r_s + V_q - e''_q\right)$
te	τ_e	Algeb	$-\tau_e + u\left(I_d e''_d + I_q e''_q\right)$
tm	τ_m	Algeb	$-\tau_m + u\left(\alpha + \beta\sigma + \sigma^2 c_2\right)$
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

5.14 PSS

Power system stabilizer group.

Common Parameters: u, name

Common Variables: vsout

Available models: *IEEEST*, *ST2CUT*

5.14.1 IEEEST

Group *PSS*

IEEEST 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.

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	*bool*	
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	*p.u.*	
VCL	V_{CL}	Upper enabling bus voltage	-999	*p.u.*	
syn		Retrieved generator idx	0		
bus		Retrieved bus idx			
Sn	S_n	Generator power base	0		

Variables (States + Algebraics)

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	*p.u.*	
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		

Variable 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	$Vs_5^{SW} + s_1^{SW}(\omega - 1) + s_4^{SW}(\tau_m - \tau_{m0}) + \frac{\tau_{m0}s_3^{SW}}{(Sb/Sn)}$
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	$WO_{LTz1}x'_{WO}$
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	$-A_1x'_{F1} + S_{ig} - y_{F1}$	A_2
F1_y	y_{F1}	State	x'_{F1}	
F2_x1	x'_{F2}	State	$-A_3x'_{F2} - x''_{F2} + y_{F1}$	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	Symbol	Type	RHS of Equation "0 = g(x, y)"
vsout	v_{sout}	Algeb	$V_{ss} z_i^{OLIM} - v_{sout}$
sig	S_{ig}	Algeb	$-S_{ig} + V s_5^{SW} + \frac{V^{dV} s_6^{SW}}{dt} + s_1^{SW} (\omega - 1) + s_2^{SW} (f - 1) + s_4^{SW} (\tau_m - \tau_{m0}) + \frac{\tau_e s_3^{SW}}{(Sb/Sn)}$
F2_y	y_{F2}	Algeb	$A_4 A_5 x'_{F2} + A_4 x''_{F2} - A_4 y_{F2} + A_6 (-A_3 x'_{F2} - x''_{F2} + y_{F1}) + F_{2LT1z1} F_{2LT2z1} F_{2LT3z1} F_{2LT4z1} (-x''_{F2} + y_{F2})$
LL1_y	y_{LL1}	Algeb	$LL_{1LT1z1} LL_{1LT2z1} (-x'_{LL1} + y_{LL1}) + T_1 (-x'_{LL1} + y_{F2}) + T_2 x'_{LL1} - T_2 y_{LL1}$
LL2_y	y_{LL2}	Algeb	$LL_{2LT1z1} LL_{2LT2z1} (-x'_{LL2} + y_{LL2}) + T_3 (-x'_{LL2} + y_{LL1}) + T_4 x'_{LL2} - T_4 y_{LL2}$
Vks_y	y_{Vks}	Algeb	$K_S y_{LL2} - y_{Vks}$
WO_y	y_{WO}	Algeb	$T_5 WO_{LTz0} (-x'_{WO} + y_{Vks}) + T_6 WO_{LTz1} x'_{WO} - T_6 y_{WO}$
Vss	V_{ss}	Algeb	$L_{SMAX} z_u^{VLIM} + L_{SMIN} z_l^{VLIM} - V_{ss} + y_{WO} z_i^{VLIM}$
tm	τ_m	ExtAlgeb	0
te	τ_e	ExtAlgeb	0
v	V	ExtAlgeb	0
f	f	ExtAlgeb	0
vi	v_i	ExtAlgeb	$u v_{sout}$

Discrete

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 [IEEEST]

Option	Symbol	Value	Info	Accepted values
freq_model		BusFreq	default freq. measurement model	('BusFreq',)

5.14.2 ST2CUT

Group *PSS*

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	*bool*	
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	*p.u.*	
VCL	V_{CL}	Upper enabling bus voltage	-999	*p.u.*	
syn		Retrieved generator idx	0		
bus		Retrieved bus idx			
Sn	S_n	Generator power base	0		

Variables (States + Algebraics)

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	*p.u.*	
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	Gain output before limiter		v_str
VSS_y	y_{VSS}	Algeb	Gain output after limiter		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		

Variable 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	$V s_5^{SW_2} + s_1^{SW_2}(\omega - 1) + s_4^{SW_2}(\tau_m - \tau_{m0}) + \frac{\tau_{m0} s_3^{SW_2}}{(Sb/Sn)}$
IN	I_N	Algeb	$y_{L1} + y_{L2}$
WO_y	y_{WO}	Algeb	$WO_{LTz1} x'_{WO}$
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	$L_{SMAX} VSS_{limzu} + L_{SMIN} VSS_{limzl} + VSS_{limzi} x_{VSS}$
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	Symbol	Type	RHS of Equation "0 = g(x, y)"
vsout	v_{sout}	Algeb	$-v_{sout} + y_{VSS} z_i^{OLIM}$
sig	S_{ig}	Algeb	$-S_{ig} + V s_5^{SW} + V^{dv} s_6^{SW} + s_1^{SW} (\omega - 1) + s_2^{SW} (f - 1) + s_4^{SW} (\tau_m - \tau_{m0}) + \frac{\tau_e s_3^{SW}}{(Sb/Sn)}$
sig2	S_{ig2}	Algeb	$-S_{ig2} + V s_5^{SW_2} + V^{dv_2} s_6^{SW_2} + s_1^{SW_2} (\omega - 1) + s_2^{SW_2} (f_2 - 1) + s_4^{SW_2} (\tau_m - \tau_{m0}) + \frac{\tau_e s_3^{SW_2}}{(Sb/Sn)}$
IN	I_N	Algeb	$-I_N + y_{L1} + y_{L2}$
WO_y	y_{WO}	Algeb	$T_3 WO_{LTz0} (I_N - x'_{WO}) + T_4 WO_{LTz1} x'_{WO} - T_4 y_{WO}$
LL1_y	y_{LL1}	Algeb	$LL_{1LT1z1} LL_{1LT2z1} (-x'_{LL1} + y_{LL1}) + T_5 (-x'_{LL1} + y_{WO}) + T_6 x'_{LL1} - T_6 y_{LL1}$
LL2_y	y_{LL2}	Algeb	$LL_{2LT1z1} LL_{2LT2z1} (-x'_{LL2} + y_{LL2}) + T_7 (-x'_{LL2} + y_{LL1}) + T_8 x'_{LL2} - T_8 y_{LL2}$
LL3_y	y_{LL3}	Algeb	$LL_{3LT1z1} LL_{3LT2z1} (-x'_{LL3} + y_{LL3}) + T_9 (-x'_{LL3} + y_{LL2}) + T_{10} x'_{LL3} - T_{10} y_{LL3}$
VSS_x	x_{VSS}	Algeb	$-x_{VSS} + y_{LL3}$
VSS_y	y_{VSS}	Algeb	$L_{SMAX} VSS_{limzu} + L_{SMIN} VSS_{limzl} + VSS_{limzi} x_{VSS} - y_{VSS}$
tm	τ_m	ExtAlgeb	0
te	τ_e	ExtAlgeb	0
v	V	ExtAlgeb	0
f	f	ExtAlgeb	0
vi	v_i	ExtAlgeb	$u v_{sout}$
v2	V	ExtAlgeb	0
f2	f_2	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
VOU	VOU	$VCUr + V_0$	ConstService
VOL	VOL	$VCLr + V_0$	ConstService

Discrete

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
freq_model		BusFreq	default freq. measurement model	('BusFreq',)

5.15 PhasorMeasurement

Phasor measurements

Common Parameters: u, name

Common Variables: am, vm

Available models: *PMU*

5.15.1 PMU

Group *PhasorMeasurement*

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	*bool*	
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 (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
am	θ_m	State	phase angle measurement	*rad.*	v_str
vm	V_m	State	voltage magnitude measurement	*p.u.(kV)*	v_str
a	θ	ExtAlgeb	Bus voltage phase angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Variable 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 "T x' = f(x, y)"	T (LHS)
am	θ_m	State	$\theta - \theta_m$	T_a
vm	V_m	State	$V - V_m$	T_v

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
a	θ	ExtAlgeb	0
v	V	ExtAlgeb	0

5.16 RenAerodynamics

Renewable aerodynamics group.

Common Parameters: u, name, rego

Common Variables: theta

Available models: *WTARA1*, *WTARV1*

5.16.1 WTARA1

Group *RenAerodynamics*

Wind turbine aerodynamics model (no wind speed details).

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
rego		Renewable governor idx			mandatory
Ka	K_a	Aerodynamics gain	1	*p.u./deg.*	non_negative
theta0	θ_0	Initial pitch angle	0	*deg.*	

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
theta	θ	Algeb	Pitch angle	*rad*	v_str
Pmg	Pmg	ExtAlgeb			

Variable 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	$-\theta\left(\theta - \theta_0\right)$

Services

Name	Symbol	Equation	Type
theta0r	θ_{0r}	$\frac{\pi\theta_0}{180}$	ConstService

5.16.2 WTARV1

Group *RenAerodynamics*

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	*bool*	
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	*m*	
ngb		gear box ratio	5		
rho		air density	1.200	*kg/m3*	
Sn	S_n		0		

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
theta	θ	Algeb	Pitch angle	*rad*	
Pmg	Pmg	ExtAlgeb			

Variable Initialization Equations

Name	Symbol	Type	Initial Value
theta	θ	Algeb	
Pmg	Pmg	ExtAlgeb	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
theta	θ	Algeb	0
Pmg	Pmg	ExtAlgeb	0

5.17 RenExciter

Renewable electrical control (exciter) group.

Common Parameters: u, name, reg

Common Variables: Pref, Qref, wg, Pord

Available models: *REECA1*

5.17.1 REECA1

Group *RenExciter*

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*.

Parameters

Name	Symbol	Description	Default	Unit	Propertie
idx		unique device idx			
u	u	connection status	1	*bool*	
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		*bool*	mandatory
VFLAG		Voltage control flag; 1-Q control, 0-V control		*bool*	mandatory
QFLAG		Q control flag; 1-V or Q control, 0-const. PF or Q		*bool*	mandatory
PFLAG		P speed-dependency flag; 1-has speed dep., 0-no dep.		*bool*	mandatory
PQFLAG		P/Q priority flag for I limit; 0-Q priority, 1-P priority		*bool*	mandatory
Vdip	V_{dip}	Low V threshold to activate Iqinj logic	0.800	*p.u.*	
Vup	V_{up}	V threshold above which to activate Iqinj logic	1.200	*p.u.*	
Trv	T_{rv}	Voltage filter time constant	0.020		
dbd1	d_{bd1}	Lower bound of the voltage deadband (<=0)	-0.020		
dbd2	d_{bd2}	Upper bound of the voltage deadband (>=0)	0.020		
Kqv	K_{qv}	Gain to compute Iqinj from V error	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	*s*	
Thld2	T_{hld2}	Time for which IPMAX is held after voltage dip ends	0	*s*	
Tp	T_p	Filter time constant for Pe	0.020	*s*	
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		

Continued on next pag

Table 2 – continued from previous page

Name	Symbol	Description	Default	Unit	Propertie
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	d_{Pmax}	Power reference max. ramp rate (>0)	999		
dPmin	d_{Pin}	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		
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 (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
s0_y	y_{s0}	State	State in lag transfer function		v_str
S1_y	y_{S_1}	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

Continued on next page

Table 3 – continued from previous page

Name	Symbol	Type	Description	Unit	Properties
Pord	$Pord$	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
Qcpf	Q_{cpf}	Algeb	Q calculated from P and power factor	*p.u.*	v_str
Qref	Q_{ref}	Algeb	external Q ref	*p.u.*	v_str
PFsel	$PFsel$	Algeb	Output of PFFLAG selector		v_str
Qerr	Q_{err}	Algeb	Reactive power error		v_str
PIQ_ys	ys_{PIQ}	Algeb	PI summation before limit		v_str
PIQ_y	y_{PIQ}	Algeb	PI output		v_str
Vsel_x	x_{Vsel}	Algeb	Gain output before limiter		v_str
Vsel_y	y_{Vsel}	Algeb	Gain output after limiter		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
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	ys_{PIV}	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	Gain output before limiter		v_str
IpHL_y	y_{IpHL}	Algeb	Gain output after limiter		v_str
IqHL_x	x_{IqHL}	Algeb	Gain output before limiter		v_str
IqHL_y	y_{IqHL}	Algeb	Gain output after limiter		v_str
a	θ	ExtAlgeb	Bus voltage angle		
v	V	ExtAlgeb	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		

Variable Initialization Equations

Name	Symbol	Type	Initial Value
s0_y	y_{s0}	State	V
S1_y	y_{S_1}	State	Pe
PIQ_xi	xi_{PIQ}	State	0.0
s4_y	y_{s_4}	State	$\frac{PFsel}{V_p}$
pfilt_y	$y_{P_{filt}}$	State	P_{ref}

Table 4 – continued from previous page

Name	Symbol	Type	Initial Value
s5_y	y_{s5}	State	P_{sel}
PIV_xi	xi_{PIV}	State	$-Iqcmd_0 SWQ_{s1}$
Pord	$Pord$	AliasState	
vp	V_p	Algeb	$Vz_i^{VLower} + 0.01z_l^{VLower}$
pfaref	Φ_{ref}	Algeb	Φ_{ref0}
Qcpf	Q_{cpf}	Algeb	Q_0
Qref	Q_{ref}	Algeb	Q_0
PFsel	$PFsel$	Algeb	$Q_{cpf} SWPF_{s1} + Q_{ref} SWPF_{s0}$
Qerr	Q_{err}	Algeb	$PFselz_i^{PFlim} + Q_{max} z_u^{PFlim} + Q_{min} z_l^{PFlim} - Qe$
PIQ_ys	ys_{PIQ}	Algeb	$K_{qp} Q_{err}$
PIQ_y	y_{PIQ}	Algeb	$PIQ_{limzi} ys_{PIQ} + PIQ_{limzl} V_{min} + PIQ_{limzu} V_{max}$
Vsel_x	x_{Vsel}	Algeb	$SWV_{s0} V_{ref1} + SWV_{s1} y_{PIQ}$
Vsel_y	y_{Vsel}	Algeb	$V_{max} Vsel_{limzu} + V_{min} Vsel_{limzl} + Vsel_{limzi} x_{Vsel}$
Verr	V_{err}	Algeb	$V_{ref0} - y_{s0}$
dbV_y	y_{dbV}	Algeb	$1.0dbV_{dbzl}\left(V_{err} - d_{bd1}\right) + 1.0dbV_{dbzu}\left(V_{err} - d_{bd2}\right)$
Iqinj	I_{qinj}	Algeb	$K_{qv} y_{dbV} z_{Vdip} + fThld\left(1 - z_{Vdip}\right)\left(I_{qfrz} p_{Thld} + K_{qv} n_{Thld} y_{dbV}\right)$
wg	ω_g	Algeb	1.0
Pref	P_{ref}	Algeb	$\frac{P_0}{\omega_g}$
Psel	P_{sel}	Algeb	$SWP_{s0} y_{P_{filt}} + SWP_{s1} \omega_g y_{P_{filt}}$
VDL1_y	$y_{V_{DL1}}$	Algeb	$\begin{cases} I_{q1} & \text{for}\: V_{q1} \geq y_{s0} \\ I_{q1} + k_{Vq12}\left(-V_{q1} + y_{s0}\right) & \text{for}\: V_{q2} \geq y_{s0} \\ I_{q2} + k_{Vq23}\left(-V_{q2} + y_{s0}\right) & \text{for}\: V_{q3} \geq y_{s0} \\ I_{q3} + k_{Vq34}\left(-V_{q3} + y_{s0}\right) & \text{for}\: V_{q4} \geq y_{s0} \\ I_{q4} & \text{otherwise} \end{cases}$
VDL2_y	$y_{V_{DL2}}$	Algeb	$\begin{cases} I_{p1} & \text{for}\: V_{p1} \geq y_{s0} \\ I_{p1} + k_{Vp12}\left(-V_{p1} + y_{s0}\right) & \text{for}\: V_{p2} \geq y_{s0} \\ I_{p2} + k_{Vp23}\left(-V_{p2} + y_{s0}\right) & \text{for}\: V_{p3} \geq y_{s0} \\ I_{p3} + k_{Vp34}\left(-V_{p3} + y_{s0}\right) & \text{for}\: V_{p4} \geq y_{s0} \\ I_{p4} & \text{otherwise} \end{cases}$
Ipmax	I_{pmax}	Algeb	$(1 - fThld_2)\left(\sqrt{I_{pmax20,nn}^2} SWPQ_{s0} + SWPQ_{s1}\left(z_{VDL2}\left(I_{maxr}\left(1 - VDL2c\right) +\right.\right.\right.$
Iqmax	I_{qmax}	Algeb	$\sqrt{I_{qmax,nn}^2} SWPQ_{s1} + SWPQ_{s0}\left(z_{VDL1}\left(I_{maxr}\left(1 - VDL1c\right) + VDL1c y_{V_{DL1}}\right) -\right.$
PIV_ys	ys_{PIV}	Algeb	$-Iqcmd_0 SWQ_{s1} + K_{vp}\left(-SWV_{s0} y_{s0} + y_{Vsel}\right)$
PIV_y	y_{PIV}	Algeb	$I_{qmax} PIV_{limzu} + I_{qmin} PIV_{limzl} + PIV_{limzi} ys_{PIV}$
Qsel	Q_{sel}	Algeb	$SWQ_{s0} y_{s_4} + SWQ_{s1} y_{PIV}$
IpHL_x	x_{IpHL}	Algeb	$\frac{y_{s5}}{V_p}$
IpHL_y	y_{IpHL}	Algeb	$I_{pmax} IpHL_{limzu} + I_{pmin} IpHL_{limzl} + IpHL_{limzi} x_{IpHL}$
IqHL_x	x_{IqHL}	Algeb	$I_{qinj} + Q_{sel}$
IqHL_y	y_{IqHL}	Algeb	$I_{qmax} IqHL_{limzu} + I_{qmin} IqHL_{limzl} + IqHL_{limzi} x_{IqHL}$
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

Table 4 – continued from previous page

Name	Symbol	Type	Initial Value
Pe	Pe	ExtAlgeb	
Qe	Qe	ExtAlgeb	
Ipcmd	$Ipcmd$	ExtAlgeb	
Iqcmd	$Iqcmd$	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
s0_y	y_{s0}	State	$V - y_{s0}$	T_{rv}
S1_y	y_{S_1}	State	$Pe - y_{S_1}$	T_p
PIQ_xi	xi_{PIQ}	State	$K_{qi} \left(1 - z_{Vdip}\right) \left(Q_{err} + 2 y_{PIQ} - 2 ys_{PIQ}\right)$	
s4_y	y_{s4}	State	$\left(1 - z_{Vdip}\right) \left(\frac{PFsel}{V_p} - y_{s4}\right)$	T_{iq}
pfilt_y	$y_{P_{filt}}$	State	$P_{ref} - y_{P_{filt}}$	0.02
s5_y	y_{s5}	State	$\left(1 - z_{Vdip}\right) \left(P_{sel} - y_{s5}\right)$	T_{pord}
PIV_xi	xi_{PIV}	State	$K_{vi} \left(1 - z_{Vdip}\right) \left(- SWV_{s0} y_{s0} + 2 y_{PIV} + y_{Vsel} - 2 ys_{PIV}\right)$	
Pord	$Pord$	AliasState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
vp	V_p	Algeb	$V z_i^{VLower} - V_p + 0.01 z_l^{VLower}$
pfaref	Φ_{ref}	Algeb	$\Phi_{ref0} - \Phi_{ref}$
Qcpf	Q_{cpf}	Algeb	$- Q_{cpf} + y_{S_1} \tan\left(\Phi_{ref}\right)$
Qref	Q_{ref}	Algeb	$Q_0 - Q_{ref}$
PFsel	$PFsel$	Algeb	$- PFsel + Q_{cpf} SWPF_{s1} + Q_{ref} SWPF_{s0}$
Qerr	Q_{err}	Algeb	$PFsel z_i^{PFlim} - Q_{err} + Q_{max} z_u^{PFlim} + Q_{min} z_l^{PFlim} - Qe$
PIQ_ys	ys_{PIQ}	Algeb	$\left(1 - z_{Vdip}\right) \left(K_{qp} Q_{err} + xi_{PIQ} - ys_{PIQ}\right)$
PIQ_y	y_{PIQ}	Algeb	$\left(1 - z_{Vdip}\right) \left(PIQ_{limzi} ys_{PIQ} + PIQ_{limzl} V_{min} + PIQ_{limzu} V_{max} - y_{PIQ}\right)$
Vsel_x	x_{Vsel}	Algeb	$SWV_{s0} V_{ref1} + SWV_{s1} y_{PIQ} - x_{Vsel}$
Vsel_y	y_{Vsel}	Algeb	$V_{max} Vsel_{limzu} + V_{min} Vsel_{limzl} + Vsel_{limzi} x_{Vsel} - y_{Vsel}$
Verr	V_{err}	Algeb	$- V_{err} + V_{ref0} - y_{s0}$
dbV_y	y_{dbV}	Algeb	$1.0 dbV_{dbzl} \left(V_{err} - d_{bd1}\right) + 1.0 dbV_{dbzu} \left(V_{err} - d_{bd2}\right) - y_{dbV}$
Iqinj	I_{qinj}	Algeb	$- I_{qinj} + K_{qv} y_{dbV} z_{Vdip} + fThld \left(1 - z_{Vdip}\right) \left(I_{qfrz} p_{Thld} + K_{qv} n_{Thld} y_{dbV}\right)$
wg	ω_g	Algeb	$1.0 - \omega_g$
Pref	P_{ref}	Algeb	$\frac{P_0}{\omega_g} - P_{ref}$
Psel	P_{sel}	Algeb	$- P_{sel} + SWP_{s0} y_{P_{filt}} + SWP_{s1} \omega_g y_{P_{filt}}$

