PFNET Python Documentation

Release 1.2.6

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CONTENTS

Welcome! This is the documentation for the Python wrapper of PFNET, last updated February 25, 2017.

What is PFNET?

PFNET is a library for modeling and analyzing electric power networks. It provides data parsers, network visualization routines, and fast and customizable constraint and objective function evaluators for modeling network optimization problems.

License

PFNET is released under the BSD 2-clause license.

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Documentation Contents

CHAPTER

ONE

GETTING STARTED

This section describes how to get started with PFNET in Python. In particular, it covers required packages, installation, and provides a quick example showing how to use this package.

1.1 Dependencies

PFNET for Python has the following dependencies:

- Numpy (>=1.8.2): the fundamental package for scientific computing in Python.
- Scipy (>=0.13.3): a collection of mathematical algorithms and functions built on top of Numpy.
- Cython (>=0.20.1): an optimising static compiler for both Python and the extended Cython programming language.
- PFNET (== 1.2.6): underlying C routines wrapped by this package (`libpfnet`).
- Graphviz (>= 2.38): graph visualization library (`libgvc`) (Optional).
- Raw parser (>=1.2.1): library for parsing power flow files in PSSE raw format version 32 (`libraw_parser`) (Optional).

1.2 Download

The latest version of PFNET can be obtained from https://github.com/ttinoco/PFNET.

1.3 Installation

After building the C library `libpfnet`, the PFNET Python module can be installed using:

```
> sudo python setup.py install
```

from the `python` directory of the PFNET package.

If `libpfnet` was built without visualization capabilities, the argument `--no_graphviz` should be passed to `setup.py`. Similarly, if `libpfnet` was build without raw parsing capabilities, the argument `--no_raw_parser` should be passed to `setup.py`.

The installation can be tested using nose as follows:

```
> python setup.py build_ext --inplace
> nosetests -v --exe
```

1.4 Example

As a quick example of how to use the PFNET Python module, consider the task of constructing a power network from a MATPOWER-converted power flow file and computing the average bus degree. This can be done as follows:

```
>>> import numpy as np
>>> from pfnet import Network

>>> net = Network()
>>> net.load('ieee14.mat')

>>> print np.average([b.degree for b in net.buses])
2.86
```

1.5 Documentation

Requirements to build the PFNET Python documentation:

- Sphinx (>=1.4).

To build the documentation, the environment variable `PFNET_DOCS` must be set. The generated files will be placed in the directory `PFNET_DOCS/python`. To generate the files, run `make html` from the `python/docs` directory of the PFNET package.

It may also be necessary to pass the environment variable with the path to the dynamic shared libraries using `LD_LIBRARY_PATH` on Linux or `DYLD_FALLBACK_LIBRARY_PATH` on Mac OSX. The command would then be:

```
> make html DYLD_FALLBACK_LIBRARY_PATH=$PFNET/lib
```

CHAPTER

TWO

POWER NETWORKS

This section describes how to create and analyze power networks using PFNET.

2.1 Overview

Power networks in PFNET are represented by objects of type `Network`. These objects are initially empty and need to be loaded with data contained in specific types of files. Once the data is loaded, the network and its components can be analyzed, visualized, and used to construct network optimization problems. After a network optimization problem is solved, the network object can be updated with the solution to perform further analysis.

An important attribute of the `Network` class is `base_power`. This quantity, which has units of MVA, is useful for converting power quantities in per unit system base power to MW or MVAr.

2.2 Loading Data

Power networks can be loaded with data using the `load()` class method. This method takes as input the filename of a supported power flow file. Information about the data parsers available in PFNET and the supported file formats can be found in Section *Data Parsers*. The following simple example shows how to load data from a power flow `mat` file:

```
>>> from pfnet import Network

>>> net = Network()
>>> print net.num_buses
0

>>> net.load('ieee14.mat')
>>> print net.num_buses
14
```

2.3 Components

Power networks have several components. These are *buses*, *branches*, *generators*, *shunt devices*, *loads*, *variable generators* (*i.e.*, non-dispatchable), and *batteries*. For obtaining an overview of the components that form a network, the class method `show_components()` can be used:

```
>>> net.show_components()

Network Components
------------------
```

```
buses             : 14
  slack           : 1
  reg by gen      : 5
  reg by tran     : 0
  reg by shunt    : 0
shunts            : 1
  fixed           : 1
  switched v      : 0
branches          : 20
  lines           : 17
  fixed trans     : 3
  phase shifters  : 0
  tap changers v  : 0
  tap changers Q  : 0
generators        : 5
  slack           : 1
  reg             : 5
  P adjust        : 5
loads             : 11
  P adjust        : 0
vargens           : 0
batteries         : 0
```

2.3.1 Buses

Buses in a power network are objects of type `Bus`. Each bus has an `index`, a `number`, and a `name` attribute that can be used to identify this bus in a network. The `index` is associated with the location of the bus in the underlying C array of bus structures, while the `number` and `name` attributes are specified in the input data. An `index`, a `number`, or a `name` can be used to extract a specific bus from a network using the `Network` class methods `get_bus()`, `get_bus_by_number()`, and `get_bus_by_name()`, respectively:

```
>>> bus = net.get_bus(10)

>>> print bus.index == 10
True

>>> other_bus = net.get_bus_by_number(bus.number)

>>> print bus == other_bus
True
```

For convenience, a list of all the buses in the network is contained in the `buses` attribute of the `Network` class.

Buses in a network can have different properties. For example, some buses can be slack buses and others can have their voltage magnitudes regulated by generators, tap-changing transformers, or switched shunt devices. The `Bus` class provides methods for checking whether a bus has specific properties. The following example shows how to get a list of all the buses whose voltage magnitudes are regulated by generators:

```
>>> reg_buses = [b for b in net.buses if b.is_regulated_by_gen()]

>>> print len(reg_buses), net.get_num_buses_reg_by_gen()
5 5
```

A bus also has information about the devices that are connected to it or that are regulating its voltage magnitude. For example, the attributes `gens` and `reg_trans` contain a list of generators connected to the bus and a list of tap-changing transformers regulating its voltage magnitude, respectively.

2.3.2 Branches

Branches in a power network are objects of type Branch and are represented mathematically by the model described in Section 2.1.2 of [TTR2015]. Each branch has an index attribute that can be used to identify this branch in a network. The Network class method get_branch() can be used to extract a branch of a given index:

```
>>> branch = net.get_branch(5)

>>> print branch.index == 5
True
```

For convenience, a list of all the branches in the network is contained in the branches attribute of the Network class.

Branches in a power network can have different properties. For example, some branches can be transmission lines, fixed transformers, tap-changing transformers, or phase-shifting transformers. Tap-changing transformers in turn can control the reactive power flowing through the branch or the voltage magnitude of a bus. The Branch class provides methods for checking whether a branch has specific properties. The following example shows how to get a list of all the branches that are transmission lines:

```
>>> lines = [br for br in net.branches if br.is_line()]

>>> print len(lines), net.get_num_lines()
17 17
```

For branches that are transformers, the Branch class attributes ratio and phase correspond to the transformer's tap ratio and phase shift, respectively. These attributes correspond to the quantities a_{km} and ϕ_{km} of the branch model described in Section 2.1.2 of [TTR2015]. The quantity a_{mk} in this model is always one.

2.3.3 Generators

Generators in a power network are objects of type Generator. Each generator has an index attribute that can be used to identify this generator in a network. The Network class method get_gen() can be used to extract a generator of a given index:

```
>>> gen = net.get_gen(2)

>>> print gen.index == 2
True
```

For convenience, a list of all the generators in the network is contained in the generators attribute of the Network class.

Generators in a power network can have different properties. For example, some generators can be slack generators and others can provide bus voltage magnitude regulation. The Generator class provides methods for checking whether a generator has specific properties. The following example shows how to get a list of all the slack generators:

```
>>> slack_gens = [g for g in net.generators if g.is_slack()]

>>> print len(slack_gens), net.get_num_slack_gens()
1 1
```

The active and reactive powers that a generator injects into the bus to which it is connected are obtained from the P and Q attributes of the Generator class. These quantities are given in units of per unit system base power. The following example computes the total active power injected into the network by generators in units of MW:

```
>>> print sum([g.P for g in net.generators])*net.base_power
272.4
```

2.3.4 Shunt Devices

Shunt devices in a power network are objects of type `Shunt`. Each shunt has an `index` attribute that can be used to identify this shunt in a network. The `Network` class method `get_shunt()` can be used to extract a shunt of a given `index`:

```
>>> shunt = net.get_shunt(0)

>>> print shunt.index == 0
True
```

For convenience, a list of all the shunt devices in the network is contained in the `shunts` attribute of the `Network` class.

As with other network components, shunt devices can have different properties. Some shunt devices can be fixed while others can be switchable and configured to regulate a bus voltage magnitude.

2.3.5 Loads

Loads in a power network are objects of type `Load`. As with other components, the `index` attribute is used to identify a load in the network. A list of all the loads in the network is contained in the `loads` attribute of the `Network` class.

Similar to generators, the active and reactive powers that a load consumes from the bus to which it is connected are obtained from the `P` and `Q` attributes of the `Load` class. They are also given in units of per unit `system base power`.

2.3.6 Variable Generators

Variable generators in a power network are objects of type `VarGenerator`. They represent non-dispatchable energy sources such as wind generators or farms and photovoltaic power plants. As with other components, the `index` attribute is used to identify a variable generator in the network. In addition to the `index` attribute, a `name` attribute is also available, which can be used to extract a specific variable generator from the network using the `Network` class method `get_vargen_by_name()`. A list of all the variable generators in the network is also contained in the `var_generators` attribute of the `Network` class.

Similar to generators, the active and reactive powers produced by a variable generator are obtained from the `P` and `Q` attributes of the `VarGenerator` class in units of per unit `system base power`. This is the output of the device in the absence of uncertainty. When there is uncertainty, the output of the device is subject to variations about `P` that have a standard deviation given by the attribute `P_std`. Output limits of a variable generator are given by the `P_min`, `P_max`, `Q_min`, and `Q_max` attributes.

The output of variable generators in a network is subject to random variations that can be correlated, especially for devices that are "nearby". The method `create_vargen_P_sigma()` of the `Network` class allows constructing a covariance matrix for these variations based on a "correlation distance" `N` and a given correlation coefficient. The cross-covariance between the variation of two devices that are connected to buses that are less than `N` branches away from each other is set such that it is consistent with the given correlation coefficient.

Lastly, since many power network input files do not have variable generator information, these devices can be added to the network by using the `add_vargens()` method of the `Network` class.

2.3.7 Batteries

Batteries are objects of type `Battery`. In addition to an `index` field, these objects contain information such as energy level `E`, charging power `P`, and more.

2.4 Properties

A `Network` object has several quantities or `properties` that provide important information about the state of the network. The following table provides a description of each of these properties.

Names	Description	Units
bus_v_max	Maximum bus voltage magnitude	per unit
bus_v_min	Minimum bus voltage magnitude	per unit
bus_v_vio	Maximum bus voltage magnitude limit violation	per unit
bus_P_mis	Maximum absolute bus active power mismatch	MW
bus_Q_mis	Maximum absolute bus reactive power mismatch	MVAr
gen_P_cost	Total active power generation cost	$/hour
gen_v_dev	Maximum set point deviation of generator-regulated voltage	per unit
gen_Q_vio	Maximum generator reactive power limit violation	MVAr
gen_P_vio	Maximum generator active power limit violation	MW
tran_v_vio	Maximum band violation of transformer-regulated voltage	per unit
tran_r_vio	Maximum tap ratio limit violation of tap-changing transformer	unitless
tran_p_vio	Maximum phase shift limit violation of phase-shifting transformer	radians
shunt_v_vio	Maximum band violation of shunt-regulated voltage	per unit
shunt_b_vio	Maximum susceptance limit violation of switched shunt device	per unit
load_P_util	Total active power consumption utility	$/hour
load_P_vio	Maximum load active power limit violation	MW
num_actions	Number of control adjustments (greater than 2% of control range)	unitless

All of these properties are attributes of the `Network` class. If there is a change in the network, the class method `update_properties()` needs to be called in order for the network properties to reflect the change. The following example shows how to update and extract properties:

```
>>> print net.bus_v_max
1.09

>>> for bus in net.buses:
...     bus.v_mag = bus.v_mag + 0.1
...

>>> print net.bus_v_max
1.09

>>> net.update_properties()

>>> print net.bus_v_max
1.19
```

For convenience, all the network properties can be extracted at once in a dictionary using the `get_properties()` class method:

```
>>> properties = net.get_properties()

>>> print properties['bus_v_max']
1.19
```

2.5 Variables

Network quantities can be specified to be `variables`. This is useful to represent network quantities with vectors and turn the network properties described above as functions of these vectors.