Table 5 – continued from previous pa

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
VDL1_y	$y_{V_{DL1}}$	Algeb	$-y_{V_{DL1}} + \begin{cases} I_{q1} & \text{for } V_{q1} \geq y_{s0} \\ I_{q1} + k_{Vq12}(-V_{q1} + y_{s0}) & \text{for } V_{q2} \geq y_{s0} \\ I_{q2} + k_{Vq23}(-V_{q2} + y_{s0}) & \text{for } V_{q3} \geq y_{s0} \\ I_{q3} + k_{Vq34}(-V_{q3} + y_{s0}) & \text{for } V_{q4} \geq y_{s0} \\ I_{q4} & \text{otherwise} \end{cases}$
VDL2_y	$y_{V_{DL2}}$	Algeb	$-y_{V_{DL2}} + \begin{cases} I_{p1} & \text{for } V_{p1} \geq y_{s0} \\ I_{p1} + k_{Vp12}(-V_{p1} + y_{s0}) & \text{for } V_{p2} \geq y_{s0} \\ I_{p2} + k_{Vp23}(-V_{p2} + y_{s0}) & \text{for } V_{p3} \geq y_{s0} \\ I_{p3} + k_{Vp34}(-V_{p3} + y_{s0}) & \text{for } V_{p4} \geq y_{s0} \\ I_{p4} & \text{otherwise} \end{cases}$
Ipmax	I_{pmax}	Algeb	$-I_{pmax} + IpmaxhfThld_2 + (1 - fThld_2)\big(\sqrt{I^2_{pmax2}}SWPQ_{s0} + SWPQ_{s1}(z_{VDL}$
Iqmax	I_{qmax}	Algeb	$\sqrt{I^2_{qmax2}}SWPQ_{s1} - I_{qmax} + SWPQ_{s0}(z_{VDL1}(I_{maxr}(1 - VDL1c) + VDL1cy_{V_{D}}$
PIV_ys	ys_{PIV}	Algeb	$(1 - z_{Vdip})(K_{vp}(-SWV_{s0}y_{s0} + y_{Vsel}) + xi_{PIV} - ys_{PIV})$
PIV_y	y_{PIV}	Algeb	$(1 - z_{Vdip})(I_{qmax}PIV_{limzu} + I_{qmin}PIV_{limzl} + PIV_{limzi}ys_{PIV} - y_{PIV})$
Qsel	Q_{sel}	Algeb	$-Q_{sel} + SWQ_{s0}y_{s_4} + SWQ_{s1}y_{PIV}$
IpHL_x	x_{IpHL}	Algeb	$-x_{IpHL} + \frac{y_{s5}}{V_p}$
IpHL_y	y_{IpHL}	Algeb	$I_{pmax}IpHL_{limzu} + I_{pmin}IpHL_{limzl} + IpHL_{limzi}x_{IpHL} - y_{IpHL}$
IqHL_x	x_{IqHL}	Algeb	$I_{qinj} + Q_{sel} - x_{IqHL}$
IqHL_y	y_{IqHL}	Algeb	$I_{qmax}IqHL_{limzu} + I_{qmin}IqHL_{limzl} + IqHL_{limzi}x_{IqHL} - y_{IqHL}$
a	θ	ExtAlgeb	0
v	V	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	$Ipcmd0$	$\frac{P_0}{V}$	ConstService
Iqcmd0	$Iqcmd0$	$-\frac{Q_0}{V}$	ConstService
pfaref0	Φ_{ref0}	$\operatorname{atan}{\left(\frac{Q_0}{P_0} \right)}$	ConstService
Volt_dip	z_{Vdip}	$1 - Vcmp_{zi}$	VarService
PIQ_flag	z^{flag}_{PIQ}	0	EventFlag
s4_flag	z^{flag}_{s4}	0	EventFlag
pThld	p_{Thld}	$T_{hld} > 0$	ConstService
nThld	n_{Thld}	$T_{hld} < 0$	ConstService
Thld_abs	$\|Thld\|$	$\operatorname{abs}{\left(T_{hld} \right)}$	ConstService
fThld	$fThld$	0	ExtendedEvent
s5_flag	z^{flag}_{s5}	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	$VDL1c$	$y_{V_{DL1}} < I_{maxr}$	VarService
VDL2c	$VDL2c$	$y_{V_{DL2}} < I_{maxr}$	VarService
Ipmax2sq0	$I^2_{pmax20,nn}$	$\begin{cases} 0.0 & \text{for}\: I^{2}_{max} - Iqcmd_{0}^{2} \leq 0.0 \\ I^{2}_{max} - Iqcmd_{0}^{2} & \text{otherwise} \end{cases}$	ConstService
Ipmax2sq	I^2_{pmax2}	$\begin{cases} 0.0 & \text{for}\: I^{2}_{max} - y_{IqHL}^{2} \leq 0.0 \\ I^{2}_{max} - y_{IqHL}^{2} & \text{otherwise} \end{cases}$	VarService
Ipmaxh	$Ipmaxh$	0	VarHold
Iqmax2sq0	$I^2_{qmax,nn}$	$\begin{cases} 0.0 & \text{for}\: I^{2}_{max} - Ipcmd_{0}^{2} \leq 0.0 \\ I^{2}_{max} - Ipcmd_{0}^{2} & \text{otherwise} \end{cases}$	ConstService
Iq-	I^2_{qmax2}	$\begin{cases} 0.0 & \text{for}\: I^{2}_{max} - y_{IpHL}^{2} \leq 0.0 \\ I^{2}_{max} - y_{IpHL}^{2} & \text{otherwise} \end{cases}$	VarService

Discrete

Name	Symbol	Type	Info
SWPF	SW_{PF}	Switcher	
SWV	SW_V	Switcher	
SWQ	SW_V	Switcher	
SWP	SW_P	Switcher	
SWPQ	SW_{PQ}	Switcher	
Vcmp	V_{cmp}	Limiter	Voltage dip comparator
VLower	$VLower$	Limiter	Limiter for lower voltage cap
PFlim	$PFlim$	Limiter	
PIQ_lim	lim_{PIQ}	HardLimiter	
Vsel_lim	lim_{Vsel}	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	$s0$	Lag	Voltage filter
S1	S_1	Lag	Pe filter
PIQ	PIQ	PITrackAWFreeze	
Vsel	$Vsel$	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	$s5$	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	$IpHL$	GainLimiter	
IqHL	$IqHL$	GainLimiter	

Config Fields in [REECA1]

Option	Symbol	Value	Info	Accepted values
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	

5.18 RenGen

Renewable generator (converter) group.

Common Parameters: u, name, bus, gen

Common Variables: Ipcmd, Iqcmd, Pe, Qe

Available models: *REGCA1*

5.18.1 REGCA1

Group *RenGen*

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
Sn	S_n	Model MVA base	100	*MVA*	
Tg	T_g	converter time const.	0.100	*s*	
Rrpwr	R_{rpwr}	Low voltage power logic (LVPL) ramp limit	10	*p.u.*	
Brkpt	B_{rkpt}	LVPL characteristic voltage 2	1	*p.u.*	
Zerox	Z_{erox}	LVPL characteristic voltage 1	0.500	*p.u*	
Lvpl1	L_{vpl1}	LVPL gain	1	*p.u*	
Volim	V_{olim}	Voltage lim for high volt. reactive current mgnt.	1.200	*p.u.*	
Lvpnt1	L_{vpnt1}	High volt. point for low volt. active current mgnt.	0.800	*p.u.*	
Lvpnt0	L_{vpnt0}	Low volt. point for low volt. active current mgnt.	0.400	*p.u.*	
Iolim	I_{olim}	lower current limit for high volt. reactive current mgnt.	-1.500	*p.u. (mach base)*	current
Tfltr	T_{fltr}	Voltage filter T const for low volt. active current mgnt.	0.100	*s*	
Khv	K_{hv}	Overvolt. compensation gain in high volt. reactive current mgnt.	0.700		
Iqrmax	I_{qrmax}	Upper limit on the ROC for reactive current	1	*p.u.*	current
Iqrmin	I_{qrmin}	Lower limit on the ROC for reactive current	-1	*p.u.*	current
Accel	A_{ccel}	Acceleration factor	0		
ra	r_a		0		
xs	x_s		0		

Variables (States + Algebraics)

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
Ipcmd	I_{pcmd}	Algeb	current component for active power		v_str
Iqcmd	I_{qcmd}	Algeb	current component for reactive power		v_str
LVG_y	$y_{L_{VG}}$	Algeb	Output of piecewise		v_str
LVPL_y	$y_{L_{VPL}}$	Algeb	Output of piecewise		v_str
Ipout	I_{pout}	Algeb	Output Ip current		v_str
HVG_x	$x_{H_{VG}}$	Algeb	Gain output before limiter		v_str
HVG_y	$y_{H_{VG}}$	Algeb	Gain output after limiter		v_str
Iqout_x	$x_{I^{qout}}$	Algeb	Gain output before limiter		v_str
Iqout_y	$y_{I^{qout}}$	Algeb	Gain output after limiter		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		

Variable Initialization Equations

Name	Symbol	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}
Ipcmd	I_{pcmd}	Algeb	I_{pcmd0}
Iqcmd	I_{qcmd}	Algeb	I_{qcmd0}
LVG_y	$y_{L_{VG}}$	Algeb	$\begin{cases} 0 & \text{for}\: L_{vpnt0} \geq V \\ k_{LVG} \left(- L_{vpnt0} + V\right) & \text{for}\: L_{vpnt1} \geq V \\ 1 & \text{otherwise} \end{cases}$
LVPL_y	$y_{L_{VPL}}$	Algeb	$\begin{cases} 9999 - 9999 z_{Lvplsw} & \text{for}\: Z_{erox} \geq y_{S_2} \\ k_{LVPL} \left(- Z_{erox} + y_{S_2}\right) - 9999 z_{Lvplsw} + 9999 & \text{for}\: B_{rkpt} \geq y_{S_2} \\ 9999 & \text{otherwise} \end{cases}$
Ipout	I_{pout}	Algeb	$I_{pcmd} y_{L_{VG}}$
HVG_x	$x_{H_{VG}}$	Algeb	$K_{hv} \left(V - V_{olim}\right)$
HVG_y	$y_{H_{VG}}$	Algeb	$HVG_{limzi} x_{H_{VG}}$
Iqout_x	$x_{I^{qout}}$	Algeb	$- y_{H_{VG}} + y_{S_1}$
Iqout_y	$y_{I^{qout}}$	Algeb	$I_{olim} Iqout_{limzl} + Iqout_{limzi} x_{I^{qout}}$
Pe	P_e	Algeb	P_0
Qe	Q_e	Algeb	Q_0
a	θ	ExtAlgeb	
v	V	ExtAlgeb	

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	Symbol	Type	RHS of Equation "0 = g(x, y)"
Ipcmd	I_{pcmd}	Algeb	$I_{pcmd0} - I_{pcmd}$
Iqcmd	I_{qcmd}	Algeb	$I_{qcmd0} - I_{qcmd}$
LVG_y	y_{LVG}	Algeb	$-y_{LVG} + \begin{cases} 0 & \text{for}\ L_{vpnt0} \geq V \\ k_{LVG}\left(-L_{vpnt0} + V\right) & \text{for}\ L_{vpnt1} \geq V \\ 1 & \text{otherwise} \end{cases}$
LVPL_y	y_{LVPL}	Algeb	$-y_{LVPL} + \begin{cases} 9999 - 9999 z_{Lvplsw} & \text{for}\ Z_{erox} \geq y_{S_2} \\ k_{LVPL}\left(-Z_{erox} + y_{S_2}\right) - 9999 z_{Lvplsw} + 9999 & \text{for}\ B_{rkpt} \geq y_{S_2} \\ 9999 & \text{otherwise} \end{cases}$
Ipout	I_{pout}	Algeb	$-I_{pout} + y_{LVG} y_{S_0}$
HVG_x	x_{HVG}	Algeb	$K_{hv}\left(V - V_{olim}\right) - x_{HVG}$
HVG_y	y_{HVG}	Algeb	$HVG_{limzi} x_{HVG} - y_{HVG}$
Iqout_x	x_{Iqout}	Algeb	$-x_{Iqout} - y_{HVG} + y_{S_1}$
Iqout_y	y_{Iqout}	Algeb	$I_{olim} Iqout_{limzl} + Iqout_{limzi} x_{Iqout} - y_{Iqout}$
Pe	P_e	Algeb	$I_{pout} V - P_e$
Qe	Q_e	Algeb	$-Q_e + V y_{Iqout}$
a	θ	ExtAlgeb	$-P_e$
v	V	ExtAlgeb	$-Q_e$

Services

Name	Symbol	Equation	Type
q0gt0	$z_{q0>0}$	$Q_0 > 0$	ConstService
q0lt0	$z_{q0<0}$	$Q_0 < 0$	ConstService
Ipcmd0	I_{pcmd0}	$\frac{P_0}{V}$	ConstService
Iqcmd0	I_{qcmd0}	$-\frac{Q_0}{V}$	ConstService
kLVG	k_{LVG}	$\frac{1}{-L_{vpnt0}+L_{vpnt1}}$	ConstService
kLVPL	k_{LVPL}	$\frac{L_{vpl1}z_{Lvplsw}}{B_{rkpt}-Z_{erox}}$	ConstService

Discrete

Name	Symbol	Type	Info
S1_lim	lim_{S_1}	AntiWindupRate	Limiter in Lag
S0_lim	lim_{S_0}	AntiWindupRate	Limiter in Lag
HVG_lim	$lim_{H_{VG}}$	HardLimiter	
Iqout_lim	$lim_{I_{qout}}$	HardLimiter	

Blocks

Name	Symbol	Type	Info
S1	S_1	LagAntiWindupRate	Iqcmd delay
LVG	L_{VG}	Piecewise	Ip gain during low voltage
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

5.19 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*

5.19.1 WTDTA1

Group *RenGovernor*

WTDTA wind turbine drive-train model.

User-provided reference speed should be specified in parameter *w0*. Internally, *w0* is set to the algebraic variable *wr0*.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
ree		Renewable exciter idx			mandatory
fn	f_n	nominal frequency	60	*Hz*	
Ht	H_t	Turbine inertia	3	*MWs/MVA*	non_zero,power
Hg	H_g	Generator inertia	3	*MWs/MVA*	non_zero,power
Dshaft	D_{shaft}	Damping coefficient	1	*p.u. (gen base)*	power
Kshaft	K_{shaft}	Spring constant	1	*p.u. (gen base)*	power
w0	ω_0	Default speed if not using a torque model	1	*p.u.*	
reg			0		
Sn	S_n		0		

Variables (States + Algebraics)

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	*p.u.*	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		

Variable 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	$\frac{P_{e0}}{K_{shaft}\omega_{r0}}$
wt	ω_t	AliasState	
wg	ω_g	AliasState	
wr0	ω_{r0}	Algeb	ω_0
Pm	P_m	Algeb	P_{e0}
pd	P_d	Algeb	0.0
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	$-1.0K_{shaft}y_{s3} - 1.0P_d + \frac{1.0P_m}{y_{s1}}$	$2H_t$
s2_y	y_{s2}	State	$1.0K_{shaft}y_{s3} + 1.0P_d - \frac{1.0Pe}{y_{s2}}$	$2H_g$
s3_y	y_{s3}	State	$1.0y_{s1} - 1.0y_{s2}$	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	Pe	ExtAlgeb	0

Services

Name	Symbol	Equation	Type
Ht2	$2H_t$	$2H_t$	ConstService
Hg2	$2H_g$	$2H_g$	ConstService

Blocks

Name	Symbol	Type	Info
s1	$s1$	Integrator	
s2	$s2$	Integrator	
s3	$s3$	Integrator	

5.19.2 WTDS

Group *RenGovernor*

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	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
ree		Renewable exciter idx			mandatory
fn	f_n	nominal frequency	60	*Hz*	
H	H_t	Total inertia	3	*MWs/MVA*	non_zero,power
D	D_{shaft}	Damping coefficient	1	*p.u.*	power
w0	ω_0	Default speed if not using a torque model	1	*p.u.*	
reg			0		
Sn	S_n		0		

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
s1_y	y_{s1}	State	Integrator output		v_str
s3_y	y_{s3}	State	Dummy 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	*p.u.*	v_str
wge	wge	ExtAlgeb			
Pe	Pe	ExtAlgeb	Retrieved Pe of RenGen		

Variable 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	$-1.0D_{shaft}\left(-\omega_{r0}+y_{s1}\right)+\frac{1.0(P_m-Pe)}{wge}$	$2H$
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	

5.20 RenPitch

Renewable generator pitch controller group.

Common Parameters: u, name, rea

Available models: *WTPTA1*

5.20.1 WTPTA1

Group *RenPitch*

Wind turbine pitch control model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
rea		Renewable aerodynamics model idx			mandatory
Kiw	K_{iw}	Pitch-control integral gain	0.100	*p.u.*	
Kpw	K_{pw}	Pitch-control proportional gain	0	*p.u.*	
Kic	K_{ic}	Pitch-compensation integral gain	0.100	*p.u.*	
Kpc	K_{pc}	Pitch-compensation proportional gain	0	*p.u.*	
Kcc	K_{cc}	Gain for P diff	0	*p.u.*	
Tp	T_{θ}	Blade response time const.	0.300	*s*	
thmax	θ_{max}	Max. pitch angle	30	*deg.*	
thmin	θ_{min}	Min. pitch angle	0	*deg.*	
dthmax	θ_{max}	Max. pitch angle rate	5	*deg.*	
dthmin	θ_{min}	Min. pitch angle rate	-5	*deg.*	
rego			0		
ree			0		

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
PIc_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
Pord	$Pord$	ExtState			
PIc_yul	$y_{PI_c}^{ul}$	Algeb			v_str
PIc_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
wt	wt	ExtAlgeb			
theta	θ	ExtAlgeb			
Pref	$Pref$	ExtAlgeb			

Variable Initialization Equations

Name	Symbol	Type	Initial Value
PIc_xi	xi_{PI_c}	State	0.0
PIw_xi	xi_{PI_w}	State	0.0
LG_y	y_{LG}	State	$1.0y_{PI_c} + 1.0y_{PI_w}$
Pord	$Pord$	ExtState	
PIc_yul	$y_{PI_c}^{ul}$	Algeb	$K_{pc}\left(Pord - Pref\right)$
PIc_y	y_{PI_c}	Algeb	$PIc_{hlzi}y_{PI_c}^{ul} + PIc_{hlzl}\theta_{min} + PIc_{hlzu}\theta_{max}$
wref	ω_{ref}	Algeb	wt
PIw_yul	$y_{PI_w}^{ul}$	Algeb	$K_{pw}\left(K_{cc}\left(Pord - Pref\right) - \omega_{ref} + wt\right)$
PIw_y	y_{PI_w}	Algeb	$PIw_{hlzi}y_{PI_w}^{ul} + PIw_{hlzl}\theta_{min} + PIw_{hlzu}\theta_{max}$
wt	wt	ExtAlgeb	
theta	θ	ExtAlgeb	
Pref	$Pref$	ExtAlgeb	

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
PIc_xi	xi_{PI_c}	State	$K_{ic}\left(Pord - Pref\right)$	
PIw_xi	xi_{PI_w}	State	$K_{iw}\left(K_{cc}\left(Pord - Pref\right) - \omega_{ref} + wt\right)$	
LG_y	y_{LG}	State	$-y_{LG} + 1.0y_{PI_c} + 1.0y_{PI_w}$	T_{θ}
Pord	$Pord$	ExtState	0	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
PIc_yul	$y_{PI_c}^{ul}$	Algeb	$K_{pc}\left(Pord - Pref\right) + xi_{PI_c} - y_{PI_c}^{ul}$
PIc_y	y_{PI_c}	Algeb	$PIc_{hlzi}y_{PI_c}^{ul} + PIc_{hlzl}\theta_{min} + PIc_{hlzu}\theta_{max} - y_{PI_c}$
wref	ω_{ref}	Algeb	$-\omega_{ref} + wt$
PIw_yul	$y_{PI_w}^{ul}$	Algeb	$K_{pw}\left(K_{cc}\left(Pord - Pref\right) - \omega_{ref} + wt\right) + xi_{PI_w} - y_{PI_w}^{ul}$
PIw_y	y_{PI_w}	Algeb	$PIw_{hlzi}y_{PI_w}^{ul} + PIw_{hlzl}\theta_{min} + PIw_{hlzu}\theta_{max} - y_{PI_w}$
wt	wt	ExtAlgeb	0
theta	θ	ExtAlgeb	$-\theta_0 + y_{LG}$
Pref	$Pref$	ExtAlgeb	0

Discrete

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

5.21 RenPlant

Renewable plant control group.

Common Parameters: u, name

Available models: *REPCA1*

5.21.1 REPCA1

Group *RenPlant*

REPCA1 plat control model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
ree		RenExciter idx			mandatory
line		Idx of line that connect to measured bus			mandatory
busr		Optional remote bus for voltage and freq. measurement			
busf		BusFreq idx for mode 2			
VCFlag		Droop flag; 0-with droop if power factor ctrl, 1-line drop comp.		*bool*	mandatory
RefFlag		Q/V select; 0-Q control, 1-V control		*bool*	mandatory
Fflag		Frequency control flag; 0-disable, 1-enable		*bool*	mandatory
PLflag		Pline ctrl. flag; 0-disable, 1-enable		*bool*	mandatory
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		

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Table 6 – continued from previous page

Name	Symbol	Description	Default	Unit	Propertie
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	*p.u. (Hz)*	
fdbd2	f_{dbd2}	Upper threshold for freq. error deadband	0.000	*p.u. (Hz)*	
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	*p.u. (MW)*	power
Pmin	P_{min}	Lower limit on power error (used by PI ctrl.)	-999	*p.u. (MW)*	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 (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
s0_y	y_{s_0}	State	State in lag transfer function		v_str
s1_y	y_{s_1}	State	State in lag transfer function		v_str
s2_xi	xi_{s_2}	State	Integrator output		v_str
s3_x	x'_{s_3}	State	State in lead-lag		v_str
s4_y	y_{s_4}	State	State in lag transfer function		v_str
s5_xi	xi_{s_5}	State	Integrator output		v_str
s6_y	y_{s_6}	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	$y_{d^{bd}}$	Algeb	Deadband type 1 output		v_str
enf	e_{nf}	Algeb	e Hardlimit output before freeze		v_str
s2_ys	ys_{s_2}	Algeb	PI summation before limit		v_str
s2_y	y_{s_2}	Algeb	PI output		v_str
s3_y	y_{s_3}	Algeb	Output of lead-lag		v_str
ferr	f_{err}	Algeb	Frequency deviation	*p.u. (Hz)*	v_str
fdbd_y	$y_{f^{dbd}}$	Algeb	Deadband type 1 output		v_str

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Table 7 – continued from previous page

Name	Symbol	Type	Description	Unit	Properties
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_{s_5}	Algeb	PI summation before limit		v_str
s5_y	y_{s_5}	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		

Variable Initialization Equations

Name	Symbol	Type	Initial Value
s0_y	y_{s_0}	State	$SWVC_{s0}\left(K_cQ_{line} + V\right) + SWVC_{s1}V_{comp}$
s1_y	y_{s_1}	State	Q_{line}
s2_xi	xi_{s_2}	State	0.0
s3_x	x'_{s_3}	State	y_{s_2}
s4_y	y_{s_4}	State	P_{line}
s5_xi	xi_{s_5}	State	0.0
s6_y	y_{s_6}	State	y_{s_5}
Vref	Q_{ref}	Algeb	V_{ref0}
Qlinef	Q_{linef}	Algeb	Q_{line0}
Refsel	R_{efsel}	Algeb	$SWRef_{s0}\left(Q_{linef} - y_{s_1}\right) + SWRef_{s1}\left(Q_{ref} - y_{s_0}\right)$
dbd_y	$y_{d^{bd}}$	Algeb	$1.0dbd_{dbzl}\left(R_{efsel} - d_{bd1}\right) + 1.0dbd_{dbzu}\left(R_{efsel} - d_{bd2}\right)$
enf	e_{nf}	Algeb	$eHL_{zi}y_{d^{bd}} + eHL_{zl}e_{min} + eHL_{zu}e_{max}$
s2_ys	ys_{s_2}	Algeb	K_pe_{hld}
s2_y	y_{s_2}	Algeb	$Q_{max}s_{2limzu} + Q_{min}s_{2limzl} + s_{2limzi}ys_{s_2}$
s3_y	y_{s_3}	Algeb	y_{s_2}
ferr	f_{err}	Algeb	$-f + f_{ref}$
fdbd_y	$y_{f^{dbd}}$	Algeb	$1.0fdbd_{dbzl}\left(-f_{dbd1} + f_{err}\right) + 1.0fdbd_{dbzu}\left(-f_{dbd2} + f_{err}\right)$
Plant_pref	P_{ref}	Algeb	P_{line0}
Plerr	P_{lerr}	Algeb	$P_{ref} - y_{s_4}$
Perr	P_{err}	Algeb	$D_{dn}fdlt_{0z1}y_{f^{dbd}} + D_{up}fdlt_{0z0}y_{f^{dbd}} + P_{lerr}SWPL_{s1}$
s5_ys	ys_{s_5}	Algeb	$K_{pg}\left(P_{err}feHL_{zi} + f_{emax}feHL_{zu} + f_{emin}feHL_{zl}\right)$
s5_y	y_{s_5}	Algeb	$P_{max}s_{5limzu} + P_{min}s_{5limzl} + s_{5limzi}ys_{s_5}$
Pext	P_{ext}	ExtAlgeb	
Qext	Q_{ext}	ExtAlgeb	
v	V	ExtAlgeb	

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Table 8 – continued from previous page