To set network quantities as variables, the `Network` class method `set_flags()` is used. This method takes as arguments a *component type*, one or more *flag types*, one or more `component properties`, and one or more `component quantities`.

Component properties are component-specific. They can be combined into a list to make properties more complex and target a specific subset of components of a given type. More information can be found in the following sections:

- *Bus Properties*
- *Branch Properties*
- *Generator Properties*
- *Load Properties*
- *Shunt Properties*
- *Variable Generator Properties*

Component quantities are also component-specific. They can be combined into a list to specify all quantities that should be affected by the method `set_flags()`. More information can be found in the following sections:

- *Bus Quantities*
- *Branch Quantities*
- *Generator Quantities*
- *Load Quantities*
- *Shunt Quantities*
- *Variable Generator Quantities*

The following example shows how to set as variables all the voltage magnitudes and angles of buses regulated by generators:

```
>>> import pfnet as pf

>>> net = pf.Network()
>>> net.load('ieee14.mat')

>>> print net.num_vars
0

>>> net.set_flags('bus',
...               'variable',
...               'regulated by generator',
...               ['voltage magnitude', 'voltage angle'])

>>> print net.num_vars, 2*net.get_num_buses_reg_by_gen()
10 10
```

Network components have a `has_flags()` method that allows checking whether flags of a certain type associated with specific quantities are set.

Once variables have been set, the *vector* containing all the current variable values can be extracted using `get_var_values()`:

```
>>> values = net.get_var_values()

>>> print type(values)
<type 'numpy.ndarray'>

>>> print values.shape
(10,)
```

The network components that have quantities set as variables have indices that can be used to locate these quantities in the vector of all variable values:

```
>>> bus = [b for b in net.buses if b.is_reg_by_gen()][0]

>>> print bus.has_flags('variable','voltage magnitude')
True

>>> bus.has_flags('variable','voltage angle')
True

>>> print bus.v_mag, net.get_var_values()[bus.index_v_mag]
1.09 1.09

>>> print bus.v_ang, net.get_var_values()[bus.index_v_ang]
-0.23 -0.23
```

A vector of variable values can be used to update the corresponding network quantities. This is done with the `Network` class method `set_var_values()`:

```
>>> bus.has_flags('variable','voltage angle')
True

>>> values = net.get_var_values()

>>> print bus.v_mag
1.09

>>> values[bus.index_v_mag] = 1.20
>>> net.set_var_values(values)

>>> print bus.v_mag
1.20
```

As we will seen in later, variables are also useful for constructing network optimization problems.

The class method `get_var_values()` can also be used to get upper or lower limits of the variables. To do this, a valid *variable value option* must be passed to this method.

In addition to the class method `set_flags()`, which allows specifying variables of components having certain properties, one can also use the `Network` class method `set_flags_of_component()` to specify variables of individual components. This is useful when the desired components cannot be targeted using the available `component properties`. For example, the following code illustrates how to set as variables the voltage magnitudes of buses whose indices are multiples of three:

```
>>> net.clear_flags()

>>> for bus in net.buses:
...     if bus.index % 3 == 0:
...         net.set_flags_of_component(bus,'variable','voltage magnitude')
```

```
>>> print net.num_vars, len([b for b in net.buses if b.index % 3 == 0]), net.num_buses
5 5 14
```

2.6 Projections

As explained above, once the network variables have been set, a vector with the current values of the selected variables is obtained with the class method `get_var_values()`. To extract subvectors that contain values of specific variables, projection matrices can be used. These *matrices* can be obtained using the class method `get_var_projection()`, which take as arguments a *component type* and one or more `component quantities`, *e.g.*, *bus quantities*. The next example sets the variables of the network to be the bus voltage magnitudes and angles of all the buses, extracts the vector of values of all variables, and then extracts two subvectors having only voltage magnitudes and only voltage angles, respectively:

```
>>> import numpy as np
>>> import pfnet as pf

>>> net = pf.Network()
>>> net.load('ieee14.mat')

>>> net.set_flags('bus',
...               'variable',
...               'any',
...               ['voltage magnitude','voltage angle'])

>>> print net.num_vars, 2*net.num_buses
28 28

>>> P1 = net.get_var_projection('bus','voltage magnitude')
>>> P2 = net.get_var_projection('bus','voltage angle')

>>> print type(P1)
<class 'scipy.sparse.coo.coo_matrix'>

>>> x = net.get_var_values()
>>> v_mags = P1*x
>>> v_angs = P2*x

>>> print v_mags
[ 1.036  1.05   1.055  1.057  1.051  1.056  1.09   1.062  1.07   1.02
  1.019  1.01   1.045  1.06 ]

>>> print v_angs
[-0.27995081 -0.26459191 -0.26302112 -0.2581342  -0.26354472 -0.26075219
 -0.23317599 -0.23335052 -0.24818582 -0.15323991 -0.18029251 -0.22200588
 -0.0869174   0. ]

>>> print np.linalg.norm(x - (P1.T*v_mags+P2.T*v_angs))
0.0
```

2.7 Contingencies

PFNET provides a convenient way to specify and analyze network contingencies. A contingency is represented by an object of type `Contingency`, and is characterized by one or more `generator` or `branch` outages. The lists of generator and branch outages of a contingency can be specified at construction, or by using the class methods `add_gen_outage()` and `add_branch_outage()`, respectively. The following example shows how to construct a contingency:

```
>>> import pfnet as pf

>>> net = pf.Network()
>>> net.load('ieee14.mat')

>>> gen = net.get_gen(3)
>>> branch = net.get_branch(2)

>>> c1 = pf.Contingency(gens=[gen],branches=[branch])

>>> print c1.num_gen_outages, c1.num_branch_outages
1 1
```

Once a contingency has been constructed, it can be applied and later cleared. This is done using the class methods `apply()` and `clear()`. The `apply()` function sets the specified generator and branches on outage and disconnects them from the network. Voltage regulation and other controls provided by generator or transformers on outage are lost. The `clear()` function undoes the changes made by the `apply()` function. The following example shows how to apply and clear contingencies, and illustrates some of the side effects:

```
>>> print c1.has_gen_outage(gen), c1.has_branch_outage(branch)
True True

>>> gen_bus = gen.bus
>>> branch_bus = branch.bus_k
>>> branch_bus = branch.bus_from # deprecated

>>> # generator and branch connected to buses
>>> print gen in gen_bus.gens, branch in branch_bus.branches
True True

>>> c1.apply()

>>> print gen.is_on_outage(), branch.is_on_outage()
True True

>>> # generator and branch disconnected from buses
>>> print gen in gen_bus.gens, branch in branch_bus.branches
False False

>>> c1.clear()

>>> print gen.is_on_outage(), branch.is_on_outage()
False False

>>> # generator and branch connected to buses again
>>> print gen in gen_bus.gens, branch in branch_bus.branches
True True
```

2.8 Multiple Time Periods

PFNET can also be used to represent and analyze power networks over multiple time periods. By default, the networks created using `Network()`, as in all the examples above, are static. To consider multiple time periods, an argument needs to be passed to the class constructor:

```
>>> net = pf.Network(5)

>>> print net.num_periods
5
```

In "multi-period" networks, certain quantities vary over time and hence are represented by vectors. Examples of such quantities are the *network properties*, generators powers, load powers, battery energy levels, bus voltages, etc. The example below shows how to set the load profile over the time periods and extract the maximum active power mismatches in the network at each time:

```
>>> for load in net.loads:
...     load.P = np.random.rand(5)

>>> print net.loads[0].P
[ 0.84  0.47  0.62  0.65  0.36]

>>> net.update_properties()

>>> print([net.bus_P_mis[t] for t in range(5)])
[81.92, 87.35, 86.71, 93.61, 89.90]
```

Lastly, for component quantities that can potentially vary over time, setting these quantities to be variables results in one variable for each time. For example, selecting the bus voltage magnitude of a bus to be variable leads to having one variable for each time period:

```
>>> bus = net.buses[3]

>>> net.set_flags_of_component(bus,'variable','voltage magnitude')

>>> print(net.num_vars)
5

>>> print bus.index_v_mag
[0 1 2 3 4]
```

CHAPTER THREE

DATA PARSERS

This section describes the different data parsers available in PFNET and the supported file types.

3.1 MATPOWER Case Files

MATPOWER is a MATLAB package for solving power flow and optimal power flow problems. It contains several power flow and optimal power flow cases defined in MATLAB files. These “M” files can be converted to CSV files using the script `mpc2mat.m`. These MATPOWER-converted CSV files have extension `.mat` and can be used to load power networks in PFNET.

3.2 ARTERE Case Files

PFNET can load networks from case files used by ARTERE, which is a software for performing power flow computations using the Newton-Raphson method. These files should have extension `.art`. Details about these data files can be found in the document “ARTERE: description of data files”.

Currently, PFNET has limited support of these files. More specifically:

- Components with open breakers are ignored.
- For LTC-V devices, tap positions are treated as continuous and the optional fields are ignored.
- The SWITCH, TRFO, PSHIFT-P, TURLIM, SVC, LFRESV, BUSPART and BRAPART records are not supported.
- Computation control parameters are ignored.

3.2.1 Added Records

Variable generators, batteries, base power, etc.

3.3 RAW Case Files

If built with raw parsing capabilities, which requires linking PFNET with `libraw_parser`, PFNET can load power networks from files with extension `.raw`. These files are used by the software PSS ® E and are widely used by North American power system operators.

CHAPTER

FOUR

VISUALIZATION

This section describes how to visualize power networks using PFNET. To have this capability, PFNET needs the Graphviz library `libgvc`.

4.1 Overview

To visualize a power network, a `Graph` objects needs to be created. To do this, one needs to specify the power `Network` that is to be associated with the graph:

```
>>> import pfnet as pf

>>> net = pf.Network()
>>> net.load('ieee14.mat')

>>> g = pf.Graph(net)
```

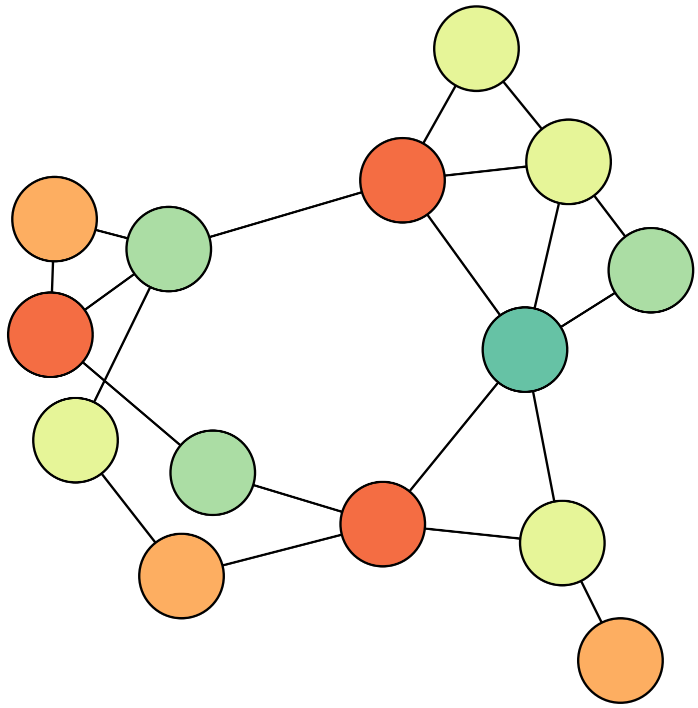
Then, a layout must be created for graph. This can be done using the `Graph` class method `set_layout`. This method uses the sfdp algorithm of Graphviz.