Name	Symbol	Type	Initial Value
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_{s_0}	State	$SWVC_{s0}\left(K_c Q_{line} + V\right) + SWVC_{s1} V_{comp} - y_{s_0}$	T_{fltr}
s1_y	y_{s_1}	State	$Q_{line} - y_{s_1}$	T_{fltr}
s2_xi	xi_{s_2}	State	$K_i\left(e_{hld} + 2y_{s_2} - 2ys_{s_2}\right)$	
s3_x	x'_{s_3}	State	$-x'_{s_3} + y_{s_2}$	T_{fv}
s4_y	y_{s_4}	State	$P_{line} - y_{s_4}$	T_p
s5_xi	xi_{s_5}	State	$K_{ig}\left(P_{err} feHL_{zi} + f_{emax} feHL_{zu} + f_{emin} feHL_{zl} + 2y_{s_5} - 2ys_{s_5}\right)$	
s6_y	y_{s_6}	State	$y_{s_5} - y_{s_6}$	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	$-R_{efsel} + SWRef_{s0}\left(Q_{linef} - y_{s_1}\right) + SWRef_{s1}\left(Q_{ref} - y_{s_0}\right)$
dbd_y	$y_{d^{bd}}$	Algeb	$1.0dbd_{dbzl}\left(R_{efsel} - d_{bd1}\right) + 1.0dbd_{dbzu}\left(R_{efsel} - d_{bd2}\right) - y_{d^{bd}}$
enf	e_{nf}	Algeb	$eHL_{zi}y_{d^{bd}} + eHL_{zl}e_{min} + eHL_{zu}e_{max} - e_{nf}$
s2_ys	ys_{s_2}	Algeb	$K_pe_{hld} + xi_{s_2} - ys_{s_2}$
s2_y	y_{s_2}	Algeb	$Q_{max}s_{2limzu} + Q_{min}s_{2limzl} + s_{2limzi}ys_{s_2} - y_{s_2}$
s3_y	y_{s_3}	Algeb	$T_{ft}\left(-x'_{s_3} + y_{s_2}\right) + T_{fv}x'_{s_3} - T_{fv}y_{s_3} + s_{3LT1z1}s_{3LT2z1}\left(-x'_{s_3} + y_{s_3}\right)$
ferr	f_{err}	Algeb	$-f - f_{err} + f_{ref}$
fdbd_y	$y_{f^{dbd}}$	Algeb	$1.0fdbd_{dbzl}\left(-f_{dbd1} + f_{err}\right) + 1.0fdbd_{dbzu}\left(-f_{dbd2} + f_{err}\right) - y_{f^{dbd}}$
Plant_pref	P_{ref}	Algeb	$P_{line0} - P_{ref}$
Plerr	P_{lerr}	Algeb	$-P_{lerr} + P_{ref} - y_{s_4}$
Perr	P_{err}	Algeb	$D_{dn}fdlt_{0z1}y_{f^{dbd}} + D_{up}fdlt_{0z0}y_{f^{dbd}} - P_{err} + P_{lerr}SWPL_{s1}$
s5_ys	ys_{s_5}	Algeb	$K_{pg}\left(P_{err}feHL_{zi} + f_{emax}feHL_{zu} + f_{emin}feHL_{zl}\right) + xi_{s_5} - ys_{s_5}$
s5_y	y_{s_5}	Algeb	$P_{max}s_{5limzu} + P_{min}s_{5limzl} + s_{5limzi}ys_{s_5} - y_{s_5}$
Pext	P_{ext}	ExtAlgeb	$SWF_{s1}y_{s_6}$
Qext	Q_{ext}	ExtAlgeb	y_{s_3}
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}	$\frac{I_{sign}\left(V_1 e^{i\theta_1} - V_2 e^{i\theta_2}\right)}{r + ix}$	VarService
Iline0	I_{line0}	I_{line}	ConstService
Pline	P_{line}	$\operatorname{re}\left(I_{sign} V_1 \operatorname{conj}\left(\frac{V_1 e^{i\theta_1} - V_2 e^{i\theta_2}}{r + ix}\right) e^{i\theta_1}\right)$	VarService
Pline0	P_{line0}	P_{line}	ConstService
Qline	Q_{line}	$\operatorname{im}\left(I_{sign} V_1 \operatorname{conj}\left(\frac{V_1 e^{i\theta_1} - V_2 e^{i\theta_2}}{r + ix}\right) e^{i\theta_1}\right)$	VarService
Qline0	Q_{line0}	Q_{line}	ConstService
Vcomp	V_{comp}	$\operatorname{abs}\left(- I_{line} \left(R_{cs} + i X_{cs}\right) + V e^{i\theta}\right)$	VarService
Vref0	V_{ref0}	$SWVC_{s0} \left(K_c Q_{line0} + V\right) + SWVC_{s1} V_{comp}$	ConstService
zf	z_f	$f_{rz} \left(V < V_{frz}\right)$	VarService
eHld	e_{hld}	0	VarHold
Freq_ref	f_{ref}	1.0	ConstService

Discrete

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_{s_2}	HardLimiter	
s3_LT1	LT_{s_3}	LessThan	
s3_LT2	LT_{s_3}	LessThan	
fdbd_db	db_{fdbd}	DeadBand	
fdlt0	f_{dlt0}	LessThan	frequency deadband output less than zero
feHL	f_{eHL}	Limiter	Limiter for power (frequency) error
s5_lim	lim_{s_5}	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
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	

5.22 RenTorque

Renewable torque (Pref) controller.

Common Parameters: u, name

Available models: *WTTQA1*

5.22.1 WTTQA1

Group *RenTorque*

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	*bool*	
name		device name			
rep		RenPitch controller idx			mandatory
Kip	K_{ip}	Pref-control integral gain	0.100	*p.u.*	
Kpp	K_{pp}	Pref-control proportional gain	0	*p.u.*	
Tp	T_p	Pe sensing time const.	0.050	*s*	
Twref	T_{wref}	Speed reference time const.	30	*s*	
Temax	T_{emax}	Max. electric torque	1.200	*p.u.*	power
Temin	T_{emin}	Min. electric torque	0	*p.u.*	power
Tflag		Tflag; 1-power error, 0-speed error		*bool*	mandatory
p1	p_1	Active power point 1	0.200	*p.u.*	power
sp1	s_{p1}	Speed power point 1	0.580	*p.u.*	
p2	p_2	Active power point 2	0.400	*p.u.*	power
sp2	s_{p2}	Speed power point 2	0.720	*p.u.*	
p3	p_3	Active power point 3	0.600	*p.u.*	power
sp3	s_{p3}	Speed power point 3	0.860	*p.u.*	
p4	p_4	Active power point 4	0.800	*p.u.*	power
sp4	s_{p4}	Speed power point 4	1	*p.u.*	
rea			0		
rego			0		
ree			0		
reg			0		
Sn	S_n		0		
w0	ω_0		0		

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
s1_y	y_{s_1}	State	State in lag transfer function		v_str
s2_y	y_{s_2}	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	$y_{f_{Pe}}$	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

Variable Initialization Equations

Name	Symbol	Type	Initial Value
s1_y	y_{s_1}	State	$1.0P_e$
s2_y	y_{s_2}	State	$1.0y_{f_{Pe}}$
PI_xi	xi_{PI}	State	$\frac{P_{ref0}}{y_{f_{Pe}}}$
wg	ω_g	ExtState	$y_{f_{Pe}}$
wt	ω_t	ExtState	$y_{f_{Pe}}$
s3_y	y_{s3}	ExtState	$\frac{P_{ref0}}{K_{shaft}\omega_g}$
fPe_y	$y_{f_{Pe}}$	Algeb	$\begin{cases} s_{p1} & \text{for}\: p_{1} \geq y_{s_1} \\ k_{p1} \left(- p_{1} + y_{s_1}\right) + s_{p1} & \text{for}\: p_{2} \geq y_{s_1} \\ k_{p2} \left(- p_{2} + y_{s_1}\right) + s_{p2} & \text{for}\: p_{3} \geq y_{s_1} \\ k_{p3} \left(- p_{3} + y_{s_1}\right) + s_{p3} & \text{for}\: p_{4} \geq y_{s_1} \\ s_{p4} & \text{otherwise} \end{cases}$
Tsel	T_{sel}	Algeb	$SWT_{s0} \left(- \omega_g + y_{s_2}\right) + \frac{SWT_{s1} \left(P_e - P_{ref0}\right)}{\omega_g}$
PI_yul	y_{PI}^{ul}	Algeb	$K_{pp} T_{sel} + \frac{P_{ref0}}{y_{f_{Pe}}}$
PI_y	y_{PI}	Algeb	$\pi_{hlzi} y_{PI}^{ul} + \pi_{hlzl} T_{emin} + \pi_{hlzu} T_{emax}$
Pe	P_e	ExtAlgeb	
wr0	ω_{r0}	ExtAlgeb	$y_{f_{Pe}}$
wge	ω_{ge}	ExtAlgeb	1.0
Pref	P_{ref}	ExtAlgeb	$\omega_g y_{PI}$

Differential Equations

Name	Symbol	Type	RHS of Equation "T x' = f(x, y)"	T (LHS)
s1_y	y_{s_1}	State	$1.0P_e - y_{s_1}$	T_p
s2_y	y_{s_2}	State	$1.0y_{f_{Pe}} - y_{s_2}$	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

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
fPe_y	$y_{f_{Pe}}$	Algeb	$-y_{f_{Pe}} + \begin{cases} s_{p1} & \text{for } p_1 \geq y_{s_1} \\ k_{p1}(-p_1 + y_{s_1}) + s_{p1} & \text{for } p_2 \geq y_{s_1} \\ k_{p2}(-p_2 + y_{s_1}) + s_{p2} & \text{for } p_3 \geq y_{s_1} \\ k_{p3}(-p_3 + y_{s_1}) + s_{p3} & \text{for } p_4 \geq y_{s_1} \\ s_{p4} & \text{otherwise} \end{cases}$
Tsel	T_{sel}	Algeb	$SWT_{s0}(-\omega_g + y_{s_2}) + \frac{SWT_{s1}(P_e - P_{ref0})}{\omega_g} - T_{sel}$
PI_yul	y_{PI}^{ul}	Algeb	$K_{pp}T_{sel} + xi_{PI} - y_{PI}^{ul}$
PI_y	y_{PI}	Algeb	$\pi_{hlzi}y_{PI}^{ul} + \pi_{hlzl}T_{emin} + \pi_{hlzu}T_{emax} - y_{PI}$
Pe	P_e	ExtAlgeb	0
wr0	ω_{r0}	ExtAlgeb	$-\omega_0 + y_{f_{Pe}}$
wge	ω_{ge}	ExtAlgeb	$1 - y_{f_{Pe}}$
Pref	P_{ref}	ExtAlgeb	$-\frac{P_{ref0}}{\omega_{ge}} + \omega_g y_{PI}$

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

Discrete

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

5.23 StaticACDC

AC DC device for power flow

Common Parameters: u, name

Available models: *VSCShunt*

5.23.1 VSCShunt

Group *StaticACDC*

Data for VSC Shunt in power flow Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
bus		idx of connected bus			mandatory
node1		Node 1 index			mandatory
node2		Node 2 index			mandatory
Vn	V_n	AC voltage rating	110		non_zero
Vdcn1	V_{dcn1}	DC voltage rating on node 1	100	*kV*	non_zero
Vdcn2	V_{dcn2}	DC voltage rating on node 2	100	*kV*	non_zero
Idcn	I_{dcn}	DC current rating	1	*kA*	non_zero
rsh	r_{sh}	AC interface resistance	0.003	*ohm*	z
xsh	x_{sh}	AC interface reactance	0.060	*ohm*	z
control		Control method: 0-PQ, 1-PV, 2-vQ or 3-vV			mandatory
v0		AC voltage setting (PV or vV) or initial guess (PQ or vQ)	1		
p0		AC active power setting	0	*pu*	
q0		AC reactive power setting	0	*pu*	
vdc0	v_{dc0}	DC voltage setting	1	*pu*	
k0		Loss coefficient - constant	0		
k1		Loss coefficient - linear	0		
k2		Loss coefficient - quadratic	0		
droop		Enable dc voltage droop control	0	*boolean*	
K		Droop coefficient	0		
vhigh		Upper voltage threshold in droop control	9999	*pu*	
vlow		Lower voltage threshold in droop control	0	*pu*	
vshmax		Maximum ac interface voltage	1.100	*pu*	
vshmin		Minimum ac interface voltage	0.900	*pu*	
Ishmax		Maximum ac current	2	*pu*	

Variables (States + Algebraics)

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		

Variable Initialization Equations

Name	Symbol	Type	Initial Value
ash	θ_{sh}	Algeb	a
vsh	V_{sh}	Algeb	v_0
psh	P_{sh}	Algeb	$p_0 \left(s_0^{mode} + s_1^{mode}\right)$
qsh	Q_{sh}	Algeb	$q_0 \left(s_0^{mode} + s_2^{mode}\right)$
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	$-P_{sh} + u \left(V_{sh} b_{sh} v \sin\left(\theta_{sh} - a\right) - V_{sh} g_{sh} v \cos\left(\theta_{sh} - a\right) + g_{sh} v^{2}\right)$
vsh	V_{sh}	Algeb	$-Q_{sh} + u \left(V_{sh} b_{sh} v \cos\left(\theta_{sh} - a\right) + V_{sh} g_{sh} v \sin\left(\theta_{sh} - a\right) - b_{sh} v^{2}\right)$
psh	P_{sh}	Algeb	$u \left(- P_{sh} + p_0\right) \left(s_0^{mode} + s_1^{mode}\right) + u \left(s_2^{mode} + s_3^{mode}\right) \left(v_1 - v_2 - v_{dc0}\right)$
qsh	Q_{sh}	Algeb	$u \left(- Q_{sh} + q_0\right) \left(s_0^{mode} + s_2^{mode}\right) + u \left(s_1^{mode} + s_3^{mode}\right) \left(- v + v_0\right)$
pdc	P_{dc}	Algeb	$P_{dc} + u \left(V_{sh}^{2} g_{sh} - V_{sh} b_{sh} v \sin\left(\theta_{sh} - a\right) - V_{sh} g_{sh} v \cos\left(\theta_{sh} - a\right)\right)$
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}	$\frac{\operatorname{re}(r_{sh}) - \operatorname{im}(x_{sh})}{(\operatorname{re}(r_{sh}) - \operatorname{im}(x_{sh}))^2 + (\operatorname{re}(x_{sh}) + \operatorname{im}(r_{sh}))^2}$	ConstService
bsh	b_{sh}	$\frac{-\operatorname{re}(x_{sh}) - \operatorname{im}(r_{sh})}{(\operatorname{re}(r_{sh}) - \operatorname{im}(x_{sh}))^2 + (\operatorname{re}(x_{sh}) + \operatorname{im}(r_{sh}))^2}$	ConstService

Discrete

Name	Symbol	Type	Info
mode	$mode$	Switcher	

5.24 StaticGen

Static generator group for power flow calculation

Common Parameters: u, name, Sn, Vn, p0, q0, ra, xs, subidx

Common Variables: p, q, a, v

Available models: *PV*, *Slack*

5.24.1 PV

Group *StaticGen*

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	*bool*	
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			
busr		bus idx for remote voltage control			
p0	p_0	active power set point in system base	0	*p.u.*	
q0	q_0	reactive power set point in system base	0	*p.u.*	
pmax	p_{max}	maximum active power in system base	999	*p.u.*	
pmin	p_{min}	minimum active power in system base	-1	*p.u.*	
qmax	q_{max}	maximim reactive power in system base	999	*p.u.*	
qmin	q_{min}	minimum reactive power in system base	-999	*p.u.*	
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	0.010		
xs	x_s	armature reactance	0.300		

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
p	p	Algeb	actual active power generation	*p.u.*	v_str
q	q	Algeb	actual reactive power generation	*p.u.*	v_str
a	θ	ExtAlgeb			
v	V	ExtAlgeb			v_str,v_setter

Variable Initialization Equations

Name	Symbol	Type	Initial Value
p	p	Algeb	p_0
q	q	Algeb	q_0
a	θ	ExtAlgeb	
v	V	ExtAlgeb	v_0

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
p	p	Algeb	$u\left(-p + p_0\right)$
q	q	Algeb	$u\left(z_i^{qlim}\left(-V + v_0\right) + z_l^{qlim}\left(-q + q_{min}\right) + z_u^{qlim}\left(-q + q_{max}\right)\right)$
a	θ	ExtAlgeb	$-pu$
v	V	ExtAlgeb	$-qu$

Discrete

Name	Symbol	Type	Info
qlim	$qlim$	SortedLimiter	

Config Fields in [PV]

Option	Symbol	Value	Info	Accepted values
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)

5.24.2 Slack

Group *StaticGen*

Slack generator.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
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			
busr		bus idx for remote voltage control			
p0	p_0	active power set point in system base	0	*p.u.*	
q0	q_0	reactive power set point in system base	0	*p.u.*	
pmax	p_{max}	maximum active power in system base	999	*p.u.*	
pmin	p_{min}	minimum active power in system base	-1	*p.u.*	
qmax	q_{max}	maximim reactive power in system base	999	*p.u.*	
qmin	q_{min}	minimum reactive power in system base	-999	*p.u.*	
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	0.010		
xs	x_s	armature reactance	0.300		
a0	θ_0	reference angle set point	0		

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
p	p	Algeb	actual active power generation	$p.u.$	v_str
q	q	Algeb	actual reactive power generation	$p.u.$	v_str
a	θ	ExtAlgeb			v_str,v_setter
v	V	ExtAlgeb			v_str,v_setter

Variable Initialization Equations

Name	Symbol	Type	Initial Value
p	p	Algeb	p_0
q	q	Algeb	q_0
a	θ	ExtAlgeb	θ_0
v	V	ExtAlgeb	v_0

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
p	p	Algeb	$u\left(z_i^{plim}\left(-\theta+\theta_0\right)+z_l^{plim}\left(-p+p_{min}\right)+z_u^{plim}\left(-p+p_{max}\right)\right)$
q	q	Algeb	$u\left(z_i^{qlim}\left(-V+v_0\right)+z_l^{qlim}\left(-q+q_{min}\right)+z_u^{qlim}\left(-q+q_{max}\right)\right)$
a	θ	ExtAlgeb	$-pu$
v	V	ExtAlgeb	$-qu$

Discrete

Name	Symbol	Type	Info
qlim	$qlim$	SortedLimiter	
plim	$plim$	SortedLimiter	

Config Fields in [Slack]

Option	Symbol	Value	Info	Accepted values
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)

5.25 StaticLoad

Static load group.

Common Parameters: u, name

Available models: *PQ*

5.25.1 PQ

Group *StaticLoad*

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).

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
bus		linked bus idx			mandatory
Vn	V_n	AC voltage rating	110	*kV*	non_zero
p0	p_0	active power load in system base	0	*p.u.*	
q0	q_0	reactive power load in system base	0	*p.u.*	
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 (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Variable 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	$u\left(I_{peq}V\gamma_{p2i} + P_{pf}\gamma_{p2p} + R_{eq}V^2\gamma_{p2z}\right)(t_{dae} > 0) + u\left(R_{lb}V^2z_l^{vcmp} + R_{ub}V^2z_u^{vcmp} + p_0z_i^{vcmp}\right)(t_{dae} \leq 0)$
v	V	ExtAlgeb	$u\left(I_{qeq}V\gamma_{q2i} + Q_{pf}\gamma_{q2q} + V^2X_{eq}\gamma_{q2z}\right)(t_{dae} > 0) + u\left(V^2X_{lb}z_l^{vcmp} + V^2X_{ub}z_u^{vcmp} + q_0z_i^{vcmp}\right)(t_{dae} \leq 0)$

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
Iqeq	I_{qeq}	$\frac{Q_{pf}}{V_0}$	ConstService

Discrete

Name	Symbol	Type	Info
vcmp	$vcmp$	Limiter	

Config Fields in [PQ]

Option	Symbol	Value	Info	Accepted values
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

5.26 StaticShunt

Static shunt compensator group.

Common Parameters: u, name

Available models: *Shunt*, *ShuntSw*

5.26.1 Shunt

Group *StaticShunt*

Static Shunt Model.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
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 (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Variable 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^2gu
v	V	ExtAlgeb	$-V^2bu$

5.26.2 ShuntSw

Group *StaticShunt*

Switched Shunt Model.

Parameters *gs*, *bs* and *bs* 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	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
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	*p.u.*	y
bs		a list literal of switched susceptances blocks	0	*p.u.*	y
ns		a list literal of the element numbers in each switched block	[0]		
vref		voltage reference	1	*p.u.*	non_zero,non_negative
dv		voltage error deadband	0.050	*p.u.*	non_zero,non_negative
dt		delay before two consecutive switching	30	*seconds*	non_negative

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb			
v	V	ExtAlgeb			

Variable 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	$V^2 geffu$
v	V	ExtAlgeb	$-V^2 beffu$

Services

Name	Symbol	Equation	Type
vlo	v_{lo}	$-dv + vref$	ConstService
vup	v_{up}	$dv + vref$	ConstService

Discrete

Name	Symbol	Type	Info
adj	adj	ShuntAdjust	shunt adjuster

Config Fields in [ShuntSw]

Option	Symbol	Value	Info	Accepted values
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

5.27 SynGen

Synchronous generator group.

Common Parameters: u, name, Sn, Vn, fn, bus, M, D

Common Variables: omega, delta, tm, te, vf, XadIfd, vd, vq, Id, Iq, a, v

Available models: *GENCLS*, *GENROU*

5.27.1 GENCLS

Group *SynGen*

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
coi		center of inertia index			
Sn	S_n	Power rating	100		
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,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		
subidx		Generator idx in plant; only used by PSS/E data	0		

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
delta	δ	State	rotor angle	*rad*	v_str
omega	ω	State	rotor speed	*pu (Hz)*	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	*pu*	v_str
XadIfd	$X_{ad}I_{fd}$	Algeb	d-axis armature excitation current	*p.u (kV)*	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		

Variable 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	$P_0 u$
vf	v_f	Algeb	$u v_{f0}$
XadIfd	$X_{ad} I_{fd}$	Algeb	$u v_{f0}$
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	$2 \pi f u \left(\omega - 1\right)$	
omega	ω	State	$\frac{u \left(- D \left(\omega - 1\right) - \tau_e + \tau_m\right)}{M}$	

Algebraic Equations

Name	Symbol	Type	RHS of Equation "0 = g(x, y)"
Id	I_d	Algeb	$I_d xq + \psi_d - v_f$
Iq	I_q	Algeb	$I_q xq + \psi_q$
vd	V_d	Algeb	$V u \sin \left(\delta - \theta\right) - V_d$
vq	V_q	Algeb	$V u \cos \left(\delta - \theta\right) - V_q$
tm	τ_m	Algeb	$- \tau_m + \tau_{m0}$
te	τ_e	Algeb	$- \tau_e + u \left(- I_d \psi_q + I_q \psi_d\right)$
vf	v_f	Algeb	$u v_{f0} - v_f$
XadIfd	$X_{ad} I_{fd}$	Algeb	$- X_{ad} I_{fd} + u v_{f0}$
psid	ψ_d	Algeb	$- \psi_d + u \left(I_q r_a + V_q\right)$
psiq	ψ_q	Algeb	$\psi_q + u \left(I_d r_a + V_d\right)$
a	θ	ExtAlgeb	$- u \left(I_d V_d + I_q V_q\right)$
v	V	ExtAlgeb	$- u \left(I_d V_q - I_q V_d\right)$

Services

Name	Symbol	Equation	Type
_V	V_c	$Ve^{i\theta}$	ConstService
_S	S	$P_0 - iQ_0$	ConstService
_I	I_c	$\frac{S}{\operatorname{conj}(V_c)}$	ConstService
_E	E	$I_c (r_a + ixq) + V_c$	ConstService
_deltac	δ_c	$\log\left(\frac{E}{\operatorname{abs}(E)}\right)$	ConstService
delta0	δ_0	$u \operatorname{im}(\delta_c)$	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}	$\operatorname{re}(I_{dq})$	ConstService
Iq0	I_{q0}	$\operatorname{im}(I_{dq})$	ConstService
vd0	V_{d0}	$\operatorname{re}(V_{dq})$	ConstService
vq0	V_{q0}	$\operatorname{im}(V_{dq})$	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}	$I_{d0} xq + I_{q0} r_a + V_{q0}$	ConstService

Config Fields in [GENCLS]

Option	Symbol	Value	Info	Accepted values
vf_lower		1	lower limit for vf warning	
vf_upper		5	upper limit for vf warning	

5.27.2 GENROU

Group *SynGen*

Round rotor generator with quadratic saturation

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
bus		interface bus id			mandatory
gen		static generator index			mandatory
coi		center of inertia index			
Sn	S_n	Power rating	100		
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,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		
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	0.204		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 (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
delta	δ	State	rotor angle	*rad*	v_str
omega	ω	State	rotor speed	*pu (Hz)*	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	*pu*	v_str
XadIfd	$X_{ad}I_{fd}$	Algeb	d-axis armature excitation current	*p.u (kV)*	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	*p.u (kV)*	v_str
a	θ	ExtAlgeb	Bus voltage phase angle		
v	V	ExtAlgeb	Bus voltage magnitude		