The `Graph` class provides routines for coloring nodes (network buses) according to different criteria. For example, buses can be colored according to reactive power mismatches:

```
>>> g.set_layout()

>>> g.color_nodes_by_mismatch(pf.BUS_MIS_REACTIVE)

>>> g.view()
```



CHAPTER

FIVE

OPTIMIZATION PROBLEMS

This section describes how to formulate power network optimization problems using PFNET.

5.1 Objective Function

The objective function ϕ for a network optimization problem created using PFNET is of the form

$$\varphi(x) = \sum_i w_i \varphi_i(x),$$

where w_i are weights, φ_i are general linear or nonlinear functions, and x is a vector of values of network quantities that have been set as variables. Each weight-function pair in the summation is represented by an object of type `Function`. To instantiate an object of this type, the function type and weight need to be specified as well as the `Network` object that is to be associated with the function. The following example sets all bus voltage magnitudes as variables and constructs a function that penalizes voltage magnitude deviations from ideal values:

```
>>> import pfnet as pf

>>> net = pf.Network()
>>> net.load('ieee14.mat')

>>> net.set_flags('bus',
...               'variable',
...               'any',
...               'voltage magnitude')

>>> func = pf.Function('voltage magnitude regularization',0.3,net)

>>> print func.type == 'voltage magnitude regularization'
True

>>> print func.weight
0.3
```

After a `Function` object is created, its value, gradient and Hessian are zero, an empty vector, and an empty matrix, respectively. Before evaluating the function at a specific vector of values, it must be analyzed using the `Function` class method `analyze()`. This routine analyzes the function and allocates the required vectors and matrices for storing its gradient and Hessian. After this, the function can be evaluated using the method `eval()`:

```
>>> x = net.get_var_values()

>>> func.analyze()

>>> func.eval(x)
```

The value $\varphi_i(x)$, gradient $\nabla\varphi_i(x)$ and Hessian $\nabla^2\varphi_i(x)$ of a function can then be extracted from the `phi`, `gphi` and `Hphi` attributes, respectively:

```
>>> print x.shape
(14,)

>>> print func.phi
0.255

>>> print type(func.gphi), func.gphi.shape
<type 'numpy.ndarray'> (14,)

>>> print type(func.Hphi), func.Hphi.shape
<class 'scipy.sparse.coo.coo_matrix'> (14, 14)
```

For the Hessian matrix, only the lower triangular part is stored.

Details about each of the different function types available in PFNET are provided below.

5.1.1 Voltage magnitude regularization

This function is associated with the string `'voltage magnitude regularization'`. It penalizes deviations of bus voltage magnitudes from ideal values. It is defined by the expression

$$\varphi(x) := \frac{1}{2}\sum_k\left(\frac{v_k - v_k^t}{\Delta v}\right)^2 + \frac{1}{2}\sum_k\left(\frac{v_k^y}{\Delta v}\right)^2 + \frac{1}{2}\sum_k\left(\frac{v_k^z}{\Delta v}\right)^2 + \frac{1}{2}\sum_k\left(\frac{v_k^h}{\Delta v}\right)^2 + \frac{1}{2}\sum_k\left(\frac{v_k^l}{\Delta v}\right)^2,$$

where v are bus voltage magnitudes, v^t are voltage magnitude set points (one for buses not regulated by generators), v^y and v^z are positive and negative deviations of v from v^t, v^h and v^l are voltage band upper and lower limit violations, and Δv is a normalization factor. Only terms that include optimization variables are included in the summation.

5.1.2 Voltage magnitude soft limit penalty

This function is associated with the string `'soft voltage magnitude limits'`. It reduces voltage (soft) limit violations by penalizing deviations of bus voltage magnitudes from the mid point of their ranges. It is defined by the expression

$$\varphi(x) := \frac{1}{2}\sum_k\left(\frac{v_k - \bar{v}_k}{\Delta v}\right)^2,$$

where v are bus voltage magnitudes, $\bar{v}$ are the mid points of their ranges, and Δv is a normalization factor. Only terms that include optimization variables are included in the summation.

5.1.3 Voltage angle regularization

This function is associated with the string `'voltage angle regularization'`. It penalizes large bus voltage angles and voltage angle differences across branches. It is defined by the expression

$$\varphi(x) := \frac{1}{2}\sum_k\left(\frac{\theta_k}{\Delta\theta}\right)^2 + \frac{1}{2}\sum_{(k,m)}\left(\frac{\theta_k - \theta_m - \phi_{km}}{\Delta\theta}\right)^2,$$

where θ are bus voltage angles, ϕ are branch phase shifts, and $\Delta\theta$ is a normalization factor. Only terms that include optimization variables are included in the summation.

5.1.4 Generator powers regularization

This function is associated with the string `'generator powers regularization'`. It penalizes deviations of generator powers from the midpoint of their ranges. It is defined by the expression

$$\varphi(x) := \frac{1}{2}\sum_k \left(\frac{P^g_k - \bar{P}_k}{\Delta P}\right)^2 + \frac{1}{2}\sum_k \left(\frac{Q^g_k - \bar{Q}_k}{\Delta Q}\right)^2,$$

where P^g and Q^g are generator active and reactive powers, $\bar{P}$ and $\bar{Q}$ are midpoints of generator active and reactive power ranges, and $\Delta P = \Delta Q$ are normalization factors. Only terms that include optimization variables are included in the summation.

5.1.5 Active power generation cost

This function is associated with the string `'generation cost'`. It measures active power generation cost by the expression

$$\varphi(x) := \sum_t \sum_k q_{k0} + q_{k1} P_k(t) + q_{k2} P_k(t)^2,$$

where $P_k(t)$ are generator active powers in per unit base system power, t is the time period, and q_{k0}, q_{k1}, and q_{k2} are constant coefficients. These coefficients correspond to the attributes `cost_coeff_Q0`, `cost_coeff_Q1` and `cost_coeff_Q2` of each `Generator` object.

5.1.6 Net Active Power Consumption Cost

This function is associated with the string `'net consumption cost'`. It measures the total cost of net active power consumption over the time periods using the price defined by the `price` attribute of each `Bus` object.

5.1.7 Active power consumption utility

This function is associated with the string `'consumption utility'`. It measures active power consumption utility by the expression

$$\varphi(x) := \sum_t \sum_k q_{k0} + q_{k1} P_k(t) + q_{k2} P_k(t)^2,$$

where $P_k(t)$ are load active powers in per unit base system power, t is the time period, and q_{k0}, q_{k1}, and q_{k2} are constant coefficients. These coefficients correspond to the attributes `util_coeff_Q0`, `util_coeff_Q1` and `util_coeff_Q2` of each `Load` object.

5.1.8 Transformer tap ratio regularization

This function is associated with the string `'tap ratio regularization'`. It penalizes deviations of tap ratios of tap-changing transformers from their initial value. It is defined by the expression

$$\varphi(x) := \frac{1}{2}\sum_k \left(\frac{t_k - t^0_k}{\Delta t}\right)^2 + \frac{1}{2}\sum_k \left(\frac{t^y_k}{\Delta t}\right)^2 + \frac{1}{2}\sum_k \left(\frac{t^z_k}{\Delta t}\right)^2,$$

where t are tap ratios of tap-changing transformers, t^0 are their initial values, t^y and t^z are positive and negative deviations of t from t^0, and Δt is a normalization factor. Only terms that include optimization variables are included in the summation.

5.1.9 Transformer phase shift regularization

This function is associated with the string `'phase shift regularization'`. It penalizes deviations of phase shifts of phase shifting transformers from their initial value. It is defined by the expression

$$\varphi(x) := \frac{1}{2}\sum_k \left(\frac{\phi_k - \phi_k^0}{\Delta\phi}\right)^2$$

where ϕ are phase shifts of phase-shifting transformers, ϕ^0 are their initial values, and $\Delta\phi$ is a normalization factor. Only terms that include optimization variables are included in the summation.

5.1.10 Switched shunt susceptance regularization

This function is associated with the string `'susceptance regularization'`. It penalizes deviations of susceptances of switched shunt devices from their initial value. It is defined by the expression

$$\varphi(x) := \frac{1}{2}\sum_k \left(\frac{b_k - b_k^0}{\Delta b}\right)^2 + \frac{1}{2}\sum_k \left(\frac{b_k^y}{\Delta b}\right)^2 + \frac{1}{2}\sum_k \left(\frac{b_k^z}{\Delta b}\right)^2,$$

where b are susceptances of switched shunt devices, b^0 are their initial values, b^y and b^z are positive and negative deviations of b from b^0, and Δb is a normalization factor. Only terms that include optimization variables are included in the summation.

5.1.11 Sparsity inducing penalty for controls

This function is associated with the string `'sparse controls penalty'`. It encourages sparse control adjustments with the expression

$$\varphi(x) := \sum_k \sqrt{\left(\frac{u_k - u_k^0}{\Delta u_k}\right)^2 + \epsilon},$$

where u are control quantities, u^0 are their current values, and ϵ is a small positive scalar. The normalization factors Δu_k are given by

$$\Delta u_k := \max\{u_k^{\max} - u_k^{\min}, \delta\},$$

where $u^{\max}$ and $u^{\min}$ are control limits, and δ is a small positive scalar. The control quantities that are considered by this function are specified using the `Network` class methods `set_flags()` or `set_flags_of_component()` using the flag type `'sparse'`.

5.2 Constraints

Constraints in PFNET are of the form

$$\begin{aligned} &Ax = b \\ &f(x) = 0 \\ &l \leq Gx \leq u, \end{aligned}$$

where A and G are sparse matrices, b, l and u are vectors, f is a vector-valued nonlinear function, and x is a vector of values of network quantities that have been set as variables. They are represented by objects of type `Constraint`. To create an object of this type, the constraint type and the network to be associated with the constraint need to be specified. The following example sets all bus voltage magnitudes and angles as variables and constructs the power flow constraints:

```
>>> import pfnet as pf

>>> net = pf.Network()
>>> net.load('ieee14.mat')

>>> net.set_flags('bus',
...                'variable',
...                'any',
...                ['voltage magnitude','voltage angle'])

>>> print net.num_vars == 2*net.num_buses
True

>>> constr = pf.Constraint('AC power balance',net)

>>> print constr.type == 'AC power balance'
True
```

Before a `Constraint` object can be used, it must be initialized using the `Constraint` class method `analyze()`. This routine analyzes the constraint and allocates the required vectors and matrices. After this, the constraint can be evaluated using the method `eval()`:

```
>>> x = net.get_var_values()

>>> constr.analyze()

>>> constr.eval(x)
```

The matrices and vectors associated with the linear constraints can be extracted from the `A`, `G`, `b`, `l` and `u` attributes of the `Constraint` object. The vector of violations and Jacobian matrix of the nonlinear constraints can be extracted from the attributes `f` and `J`, respectively. Also, the Hessian matrix of any individual nonlinear constraint $f_i(x) = 0$ can be extracted using the class method `get_H_single()`. The following example shows how to extract the largest power flow mismatch in per unit `system base power` and the Hessian matrix corresponding to the active power balance constraint of a bus:

```
>>> import numpy as np

>>> f = constr.f

>>> print type(f), f.shape
<type 'numpy.ndarray'>  (28,)

>>> print np.linalg.norm(f,np.inf)
0.042

>>> bus = net.get_bus(5)
>>> Hi = constr.get_H_single(bus.index_P)

>>> print type(Hi), Hi.shape, Hi.nnz
<class 'scipy.sparse.coo.coo_matrix'> (28, 28) 27
```

As before, all Hessian matrices have stored only the lower triangular part. In addition to being possible to extract Hessian matrices of individual nonlinear constraints, it is also possible to construct any linear combination of these individual Hessian matrices. This can be done using the `Constraint` class method `combine_H()`. After this, the resulting matrix can be extracted from the `H_combined` attribute:

```
>>> coefficients = np.random.randn(f.size)
```

```
>>> constr.combine_H(coefficients)
>>> H = constr.H_combined

>>> print type(H), H.shape, H.nnz
<class 'scipy.sparse.coo.coo_matrix'> (28, 28) 564
```

Lastly, Lagrange multiplier estimates of the linear and nonlinear constraints can be used to store sensitivity information in the network components associated with the constraints. This is done using the class method `store_sensitivities()`. Component-specific attributes that store sensitivity information are described in the *API Reference* section.

Details about each of the different constraint types available in PFNET are provided below.

5.2.1 AC Power balance

This constraint is associated with the string `'AC power balance'`. It enforces active and reactive power balance at every bus of the network. It is given by

$$(P_k^g + jQ_k^g) - (P_k^l + jQ_k^l) - S_k^{sh} - \sum_{m\in[n]} S_{km} = 0, \; \forall\, k \in [n],$$

where P^g and Q^g are generator active and reactive powers, P^l and Q^l are load active and reactive powers, S^{sh} are apparent powers flowing out of buses through shunt devices, S are apparent powers flowing out of buses through branches, n is the number of buses, and $[n] := \{1,\dots,n\}$.

5.2.2 DC Power balance

This constraint is associated with the string `'DC power balance'`. It enforces "DC" active power balance at every bus of the network. It is given by

$$P_k^g - P_k^l + \sum_{m\in[n]} b_{km}\left(\theta_k - \theta_m - \phi_{km}\right) = 0, \; \forall\, k \in [n],$$

where P^g are generator active powers, P^l are load active powers, b_{km} are branch susceptances, θ_k are bus voltage angles, ϕ_{km} are phase shifts of phase-shifting transformers, n is the number of buses, and $[n] := \{1,\dots,n\}$.

5.2.3 Linearized AC Power balance

This constraint is associated with the string `'linearized AC power balance'`. It enforces active and reactive power balance at every bus of the network using a first-order Taylor expansion of the AC power balance constraints. It is given by

$$J(x_0)x = J(x_0)x_0 - f(x_0),$$

where x_0 is the vector of current variable values, $f(x_0)$ is the vector of AC bus power mismatches, and $J(x_0)$ is the Jacobian of f at x_0.

5.2.4 DC branch flow limits

This constraint is associated with the string `'DC branch flow limits'`. It enforces branch "DC" power flow limits due to thermal ratings. It is given by

$$-P_{km}^{\max} \le -b_{km}\left(\theta_k - \theta_m - \phi_{km}\right) \le P_{km}^{\max},$$

for each branch (k,m), where b_{km} are branch susceptances, θ_k are bus voltage angles, ϕ_{km} are phase shifts of phase-shifting transformers, and $P_{km}^{\max}$ are branch power flow limits.

5.2.5 Variable fixing

This constraint is associated with the string `'variable fixing'`. It constrains specific variables to be fixed at their current value. The variables to be fixed are specified using the `Network` class methods `set_flags()` or `set_flags_of_component()` with the flag type `'fixed'`.

5.2.6 Variable bounds

This constraint is associated with the string `'variable bounds'`. It constrains specific variables to be inside their bounds. The variables to be bounded are specified using the `Network` class methods `set_flags()` or `set_flags_of_component()` with the flag type `'bounded'`.

Variable bounds can also be expressed as nonlinear equality constraints using the techniques described in Section 4.3.3 of [TTR2015]. The string associated with this constraint type is `'variable nonlinear bounds'`.

5.2.7 Generator participation

This constraint is associated with the string `'generator active power participation'` and `'generator reactive power participation'`. It enforces specific active power participations among slack generators, or reactive power participations among generators regulating the same bus voltage magnitude. For slack generators, all participate with equal active powers. For voltage regulating generators, each one participates with the same fraction of its total resources. More specifically, this constraint enforces

$$P_k^g = P_m^g,$$

for all slack generators k and m connected to the same bus, or

$$\frac{Q_k^g - Q_k^{\min}}{Q_k^{\max} - Q_k^{\min}} = \frac{Q_m^g - Q_m^{\min}}{Q_m^{\max} - Q_m^{\min}},$$

for all generators k and m regulating the same bus voltage magnitude, where $Q^{\min}$ and $Q^{\max}$ are generator reactive power limits.

5.2.8 Voltage set-point regulation by generators

This constraint is associated with the string `'voltage regulation by generators'`. It enforces voltage set-point regulation by generators. It approximates the constraints

$$\begin{aligned} v_k &= v_k^t + v_k^y - v_k^z \\ 0 &\leq (Q_k - Q_k^{\min}) \perp v_k^y \geq 0 \\ 0 &\leq (Q_k^{\max} - Q_k) \perp v_k^z \geq 0, \end{aligned}$$

for each bus k whose voltage is regulated by generators, where v are bus voltage magnitudes, v^t are their set points, v^y and v^z are positive and negative deviations of v from v^t, and Q, $Q^{\max}$ and $Q^{\min}$ are aggregate reactive powers and limits of the generators regulating the same bus voltage magnitude.

5.2.9 Voltage band regulation by transformers

This constraint is associated with the string `'voltage regulation by transformers'`. It enforces voltage band regulation by tap-changing transformers. It approximates the constraints

$$
\begin{aligned}
&t_k = t_k^0 + t_k^y - t_k^z \\
&0 \leq (v_k + v_k^l - v_k^{\min}) \perp t_k^y \geq 0 \\
&0 \leq (v_k^{\max} - v_k + v_k^h) \perp t_k^z \geq 0 \\
&0 \leq (t_k^{\max} - t_k) \perp v_k^l \geq 0 \\
&0 \leq (t_k - t_k^{\min}) \perp v_k^h \geq 0,
\end{aligned}
$$

for each bus k whose voltage is regulated by tap-changing transformers, where v are bus voltage magnitudes, $v^{\max}$ and $v^{\min}$ are their band limits, v^l and v^h are voltage violations of band lower and upper limits, t are transformer tap ratios, t^0, $t^{\max}$ and $t^{\min}$ are their current values and limits, and t^y and t^z are positive and negative deviations of t from t^0. The above equations assume that the sensitivity between voltage magnitude and transformer tap ratio is positive. If it is negative, t^y and t^z are interchanged in the first two complementarity constraints, and v^l and v^h are interchanged in the bottom two complementarity constraints.

5.2.10 Voltage band regulation by switched shunts

This constraint is associated with the string `'voltage regulation by shunts'`. It enforces voltage band regulation by switched shunt devices. It approximates the constraints

$$
\begin{aligned}
&b_k = b_k^0 + b_k^y - b_k^z \\
&0 \leq (v_k + v_k^l - v_k^{\min}) \perp b_k^y \geq 0 \\
&0 \leq (v_k^{\max} - v_k + v_k^h) \perp b_k^z \geq 0 \\
&0 \leq (b_k^{\max} - b_k) \perp v_k^l \geq 0 \\
&0 \leq (b_k - b_k^{\min}) \perp v_k^h \geq 0,
\end{aligned}
$$

for each bus k whose voltage is regulated by switched shunt devices, where v are bus voltage magnitudes, $v^{\max}$ and $v^{\min}$ are their band limits, v^l and v^h are voltage violations of band lower and upper limits, b are switched shunt susceptances, b^0, $b^{\max}$ and $b^{\min}$ are their current values and limits, and b^y and b^z are positive and negative deviations of b from b^0 .

5.2.11 Generator active power ramp limits

This constraint is associated with the string `'generator ramp limits'`. It enforces generator active power ramping limits. It is given by

$$
-\delta P_k^{\max} \leq P_k(t) - P_k(t-1) \leq \delta P^{\max}
$$

for each generator k and time period t, where $P_k(t)$ are generator active powers, and $\delta P_k^{\max}$ are generator ramping limits. The ramping limits are defined by the `dP_max` attribute of each `Generator` object. For $t = 0$, $P_k(t-1)$ is the `P_prev` attribute of a `Generator`.

5.3 Problems

Optimization problems constructed with PFNET are of the form

$$\begin{aligned} \text{minimize} \quad & \varphi(x) \\ \text{subject to} \quad & Ax = b \\ & f(x) = 0 \\ & l \leq Gx \leq u, \end{aligned}$$

As already noted, the objective function φ is a weighted sum of functions φ_i. The linear and nonlinear constraints $Ax = b$, $l \leq Gx \leq u$, and $f(x) = 0$ correspond to one or more of the constraints described above. An optimization problem in PFNET is represented by an object of type `Problem`.

After instantiation, a `Problem` is empty and one needs to specify the `Network` that is to be associated with the problem, the `Constraints` to include, and the `Functions` that form the objective function. This can be done using the `Problem` class methods `set_network()`, `add_constraint()`, and `add_function()`. The following example shows how to construct a simple power flow problem and solve it using the Newton-Raphson method:

```python
import pfnet as pf
from numpy import hstack
from numpy.linalg import norm
from scipy.sparse import bmat
from scipy.sparse.linalg import spsolve

def NRsolve(net):

    net.clear_flags()

    # bus voltage angles
    net.set_flags('bus',
                  'variable',
                  'not slack',
                  'voltage angle')

    # bus voltage magnitudes
    net.set_flags('bus',
                  'variable',
                  'not regulated by generator',
                  'voltage magnitude')

    # slack gens active powers
    net.set_flags('generator',
                  'variable',
                  'slack',
                  'active power')

    # regulator gens reactive powers
    net.set_flags('generator',
                  'variable',
                  'regulator',
                  'reactive power')

    p = pf.Problem()
    p.set_network(net)
    p.add_constraint('AC power balance')
    p.add_constraint('generator active power participation')
    p.add_constraint('generator reactive power participation')
```

```
p.analyze()

x = p.get_init_point()
p.eval(x)

residual = lambda x: hstack((p.A*x-p.b,p.f))

while norm(residual(x)) > 1e-4:
    x = x + spsolve(bmat([[p.A],[p.J]],format='csr'),-residual(x))
    p.eval(x)

net.set_var_values(x)
net.update_properties()
```

The above routine can then be used as follows:

```
>>> net = Network()
>>> net.load('case3012wp.mat')

>>> print net.bus_P_mis, net.bus_Q_mis
2.79e+0 1.56e+1

>>> NRsolve(net)

>>> print net.bus_P_mis, net.bus_Q_mis
2.37e-6 3.58e-6
```

As shown in the example, the `Problem` class method `analyze()` needs to be called before the vectors and matrices associated with the problem constraints and functions can be used. The method `eval()` can then be used for evaluating the problem objective and constraint functions at different points. As is the case for `Constraints`, a `Problem` has a method `combine_H()` for forming linear combinations of individual constraint Hessians, and a method `store_sensitivities()` for storing sensitivity information in the network components associated with the constraints.

CHAPTER

SIX

API REFERENCE

6.1 Vector

class `numpy.ndarray`
See numpy documentation.

6.2 Matrix

class `scipy.sparse.coo_matrix`
See scipy documentation.

6.3 Bus

6.3.1 Bus Properties

'any'

'slack'

'regulated by generator'

'regulated by transformer'

'regulated by shunt'

'not slack'

'not regulated by generator'

6.3.2 Bus Quantities

'all'

'voltage angle'

'voltage magnitude'

'voltage magnitude deviation'

'voltage magnitude violation'

6.3.3 Bus Sensitivities

pfnet.**BUS_SENS_LARGEST**
Largest objective function sensitivity with respect to constraints involving this bus.

pfnet.**BUS_SENS_P_BALANCE**
Objective function sensitivity with respect to active power balance.

pfnet.**BUS_SENS_Q_BALANCE**
Objective function sensitivity with respect to reactive power balance.

pfnet.**BUS_SENS_V_MAG_U_BOUND**
Objective function sensitivity with respect to voltage magnitude upper bound.

pfnet.**BUS_SENS_V_MAG_L_BOUND**
Objective function sensitivity with respect to voltage magnitude lower bound.

pfnet.**BUS_SENS_V_ANG_U_BOUND**
Objective function sensitivity with respect to voltage angle upper bound.

pfnet.**BUS_SENS_V_ANG_L_BOUND**
Objective function sensitivity with respect to voltage angle lower bound.

pfnet.**BUS_SENS_V_REG_BY_GEN**
Objective function sensitivity with respect to voltage magnitude regulation by generators.

pfnet.**BUS_SENS_V_REG_BY_TRAN**
Objective function sensitivity with respect to voltage magnitude regulation by tap-changing transformers.

pfnet.**BUS_SENS_V_REG_BY_SHUNT**
Objective function sensitivity with respect to voltage magnitude regulation by switched shunt devices.

6.3.4 Bus Power Mismatches

pfnet.**BUS_MIS_LARGEST**
Largest bus power mismatch.

pfnet.**BUS_MIS_ACTIVE**
Bus active power mismatch.

pfnet.**BUS_MIS_REACTIVE**
Bus reactive power mismatch.