Variable Initialization Equations

Name	Symbol	Type	Initial Value
delta	δ	State	δ_0
omega	ω	State	u
e1q	e'_q	State	$e'_{q0}u$
e1d	e'_d	State	e'_{d0}
e2d	e''_d	State	$e''_{d0}u$
e2q	e''_q	State	e''_{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	P_0u
vf	v_f	Algeb	uv_{f0}
XadIfd	$X_{ad}I_{fd}$	Algeb	uv_{f0}
psid	ψ_d	Algeb	$\psi_{d0}u$
psiq	ψ_q	Algeb	$\psi_{q0}u$
psi2q	ψ_{aq}	Algeb	ψ_{aq0}
psi2d	ψ_{ad}	Algeb	$\psi_{ad0}u$
psi2	ψ_a	Algeb	$u \operatorname{abs}\left(\psi''_{0,dq}\right)$
Se	$S_e(\lvert\psi_a\rvert)$	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	$\frac{u(-D(\omega-1)-\tau_e+\tau_m)}{M}$	
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	$I_q \left(x'_q - x_l\right) - e''_q + e'_d$	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	$-\tau_e + u\left(-I_d \psi_q + I_q \psi_d\right)$
vf	v_f	Algeb	$u v_{f0} - v_f$
XadIfd	$X_{ad} I_{fd}$	Algeb	$-X_{ad} I_{fd} + u\left(S_e(\lvert\psi_a\rvert)\psi_{ad} + e'_q + \left(-x'_d + x_d\right)\left(I_d \gamma_{d1} - \gamma_{d2} e''_d + \gamma_{d2} e'_q\right)\right)$
psid	ψ_d	Algeb	$-\psi_d + u\left(I_q r_a + V_q\right)$
psiq	ψ_q	Algeb	$\psi_q + u\left(I_d r_a + V_d\right)$
psi2q	ψ_{aq}	Algeb	$\gamma_{q1} e'_d - \psi_{aq} + e''_q\left(1 - \gamma_{q1}\right)$
psi2d	ψ_{ad}	Algeb	$\gamma_{d1} e'_q + \gamma_{d2} e''_d\left(x'_d - x_l\right) - \psi_{ad}$
psi2	ψ_a	Algeb	$-\psi_a^2 + \psi_{ad}^2 + \psi_{aq}^2$
Se	$S_e(\lvert\psi_a\rvert)$	Algeb	$B^q_{SAT} z_0^{SL}\left(-A^q_{SAT} + \psi_a\right)^2 - S_e(\lvert\psi_a\rvert)\psi_a$
XaqI1q	$X_{aq} I_{1q}$	Algeb	$S_e(\lvert\psi_a\rvert)\gamma_{qd}\psi_{aq} - X_{aq} I_{1q} + e'_d + \left(-x'_q + x_q\right)\left(-I_q \gamma_{q1} - \gamma_{q2} e''_q + \gamma_{q2} e'_d\right)$
a	θ	ExtAlgeb	$-u\left(I_d V_d + I_q V_q\right)$
v	V	ExtAlgeb	$-u\left(I_d V_q - I_q V_d\right)$

Services

Name	Symbol	Equation	Type
gd1	γ_{d1}	$\frac{x''_d - x_l}{x'_d - x_l}$	ConstService
gq1	γ_{q1}	$\frac{x''_q - x_l}{x'_q - x_l}$	ConstService
gd2	γ_{d2}	$\frac{-x''_d + x'_d}{\left(x'_d - x_l\right)^2}$	ConstService
gq2	γ_{q2}	$\frac{-x''_q + x'_q}{\left(x'_q - x_l\right)^2}$	ConstService
gqd	γ_{qd}	$\frac{-x_l + x_q}{x_d - x_l}$	ConstService
_S12	$S_{1.2}$	$S_{1.2} -_f S12 + 1$	ConstService
SAT_E1	E^{1c}_{SAT}	1.0	ConstService
SAT_E2	E^{2c}_{SAT}	1.2	ConstService
SAT_SE1	SE^{1c}_{SAT}	$S_{1.0}$	ConstService
SAT_SE2	SE^{2c}_{SAT}	$S_{1.2} - 2z^{SE2}_{SAT} + 2$	ConstService
SAT_a	a_{SAT}	$\sqrt{\frac{E^{1c}_{SAT} SE^{1c}_{SAT}}{E^{2c}_{SAT} SE^{2c}_{SAT}}}\left(\left(SE^{2c}_{SAT} > 0\right) + \left(SE^{2c}_{SAT} < 0\right)\right)$	ConstService
SAT_A	A^q_{SAT}	$E^{2c}_{SAT} - \frac{E^{1c}_{SAT} - E^{2c}_{SAT}}{a_{SAT} - 1}$	ConstService
SAT_B	B^q_{SAT}	$\frac{E^{2c}_{SAT} SE^{2c}_{SAT}\left(a_{SAT} - 1\right)^2\left(\left(a_{SAT} > 0\right) + \left(a_{SAT} < 0\right)\right)}{\left(E^{1c}_{SAT} - E^{2c}_{SAT}\right)^2}$	ConstService

Continued on next page

Table 9 – continued from previous page

Name	Symbol	Equation	Type
_V	V_c	$Ve^{i\theta}$	ConstService
_S	S	$P_0 - iQ_0$	ConstService
_Zs	Z_s	$r_a + ix''_d$	ConstService
_It	I_t	$\frac{S}{\mathrm{conj}\left(V_c\right)}$	ConstService
_Is	I_s	$I_t + \frac{V_c}{Z_s}$	ConstService
psi20	ψ''_0	$I_s Z_s$	ConstService
psi20_arg	$\theta_{\psi''0}$	$\arg\left(\psi''_0\right)$	ConstService
psi20_abs	$\lvert\psi''_0\rvert$	$\mathrm{abs}\left(\psi''_0\right)$	ConstService
_It_arg	θ_{It0}	$\arg\left(I_t\right)$	ConstService
_psi20_It_arg	$\theta_{\psi aIt}$	$-\theta_{It0} + \theta_{\psi''0}$	ConstService
Se0	S_{e0}	$\frac{B^q_{SAT}\left(-A^q_{SAT} + \lvert\psi''_0\rvert\right)^2\left(\lvert\psi''_0\rvert \geq A^q_{SAT}\right)}{\lvert\psi''_0\rvert}$	ConstService
_a	a'	$\lvert\psi''_0\rvert\left(S_{e0}\gamma_{qd} + 1\right)$	ConstService
_b	b'	$\left(x''_q - x_q\right)\mathrm{abs}\left(I_t\right)$	ConstService
delta0	δ_0	$\theta_{\psi''0} + \mathrm{atan}\left(\frac{b'\cos\left(\theta_{\psi aIt}\right)}{-a' + b'\sin\left(\theta_{\psi aIt}\right)}\right)$	ConstService
_Tdq	T_{dq}	$-i\sin\left(\delta_0\right) + \cos\left(\delta_0\right)$	ConstService
psi20_dq	$\psi''_{0,dq}$	$T_{dq}\psi''_0$	ConstService
It_dq	$I_{t,dq}$	$\mathrm{conj}\left(I_t T_{dq}\right)$	ConstService
psi2d0	ψ_{ad0}	$\mathrm{re}\left(\psi''_{0,dq}\right)$	ConstService
psi2q0	ψ_{aq0}	$-\mathrm{im}\left(\psi''_{0,dq}\right)$	ConstService
Id0	I_{d0}	$\mathrm{im}\left(I_{t,dq}\right)$	ConstService
Iq0	I_{q0}	$\mathrm{re}\left(I_{t,dq}\right)$	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}	$u\left(I_{d0}\left(I_{d0}r_a + V_{d0}\right) + I_{q0}\left(I_{q0}r_a + V_{q0}\right)\right)$	ConstService
vf0	v_{f0}	$I_{d0}\left(-x''_d + x_d\right) + \psi_{ad0}\left(S_{e0} + 1\right)$	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}	$I_{d0}\left(x'_d - x_d\right) - S_{e0}\psi_{ad0} + v_{f0}$	ConstService
e1d0	e'_{d0}	$I_{q0}\left(-x'_q + x_q\right) - S_{e0}\gamma_{qd}\psi_{aq0}$	ConstService
e2d0	e''_{d0}	$I_{d0}\left(-x_d + x_l\right) - S_{e0}\psi_{ad0} + v_{f0}$	ConstService
e2q0	e''_{q0}	$-I_{q0}\left(x_l - x_q\right) - S_{e0}\gamma_{qd}\psi_{aq0}$	ConstService

Discrete

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
vf_lower		1	lower limit for vf warning	
vf_upper		5	upper limit for vf warning	

5.28 TimedEvent

Timed event group

Common Parameters: u, name

Available models: *Toggler*, *Fault*, *Alter*

5.28.1 Toggler

Group *TimedEvent*

Time-based connectivity status toggler.

Toggler is used to toggle the connection status of a device at a predefined time. Both the model name (or group name) and the device idx need to be provided.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
model		model or group name of the device			mandatory
dev		idx of the device to control			mandatory
t		switch time for connection status	-1		mandatory

Services

Name	Symbol	Equation	Type
_u	u	1	ConstService

5.28.2 Fault

Group *TimedEvent*

Three-phase to ground fault.

Two times, *tf* and *tc*, can be defined for fault on for fault clearance.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
bus		linked bus idx			mandatory
tf		Bus fault start time	-1	*second*	mandatory
tc		Bus fault end time	-1	*second*	
xf	x_f	Fault to ground impedance (positive)	0.000	*p.u.(sys)*	
rf	x_f	Fault to ground resistance (positive)	0	*p.u.(sys)*	

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
a	θ	ExtAlgeb	Bus voltage angle	*p.u.(kV)*	
v	V	ExtAlgeb	Bus voltage magnitude	*p.u.(kV)*	

Variable 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	$\frac{\operatorname{re}\left(x_f\right)-\operatorname{im}\left(x_f\right)}{\left(\operatorname{re}\left(x_f\right)-\operatorname{im}\left(x_f\right)\right)^2+\left(\operatorname{re}\left(x_f\right)+\operatorname{im}\left(x_f\right)\right)^2}$	ConstService
bf	b_f	$\frac{-\operatorname{re}\left(x_f\right)-\operatorname{im}\left(x_f\right)}{\left(\operatorname{re}\left(x_f\right)-\operatorname{im}\left(x_f\right)\right)^2+\left(\operatorname{re}\left(x_f\right)+\operatorname{im}\left(x_f\right)\right)^2}$	ConstService
uf	u_f	0	ConstService

Config Fields in [Fault]

Option	Symbol	Value	Info	Accepted values
restore		1	restore algebraic variables to pre-fault values	(0, 1)
scale		1	scaling factor of restored algebraic values	

5.28.3 Alter

Group *TimedEvent*

Model for altering device internal data (service or param) at a given time.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
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 ramdom sampling	0		
lb		lower bound of random sampling	0		
ub		upper bound of random sampling	0		

Discrete

Name	Symbol	Type	Info
SW	SW	Switcher	Switcher for alteration method

5.29 TurbineGov

Turbine governor group for synchronous generator.

Common Parameters: u, name

Common Variables: pout

Available models: *TG2*, *TGOV1*, *TGOV1N*, *TGOV1DB*, *IEEEG1*

5.29.1 TG2

Group *TurbineGov*

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
syn		Synchronous generator idx			mandatory,unique
Tn	T_n	Turbine power rating. Equal to *Sn* if not provided.		*MVA*	
wref0	ω_{ref0}	Base speed reference	1	*p.u.*	
R	R	Speed regulation gain (mach. base default)	0.050	*p.u.*	ipower
pmax	p_{max}	Maximum power output	999	*p.u.*	power
pmin	p_{min}	Minimum power output	0	*p.u.*	power
dbl	L_{db}	Deadband lower limit	-0.000	*p.u.*	
dbu	U_{db}	Deadband upper limit	0.000	*p.u.*	
dbc	C_{db}	Deadband neutral value	0	*p.u.*	
T1	T_1	Transient gain time	0.200		
T2	T_2	Governor time constant	10		
Sg	S_n	Rated power from generator	0	*MVA*	
Vn	V_n	Rated voltage from generator	0	*kV*	

Variables (States + Algebraics)

Name	Symbol	Type	Description	Unit	Properties
ll_x	x'_{ll}	State	State in lead-lag		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
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	ExtAlgeb	Mechanical power interface to SynGen		

Variable 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	$\tau_{m0} u$
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	$-\omega_{dev} + u \left(-\omega + \omega_{ref}\right)$
w_dm	ω_{dm}	Algeb	$L_{db} z_{lr}^{w_{db}} + U_{db} z_{ur}^{w_{db}} + \omega_{dev} \left(1 - z_i^{w_{db}}\right) - \omega_{dm}$
w_dmg	ω_{dmG}	Algeb	$G \omega_{dm} - \omega_{dmG}$
ll_y	y_{ll}	Algeb	$T_1 \left(\omega_{dmG} - x'_{ll}\right) + T_2 x'_{ll} - T_2 y_{ll} + ll_{LT1z1} ll_{LT2z1} \left(-x'_{ll} + y_{ll}\right)$
pnl	P_{nl}	Algeb	$-P_{nl} + P_{ref0} + y_{ll}$
tm	τ_m	ExtAlgeb	$u \left(P_{out} - \tau_{m0}\right)$

Services

Name	Symbol	Equation	Type
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
gain	G	$\frac{u}{R}$	ConstService

Discrete

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
deadband	$z_{deadband}$	0	enable input dead band	(0, 1)
hardlimit	$z_{hardlimit}$	1	enable output hard limit	(0, 1)

5.29.2 TGOV1

Group *TurbineGov*

TGOV1 turbine governor model.

Implements the PSS/E TGOV1 model without deadband.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
syn		Synchronous generator idx			mandatory,unique
Tn	T_n	Turbine power rating. Equal to *Sn* if not provided.		*MVA*	
wref0	ω_{ref0}	Base speed reference	1	*p.u.*	
R	R	Speed regulation gain (mach. base default)	0.050	*p.u.*	ipower
VMAX	V_{max}	Maximum valve position	1.200	*p.u.*	power
VMIN	V_{min}	Minimum valve position	0	*p.u.*	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*	
Vn	V_n	Rated voltage from generator	0	*kV*	

Variables (States + Algebraics)

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	*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 under speed	*p.u.*	v_str
pd	P_d	Algeb	Pref plus under speed times gain	*p.u.*	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
tm	τ_m	ExtAlgeb	Mechanical power interface to SynGen		

Variable 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	$\tau_{m0}u$
wref	ω_{ref}	Algeb	ω_{ref0}
pref	P_{ref}	Algeb	$R\tau_{m0}$
wd	ω_{dev}	Algeb	0
pd	P_d	Algeb	$\tau_{m0}u$
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	$D_t \omega_{dev} - P_{out} + y_{LL}$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
pref	P_{ref}	Algeb	$P_{ref0} R - P_{ref}$
wd	ω_{dev}	Algeb	$-\omega - \omega_{dev} + \omega_{ref}$
pd	P_d	Algeb	$Gu \left(P_{aux} + P_{ref} + \omega_{dev}\right) - P_d$
LL_y	y_{LL}	Algeb	$LL_{LT1z1} LL_{LT2z1} \left(- x'_{LL} + y_{LL}\right) + T_2 \left(- x'_{LL} + y_{LAG}\right) + T_3 x'_{LL} - T_3 y_{LL}$
tm	τ_m	ExtAlgeb	$u \left(P_{out} - \tau_{m0}\right)$

Services

Name	Symbol	Equation	Type
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
gain	G	$\frac{u}{R}$	ConstService

Discrete

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	

5.29.3 TGOV1N

Group *TurbineGov*

New TGOV1 (TGOV1N) turbine governor model.

New TGOV1 model with *pref* and *paux* summed after the gain. This model is useful for incorporating AGC and scheduling signals without having to know the droop.

Scheduling changes should write to the *v* fields of *pref0* and *qref0* in place. AGC signal should write to that of *paux0* in place.

Modifying *tm0* is not allowed.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
syn		Synchronous generator idx			mandatory,unique
Tn	T_n	Turbine power rating. Equal to *Sn* if not provided.		*MVA*	
wref0	ω_{ref0}	Base speed reference	1	*p.u.*	
R	R	Speed regulation gain (mach. base default)	0.050	*p.u.*	ipower
VMAX	V_{max}	Maximum valve position	1.200	*p.u.*	power
VMIN	V_{min}	Minimum valve position	0	*p.u.*	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*	
Vn	V_n	Rated voltage from generator	0	*kV*	

Variables (States + Algebraics)

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	*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 under speed	*p.u.*	v_str
pd	P_d	Algeb	Pref plus under speed times gain	*p.u.*	v_str
LL_y	y_{LL}	Algeb	Output of lead-lag		v_str
tm	τ_m	ExtAlgeb	Mechanical power interface to SynGen		

Variable 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	$\tau_{m0} u$
wref	ω_{ref}	Algeb	ω_{ref0}
pref	P_{ref}	Algeb	τ_{m0}
wd	ω_{dev}	Algeb	0
pd	P_d	Algeb	$\tau_{m0} u$
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	$D_t \omega_{dev} - P_{out} + y_{LL}$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
pref	P_{ref}	Algeb	$P_{ref0} - P_{ref}$
wd	ω_{dev}	Algeb	$-\omega - \omega_{dev} + \omega_{ref}$
pd	P_d	Algeb	$-P_d + u\left(G \omega_{dev} + P_{aux} + P_{ref}\right)$
LL_y	y_{LL}	Algeb	$LL_{LT1z1} LL_{LT2z1}\left(-x'_{LL} + y_{LL}\right) + T_2\left(-x'_{LL} + y_{LAG}\right) + T_3 x'_{LL} - T_3 y_{LL}$
tm	τ_m	ExtAlgeb	$u\left(P_{out} - \tau_{m0}\right)$

Services

Name	Symbol	Equation	Type
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
gain	G	$\frac{u}{R}$	ConstService

Discrete

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	

5.29.4 TGOV1DB

Group *TurbineGov*

TGOV1 turbine governor model with speed input deadband.

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
syn		Synchronous generator idx			mandatory,unique
Tn	T_n	Turbine power rating. Equal to *Sn* if not provided.		*MVA*	
wref0	ω_{ref0}	Base speed reference	1	*p.u.*	
R	R	Speed regulation gain (mach. base default)	0.050	*p.u.*	ipower
VMAX	V_{max}	Maximum valve position	1.200	*p.u.*	power
VMIN	V_{min}	Minimum valve position	0	*p.u.*	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	*p.u.*	
dbU	db_U	Upper bound of deadband	0	*p.u.*	
Sg	S_n	Rated power from generator	0	*MVA*	
Vn	V_n	Rated voltage from generator	0	*kV*	

Variables (States + Algebraics)

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	*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 under speed	*p.u.*	v_str
pd	P_d	Algeb	Pref plus under speed times gain	*p.u.*	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		

Variable 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	$\tau_{m0} u$
wref	ω_{ref}	Algeb	ω_{ref0}
pref	P_{ref}	Algeb	$R\tau_{m0}$
wd	ω_{dev}	Algeb	0
pd	P_d	Algeb	$\tau_{m0} u$
LL_y	y_{LL}	Algeb	y_{LAG}
DB_y	y_{DB}	Algeb	$1.0 DB_{dbzl} \left(\omega_{dev} - db_L\right) + 1.0 DB_{dbzu} \left(\omega_{dev} - db_U\right)$
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	$-\omega - \omega_{dev} + \omega_{ref}$
pd	P_d	Algeb	$Gu\left(P_{aux} + P_{ref} + y_{DB}\right) - P_d$
LL_y	y_{LL}	Algeb	$LL_{LT1z1} LL_{LT2z1}\left(-x'_{LL} + y_{LL}\right) + T_2\left(-x'_{LL} + y_{LAG}\right) + T_3 x'_{LL} - T_3 y_{LL}$
DB_y	y_{DB}	Algeb	$1.0 DB_{dbzl}\left(\omega_{dev} - db_L\right) + 1.0 DB_{dbzu}\left(\omega_{dev} - db_U\right) - y_{DB}$
tm	τ_m	ExtAlgeb	$u\left(P_{out} - \tau_{m0}\right)$

Services

Name	Symbol	Equation	Type
pref0	P_{ref0}	τ_{m0}	ConstService
paux0	P_{aux0}	0	ConstService
gain	G	$\frac{u}{R}$	ConstService

Discrete

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 under speed

5.29.5 IEEEG1

Group *TurbineGov*

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 + ... + K8 = 1.0. If the second generator is not connected, K1 + K3 + K5 + K7 = 1, and K2 + K4 + K6 + K8 = 0.

IEEEG1 does not yet support the change of reference (scheduling).

Parameters

Name	Symbol	Description	Default	Unit	Properties
idx		unique device idx			
u	u	connection status	1	*bool*	
name		device name			
syn		Synchronous generator idx			mandatory,unique
Tn	T_n	Turbine power rating. Equal to *Sn* if not provided.		*MVA*	
wref0	ω_{ref0}	Base speed reference	1	*p.u.*	
syn2		Optional SynGen idx			
K	K	Gain (1/R) in mach. base	20	*p.u. (power)*	power
T1	T_1	Gov. lag time const.	1		
T2	T_2	Gov. lead time const.	1		
T3	T_3	Valve controller time const.	0.100		
UO	U_o	Max. valve opening rate	0.100	*p.u./sec*	
UC	U_c	Max. valve closing rate	-0.100	*p.u./sec*	
PMAX	P_{MAX}	Max. turbine power	5		power
PMIN	P_{MIN}	Min. turbine power	0		power
T4	T_4	Inlet piping/steam bowl time constant	0.400		
K1	K_1	Fraction of power from HP	0.500		
K2	K_2	Fraction of power from LP	0		
T5	T_5	Time constant of 2nd boiler pass	8		
K3	K_3	Fraction of HP shaft power after 2nd boiler pass	0.500		
K4	K_4	Fraction of LP shaft power after 2nd boiler pass	0		
T6	T_6	Time constant of 3rd boiler pass	0.500		
K5	K_5	Fraction of HP shaft power after 3rd boiler pass	0		
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*	
Vn	V_n	Rated voltage from generator	0	*kV*	
Sg2	S_{n2}	Rated power of Syn2	0	*MVA*	

Variables (States + Algebraics)

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		

Variable 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	$\tau_{m0}u$
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	$K_1 y_{L4} + K_3 y_{L5} + K_5 y_{L6} + K_7 y_{L7}$
PLP	P_{LP}	Algeb	$K_2 y_{L4} + K_4 y_{L5} + K_6 y_{L6} + K_8 y_{L7}$
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	$P_{HP} - P_{out}$
wref	ω_{ref}	Algeb	$\omega_{ref0} - \omega_{ref}$
wd	ω_{dev}	Algeb	$-\omega - \omega_{dev} + \omega_{ref}$
LL_y	y_{LL}	Algeb	$KT_1 x'_{LL} + KT_2 \left(\omega_{dev} - x'_{LL}\right) + LL_{LT1z1} LL_{LT2z1} \left(-K x'_{LL} + y_{LL}\right) - T_1 y_{LL}$
vs	V_s	Algeb	$-V_s + \frac{P_{aux} + tm_{012} - y_{IAW} + y_{LL}}{T_3}$
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	$K_1 y_{L4} + K_3 y_{L5} + K_5 y_{L6} + K_7 y_{L7} - P_{HP}$
PLP	P_{LP}	Algeb	$K_2 y_{L4} + K_4 y_{L5} + K_6 y_{L6} + K_8 y_{L7} - P_{LP}$
tm	τ_m	ExtAlgeb	$u \left(P_{out} - \tau_{m0}\right)$
tm2	τ_{m2}	ExtAlgeb	$u z_{syn2} \left(P_{LP} - \tau_{m02}\right)$

Services

Name	Symbol	Equation	Type
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
_tm0K2	$_t m0K2$	$\tau_{m0} z_{syn2} \left(K_2 + K_4 + K_6 + K_8\right)$	PostInitService
_tm02K1	$_t m02K1$	$\tau_{m02} \left(K_1 + K_3 + K_5 + K_7\right)$	PostInitService
tm012	$tm012$	$\tau_{m02} + \tau_{m0}$	ConstService

Discrete

Name	Symbol	Type	Info
LL_LT1	LT_{LL}	LessThan	
LL_LT2	LT_{LL}	LessThan	
HL	HL	HardLimiter	Limiter on valve acceleration
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

5.30 Undefined

The undefined group. Holds models with no `group`.