6.3.5 Bus Class

class pfnet.**Bus**(*num_periods=1*, *alloc=True*)
Bus class.

Parameters **alloc** : {True, False}

num_periods : int

P_mis
Bus active power mismatch (p.u. system base MVA) (float or array).

Q_mis
Bus reactive power mismatch (p.u. system base MVA) (float or array).

bats
Same as batteries.

batteries
List of `batteries` connected to this bus (list).

branches
List of `branches` incident on this bus (list).

branches_from
Deprecated since version 1.2.5: Same as `branches_k`.

branches_k
List of `branches` that have this bus on the "k" (aka "from" or "i") side (list).

branches_m
List of `branches` that have this bus on the "m" (aka "to" or "j") side (list).

branches_to
Deprecated since version 1.2.5: Same as `branches_m`.

degree
Bus degree (number of incident branches) (float).

generators
List of `generators` connected to this bus (list).

gens
Same as `generators`.

get_largest_mis (*self*, *t=0*)
Gets the bus power mismatch of largest absolute value.

Parameters **t** : int (time period)

Returns **mis** : float

get_largest_mis_type (*self*, *t=0*)
Gets the type of bus power mismatch of largest absolute value.

Parameters **t** : int (time period)

Returns **type** : int

get_largest_sens (*self*, *t=0*)
Gets the bus sensitivity of largest absolute value.

Parameters **t** : int (time period)

Returns **sens** : float

get_largest_sens_type (*self*, *t=0*)
Gets the type of bus sensitivity of largest absolute value.

Parameters **t** : int (time period)

Returns **type** : int

get_num_vars (*self*, *q*, *t_start=0*, *t_end=None*)
Gets number of variables associated with the given quantity.

Parameters **q** : string or list of strings (*Bus Quantities*)

t_start : int

t_end : int

Returns **num** : int

get_quantity (*self*, *type*, *t=0*)
Gets the bus quantity of the given type.

Parameters **type** : int (*Bus Sensitivities*:, *Bus Power Mismatches*)

t : int (time period)

Returns **value** : float

get_total_gen_P (*self*, *t=0*)
Gets the total active power injected by generators connected to this bus.

Parameters **t** : int (time period)

Returns **P** : float

get_total_gen_Q (*self*, *t=0*)
Gets the total reactive power injected by generators connected to this bus.

Parameters **t** : int (time period)

Returns **Q** : float

get_total_gen_Q_max (*self*)
Gets the largest total reactive power that can be injected by generators connected to this bus.

Returns **Q_max** : float

get_total_gen_Q_min (*self*)
Gets the smallest total reactive power that can be injected by generators connected to this bus.

Returns **Q_min** : float

get_total_load_P (*self*, *t=0*)
Gets the total active power consumed by loads connected to this bus.

Parameters **t** : int (time period)

Returns **P** : float

get_total_load_Q (*self*, *t=0*)
Gets the total reactive power consumed by loads connected to this bus.

Parameters **t** : int (time period)

Returns **Q** : float

get_total_shunt_b (*self*, *t=0*)
Gets the combined susceptance of shunt devices connected to this bus.

Parameters **t** : int (time period)

Returns **b** : float

get_total_shunt_g (*self*)
Gets the combined conductance of shunt devices connected to this bus.

Returns **g** : float

has_flags (*self*, *flag_type*, *q*)
Determines whether the bus has the flags associated with certain quantities set.

Parameters **flag_type** : string (*Flag Types*)

q : string or list of strings (*Bus Quantities*)

Returns **flag** : {`True`, `False`}

index
Bus index (int).

index_P
Index of bus active power mismatch (int).

index_Q
Index for bus reactive power mismatch (int).

index_v_ang
Index of voltage angle variable (int or array).

index_v_mag
Index of voltage magnitude variable (int or array).

index_vh
Index of voltage high limit violation variable (int or array).

index_vl
Index of voltage low limit violation variable (int or array).

index_y
Index of voltage magnitude positive deviation variable (int or array).

index_z
Index of voltage magnitude negative deviation variable (int or array).

is_equal (*self*, *other*)
Determines whether bus is equal to given bus.

Parameters other : `Bus`

is_regulated_by_gen (*self*)
Determines whether the bus is regulated by a generator.

Returns flag : {`True`, `False`}

is_regulated_by_shunt (*self*)
Determines whether the bus is regulated by a shunt device.

Returns flag : {`True`, `False`}

is_regulated_by_tran (*self*)
Determines whether the bus is regulated by a transformer.

Returns flag : {`True`, `False`}

is_slack (*self*)
Determines whether the bus is a slack bus.

Returns flag : {`True`, `False`}

loads
List of `loads` connected to this bus (list).

name
Bus name (sting).

num_periods
Number of time periods (int).

number
Bus number (int).

obj_type
Object type (string).

price
Bus energy price (float or array) ($ / (hr p.u.)).

reg_generators
List of `generators` regulating the voltage magnitude of this bus (list).

reg_gens
Same as `reg_generators`.

reg_shunts
List of `switched shunt devices` regulating the voltage magnitude of this bus (list).

reg_trans
List of `tap-changing transformers` regulating the voltage magnitude of this bus (list).

sens_P_balance
Objective function sensitivity with respect to bus active power balance (float or array).

sens_Q_balance
Objective function sensitivity with respect to bus reactive power balance (float or array).

sens_v_ang_l_bound
Objective function sensitivity with respect to voltage angle lower bound (float or array).

sens_v_ang_u_bound
Objective function sensitivity with respect to voltage angle upper bound (float or array).

sens_v_mag_l_bound
Objective function sensitivity with respect to voltage magnitude lower bound (float or array).

sens_v_mag_u_bound
Objective function sensitivity with respect to voltage magnitude upper bound (float or array).

sens_v_reg_by_gen
Objective function sensitivity with respect to bus voltage regulation by generators (float or array).

sens_v_reg_by_shunt
Objective function sensitivity with respect to bus voltage regulation by shunts (float or array).

sens_v_reg_by_tran
Objective function sensitivity with respect to bus voltage regulation by transformers (float or array).

set_price (*self*, *p*, *t=0*)
Sets bus energy price.

Parameters **p** : float

t : int

set_v_ang (*self*, *v*, *t=0*)
Sets bus voltage angle.

Parameters **v** : float

t : int

set_v_mag (*self*, *v*, *t=0*)
Sets bus voltage magnitude.

Parameters **v** : float

t : int

show (*self*, *t=0*)
Shows bus properties.

Parameters t : int (time period)

v_ang
Bus voltage angle (radians) (float or array).

v_mag
Bus volatge magnitude (p.u. bus base kv) (float or array).

v_max
Bus volatge upper bound (p.u. bus base kv) (float).

v_min
Bus voltage lower bound (p.u. bus base kv) (float).

v_set
Bus voltage set point (p.u. bus base kv) (float or array). Equals one if bus is not regulated by a generator.

var_generators
List of `variable generators` connected to this bus (list).

var_gens
Same as `var_generators`.

6.4 Branch

6.4.1 Branch Properties

'any'

'tap changer'

'tap changer - v' (controls voltage magnitude)

'tap changer - Q' (controls reactive flow)

'phase shifter'

'not on outage'

6.4.2 Branch Quantities

'all'

'phase shift'

'tap ratio'

'tap ratio deviation'

6.4.3 Branch Class

class pfnet.**Branch** (*num_periods=1*, *alloc=True*)
Branch class.

Parameters **alloc** : {`True`, `False`}

num_periods : int

`P_from_to`
Deprecated since version 1.2.5: Same as `P_km`.

`P_k_shunt`
Real power flow into the shunt element at bus "k" (aka "from") (p.u.) (float or array).

`P_km`
Real power flow at bus "k" towards bus "m" (from -> to) (p.u.) (float or array).

`P_km_DC`
Active power flow (DC approx.) from bus "k/from" to bus "m/to" (float).

`P_km_series`
Real power flow at bus "k" towards bus "m" over the series impedance of the line (from -> to) (p.u.) (float or array).

`P_m_shunt`
Real power flow into the shunt element at bus "m" (aka "to") (p.u.) (float or array).

`P_mk`
Real power flow at bus "m" towards bus "k" (to -> from) (p.u.) (float or array).

`P_mk_DC`
Active power flow (DC approx.) from bus "m/to" to bus "k/from" (float).

`P_mk_series`
Real power flow at bus "m" towards bus "k" over the series impedance of the line (to -> from) (p.u.) (float or array).

`P_series_from_to`
Deprecated since version 1.2.5: Same as `P_km_series`.

`P_series_to_from`
Deprecated since version 1.2.5: Same as `P_mk_series`.

`P_shunt_from`
Deprecated since version 1.2.5: Same as `P_k_shunt`.

`P_shunt_to`
Deprecated since version 1.2.5: Same as `P_m_shunt`.

`P_to_from`
Deprecated since version 1.2.5: Same as `P_mk`.

`Q_from_to`
Deprecated since version 1.2.5: Same as `Q_km`.

`Q_k_shunt`
Reactive power flow into the shunt element bus "k" (aka "from") (p.u.) (float or array).

`Q_km`
Reactive power flow at bus "k" towards bus "m" (from -> to) (p.u.) (float or array).

`Q_km_series`
Reactive power flow at bus "k" towards bus "m" over the series impedance of the line (from -> to) (p.u.) (float or array).

`Q_m_shunt`
Reactive power flow into the shunt element at bus "m" (aka "to") (p.u.) (float or array).

Q_mk
Reactive power flow at bus "m" towards bus "k" (to -> from) (p.u.) (float or array).

Q_mk_series
Reactive power flow at bus "m" towards bus "k" over the series impedance of the line (to -> from) (p.u.) (float or array).

Q_series_from_to
Deprecated since version 1.2.5: Same as `Q_km_series`.

Q_series_to_from
Deprecated since version 1.2.5: Same as `Q_mk_series`.

Q_shunt_from
Deprecated since version 1.2.5: Same as `Q_k_shunt`.

Q_shunt_to
Deprecated since version 1.2.5: Same as `Q_m_shunt`.

Q_to_from
Deprecated since version 1.2.5: Same as `Q_mk`.

b
Branch series susceptance (p.u.) (float).

b_from
Deprecated since version 1.2.5: Same as `b_k`.

b_k
Branch shunt susceptance at the "k" (aka "from" or "i") side (p.u.) (float).

b_m
Branch shunt susceptance at the "m" (aka "to" or "j") side (p.u.) (float).

b_to
Deprecated since version 1.2.5: Same as `b_m`.

bus_from
Deprecated since version 1.2.5: Same as `bus_k`.

bus_k
`Bus` connected to the "k" (aka "from" or "i") side.

bus_m
`Bus` connected to the "m" (aka "to" or "j") side.

bus_to
Deprecated since version 1.2.5: Same as `bus_m`.

g
Branch series conductance (p.u.) (float).

g_from
Deprecated since version 1.2.5: Same as `g_k`.

g_k
Branch shunt conductance at the "k" (aka "from" or "i") side (p.u.) (float).

g_m
Branch shunt conductance at the "m" (aka "to" or "j") side (p.u.) (float).

g_to
Deprecated since version 1.2.5: Same as `g_m`.

get_P_k_shunt (*self*, *var_values=None*)
Gets the real power flow into the shunt element at bus "k" (aka "from") (p.u.)

Parameters **var_values** : ndarray

Returns **P_k_shunt** : float or ndarray

get_P_km (*self*, *var_values=None*)
Gets the real power flow at bus "k" towards bus "m" (from -> to) (p.u.)

Parameters **var_values** : ndarray

Returns **P_km** : float or ndarray

get_P_km_series (*self*, *var_values=None*)
Gets the real power flow at bus "k" towards bus "m" over the series impedance of the line (from -> to) (p.u.)

Parameters **var_values** : ndarray

Returns **P_km_series** : float or ndarray

get_P_m_shunt (*self*, *var_values=None*)
Gets the real power flow into the shunt element at bus "m" (aka "to") (p.u.)

Parameters **var_values** : ndarray

Returns **P_m_shunt** : float or ndarray

get_P_mk (*self*, *var_values=None*)
Gets the real power flow at bus "m" towards bus "k" (to -> from) (p.u.)