Common Parameters: u, name

CHAPTER 6

Config References

6.1 System

Option	Value	Info	Accepted values
freq	60	base frequency [Hz]	float
mva	100	system base MVA	float
store_z	0	store limiter status in TDS output	(0, 1)
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_protocol	ipc		
dime_address	/tmp/dime2		
dime_port	5000		
numba	0	use numba for JIT compilation	(0, 1)
numba_parallel	0	enable parallel for numba.jit	(0, 1)
save_pycode	0	save generated code to ~/.andes	(0, 1)
yapf_pycode	0	format generated code with yapf	(0, 1)
use_pycode	0	use generated, saved Python code	(0, 1)

6.2 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')
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)

6.3 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)
tol	0.000	convergence tolerance	float
t0	0	simulation starting time	>=0
tf	20	simulation ending time	>t0
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	the initial step step size	float
max_iter	15	maximum number of iterations	>=10
refresh_event	0	refresh events at each step	(0, 1)
g_scale	1	scale algebraic residuals with time step size	positive
qrt	0	quasi-real-time stepping	bool
kqrt	1	quasi-real-time scaling factor; kqrt > 1 means slowing down	positive
store_f	0	store RHS of diff. equations	(0, 1)
store_g	0	store RHS of algebraic equations	(0, 1)

6.4 EIG

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)
plot	0	show plot after computation	(0, 1)

CHAPTER 7

Frequently Asked Questions

7.1 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.

7.2 Modeling

7.2.1 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 `Toggler`. See the example in `cases/kundur/kundur_full.xlsx`. One does not need to manually trigger a Jacobian matrix rebuild because `Toggler` automatically triggers it using the new connectivity status.

CHAPTER 8

Troubleshooting

8.1 Import Errors

8.1.1 ImportError: DLL load failed

Platform: Windows, error message:

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

This usually happens when andes is not installed in a Conda environment but instead in a system-wide Python whose library path was not correctly set in environment variables.

The easiest fix is to install andes in a Conda environment.

8.2 Runtime Errors

8.2.1 EOFError: Ran out of input

The error message looks like

```
Traceback (most recent call last):
  File "/home/user/miniconda3/envs/andes/bin/andes", line 11, in <module>
    load_entry_point('andes', 'console_scripts', 'andes')()
  File "/home/user/repos/andes/andes/cli.py", line 179, in main
    return func(cli=True, **vars(args))
  File "/home/user/repos/andes/andes/main.py", line 514, in run
    system = run_case(cases[0], codegen=codegen, **kwargs)
  File "/home/user/repos/andes/andes/main.py", line 304, in run_case
    system = load(case, codegen=codegen, **kwargs)
```

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```
  File "/home/user/repos/andes/andes/main.py", line 284, in load
    system.undill()
  File "/home/user/repos/andes/andes/system.py", line 980, in undill
    loaded_calls = self._load_pkl()
  File "/home/user/repos/andes/andes/system.py", line 963, in _load_pkl
    loaded_calls = dill.load(f)
  File "/home/user/miniconda3/envs/andes/lib/python3.7/site-packages/dill/_
↪dill.py", line 270, in load
    return Unpickler(file, ignore=ignore, **kwds).load()
  File "/home/user/miniconda3/envs/andes/lib/python3.7/site-packages/dill/_
↪dill.py", line 473, in load
    obj = StockUnpickler.load(self)
EOFError: Ran out of input
```

Resolution:

The error indicates the file for generated code is corrupt or inaccessible. It can be fixed by running `andes prepare` from the command line.

If the issue persists, try removing `~/.andes/calls.pkl` and running `andes prepare` agian.

CHAPTER 9

Miscellaneous

9.1 Notes

9.1.1 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 is applicable to both state or 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 freed 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 complicate 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.gy` 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, 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 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.

9.2 Per Unit System

The bases for AC system are

- S_b^{ac}: three-phase power in MVA. By default, $S_b^{ac} = 100MVA$ (in `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.

9.3 Profiling Import

To speed up the command-line program, import profiling is used to breakdown 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.

CHAPTER 10

Release Notes

The APIs before v3.0.0 are in beta and may change without prior notice.

10.1 v1.2 Notes

10.1.1 v1.2.7

- 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.

10.1.2 v1.2.6 (2020-12-01)

- Added *TGOV1N* 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).

10.1.3 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.

10.1.4 v1.2.4 (2020-11-13)

- Added switched shunt class *ShuntSw*.
- BaseParam takes *inconvert* and *oconvert* for converting parameter elements from and to files.

10.1.5 v1.2.3 (2020-11-02)

- Support variable *sys_mva* (system base mva) in equation strings.
- Default support for KVXOPT through `pip` installation.

10.1.6 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 `kvxopt` as a drop-in replacement for `cvxopt` to bring KLU to Windows (and other platforms).
- Added `kvxopt` as a dependency for PyPI installation.

10.1.7 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.

10.1.8 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`.

10.2 v1.1 Notes

10.2.1 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.

10.2.2 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.

10.2.3 v1.1.3 (2020-09-05)

- Improved documentation.
- Minor bug fixes.

10.2.4 v1.1.2 (2020-09-03)

- Patched time-domain for continuing simulation.

10.2.5 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.

10.2.6 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*.

10.3 v1.0 Notes

10.3.1 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*.

10.3.2 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.

10.3.3 v1.0.6 (2020-07-08)

- Patched step size adjustment algorithm.
- Added Area Control Error (ACE) model.

10.3.4 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.

10.3.5 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.

10.3.6 v1.0.3 (2020-06-02)

- Patches *PQ* model equations where the "or" logic "|" 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.

10.3.7 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.

10.3.8 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.

10.3.9 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.

10.4 Pre-v1.0.0

10.4.1 v0.9.4 (2020-05-20)

- Added exciter models EXST1, ESST3A, ESDC2A, SEXS, and IEEEX1, 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.

10.4.2 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.

10.4.3 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*.

10.4.4 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.

10.4.5 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 IEEEST stabilizer.
- Implemented COI for generator speed and angle measurement.

10.4.6 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 IEEEST stabilizer with some fixes needed.

10.4.7 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 1* for debug output with levels and line numbers.

10.4.8 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;

10.4.9 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.

10.4.10 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.

10.4.11 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.

CHAPTER 11

License

11.1 GNU Public License v3

CHAPTER 12

Subpackages

12.1 andes.core package

12.1.1 Submodules

12.1.2 andes.core.block module

class andes.core.block.**Block**(*name: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = None*, *namespace: str = 'local'*)

Bases: `object`

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
   |
LeadLag A  exports (x, y)
   |
Lag B      exports (x, y)
```

SomeModel instance M contains an instance of LeadLag block named A, which contains an instance of a Lag block named B. Both A and B exports two variables `x` and `y`.

In the code of Model, 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)
        self.vars = {..., 'A': self.A}
```

The `__setattr__` magic of LeadLag takes over the construction and assigns `A_B` to *B.name*, given A's name provided at run time. *self.A* is exported with the internal name `A` at the end.

Again, the LeadLag instance name (*A* in this example) MUST be provided in *SomeModel*'s constructor for the name prepending to work correctly. If there is more than one level of nesting, other than the leaf-level block, all parent blocks' names must be provided at instantiation.

When A is picked up by *SomeModel.__setattr__*, B is captured from A's exports. 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`.

In this way, B's `define()` needs no modification since the naming rule is the same. For example, B's internal y is always `{self.name}_y`, although B has gotten a new name `A_B`.

class_name
Return the class name.

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'
```

static enforce_tex_name(*fields*)
Enforce tex_name is not None

export()
Method for exporting instances defined in this class in a dictionary. This method calls the `define` method first and returns `self.vars`.

Returns

dict Keys are the (last section of the) variable name, and the values are the attribute instance.

f_numeric(***kwargs*)
Function call to update differential equation values.

This function should modify the `e` value of block `State` and `ExtState` in place.

g_numeric(***kwargs*)
Function call to update algebraic equation values.

This function should modify the `e` value of block `Algeb` and `ExtAlgeb` in place.

j_numeric()
This function stores the constant and variable jacobian information in corresponding lists.

Constant jacobians are stored by indices and values in, for example, *ifxc*, *jfxc* and *vfxc*. Value scalars or arrays are stored in *vfxc*.

Variable jacobians are stored by indices and functions. The function shall return the value of the corresponding jacobian elements.

j_reset()
Helper function to clear the lists holding the numerical Jacobians.

This function should be only called once at the beginning of `j_numeric` in blocks.

class andes.core.block.**DeadBand1**(*u*, *center*, *lower*, *upper*, *gain=1.0*, *enable=True*, *name=None*, *tex_name=None*, *info=None*, *namespace='local'*)
Bases: *andes.core.block.Block*

Deadband type 1.

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

```
       |    /
______|__/___    -> Gain -> DeadBand1_y
   /   |
  /    |
```

define()

Notes

Implemented equation:

$$0 = center + z_u * (u - upper) + z_l * (u - lower) - y$$

class andes.core.block.**Gain**(*u*, *K*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.block.Block*

Gain block.

```
      ___
u -> | K | -> y
      ‾‾‾
```

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*, *lower*, *upper*, *no_lower=False*, *no_upper=False*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.block.Block*

Gain followed by a limiter.

Exports the limited output *y*, unlimited output *x*, and HardLimiter *lim*.

```
     _____          upper
    |     |          /-----
u ->|  K  | -> x  /  -> y
    |     |  _____/
    ‾‾‾‾‾‾   lower
```

TODO: Add an extra gain block "R" for y.

Parameters

u [str, BaseVar] Input variable, or an equation string for constructing an anonymous variable

define()
TODO: write docstring

class andes.core.block.**HVGate**(*u1*, *u2*, *name=None*, *tex_name=None*, *info=None*)
Bases: *andes.core.block.Block*

High Value Gate. Outputs the maximum of two inputs.

```
      ________
u1 -> | HV Gate |
      |         | ->  y
u2 -> |  (MAX)  |
      |_________|
```

define()
Implemented equations and initial conditions

$$0 = s_0^{sl} u_1 + s_1^{sl} u_2 - y y_0 = maximum(u_1, u_2)$$

Notes

In the implementation, one should not use

```
self.y.v_str = f'maximum({self.u1.name}, {self.u2.name})',
```

because SymPy processes this equation to *{self.u1.name}*. Not sure if this is a bug or intended.

class andes.core.block.**Integrator**(*u*, *T*, *K*, *y0*, *name=None*, *tex_name=None*, *info=None*)
Bases: *andes.core.block.Block*

Integrator block.

```
     ______
u -> | K/sT | -> y
     |______|
```

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*)

Bases: *andes.core.block.Block*

Integrator block with anti-windup limiter.

```
             upper
           /-----
       ______
u  -> | K/sT | -> y
       ‾‾‾‾‾‾
   _____/
   lower
```

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.**LVGate**(*u1*, *u2*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.block.Block*

Low Value Gate. Outputs the minimum of the two inputs.

```
        _________
u1 -> | LV Gate |
       |         | ->  y
u2 -> |  (MIN)  |
       |_________|
```

define()

Implemented equations and initial conditions

$$0 = s_0^{sl} u_1 + s_1^{sl} u_2 - y y_0 = minimum(u_1, u_2)$$

Notes

Same problem as *HVGate* as *minimum* does not sympify correctly.

class andes.core.block.**Lag**(*u*, *T*, *K*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.block.Block*

Lag (low pass filter) transfer function.

```
        ________
       |        |
       |   K    |
u ->   | ------ |  -> y
       | 1 + sT |
       |________|
```

Exports one state variable *y* as the output.

Parameters

- **K** Gain
- **T** Time constant
- **u** Input variable

define()

Notes

Equations and initial values are

$$T\dot{y} = (Ku - y)$$
$$y^{(0)} = Ku$$

class andes.core.block.**Lag2ndOrd**(*u*, *K*, *T1*, *T2*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.block.Block*

Second order lag transfer function (low-pass filter)

```
        ____________________
       |                    |
       |          K         |
u ->   | ------------------ |  -> y
       | 1 + sT1 + s^2 T2   |
       |____________________|
```

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

$$
\begin{aligned}
T_2 \dot{x} &= Ku - y - T_1 x \\
\dot{y} &= x \\
x^{(0)} &= 0 \\
y^{(0)} &= Ku
\end{aligned}
$$

class andes.core.block.**LagAWFreeze**(*u*, *T*, *K*, *lower*, *upper*, *freeze*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.block.LagAntiWindup*

Lag with anti-windup limiter and state freeze.

The output *y* is a state variable.

define()

Notes

Equations and initial values are

$$
\begin{aligned}
T \dot{y} &= (1 - freeze)(Ku - y) \\
y^{(0)} &= Ku
\end{aligned}
$$

class andes.core.block.**LagAntiWindup**(*u*, *T*, *K*, *lower*, *upper*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.block.Block*

Lag (low pass filter) transfer function block with an anti-windup limiter.

```
               upper
             /------
      ______________
      |     K       |
u ->  | ----------  | -> y
      |   1 + sT    |
      ______________
  _______/
  lower
```

Exports one state variable *y* as the output and one AntiWindup instance *lim*.

Parameters

K Gain

T Time 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, 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*)

Bases: *andes.core.block.Block*

Lag (low pass filter) transfer function block with a rate limiter and an anti-windup limiter.

```
             upper && rate_upper
           /------
      _________
     |    K    |
u -> | ------- | -> y
     | 1 + sT  |
     |_________|
   ______/
   lower & rate_lower
```

Exports one state variable *y* as the output and one AntiWindupRate instance *lim*.

Parameters

K Gain

T Time constant

u Input variable

define()

Notes

Equations and initial values are

$$T\dot{y} = (Ku - y)$$
$$y^{(0)} = Ku$$

class andes.core.block.**LagFreeze**(*u, T, K, freeze, name=None, tex_name=None, info=None*)

Bases: *andes.core.block.Lag*

Lag with a state freeze input.

define()

Notes

Equations and initial values are

$$T\dot{y} = (1 - freeze) * (Ku - y)$$
$$y^{(0)} = Ku$$

class andes.core.block.**LagRate**(*u*, *T*, *K*, *rate_lower*, *rate_upper*, *rate_no_lower=False*, *rate_no_upper=False*, *rate_lower_cond=None*, *rate_upper_cond=None*, *name=None*, *tex_name=None*, *info=None*)

Bases: `andes.core.block.Block`

Lag (low pass filter) transfer function block with a rate limiter and an anti-windup limiter.

```
              rate_upper
            /
         _______
        |  K    |
u ->    | ----- |  -> y
        | 1 + sT|
        |_______
          /
rate_lower
```

Exports one state variable *y* as the output and one AntiWindupRate instance *lim*.

Parameters

K Gain

T Time constant

u Input variable

define()

Notes

Equations and initial values are

$$T\dot{y} = (Ku - y)$$
$$y^{(0)} = Ku$$

class andes.core.block.**LeadLag**(*u*, *T1*, *T2*, *K=1*, *zero_out=True*, *name=None*, *tex_name=None*, *info=None*)

Bases: `andes.core.block.Block`

Lead-Lag transfer function block in series implementation

```
        ______________
       |              |
       |   1 + sT1    |
u ->   | K ________   | -> y
       |   1 + sT2    |
       |______________|
```

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

$$
\begin{aligned}
T_2 \dot{x'} &= (u - x') \\
T_2 y &= K T_1 (u - x') + K T_2 x' + E_2 \text{ , where} \\
E_2 &= \begin{cases} (y - K x') & \text{if } T_1 = T_2 = 0 \& zero\_out = True \\ 0 & \text{otherwise} \end{cases} \\
x'^{(0)} &= u \\
y^{(0)} &= K u
\end{aligned}
$$

class andes.core.block.**LeadLag2ndOrd**(*u*, *T1*, *T2*, *T3*, *T4*, *zero_out=False*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.block.Block*

Second-order lead-lag transfer function block

```
        ___________________
       |                   |
       | 1 + sT3 + s^2 T4  |
u ->   | ________________  | -> y
       | 1 + sT1 + s^2 T2  |
       |___________________|
```

Exports two internal states (*x1* and *x2*) and output algebraic variable *y*.

TODO: instead of implementing *zero_out* using *LessThan* and an additional term, consider correcting all parameters to 1 if all are 0.

define()

Notes

Implemented equations and initial values are

$$
\begin{aligned}
T_2 \dot{x}_1 &= u - x_2 - T_1 x_1 \\
\dot{x}_2 &= x_1 \\
T_2 y &= T_2 x_2 + T_2 T_3 x_1 + T_4 (u - x_2 - T_1 x_1) + E_2 \,, \text{ where} \\
E_2 &= \begin{cases} (y - x_2) & \text{if } T_1 = T_2 = T_3 = T_4 = 0 \& zero\_out = True \\ 0 & \text{otherwise} \end{cases} \\
x_1^{(0)} &= 0 \\
x_2^{(0)} &= y^{(0)} = u
\end{aligned}
$$

class andes.core.block.**LeadLagLimit**(*u*, *T1*, *T2*, *lower*, *upper*, *name=None*, *tex_name=None*, *info=None*)

Bases: `andes.core.block.Block`

Lead-Lag transfer function block with hard limiter (series implementation)

```
          ___________           upper
         |           |           /-----
         | 1 + sT1   |
u ->     | _______   | -> ynl / -> y
         |           |  _____/
         | 1 + sT2   |
         |___________| lower
```

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

$$
\begin{aligned}
T_2 \dot{x'} &= (u - x') \\
T_2 y &= T_1 (u - x') + T_2 x' \\
x'^{(0)} &= y^{(0)} = u
\end{aligned}
$$

class andes.core.block.**LimiterGain**(*u*, *K*, *lower*, *upper*, *no_lower=False*, *no_upper=False*, *sign_lower=1*, *sign_upper=1*, *name=None*, *tex_name=None*, *info=None*)

Bases: `andes.core.block.Block`

Limiter followed by a gain.

Exports the limited output *y*, unlimited output *x*, and HardLimiter *lim*.

```
             upper  _____
             /-----|     |
u  ->       /  ->  |  K  | -> y
    _______/       |     |
    lower          |_____|
```

The intermediate variable before the gain is not saved.

Parameters

u [str, BaseVar] Input variable, or an equation string for constructing an anonymous variable

define()

TODO: write docstring

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*)

Bases: *andes.core.block.PIController*

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

$$\dot{x_i} = k_i * (u - ref)$$
$$y = x_i + k_p * (u - ref)$$

class andes.core.block.**PIController**(*u, kp, ki, ref=0.0, x0=0.0, name=None, tex_name=None, info=None*)

Bases: *andes.core.block.Block*

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

$$\dot{x_i} = k_i * (u - ref)$$
$$y = x_i + k_p * (u - ref)$$

class andes.core.block.**PIControllerNumeric**(*u*, *kp*, *ki*, *ref=0.0*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.block.Block*

A PI Controller implemented with numerical function calls.

ref must not be a variable.

define()

Skip the symbolic definition

f_numeric(***kwargs*)

Function call to update differential equation values.

This function should modify the `e` value of block `State` and `ExtState` in place.

g_numeric(***kwargs*)

Function call to update algebraic equation values.

This function should modify the `e` value of block `Algeb` and `ExtAlgeb` in place.

j_numeric()

This function stores the constant and variable jacobian information in corresponding lists.

Constant jacobians are stored by indices and values in, for example, *ifxc*, *jfxc* and *vfxc*. Value scalars or arrays are stored in *vfxc*.

Variable jacobians are stored by indices and functions. The function shall return the value of the corresponding jacobian elements.

class andes.core.block.**PIFreeze**(*u*, *kp*, *ki*, *freeze*, *ref=0.0*, *x0=0.0*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.block.PIController*

PI controller with state freeze.

Freezes state when the corresponding *freeze == 1*.

Notes

Tested in *experimental.TestPITrackAW.PIFreeze*.

define()

Notes

One state variable `xi` and one algebraic variable `y` are added.

Equations implemented are

$$\dot{x_i} = k_i * (u - ref)$$
$$y = (1 - freeze) * (x_i + k_p * (u - ref)) + freeze * y$$

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*)

Bases: *andes.core.block.Block*

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.**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*)

Bases: *andes.core.block.PITrackAW*

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.**Piecewise**(*u*, *points: Union[List[T], Tuple]*, *funs: Union[List[T], Tuple]*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.block.Block*

Piecewise block. Outputs an algebraic variable *y*.

This block takes a list of *N* points, *[x0, x1, ...x_{n-1}]* to define N+1 ranges, namely (-inf, x0), (x0, x1), ..., (x_{n-1}, +inf). and a list of *N+1* function strings *[fun0, ..., fun_n]*.

Inputs that fall within each range applies the corresponding function. The first range (-inf, x0) applies *fun_0*, and the last range (x_{n-1}, +inf) applies the last function *fun_n*.

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.**Washout**(*u*, *T*, *K*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.block.Block*

Washout filter (high pass) block.

```
        ┌────────┐
        │   sK   │
u   ->  │ ────── │ ->  y
        │ 1 + sT │
        └────────┘
```

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*)

Bases: *andes.core.block.Washout*

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:

$$T\dot{x'} = (u - x')$$
$$Ty = z_0 K(u - x') + z_1 T x$$
$$x'^{(0)} = u$$
$$y^{(0)} = 0$$

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.

12.1.3 andes.core.discrete module

class andes.core.discrete.**AntiWindup**(*u, lower, upper, enable=True, no_lower=False, no_upper=False, sign_lower=1, sign_upper=1, name=None, tex_name=None, info=None, state=None*)

Bases: *andes.core.discrete.Limiter*

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.

check_eq()

Check the variables and equations and set the limiter flags. Reset differential equation values based on limiter flags.

Notes

The current implementation reallocates memory for *self.x_set* in each call. Consider improving for speed. (TODO)

check_var(**args, **kwargs*)

This function is empty. Defers *check_var* to *check_eq*.

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*)

Bases: *andes.core.discrete.AntiWindup*, *andes.core.discrete.RateLimiter*

Anti-windup limiter with rate limits

check_eq()

Check the variables and equations and set the limiter flags. Reset differential equation values based on limiter flags.

Notes

The current implementation reallocates memory for *self.x_set* in each call. Consider improving for speed. (TODO)

class andes.core.discrete.**Average**(*u*, *mode='step'*, *delay=0*, *name=None*, *tex_name=None*, *info=None*)

Bases: `andes.core.discrete.Delay`

Compute the average of a BaseVar over a period of time or a number of samples.

check_var(*dae_t*, **args*, ***kwargs*)

This function is called in `l_update_var` before evaluating equations.

It should update internal flags only.

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*)

Bases: `andes.core.discrete.Limiter`

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'
```

check_var(**args*, ***kwargs*)

Notes

Updates three flags: zi, zu, zl based on the following rules:

zu: 1 if u > upper; 0 otherwise.

zl: 1 if u < lower; 0 otherwise.

zi: not(zu or zl);

class andes.core.discrete.**DeadBandRT**(*u*, *center*, *lower*, *upper*, *enable=True*)

Bases: *andes.core.discrete.DeadBand*

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) + \
                 dbl * db_zlr + \
                 dbu * db_zur - var_out'
```

check_var (**args*, ***kwargs*)

Notes

Updates five flags: zi, zu, zl; zur, and zlr based on the following rules:

zu: 1 if u > upper; 0 otherwise.

zl: 1 if u < lower; 0 otherwise.

zi: not(zu or zl);

zur:

- set to 1 when (previous zu + present zi == 2)
- hold when (previous zi == zi)
- clear otherwise

zlr:

- set to 1 when (previous zl + present zi == 2)
- hold when (previous zi == zi)
- clear otherwise

class andes.core.discrete.**Delay** (*u*, *mode='step'*, *delay=0*, *name=None*, *tex_name=None*, *info=None*)

Bases: `andes.core.discrete.Discrete`

Delay class to memorize past variable values.

Delay allows to impose a predefined "delay" (in either steps or seconds) for an input variable. The amount of delay is a scalar and has to be fixed at model definition in the current implementation.

check_var (*dae_t*, **args*, ***kwargs*)

This function is called in `l_update_var` before evaluating equations.

It should update internal flags only.

list2array(*n*)
Allocate memory for storage arrays.

class andes.core.discrete.**Derivative**(*u*, *name=None*, *tex_name=None*, *info=None*)
Bases: *andes.core.discrete.Delay*

Compute the derivative of an algebraic variable using numerical differentiation.

check_var(*dae_t*, **args*, ***kwargs*)
This function is called in `l_update_var` before evaluating equations.

It should update internal flags only.

class andes.core.discrete.**Discrete**(*name=None*, *tex_name=None*, *info=None*, *no_warn=False*, *min_iter=2*, *err_tol=0.01*)
Bases: `object`

Base discrete class.

Discrete classes export flag arrays (usually boolean) .

check_eq()
This function is called in `l_check_eq` after updating equations.

It updates internal flags, set differential equations, and record pegged variables.

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

check_var(**args*, ***kwargs*)
This function is called in `l_update_var` before evaluating equations.

It should update internal flags only.

class_name

get_names()
Available symbols from this class

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.

get_values()

list2array(*n*)

warn_init_limit()
Warn if initialized at limits.

class andes.core.discrete.**HardLimiter**(*u*, *lower*, *upper*, *enable=True*, *name=None*, *tex_name=None*, *info=None*, *min_iter: int = 2*, *err_tol: float = 0.01*, *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*)

Bases: *andes.core.discrete.Limiter*

Hard limiter for algebraic or differential variable. This class is an alias of *Limiter*.

class andes.core.discrete.**LessThan**(*u*, *bound*, *equal=False*, *enable=True*, *name=None*, *tex_name=None*, *info=None*, *cache=False*, *z0=0*, *z1=1*)

Bases: *andes.core.discrete.Discrete*

Less than (<) comparison function.

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.

check_var(**args*, ***kwargs*)
If enabled, set flags based on inputs. Use cached values if enabled.

class andes.core.discrete.**Limiter**(*u*, *lower*, *upper*, *enable=True*, *name=None*, *tex_name=None*, *info=None*, *min_iter: int = 2*, *err_tol: float = 0.01*, *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*)

Bases: *andes.core.discrete.Discrete*

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 (>= or <=).

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 `zu = zl = 0`, `zi = 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

check_var(**args*, ***kwargs*)
Evaluate the flags.

class andes.core.discrete.**RateLimiter**(*u*, *lower*, *upper*, *enable=True*, *no_lower=False*, *no_upper=False*, *lower_cond=None*, *upper_cond=None*, *name=None*, *tex_name=None*, *info=None*)

Bases: `andes.core.discrete.Discrete`

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 Anti-Windup limiter. Use *AntiWindupRate* for a rate-limited anti-windup limiter.

Notes

RateLimiter inherits from Discrete to avoid internal naming conflicts with *Limiter*.

check_eq()

This function is called in `l_check_eq` after updating equations.

It updates internal flags, set differential equations, and record pegged variables.

class andes.core.discrete.**Sampling**(*u*, *interval=1.0*, *offset=0.0*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.discrete.Discrete*

Sample an input variable repeatedly at a given time interval.

check_var(*dae_t*, **args*, ***kwargs*)

Check and update the output.

Notes

Present output stored in *v*. Output of the last step is stored in *_last_v*. Time for the last output is stored in *_last_t*.

Initially, store *v* and *_last_v*.

If time progresses and *dae_t* is a multiple of *period*, update *_last_v* and then *v*. Record *_last_t*.

If time does not progress, update *v*.

If time rewinds, restore *_last_v* to *v*.

list2array(*n*)

class andes.core.discrete.**Selector**(**args*, *fun*, *tex_name=None*, *info=None*)

Bases: *andes.core.discrete.Discrete*

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.

See also:

numpy.ufunc.reduce NumPy reduce function

andes.core.block.HVGate

andes.core.block.LVGate

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*.

check_var (**args*, ***kwargs*)
Set the i-th variable's flags to 1 if the return of the reduce function equals the i-th input.

class andes.core.discrete.**ShuntAdjust** (***, *v*, *lower*, *upper*, *bsw*, *gsw*, *dt*, *enable=True*, *min_iter=2*, *err_tol=0.01*, *name=None*, *tex_name=None*, *info=None*, *no_warn=False*)

Bases: *andes.core.discrete.Discrete*

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

min_iter [int] Minimum iteration number to enable shunt switching

err_tol [float] Minimum iteration tolerance to enable switching

check_var (*dae_t*, **args*, *niter=None*, *err=None*, ***kwargs*)
Check voltage and perform shunt switching.

Parameters

niter [int or None] Current iteration step

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*, *zu=0.0*, *zl=0.0*, *zi=1.0*, *ql=0.0*, *qu=0.0*)

Bases: `andes.core.discrete.Limiter`

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.

calc_select()

Set *n_select* automatically.

check_var(**args*, *niter=None*, *err=None*, ***kwargs*)

Check for the largest and smallest *n_select* elements.

list2array(*n*)

Initialize maximum and minimum *n_select* based on input size.

class andes.core.discrete.**Switcher**(*u, options: Union[list, Tuple], info: str = None, name: str = None, tex_name: str = None, cache=True*)

Bases: `andes.core.discrete.Discrete`

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 IEEEST 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.

check_var(**args*, ***kwargs*)
Set the switcher flags based on inputs. Uses cached flags if cache is set to True.

list2array(*n*)
This forces to evaluate Switcher upon System setup

12.1.4 andes.core.model module

Base class for building ANDES models.

class andes.core.model.**Documenter**(*parent*)
Bases: `object`

Helper class for documenting models.

Parameters

parent [Model] The *Model* instance to document

get(*max_width=78*, *export='plain'*)
Return the model documentation in table-formatted string.

Parameters

max_width [int] Maximum table width. Automatically et to 0 if format is `rest`.

export [str, ('plain', 'rest')] Export format. Use fancy table if is `rest`.

Returns

str A string with the documentations.

class andes.core.model.**Model**(*system=None*, *config=None*)
Bases: `object`

Base class for power system DAE models.

After subclassing *ModelData*, subclass *Model*' to complete a DAE model. Subclasses of *Model* defines DAE variables, services, and other types of parameters, in the constructor `__init__`.

Notes

To modify parameters or services use `set()`, which writes directly to the given attribute, or `alter()`, which converts parameters to system base like that for input data.

Examples

Take the static PQ as an example, the subclass of *Model*, *PQ*, should looks 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`.

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 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. It 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 variables 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))"

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 implements a piecewise 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

a_reset()

Reset addresses to empty and reset flags.address to `False`.

alter(*src*, *idx*, *value*)

Alter input parameter or service values.

If operates on a parameter, the input should be in the same base as that in the input file. This function will convert the new value to system-base per unit.

Parameters

src [str] The parameter name to alter

idx [str, float, int] The device to alter

value [float] The desired value

class_name

Return the class name

doc(*max_width=78*, *export='plain'*)

Retrieve model documentation as a string.

e_clear()

Clear equation value arrays associated with all internal variables.

f_numeric(***kwargs*)

Custom fcall functions. Modify equations directly.

f_update()

Evaluate differential equations.

Notes

In-place equations: added to the corresponding DAE array. Non-inplace equations: in-place set to internal array to overwrite old values (and avoid clearing).

g_numeric(***kwargs*)

Custom gcall functions. Modify equations directly.

g_update()

Evaluate algebraic equations.

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]`

get_init_order ()
Get variable initialization order and send to *logger.info*.

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 address of arrays changed. After initialization, all array assignments are inplace. 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.

get_md5 ()
Return the md5 hash of concatenated equation strings.

get_times ()
Get event switch_times from *TimerParam*.

Returns

list A list containing all switching times defined in TimerParams

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

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

init_iter()

Solve the initialization equation using the Newton-Krylov method.

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*.

j_update()

Update Jacobian elements.

Values are stored to `Model.triplets[jname]`, where `jname` is a jacobian name.

Returns

None

l_check_eq()

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

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

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 [:]).

numba_jitify(*parallel=False*, *cache=False*)

Optionally convert *self.calls.f* and *self.calls.g* to JIT compiled functions.

This function can be turned on by setting `System.config.numba` to `1`.

> **Warning:** This feature is experimental and does not guarantee a speed up. In fact, the program will likely end up slower due to compilation.

post_init_check()
Post init checking. Warns if values of *InitChecker* is not True.

prepare(*quick=False*)
Symbolic processing and code generation.

refresh_inputs()
This is the helper function to refresh inputs.

The functions collects objects into OrderedDict and store to *self._input* and *self._input_z*.

Returns

None

refresh_inputs_arg()
Refresh inputs for each function with individual argument list.

s_numeric(***kwargs*)
Custom service value functions. Modify `Service.v` directly.

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.

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.

s_update_post()
Update post-initialization services.

s_update_var()
Update VarService.

set(*src*, *idx*, *attr*, *value*)
Set the value of an attribute of a model property.

Performs `self.<src>.<attr>[idx] = value`.

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.

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 has 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.

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*.

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.

v_numeric(***kwargs*)

Custom variable initialization function.

class andes.core.model.**ModelCache**

Bases: `object`

Class for caching the return value of callback functions.

Check `ModelCache.__dict__.keys()` for fields.

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

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

class andes.core.model.**ModelCall**

Bases: `object`

Class for storing generated function calls and Jacobians.

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.

class andes.core.model.**ModelData** (**args*, *three_params=True*, ***kwargs*)

Bases: `object`

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 *GENCLS* should be named *GENCLSData*.

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.

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.

as_df()

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.

as_df_in()

Export all parameters from original input (`vin`) as a *pandas.DataFrame*. This function utilizes *as_dict* for preparing data.

Returns

DataFrame A `pandas.DataFrame` containing all model data. An *uid* column is prepended.

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).

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

find_param(*prop*)

Find params with the given property and return in an OrderedDict.

Parameters

prop [str] Property name

Returns

OrderedDict

class andes.core.model.**SymProcessor**(*parent*)

Bases: `object`

A helper class for symbolic processing and code generation.

Parameters

parent [Model] The *Model* instance to document

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.

non_vars_dict [OrderedDict] symbols in `input_syms` but not in `var_syms`.

generate_equations()

generate_init()
Generate lambda functions for initial values.

generate_jacobians()
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_pretty_print()
Generate pretty print variables and equations.

generate_pycode()
Create output source code file for generated code. NOT WORKING NOW.

generate_services()
Generate calls for services, including `ConstService`, `VarService` among others.

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)

non_vars_dict [OrderedDict] name-symbol pair of all non-variables, namely, (inputs_dict - vars_dict)

12.1.5 andes.core.param module

class andes.core.param.**BaseParam**(*default: Union[float, str, int, None] = None, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, mandatory: bool = False, export: bool = True, iconvert: Optional[Callable] = None, oconvert: Optional[Callable] = None*)

Bases: `object`

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`.

> **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.

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`.

class_name

Return the class name.

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

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.

n

Return the count of elements in the value array.

class andes.core.param.**DataParam**(*default: Union[float, str, int, None] = None, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, mandatory: bool = False, export: bool = True, iconvert: Optional[Callable] = None, oconvert: Optional[Callable] = None*)

Bases: `andes.core.param.BaseParam`

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

class andes.core.param.**ExtParam**(*model: str*, *src: str*, *indexer=None*, *vtype=<class 'float'>*, *allow_none=False*, *default=0.0*, ***kwargs*)

Bases: `andes.core.param.NumParam`

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.

Attributes

parent_model [Model] The parent model providing the original parameter.

add(*value=None*)

ExtParam has an empty *add* method.

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.

restore()

ExtParam has an empty *restore* method

to_array()

Convert to array when d_type is not str

class andes.core.param.**IdxParam**(*default: Union[float, str, int, None] = None*, *name: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = None*, *unit: Optional[str] = None*, *mandatory: bool = False*, *unique: bool = False*, *export: bool = True*, *model: Optional[str] = None*, *iconvert: Optional[Callable] = None*, *oconvert: Optional[Callable] = None*)

Bases: `andes.core.param.BaseParam`

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')
```

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`.

class andes.core.param.**NumParam**(*default: Union[float, str, Callable, None] = None, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, vrange: Union[List[T], Tuple, None] = None, vtype: Optional[Type[CT_co]] = <class 'float'>, iconvert: Optional[Callable] = None, oconvert: Optional[Callable] = 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*)

Bases: *andes.core.param.BaseParam*

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.

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

restore()

Restore parameter to the original input by copying `self.vin` to `self.v`.

pu_coeff will not be overwritten.

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

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.

class andes.core.param.**TimerParam**(*callback: Optional[Callable] = None, default: Union[float, str, Callable, None] = None, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, non_zero: bool = False, mandatory: bool = False, export: bool = True*)

Bases: *`andes.core.param.NumParam`*

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 toggler class *Toggler* takes a parameter *t* for the toggle time. Inside `Toggler.__init__`, one would have

```
self.t = TimerParam()
```

The *Toggler* class also needs to define a method for togging 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 `Toggler.__init__`, assign the function as the callback for *self.t*

```
self.t.callback = self._u_switch
```

is_time(*dae_t*)

Element-wise check if the DAE time is the same as the parameter value. The current implementation uses *np.isclose*

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.

See also:

numpy.isclose See NumPy.isclose for the warning on absolute tolerance

12.1.6 andes.core.service module

class andes.core.service.**ApplyFunc**(*u*, *func*, *name=None*, *tex_name=None*, *info=None*, *cache=True*)

Bases: *andes.core.service.BaseService*

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.

v

class andes.core.service.**BackRef**(***kwargs*)

Bases: *andes.core.service.BaseService*

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.**BaseService**(*name: str = None*, *tex_name: str = None*, *info: str = None*, *vtype: Type[CT_co] = None*)

Bases: `object`

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

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).

class_name

Return the class name

get_names()

Return *name* in a list

Returns

list A list only containing the name of the service variable

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

class andes.core.service.**ConstService**(*v_str: Optional[str] = None*, *v_numeric: Optional[Callable] = None*, *vtype: Optional[type] = None*, *name: Optional[str] = None*, *tex_name=None*, *info=None*)

Bases: *andes.core.service.BaseService*

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*'.

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

Attributes

v [array-like or a scalar] ConstService value

class andes.core.service.**CurrentSign**(*bus*, *bus1*, *bus2*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.service.ConstService*

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*exp(1j*a1) - v2*exp(1j*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(-)
```

check(***kwargs*)

class andes.core.service.**DataSelect**(*optional*, *fallback*, *name: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = None*)

Bases: *andes.core.service.BaseService*

Class for selecting values for optional DataParam or NumParam.

This service is a v-provider that uses optional DataParam if available with a fallback.

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)
```

v

class `andes.core.service.`**`DeviceFinder`**(*u*, *link*, *idx_name*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.service.BaseService*

Service for finding indices of optionally linked devices.

If not provided, *DeviceFinder* will add devices at the beginning of *System.setup*.

Examples

IEEEST stabilizer takes an optional *busf* (IdxParam) for specifying the connected BusFreq, which is needed for mode 6. To avoid reimplementing *BusFreq* within IEEEST, one can do

```
self.busfreq = DeviceFinder(self.busf, link=self.buss, idx_name='bus')
```

where *self.busf* is the optional input, *self.buss* is the bus indices that *busf* should measure, and *idx_name* is the name of a BusFreq parameter through which the measured bus indices are specified. For each *None* values in *self.busf*, a *BusFreq* is created to measure the corresponding bus in *self.buss*.

That is, `BusFreq.[idx_name].v = [link]`. *DeviceFinder* will find / create *BusFreq* devices so that the returned list of *BusFreq* indices are connected to *self.buss*, respectively.

`find_or_add`(*system*)

Find or add devices.

Points *self.u.v* to the found or newly added devices.

Find devices one by one. Devices previously added in this function can be used later without duplication.

v

class andes.core.service.**EventFlag**(*u, vtype: Optional[type] = None, name: Optional[str] = None, tex_name=None, info=None*)

Bases: *andes.core.service.VarService*

Service to flag events.

EventFlag.v stores the values of the input variable from the previous iteration/step.

check(***kwargs*)
Check status and set event flags.

class andes.core.service.**ExtService**(*model: str, src: str, indexer: Union[andes.core.param.BaseParam, andes.core.service.BaseService], attr: str = 'v', allow_none: bool = False, default=0, name: str = None, tex_name: str = None, vtype=None, info: str = None*)

Bases: *andes.core.service.BaseService*

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 GENCLSModel(Model):
    def __init__(...):
        ...
        self.p0 = ExtService(src='p',
                             model='StaticGen',
                             indexer=self.gen,
                             tex_name='P_0')
```

link_external(*ext_model*)
Method to be called by `System` for getting values from the external model or group.

Parameters

ext_model An instance of a model or group provided by System

class andes.core.service.**ExtendedEvent**(*u*, *t_ext: Union[int, float, andes.core.param.BaseParam, andes.core.service.BaseService] = 0.0*, *trig: str = 'rise'*, *enable=True*, *v_disabled=0*, *extend_only=False*, *vtype: Optional[type] = None*, *name: Optional[str] = None*, *tex_name=None*, *info=None*)

Bases: `andes.core.service.VarService`

Service to flag events that extends for period of time after event disappears.

EventFlag.v stores the flags whether the extended time has completed. Outputs will become 1 once then event starts until the extended time ends.

Parameters

trig [str, rise, fall] Triggering edge for the inception 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.

assign_memory(*n*)

Assign memory for internal data.

check(***kwargs*)

Check if an extended event is in place.

Supplied as a `v_numeric` to `VarService`.

class andes.core.service.**FlagCondition**(*u*, *func*, *flag=1*, *name=None*, *tex_name=None*, *info=None*, *cache=True*)

Bases: `andes.core.service.BaseService`

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).

v

class andes.core.service.**FlagGreaterThan**(*u*, *value=0.0*, *flag=1*, *equal=False*, *name=None*, *tex_name=None*, *info=None*, *cache=True*)

Bases: *andes.core.service.FlagCondition*

Service for flagging parameters > or >= the given value element-wise.

Parameters that satisfy the comparison (u > or >= value) will 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*)

Bases: *andes.core.service.FlagCondition*

Service for flagging parameters < or <= the given value element-wise.

Parameters that satisfy the comparison (u < or <= value) will flagged as *flag* (1 by default).

class andes.core.service.**FlagValue**(*u*, *value*, *flag=0*, *name=None*, *tex_name=None*, *info=None*, *cache=True*)

Bases: *andes.core.service.BaseService*

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).

v

class andes.core.service.**IdxRepeat**(*u*, *ref*, ***kwargs*)

Bases: *andes.core.service.OperationService*

Helper class to repeat IdxParam.

This class has the same functionality as *andes.core.service.NumRepeat* but only operates on IdxParam, DataParam or NumParam.

v
Return values stored in *self._v*. May be overloaded by subclasses.

class andes.core.service.**InitChecker**(*u*, *lower=None*, *upper=None*, *equal=None*, *not_equal=None*, *enable=True*, *error_out=False*, ***kwargs*)
Bases: *andes.core.service.OperationService*

Class for checking init values against known typical values.

Instances will be stored in *Model.services_post* and *Model.services_icheck*, 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`.

check()
Check the bounds and equality conditions.

class andes.core.service.**NumReduce**(*u*, *ref: andes.core.service.BackRef*, *fun: Callable*, *name=None*, *tex_name=None*, *info=None*, *cache=True*)
Bases: *andes.core.service.OperationService*

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 `Vn` in one Area. In the `Area` class, one defines

```
class AreaModel(...):
    def __init__(...):
        ...
        # backward reference from `Bus`
        self.Bus = BackRef()

        # collect the Vn 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	Vn
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]`.

v

Return the reduced values from the reduction function in an array

Returns

The array `self._v` storing the reduced values

class andes.core.service.**NumRepeat**(*u*, *ref*, ***kwargs*)

Bases: *andes.core.service.OperationService*

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.

v

Return the values of the repeated values in a sequential 1-D array

Returns

The array, `self._v` storing the repeated values

class andes.core.service.**NumSelect**(*optional*, *fallback*, *name: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = None*)

Bases: *andes.core.service.OperationService*

Class for selecting values for optional NumParam.

NumSelect works with internal and external parameters.

Notes

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)
```

v

Return values stored in *self._v*. May be overloaded by subclasses.

class andes.core.service.**OperationService**(*name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.service.BaseService*

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

v

Return values stored in *self._v*. May be overloaded by subclasses.

class andes.core.service.**ParamCalc**(*param1*, *param2*, *func*, *name=None*, *tex_name=None*, *info=None*, *cache=True*)

Bases: *andes.core.service.BaseService*

Parameter calculation service.

Useful to create parameters calculated instantly from existing ones.

v

class andes.core.service.**PostInitService**(*v_str: Optional[str] = None, v_numeric: Optional[Callable] = None, vtype: Optional[type] = None, name: Optional[str] = None, tex_name=None, info=None*)

Bases: *andes.core.service.ConstService*

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 *vf* variable is initialized followed by other variables. One can store the initial *vf* into *vf0* so that equation `vf - vf0 = 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 *vf0*, in order to correctly initialize *vf*.

class andes.core.service.**RandomService**(*func=<built-in method rand of numpy.random.mtrand.RandomState object>, **kwargs*)

Bases: *andes.core.service.BaseService*

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.

v

This class has *v* wrapped by a property decorator.

Returns

array-like Randomly generated service variables

class andes.core.service.**RefFlatten**(*ref*, ***kwargs*)

Bases: *andes.core.service.OperationService*

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,
                  )
```

v

Return values stored in *self._v*. May be overloaded by subclasses.

class andes.core.service.**Replace**(*old_val*, *flt*, *new_val*, *name=None*, *tex_name=None*, *info=None*, *cache=True*)

Bases: *andes.core.service.BaseService*

Replace parameters with new values if the function returns True

v

class andes.core.service.**SwBlock**(***, *init*, *ns*, *blocks*, *ext_sel=None*, *name=None*, *tex_name=None*, *info=None*)

Bases: *andes.core.service.OperationService*

Service type for switched shunt blocks.

adjust(*amount*)

Adjust capacitor banks by an amount.

check_data()

Check data consistency.

find_sel()

Determine the initial shunt selection level.

set_v()

Set values to *_v* based on *sel*.

v
Return values stored in *self._v*. May be overloaded by subclasses.

class andes.core.service.**VarHold**(*u*, *hold*, *vtype=None*, *name=None*, *tex_name=None*, *info=None*)
Bases: *andes.core.service.VarService*

Service for holding the input when the hold state is on.

check(***kwargs*)

class andes.core.service.**VarService**(*v_str: Optional[str] = None*, *v_numeric: Optional[Callable] = None*, *vtype: Optional[type] = None*, *name: Optional[str] = None*, *tex_name=None*, *info=None*)
Bases: *andes.core.service.ConstService*

Variable service that gets updated in each step/loop as variables change.

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.

> **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 (vd + jvq), (Id + jIq) 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))',
    )
```

12.1.7 andes.core.solver module

Sparse solvers wrapper.

class andes.core.solver.**CuPySolver**
Bases: *andes.core.solver.SciPySolver*

CuPy lsqr solver (GPU-based).

solve(*A*, *b*)
Solve linear systems.

Parameters

A [scipy.csc_matrix] Sparse N-by-N matrix

b [numpy.ndarray] Dense 1-dimensional array of size N

Returns

np.ndarray Solution x to $Ax = b$

class andes.core.solver.**KLUSolver**
Bases: *andes.core.solver.SuiteSparseSolver*

KLU solver.

Requires package `kvxoptklu`.

linsolve(*A*, *b*)
Solve linear equation set `Ax = b` and returns the solutions in a 1-D array.

This function performs both symbolic and numeric factorizations every time, and can be slower than `Solver.solve`.

Parameters

A Sparse matrix

b RHS of the equation

Returns

The solution in a 1-D np array.

class andes.core.solver.**SciPySolver**
Bases: `object`

Base class for scipy family solvers.

clear()

linsolve(*A*, *b*)
Exactly same functionality as *solve*.

solve(*A*, *b*)
Solve linear systems.