Parameters **var_values** : ndarray

Returns **P_mk** : float or ndarray

get_P_mk_series (*self*, *var_values=None*)
Gets the real power flow at bus "m" towards bus "k" over the series impedance of the line (to -> from) (p.u.)

Parameters **var_values** : ndarray

Returns **P_mk_series** : float or ndarray

get_Q_k_shunt (*self*, *var_values=None*)
Gets the reactive power flow into the shunt element bus "k" (aka "from") (p.u.)

Parameters **var_values** : ndarray

Returns **Q_k_shunt** : float or ndarray

get_Q_km (*self*, *var_values=None*)
Gets the reactive power flow at bus "k" towards bus "m" (from -> to) (p.u.)

Parameters **var_values** : ndarray

Returns **Q_km** : float or ndarray

get_Q_km_series (*self*, *var_values=None*)
Gets the reactive power flow at bus "k" towards bus "m" over the series impedance of the line (from -> to) (p.u.)

Parameters **var_values** : ndarray

Returns **Q_km_series** : float or ndarray

get_Q_m_shunt (*self*, *var_values=None*)
Gets the reactive power flow into the shunt element at bus "m" (aka "to") (p.u.)

Parameters **var_values** : `ndarray`

Returns **Q_m_shunt** : float or `ndarray`

get_Q_mk (*self*, *var_values=None*)
Gets the reactive power flow at bus "m" towards bus "k" (to -> from) (p.u.)

Parameters **var_values** : `ndarray`

Returns **Q_mk** : float or `ndarray`

get_Q_mk_series (*self*, *var_values=None*)
Gets the reactive power flow at bus "m" towards bus "k" over the series impedance of the line (to -> from) (p.u.)

Parameters **var_values** : `ndarray`

Returns **Q_mk_series** : float or `ndarray`

has_flags (*self*, *flag_type*, *q*)
Determines whether the branch has the flags associated with specific quantities set.

Parameters **flag_type** : string (*Flag Types*)

q : string or list of strings (*Branch Quantities*)

Returns **flag** : {`True`, `False`}

has_pos_ratio_v_sens (*self*)
Determines whether tap-changing transformer has positive sensitivity between tap ratio and controlled bus voltage magnitude.

Returns **flag** : {`True`, `False`}

index
Branch index (int).

index_phase
Index of transformer phase shift variable (int or array).

index_ratio
Index of transformer tap ratio variable (int or array).

index_ratio_y
Index of transformer tap ratio positive deviation variable (int or array).

index_ratio_z
Index of transformer tap ratio negative deviation variable (int or array).

is_equal (*self*, *other*)
Determines whether branch is equal to given branch.

Parameters **other** : `Branch`

is_fixed_tran (*self*)
Determines whether branch is fixed transformer.

Returns **flag** : {`True`, `False`}

is_line (*self*)
Determines whether branch is transmission line.

Returns **flag** : {`True`, `False`}

is_on_outage(*self*)
Determines whether branch in on outage.

Returns flag : {True, False}

is_phase_shifter(*self*)
Determines whether branch is phase shifter.

Returns flag : {True, False}

is_tap_changer(*self*)
Determines whether branch is tap-changing transformer.

Returns flag : {True, False}

is_tap_changer_Q(*self*)
Determines whether branch is tap-changing transformer that regulates reactive power flow.

Returns flag : {True, False}

is_tap_changer_v(*self*)
Determines whether branch is tap-changing transformer that regulates bus voltage magnitude.

Returns flag : {True, False}

num_periods
Number of time periods (int).

obj_type
Object type (string).

outage
Flag that indicates whehter branch is on outage.

phase
Transformer phase shift (radians) (float or array).

phase_max
Transformer phase shift upper limit (radians) (float).

phase_min
Transformer phase shift lower limit (radians) (float).

ratingA
Branch thermal rating A (p.u. system base power) (float).

ratingB
Branch thermal rating B (p.u. system base power) (float).

ratingC
Branch thermal rating C (p.u. system base power) (float).

ratio
Transformer tap ratio (float or array).

ratio_max
Transformer tap ratio upper limit (float).

ratio_min
Transformer tap ratio lower limit (float).

reg_bus
Bus whose voltage is regulated by this tap-changing transformer.

sens_P_l_bound
Objective function sensitivity with respect to active power flow lower bound (float or array).

sens_P_u_bound
Objective function sensitivity with respect to active power flow upper bound (float or array).

6.5 Generator

6.5.1 Generator Properties

'any'

'slack'

'regulator'

'not slack'

'not regulator'

'not on outage'

'adjustable active power'

6.5.2 Generator Quantities

'all'

'active power'

'reactive power'

6.5.3 Generator Class

class pfnet.**Generator**(*num_periods=1*, *alloc=True*)
Generator class.

Parameters **alloc** : {True, False}

num_periods : int

P
Generator active power (p.u. system base MVA) (float or array).

P_cost
Active power generation cost ($/hr) (float or array).

P_max
Generator active power upper limit (p.u. system base MVA) (float).

P_min
Generator active power lower limit (p.u. system base MVA) (float).

P_prev
Generator active power during the previous time period (p.u. system base MVA) (float or array).

Q
Generator reactive power (p.u. system base MVA) (float or array).

Q_max
Generator reactive power upper limit (p.u. system base MVA) (float).

Q_min
Generator reactive power lower limit (p.u. system base MVA) (float).

bus
`Bus` to which generator is connected.

cost_coeff_Q0
Coefficient for genertion cost function (constant term, units of $/hr).

cost_coeff_Q1
Coefficient for genertion cost function (linear term, units of $/(hr p.u.)).

cost_coeff_Q2
Coefficient for genertion cost function (quadratic term, units of $/(hr p.u.^2)).

dP_max
Generator active power ramping limit (p.u. system base MVA) (float).

has_flags (*self*, *flag_type*, *q*)
Determines whether the generator has the flags associated with certain quantities set.

Parameters **flag_type** : string (*Flag Types*)

q : string or list of strings (*Generator Quantities*)

Returns **flag** : {`True`, `False`}

index
Generator index (int).

index_P
Index of generator active power variable (int or array).

index_Q
Index of generator reactive power variable (int or array).

is_P_adjustable (*self*)
Determines whether generator has adjustable active power.

Returns **flag** : {`True`, `False`}

is_equal (*self*, *other*)
Determines whether generator is equal to given generator.

Parameters **other** : `Generator`

is_on_outage (*self*)
Determines whether generator in on outage.

Returns **flag** : {`True`, `False`}

is_regulator (*self*)
Determines whether generator provides voltage regulation.

Returns **flag** : {`True`, `False`}

is_slack (*self*)
Determines whether generator is slack.

Returns **flag** : {`True`, `False`}

num_periods
Number of time periods (int).

obj_type
Object type (string).

outage
Flag that indicates whehter generator is on outage.

reg_bus
`Bus` whose voltage is regulated by this generator.

sens_P_l_bound
Objective function sensitivity with respect to active power lower bound (float or array).

sens_P_u_bound
Objective function sensitivity with respect to active power upper bound (float or array).

set_P (*self, P, t=0*)
" Sets active power.

Parameters **P** : float

t = int :

set_Q (*self, Q, t=0*)
" Sets reactive power.

Parameters **Q** : float

t = int :

6.6 Shunt

6.6.1 Shunt Properties

'any'

'switching - v' (controls voltage magnitude)

6.6.2 Shunt Quantities

'all'

'susceptance'

'susceptance deviation'

6.6.3 Shunt Class

class pfnet.**Shunt** (*num_periods=1, alloc=True*)
Shunt class.

Parameters **alloc** : {`True`, `False`}

num_periods : int

b
Shunt susceptance (p.u.) (float or array).

b_max
Shunt susceptance upper limit (p.u.) (float).

b_min
Shunt susceptance lower limit (p.u.) (float).

bus
Bus to which the shunt devices is connected.

g
Shunt conductance (p.u.) (float).

has_flags (*self*, *flag_type*, *q*)
Determines whether the shunt devices has flags associated with certain quantities set.

Parameters **flag_type** : string (*Flag Types*)

q : string or list of strings (*Bus Quantities*)

Returns **flag** : {True, False}

index
Shunt index (int).

index_b
Index of shunt susceptance variable (int or array).

index_y
Index of shunt susceptance positive deviation variable (int or array).

index_z
Index of shunt susceptance negative deviation variable (int or array).

is_fixed (*self*)
Determines whether the shunt device is fixed (as opposed to switched).

Returns **flag** : {True, False}

is_switched_v (*self*)
Determines whether the shunt is switchable and regulates bus voltage magnitude.

Returns **flag** : {True, False}

num_periods
Number of time periods (int).

obj_type
Object type (string).

reg_bus
Bus whose voltage magnitude is regulated by this shunt device.

6.7 Load

6.7.1 Load Properties

'any'

'adjustable active power'

6.7.2 Load Quantities

'all'

'active power'

6.7.3 Load Class

class pfnet.**Load**(*num_periods=1*, *alloc=True*)

Load class.

Parameters **alloc** : {True, False}

num_periods : int

P

Load active power (p.u. system base MVA) (float or array).

P_max

Load active power upper limit (p.u. system base MVA) (float).

P_min

Load active power lower limit (p.u. system base MVA) (float).

P_util

Active power load utility ($/hr) (float or array).

Q

Load reactive power (p.u. system base MVA) (float or array).

bus

Bus to which load is connected.

has_flags(*self*, *flag_type*, *q*)

Determines whether the load has the flags associated with certain quantities set.

Parameters **flag_type** : string (*Flag Types*)

q : string or list of strings (*Load Quantities*)

Returns **flag** : {True, False}

index

Load index (int).

index_P

Index of load active power variable (int or array).

is_P_adjustable(*self*)

Determines whether the load has adjustable active power.

Returns **flag** : {True, False}

num_periods

Number of time periods (int).

obj_type

Object type (string).

sens_P_l_bound

Objective function sensitivity with respect to active power lower bound (float or array).

sens_P_u_bound
Objective function sensitivity with respect to active power upper bound (float or array).

set_P (*self*, *P*, *t=0*)
" Sets active power.

Parameters P : float

t = int :

set_Q (*self*, *Q*, *t=0*)
" Sets reactive power.

Parameters Q : float

t = int :

util_coeff_Q0
Coefficient for consumption utility function (constant term, units of $/hr).

util_coeff_Q1
Coefficient for consumption utility function (linear term, units of $/(hr p.u.)).

util_coeff_Q2
Coefficient for consumption utility function (quadratic term, units of $/(hr p.u.^2)).

6.8 Variable Generator

6.8.1 Variable Generator Properties

'any'

6.8.2 Variable Generator Quantities

'all'

'active power'

'reactive power'

6.8.3 Variable Generator Class

class pfnet.**VarGenerator** (*num_periods=1*, *alloc=True*)
Variable generator class.

Parameters alloc : {True, False}

num_periods : int

P
Variable generator active power (p.u. system base MVA) (float or array).

P_max
Variable generator active power upper limit (p.u. system base MVA) (float).

P_min
Variable generator active power lower limit (p.u. system base MVA) (float).

P_std
Variable generator active power standard deviation (p.u. system base MVA) (float or array).

Q
Variable generator reactive power (p.u. system base MVA) (float or array).

Q_max
Variable generator maximum reactive power (p.u. system base MVA) (float).

Q_min
Variable generator minimum reactive power (p.u. system base MVA) (float).

bus
`Bus` to which variable generator is connected.

has_flags (*self*, *flag_type*, *q*)
Determines whether the variable generator has the flags associated with certain quantities set.

Parameters **flag_type** : string (*Flag Types*)

q : string or list of strings (*Variable Generator Quantities*)

Returns **flag** : {`True`, `False`}

index
Variable generator index (int).

index_P
Index of variable generator active power variable (int or array).

index_Q
Index of variable generator reactive power variable (int or array).

name
Variable generator name (string).

num_periods
Number of time periods (int).

obj_type
Object type (string).

set_P (*self*, *P*, *t=0*)
" Sets active power.

Parameters **P** : float

t = int :

set_P_std (*self*, *P*, *t=0*)
" Sets active power standard deviation.

Parameters **P** : float

t = int :

set_Q (*self*, *Q*, *t=0*)
" Sets reactive power.