Parameters

A [scipy.csc_matrix] Sparse N-by-N matrix

b [numpy.ndarray] Dense 1-dimensional array of size N

Returns

np.ndarray Solution x to $Ax = b$

to_csc(*A*)
Convert A to scipy.sparse.csc_matrix.

Parameters

A [kvxopt.spmatrix] Sparse N-by-N matrix

Returns

scipy.sparse.csc_matrix Converted csc_matrix

class andes.core.solver.**Solver**(*sparselib='umfpack'*)

Bases: object

Sparse matrix solver class.

This class wraps UMFPACK, KLU, SciPy and CuPy solvers to provide an unified interface for solving sparse linear equations `Ax = b`.

Provides methods `solve`, `linsolve` and `clear`.

clear()

Remove all cached objects.

linsolve(*A*, *b*)

Solve linear equations without caching facorization. Performs full factorization each call.

Parameters

A [kvxopt.spmatrix] Sparse N-by-N matrix

b [kvxopt.matrix or numpy.ndarray] Dense N-by-1 matrix

Returns

numpy.ndarray Dense N-by-1 array

solve(*A*, *b*)

Solve linear equations and cache factorizations if possible.

Parameters

A [kvxopt.spmatrix] Sparse N-by-N matrix

b [kvxopt.matrix or numpy.ndarray] Dense N-by-1 matrix

Returns

numpy.ndarray Dense N-by-1 array

class andes.core.solver.**SpSolve**

Bases: *andes.core.solver.SciPySolver*

scipy.sparse.linalg.spsolve Solver.

solve(*A*, *b*)

Solve linear systems.

Parameters

A [scipy.csc_matrix] Sparse N-by-N matrix

b [numpy.ndarray] Dense 1-dimensional array of size N

Returns

np.ndarray Solution x to $Ax = b$

class andes.core.solver.**SuiteSparseSolver**

Bases: `object`

Base SuiteSparse solver interface.

Need to be derived by specific solvers such as UMFPACK or KLU.

clear()

Remove all cached PyCapsule of C objects

linsolve(*A*, *b*)

Solve linear equation set `Ax = b` and returns the solutions in a 1-D array.

This function performs both symbolic and numeric factorizations every time, and can be slower than `Solver.solve`.

Parameters

A Sparse matrix

b RHS of the equation

Returns

The solution in a 1-D np array.

solve(*A*, *b*)

Solve linear system `Ax = b` using numeric factorization `N` and symbolic factorization `F`. Store the solution in `b`.

This function caches the symbolic factorization in `self.F` and is faster in general. Will attempt `Solver.linsolve` if the cached symbolic factorization is invalid.

Parameters

A Sparse matrix for the equation set coefficients.

F The symbolic factorization of A or a matrix with the same non-zero shape as `A`.

N Numeric factorization of A.

b RHS of the equation.

Returns

numpy.ndarray The solution in a 1-D ndarray

class andes.core.solver.**UMFPACKSolver**

Bases: *andes.core.solver.SuiteSparseSolver*

UMFPACK solver.

Utilizes `kvxopt.umfpack` for factorization.

linsolve(*A*, *b*)

Solve linear equation set `Ax = b` and returns the solutions in a 1-D array.

This function performs both symbolic and numeric factorizations every time, and can be slower than `Solver.solve`.

Parameters

A Sparse matrix

b RHS of the equation

Returns

The solution in a 1-D np array.

12.1.8 andes.core.common module

class andes.core.common.**Config**(*name*, *dct=None*, ***kwargs*)

Bases: `object`

A class for storing system, model and routine configurations.

add(*dct=None*, ***kwargs*)

Add config fields from a dictionary or keyword args.

Existing configs will NOT be overwritten.

add_extra(*dest*, *dct=None*, ***kwargs*)

Add extra contents for config.

Parameters

dest [str] Destination string in *_alt*, *_help* or *_tex*.

dct [OrderedDict, dict] key: value pairs

as_dict(*refresh=False*)

Return the config fields and values in an `OrderedDict`.

Values are cached in *self._dict* unless refreshed.

check()

Check the validity of config values.

doc(*max_width=78*, *export='plain'*, *target=False*, *symbol=True*)

load(*config*)

Load from a ConfigParser object, `config`.

tex_names

class andes.core.common.**DummyValue**(*value*)

Bases: `object`

Class for converting a scalar value to a dummy parameter with *name* and *tex_name* fields.

A DummyValue object can be passed to Block, which utilizes the *name* field to dynamically generate equations.

Notes

Pass a numerical value to the constructor for most use cases, especially when passing as a v-provider.

class andes.core.common.**JacTriplet**

Bases: `object`

Storage class for Jacobian triplet lists.

append_ijv(*j_full_name*, *ii*, *jj*, *vv*)

Append triplets to the given sparse matrix triplets.

Parameters

j_full_name [str] Full name of the sparse Jacobian. If is a constant Jacobian, append 'c' to the Jacobian name.

ii [array-like] Row indices

jj [array-like] Column indices

vv [array-like] Value indices

clear_ijv()

Clear stored triplets for all sparse Jacobian matrices

ijv(*j_full_name*)

Return triplet lists in a tuple in the order or (ii, jj, vv)

merge(*triplet*)

Merge another triplet into this one.

zip_ijv(*j_full_name*)

Return a zip iterator in the order of (ii, jj, vv)

class andes.core.common.**ModelFlags**(*collate=False*, *pflow=False*, *tds=False*, *pflow_init=None*, *tds_init=None*, *series=False*, *nr_iter=False*, *f_num=False*, *g_num=False*, *j_num=False*, *s_num=False*, *sv_num=False*)

Bases: `object`

Model flags.

Parameters

collate [bool] True: collate variables by device; False: by variable. Non-collate (continuous memory) has faster computation speed.

pflow [bool] True: called during power flow

tds [bool] True if called during tds; if is False, `dae_t` cannot be used

pflow_init [bool or None] True if initialize pflow; False otherwise; None default to *pflow*

tds_init [bool or None] True if initialize tds; False otherwise; None default to *tds*

series [bool] True if is series device

nr_iter [bool] True if is series device

f_num [bool] True if the model defines *f_numeric*

g_num [bool] True if the model defines *g_numeric*

j_num [bool] True if the model defines *j_numeric*

s_num [bool] True if the model defines *s_numeric*

sv_num [bool] True if the model defines *s_numeric_var*

jited [bool] True if numba JIT code is generated

update(*dct*)

andes.core.common.**dummify**(*param*)

Dummify scalar parameter and return a DummyValue object. Do nothing for BaseParam instances.

Parameters

param [float, int, str, BaseParam] parameter object or scalar value

Returns

DummyValue(param) if param is a scalar; param itself, otherwise.

12.1.9 andes.core.var module

class andes.core.var.**Algeb**(*name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, v_str: Union[str, float, None] = None, v_iter: Optional[str] = None, e_str: Optional[str] = None, discrete: Optional[andes.core.discrete.Discrete] = None, v_setter: Optional[bool] = False, e_setter: Optional[bool] = False, addressable: Optional[bool] = True, export: Optional[bool] = True, diag_eps: Optional[float] = 0.0*)

Bases: *andes.core.var.BaseVar*

Algebraic variable class, an alias of the *BaseVar*.

Attributes

e_code [str] Equation code string, equals string literal `g`

v_code [str] Variable code string, equals string literal `y`

e_code = 'g'

v_code = 'y'

class andes.core.var.**AliasAlgeb**(*var, **kwargs*)

Bases: *andes.core.var.ExtAlgeb*

Alias algebraic variable. Essentially `ExtAlgeb` that links to a 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.

class andes.core.var.**AliasState**(*var*, ***kwargs*)

Bases: *andes.core.var.ExtState*

Alias state variable.

Refer to the docs of `AliasAlgeb`.

class andes.core.var.**BaseVar**(*name: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = None*, *unit: Optional[str] = None*, *v_str: Union[str, float, None] = None*, *v_iter: Optional[str] = None*, *e_str: Optional[str] = None*, *discrete: Optional[andes.core.discrete.Discrete] = None*, *v_setter: Optional[bool] = False*, *e_setter: Optional[bool] = False*, *addressable: Optional[bool] = True*, *export: Optional[bool] = True*, *diag_eps: Optional[float] = 0.0*)

Bases: `object`

Base variable class.

Derived classes *State* and *Algeb* should be used to build model variables.

Parameters

name [str, optional] Variable name

info [str, optional] Descriptive information

unit [str, optional] Unit

tex_name [str] LaTeX-formatted variable name. If is None, use *name* instead.

discrete [Discrete] Associated discrete component. Will call *check_var* on the discrete component.

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

class_name

get_names()

reset()

Reset the internal numpy arrays and flags.

set_address(*addr: numpy.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

set_arrays(*dae*)
Set the equation and values arrays.

It slicing into DAE (when contiguous) or allocating new memory (when not contiguous).

Parameters

dae [DAE] Reference to System.dae

class andes.core.var.**ExtAlgeb**(*model: str, src: str, indexer: Union[List[T], numpy.ndarray, andes.core.param.BaseParam, andes.core.service.BaseService, None] = None, allow_none: Optional[bool] = False, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, v_str: Union[str, float, None] = None, v_iter: Optional[str] = None, e_str: Optional[str] = None, v_setter: Optional[bool] = False, e_setter: Optional[bool] = False, addressable: Optional[bool] = True, export: Optional[bool] = True, diag_eps: Optional[float] = 0.0*)

Bases: *andes.core.var.ExtVar*

External algebraic variable type.

e_code = 'g'

v_code = 'y'

class andes.core.var.**ExtState**(*model: str, src: str, indexer: Union[List[T], numpy.ndarray, andes.core.param.BaseParam, andes.core.service.BaseService, None] = None, allow_none: Optional[bool] = False, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, v_str: Union[str, float, None] = None, v_iter: Optional[str] = None, e_str: Optional[str] = None, v_setter: Optional[bool] = False, e_setter: Optional[bool] = False, addressable: Optional[bool] = True, export: Optional[bool] = True, diag_eps: Optional[float] = 0.0*)

Bases: *andes.core.var.ExtVar*

External state variable type.

> **Warning:** `ExtState` is not allowed to set `t_const`, as it will conflict with the source `State` variable. In fact, one should not set `e_str` for `ExtState`.

e_code = 'f'

t_const = None

v_code = 'x'

class andes.core.var.**ExtVar**(*model: str, src: str, indexer: Union[List[T], numpy.ndarray, andes.core.param.BaseParam, andes.core.service.BaseService, None] = None, allow_none: Optional[bool] = False, name: Optional[str] = None, tex_name: Optional[str] = None, info: Optional[str] = None, unit: Optional[str] = None, v_str: Union[str, float, None] = None, v_iter: Optional[str] = None, e_str: Optional[str] = None, v_setter: Optional[bool] = False, e_setter: Optional[bool] = False, addressable: Optional[bool] = True, export: Optional[bool] = True, diag_eps: Optional[float] = 0.0*)

Bases: *andes.core.var.BaseVar*

Externally defined algebraic variable

This class is used to retrieve the addresses of externally- defined variable. The *e* value of the *ExtVar* will be added to the corresponding address in the DAE equation.

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] True to allow None in indexer

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.

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.

set_address (*addr*, *contiguous=False*)
Empty function.

set_arrays (*dae*)
Empty function.

class andes.core.var.**State** (*name: Optional[str] = None*, *tex_name: Optional[str] = None*, *info: Optional[str] = None*, *unit: Optional[str] = None*, *v_str: Union[str, float, None] = None*, *v_iter: Optional[str] = None*, *e_str: Optional[str] = None*, *discrete: Optional[andes.core.discrete.Discrete] = None*, *t_const: Union[andes.core.param.BaseParam, andes.core.common.DummyValue, andes.core.service.BaseService, None] = None*, *v_setter: Optional[bool] = False*, *e_setter: Optional[bool] = False*, *addressable: Optional[bool] = True*, *export: Optional[bool] = True*, *diag_eps: Optional[float] = 0.0*)

Bases: `andes.core.var.BaseVar`

Differential variable class, an alias of the *BaseVar*.

Parameters

t_const [BaseParam, DummyValue] Left-hand time constant for the differential equation. Time constants will not be evaluated as part of the differential equation. They will be collected to array *dae.Tf* to multiply to the right-hand side *dae.f*.

Attributes

e_code [str] Equation code string, equals string literal `f`

v_code [str] Variable code string, equals string literal `x`

e_code = 'f'

v_code = 'x'

12.1.10 Module contents

Import subpackage classes

12.2 andes.io package

12.2.1 Submodules

12.2.2 andes.io.matpower module

Simple MATPOWER format parser

andes.io.matpower.**read**(*system*, *file*)
Read a MATPOWER data file into mpc and build andes device elements

andes.io.matpower.**testlines**(*fid*)

12.2.3 andes.io.psse module

PSS/E file parser.

Include a RAW parser and a DYR parser.

andes.io.psse.**get_block_lines**(*b*, *mdata*)
Return the number of lines based on data

andes.io.psse.**read**(*system*, *file*)
read PSS/E RAW file v32 format

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

andes.io.psse.**sort_psse_models**(*dyr_yaml*)
Sort supported models so that model names are ordered by dependency.

andes.io.psse.**testlines**(*fid*)
Check the raw file for frequency base

12.2.4 andes.io.txt module

andes.io.txt.**dump_data**(*text*, *header*, *rowname*, *data*, *file*, *width=14*, *precision=5*)

12.2.5 andes.io.xlsx module

Excel reader and writer for ANDES power system parameters

This module utilizes xlsxwriter and pandas.Frame. While I like the simplicity of the dome format, spreadsheet data is easier to read and edit.

`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] Path to the input file

Returns

System System instance after succeeded

`andes.io.xlsx.testlines`(*fid*)

`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

12.2.6 Module contents

`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.

andes.io.**get_output_ext**(*out_format*)

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

andes.io.**parse**(*system*)

Parse input file with the given format in *system.files.input_format*.

Returns

bool True if successful; False otherwise.

12.3 andes.models package

12.3.1 Submodules

12.3.2 andes.models.area module

class andes.models.area.**ACE**(*system*, *config*)

Bases: *andes.models.area.ACEc*

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*.

class andes.models.area.**ACEData**

Bases: *andes.core.model.ModelData*

Area Control Error data

class andes.models.area.**ACEc**(*system*, *config*)

Bases: *andes.models.area.ACEData*, *andes.core.model.Model*

Area Control Error model.

Continuous frequency sampling. System base frequency from `system.config.freq` is used.

Note: area idx is automatically retrieved from *bus*.

class andes.models.area.**Area**(*system*, *config*)

Bases: *andes.models.area.AreaData*, *andes.core.model.Model*

Area model.

Area collects back references from the Bus model and the ACTopology group.

bus_table()

Return a formatted table with area idx and bus idx correspondence

Returns

str Formatted table

class andes.models.area.**AreaData**

Bases: *andes.core.model.ModelData*

12.3.3 andes.models.bus module

class andes.models.bus.**Bus**(*system=None*, *config=None*)

Bases: *andes.core.model.Model*, *andes.models.bus.BusData*

AC Bus model.

Power balance equation have the form of `load - injection = 0`. Namely, load is positively summed, while injections are negative.

class andes.models.bus.**BusData**

Bases: *andes.core.model.ModelData*

Class for Bus data

12.3.4 andes.models.governor module

class andes.models.governor.**IEEEG1**(*system*, *config*)

Bases: *andes.models.governor.IEEEG1Data*, *andes.models.governor.IEEEG1Model*

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 + ... + K8 = 1.0. If the second generator is not connected, K1 + K3 + K5 + K7 = 1, and K2 + K4 + K6 + K8 = 0.

IEEEG1 does not yet support the change of reference (scheduling).

class andes.models.governor.**IEEEG1Data**
Bases: *andes.models.governor.TGBaseData*

class andes.models.governor.**IEEEG1Model**(*system*, *config*)
Bases: *andes.models.governor.TGBase*

class andes.models.governor.**TG2**(*system*, *config*)
Bases: *andes.models.governor.TG2Data*, *andes.models.governor.TGBase*

class andes.models.governor.**TG2Data**
Bases: *andes.models.governor.TGBaseData*

class andes.models.governor.**TGBase**(*system*, *config*, *add_sn=True*, *add_tm0=True*)
Bases: *andes.core.model.Model*

Base Turbine Governor model.

Parameters

add_sn [bool] True to add `NumSelect` Sn; False to add later in custom models. This is useful when the governor connects to two generators.

add_tm0 [bool] True to add `ExtService` `tm0`.

class andes.models.governor.**TGBaseData**
Bases: *andes.core.model.ModelData*

Base data for turbine governors.

class andes.models.governor.**TGOV1**(*system*, *config*)
Bases: *andes.models.governor.TGOV1Data*, *andes.models.governor.TGOV1Model*

TGOV1 turbine governor model.

Implements the PSS/E TGOV1 model without deadband.

class andes.models.governor.**TGOV1DB**(*system*, *config*)
Bases: *andes.models.governor.TGOV1DBData*, *andes.models.governor.TGOV1DBModel*

TGOV1 turbine governor model with speed input deadband.

class andes.models.governor.**TGOV1DBData**
Bases: *andes.models.governor.TGOV1Data*

class andes.models.governor.**TGOV1DBModel**(*system*, *config*)
Bases: *andes.models.governor.TGOV1Model*

class andes.models.governor.**TGOV1Data**
Bases: *andes.models.governor.TGBaseData*

class andes.models.governor.**TGOV1Model**(*system*, *config*)
Bases: *andes.models.governor.TGBase*

class andes.models.governor.**TGOV1ModelAlt**(*system*, *config*)
Bases: *andes.models.governor.TGBase*

An alternative implementation of TGOV1 from equations (without using Blocks).

class andes.models.governor.**TGOV1N**(*system*, *config*)
Bases: *andes.models.governor.TGOV1Data*, *andes.models.governor.TGOV1NModel*

New TGOV1 (TGOV1N) turbine governor model.

New TGOV1 model with *pref* and *paux* summed after the gain. This model is useful for incorporating AGC and scheduling signals without having to know the droop.

Scheduling changes should write to the *v* fields of *pref0* and *qref0* in place. AGC signal should write to that of *paux0* in place.

Modifying *tm0* is not allowed.

class andes.models.governor.**TGOV1NModel**(*system*, *config*)
Bases: *andes.models.governor.TGOV1Model*

New TGOV1 model with *pref* and *paux* summed after the gain.

12.3.5 andes.models.group module

class andes.models.group.**ACLine**
Bases: *andes.models.group.GroupBase*

class andes.models.group.**ACTopology**
Bases: *andes.models.group.GroupBase*

class andes.models.group.**Calculation**
Bases: *andes.models.group.GroupBase*

Group of classes that calculates based on other models.

class andes.models.group.**Collection**
Bases: *andes.models.group.GroupBase*

Collection of topology models

class andes.models.group.**DCLink**
Bases: *andes.models.group.GroupBase*

Basic DC links

class andes.models.group.**DCTopology**
Bases: *andes.models.group.GroupBase*

class andes.models.group.**DG**
Bases: *andes.models.group.GroupBase*

Distributed generation (small-scale).

class andes.models.group.**DynLoad**
Bases: *andes.models.group.GroupBase*

Dynamic load group.

class andes.models.group.**Exciter**
Bases: *andes.models.group.GroupBase*

Exciter group for synchronous generators.

class andes.models.group.**Experimental**
Bases: *andes.models.group.GroupBase*

Experimental group

class andes.models.group.**FreqMeasurement**
Bases: *andes.models.group.GroupBase*

Frequency measurements.

class andes.models.group.**GroupBase**
Bases: object

Base class for groups.

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

add_model(*name: str*, *instance*)
Add a Model instance to group.

Parameters

name [str] Model name

instance [Model] Model instance

Returns

None

class_name

doc(*export='plain'*)
Return the documentation of the group in a string.

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

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.

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.

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.

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.

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

n

Total number of devices.

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.

class andes.models.group.**Information**

Bases: *andes.models.group.GroupBase*

Group for information container models.

class andes.models.group.**Motor**

Bases: *andes.models.group.GroupBase*

Induction Motor group

class andes.models.group.**PSS**

Bases: *andes.models.group.GroupBase*

Power system stabilizer group.

class andes.models.group.**PhasorMeasurement**

Bases: *andes.models.group.GroupBase*

Phasor measurements

class andes.models.group.**RenAerodynamics**

Bases: *andes.models.group.GroupBase*

Renewable aerodynamics group.

class andes.models.group.**RenExciter**

Bases: *andes.models.group.GroupBase*

Renewable electrical control (exciter) group.

class andes.models.group.**RenGen**

Bases: *andes.models.group.GroupBase*

Renewable generator (converter) group.

class andes.models.group.**RenGovernor**
Bases: *andes.models.group.GroupBase*

Renewable turbine governor group.

class andes.models.group.**RenPitch**
Bases: *andes.models.group.GroupBase*

Renewable generator pitch controller group.

class andes.models.group.**RenPlant**
Bases: *andes.models.group.GroupBase*

Renewable plant control group.

class andes.models.group.**RenTorque**
Bases: *andes.models.group.GroupBase*

Renewable torque (Pref) controller.

class andes.models.group.**StaticACDC**
Bases: *andes.models.group.GroupBase*

AC DC device for power flow

class andes.models.group.**StaticGen**
Bases: *andes.models.group.GroupBase*

Static generator group for power flow calculation

class andes.models.group.**StaticLoad**
Bases: *andes.models.group.GroupBase*

Static load group.

class andes.models.group.**StaticShunt**
Bases: *andes.models.group.GroupBase*

Static shunt compensator group.

class andes.models.group.**SynGen**
Bases: *andes.models.group.GroupBase*

Synchronous generator group.

class andes.models.group.**TimedEvent**
Bases: *andes.models.group.GroupBase*

Timed event group

class andes.models.group.**TurbineGov**
Bases: *andes.models.group.GroupBase*

Turbine governor group for synchronous generator.

class andes.models.group.**Undefined**
Bases: *andes.models.group.GroupBase*

The undefined group. Holds models with no `group`.

12.3.6 andes.models.line module

class andes.models.line.**Line**(*system=None*, *config=None*)

Bases: *andes.models.line.LineData*, *andes.core.model.Model*

AC transmission line model.

To reduce the number of variables, line injections are summed at bus equations and are not stored. Current injections are not computed.

class andes.models.line.**LineData**

Bases: *andes.core.model.ModelData*

12.3.7 andes.models.pq module

class andes.models.pq.**PQ**(*system=None*, *config=None*)

Bases: *andes.models.pq.PQData*, *andes.core.model.Model*

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).

class andes.models.pq.**PQData**

Bases: *andes.core.model.ModelData*

12.3.8 andes.models.pv module

class andes.models.pv.**PV**(*system=None*, *config=None*)

Bases: *andes.models.pv.PVData*, *andes.models.pv.PVModel*

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.

class andes.models.pv.**PVData**

Bases: *andes.core.model.ModelData*

class andes.models.pv.**PVModel**(*system=None*, *config=None*)
Bases: *andes.core.model.Model*

PV generator model (power flow) with q limit and PV-PQ conversion.

class andes.models.pv.**Slack**(*system=None*, *config=None*)
Bases: *andes.models.pv.SlackData*, *andes.models.pv.PVModel*

Slack generator.

class andes.models.pv.**SlackData**
Bases: *andes.models.pv.PVData*

12.3.9 andes.models.shunt module

class andes.models.shunt.**Shunt**(*system=None*, *config=None*)
Bases: *andes.models.shunt.ShuntData*, *andes.models.shunt.ShuntModel*

Static Shunt Model.

class andes.models.shunt.**ShuntData**(*system=None*, *name=None*)
Bases: *andes.core.model.ModelData*

class andes.models.shunt.**ShuntModel**(*system=None*, *config=None*)
Bases: *andes.core.model.Model*

Shunt equations.

class andes.models.shunt.**ShuntSw**(*system=None*, *config=None*)
Bases: *andes.models.shunt.ShuntSwData*, *andes.models.shunt.ShuntSwModel*

Switched Shunt Model.

Parameters *gs*, *bs* and *bs* 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*.

class andes.models.shunt.**ShuntSwData**
Bases: *andes.models.shunt.ShuntData*

Data for switched shunts.

class andes.models.shunt.**ShuntSwModel**(*system*, *config*)
Bases: *andes.models.shunt.ShuntModel*

Switched shunt model.

andes.models.shunt.**list_iconv**(*x*)
Helper function to convert a list literal into a numpy array.

andes.models.shunt.**list_oconv**(*x*)
Convert list into a list literal.

12.3.10 andes.models.synchronous module

Synchronous generator classes

class andes.models.synchronous.**Flux0**
Bases: object

Flux model without electro-magnetic transients and ignore speed deviation

class andes.models.synchronous.**Flux1**
Bases: object

Flux model without electro-magnetic transients but considers speed deviation.

class andes.models.synchronous.**Flux2**
Bases: object

Flux model with electro-magnetic transients.

class andes.models.synchronous.**GENBase**(*system, config*)
Bases: *andes.core.model.Model*

v_numeric(***kwargs*)
Custom variable initialization function.

class andes.models.synchronous.**GENBaseData**
Bases: *andes.core.model.ModelData*

class andes.models.synchronous.**GENCLS**(*system, config*)
Bases: *andes.models.synchronous.GENBaseData*, *andes.models.synchronous.GENBase*, *andes.models.synchronous.GENCLSModel*, *andes.models.synchronous.Flux0*

class andes.models.synchronous.**GENCLSModel**
Bases: object

class andes.models.synchronous.**GENROU**(*system, config*)
Bases: *andes.models.synchronous.GENROUData*, *andes.models.synchronous.GENBase*, *andes.models.synchronous.GENROUModel*, *andes.models.synchronous.Flux0*

Round rotor generator with quadratic saturation

class andes.models.synchronous.**GENROUData**
Bases: *andes.models.synchronous.GENBaseData*

class andes.models.synchronous.**GENROUModel**
Bases: object

12.3.11 andes.models.timer module

class andes.models.timer.**Alter**(*system*, *config*)

Bases: *andes.models.timer.AlterData*, *andes.models.timer.AlterModel*

Model for altering device internal data (service or param) at a given time.

class andes.models.timer.**AlterData**

Bases: *andes.core.model.ModelData*

Data for Alter, which altera values of the given device at a certain time.

Alter can be used in various timed applications, such as applying load changing, tap changing, step response, etc.

class andes.models.timer.**AlterModel**(*system*, *config*)

Bases: *andes.core.model.Model*

class andes.models.timer.**Fault**(*system*, *config*)

Bases: *andes.core.model.ModelData*, *andes.core.model.Model*

Three-phase to ground fault.

Two times, *tf* and *tc*, can be defined for fault on for fault clearance.

apply_fault(*is_time: numpy.ndarray*)

Apply fault and store pre-fault algebraic variables (voltages and other algebs) to *self._vstore*.

clear_fault(*is_time: numpy.ndarray*)

Clear fault and restore pre-fault bus algebraic variables (voltages and others).

class andes.models.timer.**Toggler**(*system*, *config*)

Bases: *andes.models.timer.TogglerData*, *andes.core.model.Model*

Time-based connectivity status toggler.

Toggler is used to toggle the connection status of a device at a predefined time. Both the model name (or group name) and the device idx need to be provided.

v_numeric(***kwargs*)

Custom initialization function that stores and restores the connectivity status.

class andes.models.timer.**TogglerData**

Bases: *andes.core.model.ModelData*

12.3.12 Module contents

The package for DAE models in ANDES.

12.4 andes.routines package

12.4.1 Submodules

12.4.2 andes.routines.base module

class andes.routines.base.**BaseRoutine**(*system=None*, *config=None*)

Bases: object

Base routine class.

Provides references to system, config, and solver.

class_name

doc(*max_width=78*, *export='plain'*)

Routine documentation interface.

init()

Routine initialization interface.

report(***kwargs*)

Report interface.

run(***kwargs*)

Routine main entry point.

summary(***kwargs*)

Summary interface

12.4.3 andes.routines.eig module

Module for eigenvalue analysis.

class andes.routines.eig.**EIG**(*system*, *config*)

Bases: *andes.routines.base.BaseRoutine*

Eigenvalue analysis routine

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

$$A_s = T^{-1}(f_x - f_y * g_y^{-1} * g_x)$$

calc_eigvals()
Solve eigenvalues of the state matrix `self.As`

Returns

None

calc_part_factor(*As=None*)
Compute participation factor of states in eigenvalues.

export_state_matrix()
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

find_zero_states()
Find the indices of non-states in x.

plot(*mu=None*, *fig=None*, *ax=None*, *left=-6*, *right=0.5*, *ymin=-8*, *ymax=8*, *damping=0.05*, *line_width=0.5*, *dpi=150*, *show=True*, *latex=True*)
Plot utility for eigenvalues in the S domain.

reorder_As()
reorder As by moving rows and cols associated with zero time constants to the end.

Returns *fx*, *fy*, *gx*, *gy*, *Tf*.

report(*x_name=None*, ***kwargs*)
Save eigenvalue analysis reports.

Returns

None

run(***kwargs*)
Run small-signal stability analysis.

summary()
Print out a summary to `logger.info`.

12.4.4 andes.routines.pflow module

Module for power flow calculation.

class andes.routines.pflow.**PFlow**(*system=None*, *config=None*)
Bases: `andes.routines.base.BaseRoutine`

Power flow calculation routine.

init()
Routine initialization interface.

newton_krylov(*verbose=False*)
Full Newton-Krylov method from SciPy.

Parameters

verbose True if verbose.

Returns

np.array Solutions *dae.xy*.

> **Warning:** The result might be wrong if discrete are in use!

nr_step()
Single step using Newton-Raphson method.

Returns

float maximum absolute mismatch

report()
Write power flow report to text file.

run(***kwargs*)
Full Newton-Raphson method.

Returns

bool convergence status

summary()
Output a summary for the PFlow routine.

12.4.5 andes.routines.tds module

ANDES module for time-domain simulation.

class andes.routines.tds.**TDS**(*system=None, config=None*)
Bases: *andes.routines.base.BaseRoutine*

Time-domain simulation routine.

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

```
     min(0.50 * h, hmin), if niter >= 15
h =  max(1.10 * h, hmax), if niter <= 6
     min(0.95 * h, hmin), otherwise
```

do_switch()
Checks if is an event time and perform switch if true.

Time is approximated with a tolerance of 1e-8.

fg_update(*models*)
Perform one round of evaluation for one iteration step. The following operations are performed in order:

- discrete flags updating through `l_update_var`
- variable service updating through `s_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`.

init()
Initialize the status, storage and values for TDS.

Returns

array-like The initial values of xy.

itm_step()
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 `self.converged`.

load_plotter()
Manually load a plotter into `TDS.plotter`.

reset()
Reset internal states to pre-init condition.

rewind(*t*)
TODO: rewind to a past time.

run (*no_pbar=False*, *no_summary=False*, ***kwargs*)
Run time-domain simulation using numerical integration.

The default method is the Implicit Trapezoidal Method (ITM).

Parameters

no_pbar [bool] True to disable progress bar

no_summary [bool, optional] True to disable the display of summary

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.

streaming_init ()
Send out initialization variables and process init from modules.

Returns

None

streaming_step ()
Sync, handle and streaming for each integration step.

Returns

None

summary ()
Print out a summary of TDS options to logger.info.

Returns

None

test_init ()
Update f and g to see if initialization is successful.

12.4.6 Module contents

12.5 andes.utils package

12.5.1 Submodules

12.5.2 andes.utils.cached module

class andes.utils.cached.**cached**(*func*, *name=None*, *doc=None*)
Bases: object

A decorator that converts a function into a lazy property. The function wrapped is called the first time to retrieve the result and then that calculated result is used the next time you access the value:

```
class Foo:

    @cached_property
    def foo(self):
        # calculate something important here
        return 42
```

The class has to have a *__dict__* in order for this property to work. See for details: http://stackoverflow.com/questions/17486104/python-lazy-loading-of-class-attributes

12.5.3 andes.utils.paths module

Utility functions for loading andes stock test cases

class andes.utils.paths.**DisplayablePath**(*path*, *parent_path*, *is_last*)
Bases: object

display_filename_prefix_last = '└──'

display_filename_prefix_middle = '├──'

display_parent_prefix_last = '│   '

display_parent_prefix_middle = '   '

displayable()

displayname

classmethod make_tree(*root*, *parent=None*, *is_last=False*, *criteria=None*)

andes.utils.paths.**cases_root**()
Return the root path to the stock cases

andes.utils.paths.**confirm_overwrite**(*outfile*, *overwrite=None*)

andes.utils.paths.**get_case**(*rpath*)
Return the path to a stock case for a given path relative to andes/cases.

To list all cases, use andes.list_cases().

Examples

To get the path to the case *kundur_full.xlsx* under folder *kundur*, do

```
andes.get_case('kundur/kundur_full.xlsx')
```

`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.

`andes.utils.paths.`**`get_dot_andes_path`**`()`
Return the path to `<HomeDir>/.andes`

`andes.utils.paths.`**`get_log_dir`**`()`
Get the directory for log file.

On Linux or macOS, `/tmp/andes` is the default. On Windows, `%APPDATA%/andes` is the default.

Returns

str The path to the temporary logging directory

`andes.utils.paths.`**`get_pkl_path`**`()`
Get the path to the picked/dilled function calls.

Returns

str Path to the calls.pkl file

`andes.utils.paths.`**`list_cases`**`(`*rpath='.', no_print=False*`)`
List stock cases under a given folder relative to `andes/cases`

`andes.utils.paths.`**`tests_root`**`()`
Return the root path to the stock cases

12.5.4 andes.utils.func module

`andes.utils.func.`**`interp_n2`**`(`*t, x, y*`)`
Interpolation function for N * 2 value arrays.

Parameters

t [float] Point for which the interpolation is calculated

x [1-d array with two values] x-axis values

y [2-d array with size N-by-2] Values corresponding to x

Returns

N-by-1 array interpolated values at *t*

`andes.utils.func.list_flatten(input_list)`
Flatten a multi-dimensional list into a flat 1-D list.

12.5.5 andes.utils.misc module

`andes.utils.misc.elapsed(t0=0.0)`
Get the elapsed time from the give time. If the start time is not given, returns the unix-time.

Returns

t [float] Elapsed time from the given time; Otherwise the epoch time.

s [str] The elapsed time in seconds in a string

`andes.utils.misc.is_interactive()`
Check if is in an interactive shell (python or ipython).

Returns

bool

`andes.utils.misc.is_notebook()`

`andes.utils.misc.to_number(s)`
Convert a string to a number. If unsuccessful, return the de-blanked string.

12.5.6 andes.utils.tab module

`class andes.utils.tab.Tab(title=None, header=None, descr=None, data=None, export='plain', max_width=78)`
Bases: `andes.utils.texttable.Texttable`

Use package `texttable` to create well-formatted tables for setting helps and device helps.

Parameters

export [('plain', 'rest')] Export format in plain text or restructuredText.

max_width [int] Maximum table width. If there are equations in cells, set to 0 to disable wrapping.

`draw()`
Draw the table and return it in a string.

`header(header_list)`
Set the header with a list.

`set_title(val)`
Set table title to `val`.

`andes.utils.tab.`**`make_doc_table`**`(`*title*, *max_width*, *export*, *plain_dict*, *rest_dict*`)`

Helper function to format documentation data into tables.

`andes.utils.tab.`**`math_wrap`**`(`*tex_str_list*, *export*`)`

Warp each string item in a list with latex math environment `$...$`.

Parameters

tex_str_list [list] A list of equations to be wrapped

export [str, ('rest', 'plain')] Export format. Only wrap equations if export format is `rest`.

12.5.7 Module contents

12.6 andes.variables package

12.6.1 Submodules

12.6.2 andes.variables.dae module

`class` `andes.variables.dae.`**`DAE`**`(`*system*`)`

Bases: `object`

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
x	Array for state variable values
y	Array for algebraic variable values
z	Array for 0/1 limiter states (if enabled)
f	Array for differential equation derivatives
Tf	Left-hand side time constant array for f
g	Array for algebraic equation mismatches

The defined scalar member attributes to store array sizes are

Scalar	Description
m	The number of algebraic variables/equations
n	The number of algebraic variables/equations
o	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

$$T\dot{x} = f(x, y)$$
$$0 = g(x, y)$$

DAE does not keep track of the association of variable and address. Only a variable instance keeps track of its addresses.

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

clear_arrays()
Reset equation and variable arrays to empty.

clear_fg()
Resets equation arrays to empty

clear_ijv()
Clear stored triplets.

clear_ts()

clear_xy()
Reset variable arrays to empty.

clear_z()
Reset status arrays to empty

fg
Return a concatenated array of [f, g].

get_name(*arr*)

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

print_array(*name*, *values=None*, *tol=None*)

reset()
Reset array sizes to zero and clear all arrays.

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.

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

set_t(*t*)

Helper function for setting time in-place

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

write_lst(*lst_path*)

Dump the variable name lst file.

Parameters

lst_path Path to the lst file.

Returns

bool succeed flag

write_npy(*file_path*)

Write TDS data into NumPy uncompressed format.

write_npz(*file_path*)

Write TDS data into NumPy compressed format.

xy

Return a concatenated array of [x, y].

xy_name
Return a concatenated list of all variable names without format.

xy_tex_name
Return a concatenated list of all variable names in LaTeX format.

xyz
Return a concatenated array of [x, y].

xyz_name
Return a concatenated list of all variable names without format.

xyz_tex_name
Return a concatenated list of all variable names in LaTeX format.

class andes.variables.dae.**DAETimeSeries**(*dae=None*)
Bases: object

DAE time series data.

df

get_data(*base_vars: Union[andes.core.var.BaseVar, List[andes.core.var.BaseVar]], a=None*)
Get time-series data for a variable instance.

Values for different variables will be stacked horizontally.

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-like of int or None] Sub-indices into the address of *base_var*. Applied to each variable.

store(*t, x, y, *, z=None, f=None, g=None*)
Store t, x, y, and z in internal storage, respectively.

Parameters

t [float] simulation time

x, y [array-like] array data for states and algebraic variables

z [array-like or None] discrete flags data

unpack(*df=False*)
Unpack dict-stored data into arrays and/or dataframes.

Parameters

df [bool] True to construct DataFrames *self.df* and *self.df_z* (time-consuming).

Returns

True when done.

unpack_df()
Construct pandas dataframes.

unpack_np()
Unpack dict data into numpy arrays.

12.6.3 andes.variables.fileman module

class andes.variables.fileman.**FileMan**(*case=None*, ***kwargs*)
Bases: object

Define a File Manager class for System

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.

set(*case=None*, ***kwargs*)
Perform the input and output set up.

andes.variables.fileman.**add_suffix**(*fullname*, *suffix*)
Add suffix to a full file name.

12.6.4 andes.variables.report module

class andes.variables.report.**Report**(*system*)
Bases: object

Report class to store system static analysis reports

info

update()
Update values based on the requested content

write()
Write report to file.

andes.variables.report.**report_info**(*system*)

12.6.5 Module contents

CHAPTER 13

Submodules

13.1 andes.cli module

`andes.cli.`**`create_parser`**`()`
The main level of command-line interface.

`andes.cli.`**`main`**`()`
Main command-line interface

`andes.cli.`**`preamble`**`()`
Log the ANDES command-line preamble at the *logging.INFO* level

13.2 andes.main module

`andes.main.`**`config_logger`**`(`*stream=True*, *file=True*, *stream_level=20*, *log_file='andes.log'*, *log_path=None*, *file_level=10*`)`
Configure a logger for the andes package with options for a *FileHandler* and a *StreamHandler*. This function is called at the beginning of `andes.main.main()`.

Parameters

stream [bool, optional] Create a *StreamHandler* for *stdout* if `True`. If `False`, the handler will not be created.

file [bool, optionsl] True if logging to `log_file`.

log_file [str, optional] Logg 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

andes.main.**doc**(*attribute=None*, *list_supported=False*, *init_seq=False*, *config=False*, ***kwargs*)
Quick documentation from command-line.

andes.main.**edit_conf**(*edit_config: Union[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.

andes.main.**find_log_path**(*lg*)
Find the file paths of the FileHandlers.

andes.main.**load**(*case*, *codegen=False*, *setup=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_putput`.

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

Warnings

——-

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.

andes.main.**misc**(*edit_config=''*, *save_config=''*, *show_license=False*, *clean=True*, *recursive=False*, *overwrite=None*, ***kwargs*)
Misc functions.

andes.main.**plot**(***kwargs*)
Wrapper for the plot tool.

`andes.main.`**`prepare`**`(`*quick=False*, *incremental=False*, *cli=False*, *full=False*, ***kwargs*`)`

Run 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.

`andes.main.`**`print_license`**`()`

Print out Andes license to stdout.

`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.

`andes.main.`**`run`**`(`*filename*, *input_path=''*, *verbose=20*, *mp_verbose=30*, *ncpu=2*, *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

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..

andes.main.**run_case**(*case*, ***, *routine='pflow'*, *profile=False*, *convert=''*, *convert_all=''*, *add_book=None*, *codegen=False*, *remove_pycapsule=False*, ***kwargs*)
Run a single simulation case.

andes.main.**save_conf**(*config_path=None*, *overwrite=None*)
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 emtpy 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.

andes.main.**selftest**(*quick=False*, ***kwargs*)
Run unit tests.

andes.main.**set_logger_level**(*lg*, *type_to_set*, *level*)
Set logging level for the given type of handler.

13.3 andes.plot module

The Andes plotting tool.

class andes.plot.**TDSData**(*full_name=None*, *mode='file'*, *dae=None*, *path=None*)
Bases: `object`

A data container for loading and plotting results from Andes time-domain simulation.

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*, *latex=True*, *dpi=150*, *line_width=1.0*, *greyscale=False*, *savefig=None*, *save_format=None*, *title=None*, ***kwargs*)
Plot with `bqplot`. Experimental and incomplete.

data_to_df()
Convert to pandas.DataFrame

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 lst 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

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)

get_call(*backend=None*)
Get the internal *plot_data* function for the specified backend.

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)

get_values(*idx*)
Return the variable values at the given indices.

Parameters

idx [list] The indicex of the variables to retrieve. *idx=0* is for Time. Variable indices start at 1.

Returns

np.ndarray Variable data

guess_event_time()
Guess the event starting time from the input data by checking when the values start to change

load_dae()
Load from DAE time series

load_lst()
Load the lst file into internal data structures *_idx*, *_fname*, *_uname*, and counts the number of variables to *nvars*.

Returns

None

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

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=150*, *line_width=1.0*, *font_size=12*, *savefig=None*, *save_format=None*, *show=True*, *title=None*, *linestyles=None*, *use_bqplot=False*, *hline1=None*, *hline2=None*, *vline1=None*, *vline2=None*, *fig=None*, *ax=None*, *backend=None*, *set_xlim=True*, *set_ylim=True*, *autoscale=False*, *legend_bbox=None*, *legend_loc=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

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] True to save to png figure file

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)

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

plot_data(*xdata*, *ydata*, ***, *xheader=None*, *yheader=None*, *xlabel=None*, *ylabel=None*, *linestyles=None*, *left=None*, *right=None*, *ymin=None*, *ymax=None*, *legend=None*, *grid=False*, *fig=None*, *ax=None*, *latex=True*, *dpi=150*, *line_width=1.0*, *font_size=12*, *greyscale=False*, *savefig=None*, *save_format=None*, *show=True*, *title=None*, *hline1=None*, *hline2=None*, *vline1=None*, *vline2=None*, *set_xlim=True*, *set_ylim=True*, *autoscale=False*, *legend_bbox=None*, *legend_loc=None*, ***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.

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]')
```

plotn(*nrows: int*, *ncols: int*, *yidxes*, *xidxes=None*, ***, *dpi=150*, *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.

andes.plot.**check_init**(*yval*, *yl*)

" Check initialization by comparing t=0 and t=end values for a flat run.

> **Warning:** This function is deprecated as the initialization check feature is built into TDS. See `TDS.test_initialization()`.

andes.plot.**eig_plot**(*name*, *args*)

andes.plot.**isfloat**(*value*)

andes.plot.**isint**(*value*)

andes.plot.**label_latexify**(*label*)

Convert a label to latex format by appending surrounding $ and escaping spaces

Parameters

label [str] The label string to be converted to latex expression

Returns

str A string with $ surrounding

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] <= uppwer.

lower [int] Lower limit. In the return list y, y[i] >= lower.

andes.plot.**scale_func**(*k*)

Return a lambda function that scales its input by k

Parameters

k [float] The scaling factor of the returned lambda function

Returns

——-

Lambda function

andes.plot.**tdsplot**(*filename*, *y*, *x=(0,)*, *tocsv=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

tocsv [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

13.4 andes.shared module

Shared constants and delayed imports.

This module imports shared libraries either directly or with *LazyImport*.

LazyImport shall only be used to imported

`andes.shared.`**`set_latex`**`()`

Enables LaTeX for matplotlib based on the *with_latex* option and *dvipng* availability.

Returns

bool True for LaTeX on, False for off

13.5 andes.system module

System class for power system data and methods

`class` `andes.system.`**`ExistingModels`**

Bases: `object`

Storage class for existing models

`class` `andes.system.`**`System`**`(`*case: Optional[str] = None*, *name: Optional[str] = None*, *config_path: Optional[str] = None*, *default_config: Optional[bool] = False*, *options: Optional[Dict[KT, VT]] = None*, ***kwargs*`)`

Bases: `object`

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.

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

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.

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

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.

call_models(*method: str*, *models: collections.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

collect_ref()
Collect indices into *BackRef* for all models.

dill()
Serialize generated numerical functions in `System.calls` with package `dill`.

The serialized file will be stored to `~/.andes/calls.pkl`, where ~ is the home directory path.

Notes

This function sets *dill.settings['recurse'] = True* to serialize the function calls recursively.

e_clear(*models: collections.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.

f_update(*models: collections.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.

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.

find_devices()
Add dependent devices for all model based on *DeviceFinder*.

find_models(*flag: Union[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.

g_update(*models: collections.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.

get_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.

get_z (*models: Union[str, List[T], collections.OrderedDict, None] = None*)
Get all discrete status flags in a numpy array.

Returns

numpy.array

import_groups ()
Import all groups classes defined in `devices/group.py`.

Groups will be stored as instances with the name as class names. All groups will be stored to dictionary `System.groups`.

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`.

import_routines ()
Import routines as defined in `routines/__init__.py`.

Routines will be stored as instances with the name as class names. All groups will be stored to dictionary `System.groups`.

Examples

`System.PFlow` is the power flow routine instance, and `System.TDS` and `System.EIG` are time-domain analysis and eigenvalue analysis routines, respectively.

init (*models: collections.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.

j_update(*models: collections.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).

l_update_eq(*models: collections.OrderedDict*)

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.

l_update_var(*models: collections.OrderedDict*, *niter=None*, *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.

link_ext_param(*model=None*)

Retrieve values for `ExtParam` for the given models.

static load_config(*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

prepare(*quick=False*, *incremental=False*)

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.

> **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()
```

reload(*case*, ***kwargs*)
Reload a new case in the same System object.

remove_pycapsule()
Remove PyCapsule objects in solvers.

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.

s_update_post(*models: collections.OrderedDict*)
Update variable services by calling `s_update_post` of models.

This function is called at the end of *System.init()*.

s_update_var(*models: collections.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*.

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.

set_address(*models*)
Set addresses for differential and algebraic variables.

set_config(*config=None*)
Set configuration for the System object.

Config for models are routines are passed directly to their constructors.

set_dae_names(*models*)
Set variable names for differential and algebraic variables, and discrete flags.

setup()
Set up system for studies.

This function is to be called after adding all device data.

store_adder_setter(*models*)
Store non-inplace adders and setters for variables and equations.

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.

store_sparse_pattern(*models: collections.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.

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

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

switch_action(*models: collections.OrderedDict*)

Invoke the actions associated with switch times.

Switch actions will be disabled if *flat=True* is passed to system.

undill()

Deserialize the function calls from `~/.andes/calls.pkl` with `dill`.

If no change is made to models, future calls to `prepare()` can be replaced with `undill()` for acceleration.

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.

vars_to_models()

Copy variable values from *System.dae* to models.

CHAPTER 14

Indices and tables

- genindex
- modindex
- search

Python Module Index

a

Index

A

B

C

D

E

F

G

H

M

N

O

P

R

S

T

U

V

W

X

Z