Parameters **Q** : float

t = int :

6.9 Battery

6.9.1 Battery Properties

'any'

6.9.2 Battery Quantities

'all'

'charging power'

'energy level'

6.9.3 Battery Class

class `pfnet.Battery`(*num_periods=1*, *alloc=True*)

Battery class.

Parameters **alloc** : {`True`, `False`}

num_periods : int

E

Battery energy level at the beginning of a period (p.u. system base MVA times time unit) (float or array).

E_final

Battery energy level at the end of the last period (p.u. system base MVA times time unit) (float).

E_init

Initial battery energy level (p.u. system base MVA times time unit) (float).

E_max

Battery energy level upper limit (p.u. system base MVA times time unit) (float).

P

Battery charging power (p.u. system base MVA) (float or array).

P_max

Battery charging power upper limit (p.u. system base MVA) (float).

P_min

Battery charging power lower limit (p.u. system base MVA) (float).

bus

`Bus` to which battery is connected.

eta_c

Battery charging efficiency (unitless) (float).

eta_d

Battery discharging efficiency (unitless) (float).

has_flags(*self*, *flag_type*, *q*)

Determines whether the battery has the flags associated with certain quantities set.

Parameters **flag_type** : string (*Flag Types*)

q : string or list of strings (*Battery Quantities*)

Returns **flag** : {`True`, `False`}

`index`
Battery index (int).

`index_E`
Index of battery energy level variable (int or array).

`index_Pc`
Index of battery charging power variable (int or array).

`index_Pd`
Index of battery discharging power variable (int or array).

`num_periods`
Number of time periods (int).

`obj_type`
Object type (string).

`set_E` (*self*, *E*, *t=0*)
Sets battery energy level.

Parameters **E** : float

t : int

`set_P` (*self*, *P*, *t=0*)
Sets battery charging power.

Parameters **P** : float

t : int

6.10 Network

6.10.1 Component Types

`'all'`

`'bus'`

`'generator'`

`'branch'`

`'shunt'`

`'load'`

`'variable generator'`

`'battery'`

`'unknown'`

6.10.2 Flag Types

`'variable'`
For selecting quantities to be variables.

'fixed'
For selecting variables to be fixed.

'bounded'
For selecting variables to be bounded.

'sparse'
For selecting control adjustments to be sparse.

6.10.3 Variable Value Options

'current'

'upper limits'

'lower limits'

6.10.4 Network Class

class pfnet.**Network**(*num_periods=1*, *alloc=True*)
Network class.

Parameters **alloc** : {True, False}

num_periods : int

add_vargens(*self*, *buses*, *penetration*, *uncertainty*, *corr_radius*, *corr_value*)
Adds variable generators to the network.

Parameters **buses** : list of Buses

penetration : float

percentage

uncertainty : float

percentage

corr_radius : int

number of branches

corr_value : float

correlation coefficient

adjust_generators(*self*)
Adjusts powers of slack and regulator generators connected to or regulating the same bus to correct generator participations without modifying the total power injected.

base_power
System base power (MVA) (float).

bats
Same as batteries.

batteries
List of network batteries (list).

branches
List of network branches (list).

bus_P_mis
Largest bus active power mismatch in the network (MW) (float or array).

bus_Q_mis
Largest bus reactive power mismatch in the network (MVAr) (float or array).

bus_v_max
Maximum bus voltage magnitude (p.u.) (float or array).

bus_v_min
Minimum bus voltage magnitude (p.u.) (float or array).

bus_v_vio
Maximum bus voltage magnitude limit violation (p.u.) (float or array).

buses
List of network `buses` (list).

clear_error (*self*)
Clear error flag and message string.

clear_flags (*self*)
Clears all the flags of all the network components.

clear_properties (*self*)
Clears all the network properties.

clear_sensitivities (*self*)
Clears all sensitivity information.

create_sorted_bus_list (*self*, *sort_by*, *t=0*)
Creates list of buses sorted in descending order according to a specific quantity.

Parameters **sort_by** : int (*Bus Sensitivities*, *Bus Power Mismatches*).

t : int

Returns **buses** : list of `Buses`

create_vargen_P_sigma (*self*, *spread*, *corr*)
Creates covariance matrix (lower triangular part) for variable vargen active powers.

Parameters **spead** : int

Determines correlation neighborhood in terms of number of edges.

corr : float

Desired correlation coefficient for neighboring vargens.

Returns **sigma** : `coo_matrix`

gen_P_cost
Total active power generation cost ($/hr) (float or array).

gen_P_vio
Largest generator active power limit violation (MW) (float or array).

gen_Q_vio
Largest generator reactive power limit violation (MVAr) (float or array).

gen_v_dev
Largest voltage magnitude deviation from set point of bus regulated by generator (p.u.) (float or array).

generators
List of network `generators` (list).

gens
Same as `generators`

get_bat (*self*, *index*)
Gets battery with the given index.

Parameters **index** : int

Returns **bat** : `Battery`

get_branch (*self*, *index*)
Gets branch with the given index.

Parameters **index** : int

Returns **branch** : `Branch`

get_bus (*self*, *index*)
Gets bus with the given index.

Parameters **index** : int

Returns **bus** : `Bus`

get_bus_by_name (*self*, *name*)
Gets bus with the given name.

Parameters **name** : string

Returns **bus** : `Bus`

get_bus_by_number (*self*, *number*)
Gets bus with the given number.

Parameters **number** : int

Returns **bus** : `Bus`

get_gen (*self*, *index*)
Gets generator with the given index.

Parameters **index** : int

Returns **gen** : `Generator`

get_gen_buses (*self*)
Gets list of buses where generators are connected.

Returns **buses** : list

get_load (*self*, *index*)
Gets load with the given index.

Parameters **index** : int

Returns **gen** : `Load`

get_load_buses (*self*)
Gets list of buses where loads are connected.

Returns **buses** : list

get_num_P_adjust_gens (*self*)
Gets number of generators in the network that have adjustable active powers.

Returns **num** : int

get_num_P_adjust_loads (*self*)
Gets number of loads in the network that have adjustable active powers.

Returns **num** : int

get_num_bats (*self*)
Same as `get_num_batteries`.

get_num_batteries (*self*)
Gets number of batteries in the network.

Returns **num** : int

get_num_branches (*self*)
Gets number of branches in the network.

Returns **num** : int

get_num_branches_not_on_outage (*self*)
Gets number of branches in the network that are not on outage.

Returns **num** : int

get_num_buses (*self*)
Gets number of buses in the network.

Returns **num** : int

get_num_buses_reg_by_gen (*self*)
Gets number of buses whose voltage magnitudes are regulated by generators.

Returns **num** : int

get_num_buses_reg_by_shunt (*self*, *only=False*)
Gets number of buses whose voltage magnitudes are regulated by switched shunt devices.

Returns **num** : int

get_num_buses_reg_by_tran (*self*, *only=False*)
Gets number of buses whose voltage magnitudes are regulated by tap-changing transformers.

Returns **num** : int

get_num_fixed_shunts (*self*)
Gets number of fixed shunts in the network.

Returns **num** : int

get_num_fixed_trans (*self*)
Gets number of fixed transformers in the network.

Returns **num** : int

get_num_generators (*self*)
Gets number of generators in the network.

Returns **num** : int

get_num_gens (*self*)
Same as `get_num_generators`.

get_num_gens_not_on_outage (*self*)
Gets number of generators in the network that are not on outage.

Returns **num** : int

get_num_lines (*self*)
Gets number of transmission lines in the network.

Returns num : int

get_num_loads (*self*)
Gets number of loads in the network.

Returns num : int

get_num_phase_shifters (*self*)
Gets number of phase-shifting transformers in the network.

Returns num : int

get_num_reg_gens (*self*)
Gets number generators in the network that provide voltage regulation.

Returns num : int

get_num_shunts (*self*)
Gets number of shunts in the network.

Returns num : int

get_num_slack_buses (*self*)
Gets number of slack buses in the network.

Returns num : int

get_num_slack_gens (*self*)
Gets number of slack generators in the network.

Returns num : int

get_num_switched_shunts (*self*)
Gets number of switched shunts in the network.

Returns num : int

get_num_tap_changers (*self*)
Gets number of tap-changing transformers in the network.

Returns num : int

get_num_tap_changers_Q (*self*)
Gets number of tap-changing transformers in the network that regulate reactive flows.

Returns num : int

get_num_tap_changers_v (*self*)
Gets number of tap-changing transformers in the network that regulate voltage magnitudes.

Returns num : int

get_num_var_generators (*self*)
Gets number of variable generators in the network.

Returns num : int

get_num_var_gens (*self*)
Same as `get_num_var_generators`.

get_properties (*self*)
Gets network properties.

Returns properties : dict

get_shunt (*self*, *index*)
Gets shunt with the given index.

Parameters index : int

Returns gen : `Shunt`

get_var_projection (*self*, *obj_type*, *q*, *t_start=0*, *t_end=None*)
Gets projection matrix for specific object variables.

Parameters obj_type : string (*Component Types*)

q : string or list of strings (*Bus Quantities*, *Branch Quantities*, *Generator Quantities*, *Shunt Quantities*, *Load Quantities*, *Variable Generator Quantities*, *Battery Quantities*)

t_start : int

t_end : int (inclusive)

get_var_values (*self*, *option='current'*)
Gets network variable values.

Parameters option : string (See var values)

Returns values : `ndarray`

get_vargen (*self*, *index*)
Gets variable generator with the given index.

Parameters index : int

Returns vargen : `VarGenerator`

get_vargen_by_name (*self*, *name*)
Gets vargen with the given name.

Parameters name : string

Returns vargen : `VarGenerator`

has_error (*self*)
Indicates whether the network has the error flag set due to an invalid operation.

Returns flag : {`True`, `False`}

load (*self*, *filename*, *output_level=0*)
Loads a network data contained in a specific file.

Parameters filename : string

output_level : int

load_P_util
Total active power consumption utility ($/hr) (float or array).

load_P_vio
Largest load active power limit violation (MW) (float or array).

loads
List of network `loads` (list).

num_actions
Number of control adjustments (int or array).

num_bats
Same as `num_batteries`.

num_batteries
Number of batteries in the network (int).

num_bounded
Number of network quantities that have been set to bounded (int).

num_branches
Number of branches in the network (int).

num_buses
Number of buses in the network (int).

num_fixed
Number of network quantities that have been set to fixed (int).

num_generators
Number of generators in the network (int).

num_gens
Same as `num_generators`.

num_loads
Number of loads in the network (int).

num_periods
Number of time periods (int).

num_shunts
Number of shunt devices in the network (int).

num_sparse
Number of network control quantities that have been set to sparse (int).

num_var_generators
Number of variable generators in the network (int).

num_vargens
Same as `num_var_generators`.

num_vars
Number of network quantities that have been set to variable (int).

set_flags (*self*, *obj_type*, *flags*, *props*, *q*)
Sets flags of network components with specific properties.

Parameters **obj_type** : string (*Component Types*)

flags : string or list of strings (*Flag Types*)

props : string or list of strings (*Bus Properties*, *Branch Properties*, *Generator Properties*, *Shunt Properties*, *Load Properties*, *Variable Generator Properties*, *Battery Properties*)

q : string or list of strings (*Bus Quantities*, *Branch Quantities*, *Generator Quantities*, *Shunt Quantities*, *Load Quantities*, *Variable Generator Quantities*, *Battery Quantities*)

set_flags_of_component (*self*, *obj*, *flags*, *q*)
Sets flags of network components with specific properties.

Parameters **obj** : `Bus`, `Branch`, `Generator`, `Load`, `Shunt`, `VarGenerator`, `Battery`

flags : string or list of strings (*Flag Types*)

q : string or list of strings (*Bus Quantities*, *Branch Quantities*, *Generator Quantities*, *Shunt Quantities*, *Load Quantities*, *Variable Generator Quantities*, *Battery Quantities*)

set_var_values (*self*, *values*)
: Sets network variable values.

    Parameters **values** : ndarray

show_buses (*self*, *number*, *sort_by*, *t=0*)
: Shows information about the most relevant network buses sorted by a specific quantity.

    Parameters **number** : int

    sort_by : int (*Bus Sensitivities*, *Bus Power Mismatches*)

    t : int (time period)

show_components (*self*)
: Shows information about the number of network components of each type.

show_properties (*self*, *t=0*)
: Shows information about the state of the network component quantities.

    Parameters **t** : int (time period)

shunt_b_vio
: Largest switched shunt susceptance limit violation (p.u.) (float or array).

shunt_v_vio
: Largest voltage magnitude band violation of voltage regulated by switched shunt device (p.u.) (float or array).

shunts
: List of network shunts (list).

tran_p_vio
: Largest transformer phase shift limit violation (float or array).

tran_r_vio
: Largest transformer tap ratio limit violation (float or array).

tran_v_vio
: Largest voltage magnitude band violation of voltage regulated by transformer (p.u.) (float or array).

update_properties (*self*, *values=None*)
: Re-computes the network properties using the given values of the network variables. If no values are given, then the current values of the network variables are used.

    Parameters **values** : ndarray

update_set_points (*self*)
: Updates voltage magnitude set points of gen-regulated buses to be equal to the bus voltage magnitudes.

var_generators
: List of network variable generators (list).

var_gens
: Same as var_generators.

vargen_corr_radius
: Correlation radius of variable generators (number of edges).

vargen_corr_value
: Correlation value (coefficient) of variable generators.

6.11 Contingency

class pfnet.**Contingency**(*gens=None*, *branches=None*, *alloc=True*)

Contingency class.

Parameters **gens** : list or `Generators`

branches : list `Branchs`

alloc : {`True`, `False`}

add_branch_outage(*self*, *br*)

Adds branch outage to contingency.

Parameters **br** : `Branch`

add_gen_outage(*self*, *gen*)

Adds generator outage to contingency.

Parameters **gen** : `Generator`

apply(*self*)

Applies outages that characterize contingency.

clear(*self*)

Clears outages that characterize contingency.

has_branch_outage(*self*, *br*)

Determines whether contingency specifies the given branch as being on outage.

Parameters **branch** : `Branch`

Returns **result** : {`True`, `False`}

has_gen_outage(*self*, *gen*)

Determines whether contingency specifies the given generator as being on outage.

Parameters **gen** : `Generator`

Returns **result** : {`True`, `False`}

num_branch_outages

Number of branch outages.

num_gen_outages

Number of generator outages.

show(*self*)

Shows contingency information.

6.12 Graph

class pfnet.**Graph**(*net*, *alloc=True*)

Graph class.

Parameters **net** : `Network`

alloc : {`True`, `False`}

clear_error(*self*)

Clear error flag and message string.

color_nodes_by_mismatch (*self*, *mis_type*, *t=0*)
Colors the graphs nodes according to their power mismatch.

Parameters **mis_type** : int (*Bus Power Mismatches*)

t : int

color_nodes_by_sensitivity (*self*, *sens_type*, *t=0*)
Colors the graphs nodes according to their sensitivity.

Parameters **sens_type** : int (*Bus Sensitivities*)

t : int

has_error (*self*)
Indicates whether the graph has the error flag set due to an invalid operation.

has_viz (*self*)
Determines whether graph has visualization capabilities.

Returns **flag** : {`True`, `False`}

set_edges_property (*self*, *prop*, *value*)
Sets property of edges. See Graphviz documentation.

Parameters **prop** : string

value : string

set_layout (*self*)
Determines and saves a layout for the graph nodes.

set_node_property (*self*, *bus*, *prop*, *value*)
Sets property of node. See Graphviz documentation.

Parameters **bus** : `Bus`

prop : string

value : string

set_nodes_property (*self*, *prop*, *value*)
Sets property of nodes. See Graphviz documentation.

Parameters **prop** : string

value : string

view (*self*, *inline=False*)
Displays the graph.

write (*self*, *format*, *filename*)
Writes the graph to a file.

Parameters **format** : string (Graphviz output formats)

filename : string

6.13 Function

6.13.1 Function Types

'voltage magnitude regularization'

'voltage angle regularization'

'generator powers regularization'

'tap ratio regularization'

'phase shift regularization'

'susceptance regularization'

'generation cost'

'sparse controls penalty'

'soft voltage magnitude limits'

'consumption utility'

'net consumption cost'

6.13.2 Function Class

class `pfnet.`**`Function`**(*ftype*, *weight*, *Network net*, *alloc=True*)

Function class.

Parameters **ftype** : string (*Function Types*)

weight : float

net : `Network`

alloc : {`True`, `False`}

`Hcounter`

Number of nonzero entries in Hessian matrix (int).

`Hphi`

Function Hessian matrix (only the lower triangular part) (`coo_matrix`).

`analyze`(*self*)

Analyzes function and allocates required vectors and matrices.

`clear_error`(*self*)

Clears error flag and string.

`del_matvec`(*self*)

Deletes matrices and vectors associated with this function.

`eval`(*self*, *var_values*)

Evaluates function value, gradient, and Hessian using the given variable values.

Parameters **var_values** : `ndarray`

`gphi`

Function gradient vector (`ndarray`).

`phi`

Function value (float).

`type`

Function type (string) (*Function Types*).

`update_network`(*self*)

Updates internal arrays to be compatible with any network changes.

weight
Function weight (float).

6.14 Constraint

6.14.1 Constraint Types

'AC power balance'

'DC power balance'

'linearized AC power balance'

'variable fixing'

'variable nonlinear bounds'

'generator active power participation'

'generator reactive power participation'

'voltage regulation by generators'

'voltage regulation by transformers'

'voltage regulation by shunts'

'DC branch flow limits'

'variable bounds'

'generator ramp limits'

6.14.2 Constraint Class

class `pfnet.`**`Constraint`** (*ctype*, *Network net*, *alloc=True*)
Contraint class.

Parameters **ctype** : string (*Constraint Types*)

net : `Network`

alloc : {`True`, `False`}

A
Matrix for linear equality constraints (`coo_matrix`).

Aconstr_index
Index of linear equality constraint (int).

Acounter
Number of nonzero entries in the matrix of linear equality constraints (int).

G
Matrix for linear inequality constraints (`coo_matrix`).

Gconstr_index
Index of linear ineqquality constraint (int).

Gcounter
Number of nonzero entries in the matrix of linear inequality constraints (int).

H_combined
Linear combination of Hessian matrices of individual nonlinear equality constraints (only the lower triangular part) (coo_matrix).

J
Jacobian matrix of nonlinear equality constraints (coo_matrix).

Jconstr_index
Index of nonlinear equality constraint (int).

Jcounter
Number of nonzero entries in the Jacobian matrix of the nonlinear equality constraints (int).

analyze (*self*)
Analyzes constraint and allocates required vectors and matrices.

b
Right-hand side vector of linear equality constraints (ndarray).

clear_error (*self*)
Clears error flag and string.

combine_H (*self*, *coeff*, *ensure_psd=False*)
Forms and saves a linear combination of the individual constraint Hessians.

Parameters **coeff** : ndarray

ensure_psd : {True, False}

del_matvec (*self*)
Deletes matrices and vectors associated with this constraint.

eval (*self*, *var_values*)
Evaluates constraint violations, Jacobian, and individual Hessian matrices.

Parameters **var_values** : ndarray

f
Vector of nonlinear equality constraint violations (ndarray).

get_H_single (*self*, *i*)
Gets the Hessian matrix (only lower triangular part) of an individual constraint.

Parameters **i** : int

Returns **H** : coo_matrix

l
Lower bound vector of linear inequality constraints (ndarray).

store_sensitivities (*self*, *sA*, *sf*, *sGu*, *sGl*)
Stores Lagrange multiplier estimates of the constraints in the power network components.

Parameters **sA** : ndarray

sensitivities for linear equality constraints ($Ax = b$)

sf : ndarray

sensitivities for nonlinear equality constraints ($f(x) = 0$)

sGu : ndarray

sensitivities for linear inequality constraints ($Gx \leq u$)

sGl : ndarray

sensitivities for linear inequality constraints ($l \leq Gx$)

type
Constraint type (string) (*Constraint Types*).

u
Upper bound vector of linear inequality constraints (`ndarray`).

update_network (*self*)
Updates internal arrays to be compatible with any network changes.

6.15 Optimization Problem

6.15.1 Problem Class

class `pfnet.`**Problem**
Optimization problem class.

A
Constraint matrix of linear equality constraints (`coo_matrix`).

G
Constraint matrix of linear inequality constraints (`coo_matrix`).

H_combined
Linear combination of Hessian matrices of individual nonlinear equality constraints (only the lower triangular part) (`coo_matrix`).

Hphi
Objective function Hessian matrix (only the lower triangular part) (`coo_matrix`).

J
Jacobian matrix of the nonlinear equality constraints (`coo_matrix`).

add_constraint (*self*, *ctype*)
Adds constraint to optimization problem.

Parameters **ctype** : string (*Constraint Types*)

add_function (*self*, *ftype*, *weight*)
Adds function to optimization problem objective.

Parameters **ftype** : string (*Function Types*)

weight : float

analyze (*self*)
Analyzes function and constraint structures and allocates required vectors and matrices.

b
Right hand side vectors of the linear equality constraints (`ndarray`).

clear (*self*)
Resets optimization problem data.

clear_error (*self*)
Clears error flag and string.

combine_H (*self*, *coeff*, *ensure_psd=False*)
Forms and saves a linear combination of the individual constraint Hessians.

Parameters **coeff** : `ndarray`

ensure_psd : {`True`, `False`}

constraints
List of `constraints` of this optimization problem (list).

eval (*self*, *var_values*)
Evaluates objective function and constraints as well as their first and second derivatives using the given variable values.

Parameters **var_values** : `ndarray`

f
Vector of nonlinear equality constraints violations (`ndarray`).

find_constraint (*self*, *ctype*)
Finds constraint of give type among the constraints of this optimization problem.

Parameters **type** : string (*Constraint Types*)

functions
List of `functions` that form the objective function of this optimization problem (list).

get_init_point (*self*)
Gets initial solution estimate from the current value of the network variables.

Returns **point** : `ndarray`

get_lower_limits (*self*)
Gets vector of lower limits for the network variables.

Returns **limits** : `ndarray`

get_network (*self*)
Gets the power network associated with this optimization problem.

get_num_linear_equality_constraints (*self*)
Gets number of linear equality constraints.

Returns **num** : int

get_num_nonlinear_equality_constraints (*self*)
Number of nonlinear equality constraints.

Returns **num** : int

get_num_primal_variables (*self*)
Gets number of primal variables.

Returns **num** : int

get_upper_limits (*self*)
Gets vector of upper limits for the network variables.

Returns **limits** : `ndarray`

gphi
Objective function gradient vector (`ndarray`).

has_error (*self*)
Indicates whether the problem has the error flag set due to an invalid operation.

Returns **flag** : {`True`, `False`}

l
Lower bound for linear inequality constraints (ndarray).

lam
Initial dual point (ndarray).

network
Power network associated with this optimization problem (Network).

nu
Initial dual point (ndarray).

num_linear_equality_constraints
Number of linear equality constraints (int).

num_nonlinear_equality_constraints
Number of nonlinear equality constraints (int).

num_primal_variables
Number of primal variables (int).

phi
Objective function value (float).

set_network (*self*, *net*)
Sets the power network associated with this optimization problem.

show (*self*)
Shows information about this optimization problem.

store_sensitivities (*self*, *sA*, *sf*, *sGu*, *sGl*)
Stores Lagrange multiplier estimates of the constraints in the power network components.

Parameters **sA** : ndarray

sensitivities for linear equality constraints ($Ax = b$)

sf : ndarray

sensitivities for nonlinear equality constraints ($f(x) = 0$)

sGu : ndarray

sensitivities for linear inequality constraints ($Gx \leq u$)

sGl : ndarray

sensitivities for linear inequality constraints ($l \leq Gx$)

u
Upper bound for linear inequality constraints (ndarray).

update_lin (*self*)
Updates linear equality constraints.

x
Initial primal point (ndarray).

6.16 References

CHAPTER SEVEN

INDICES AND TABLES

- *genindex*
- *modindex*
- *search*

[TTR2015] T. Tinoco De Rubira, *Numerical Optimization and Modeling Techniques for Power System Operations and Planning*. PhD thesis, Stanford University, March 2015.

PYTHON MODULE INDEX

p

PYTHON MODULE INDEX

p

A

B

C

D

E

F

G

H

I

J

L

N

O

P

Q

R

S

T

U

V

W

X