SuperOPF Framework:

Full AC network Integrated Core Solver (BSI-SuperOPF)

User Guide

Version 4.5

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BSI

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Section 1. **Introduction Full AC network Integrated Core Solver (BSI-SuperOPF)**

Security constrained optimal power flow programs are important tools for ensuring correct dispatch of supply while respecting the many constraints imposed by the delivery system power grid. Current state-of-the art production-grade tools typically break the relevant optimization problems down into sequences of sub-problems, often using DC approximations to model the transmission and replace voltage and adequacy requirements with corresponding proxy constraints. Given the deregulated power market, this approach can obscure real weakness in the power system.

Previous research has been done to create a framework called SuperOPF that provides proper allocation and valuation of resources through true co-optimization across multiple scenarios with a full AC network implemented in research-grade software code. The current SuperOPF implementation currently lacks certain functional and performance capabilities necessary for a tool to be adopted in the energy industry. The research and development under this work addresses these issues for the SuperOPF core solver component. The core solver is the computational engine to process the optimization problem under the SuperOPF framework.

The BSI-SuperOPF is a production-grade software (fast, robust) implementation of a core solver integrated in the SuperOPF Framework. The work includes handling utility industry standard network models, data management for SuperOPF constructs, handling of control variables for real and reactive power and support for objective functions of cost, losses and minimum violations of target voltage profiles. Besides these conventional aspects, the BSI-SuperOPF also possesses the capability of handling static and dynamic stability requirements, handling contingent and varying load and generation scenarios, and handling renewable energy penetrations.

Section 2. **BSI-SuperOPF Getting Started**

A. Using BSI-SuperOPF – Overview

The basic principles used as guidelines for the user interface design are as follows.

- Tool button selections are divided into two categories by function and are located in two areas of the main window. A toolbar strip in the upper part is for selection of program action. The buttons near the lower border of the window are for selection of the data display.
- The Top-level Menu area lists all actions and configurations. An adaptive right-click menu (brought up by a right mouse click is tailored for specific action)
- Displays are organized in three levels.
  - The first level has two components, the top panel for summary information and the lower panel for detailed information for the Interface selected in the summary area.
  - The second level lists more detailed information.
  - The third level lists control results when user applies new controls.
- Clicking of the index-style tab button connected to specific information is used to navigate among parallel information displays; for example, ____

B. Launching BSI-SuperOPF

A user starts BSI-SuperOPF by clicking the desktop icon shown here.

SuperOPF

BsiOpfGui

A splash screen is first showed up when the BSI-SuperOPF program is started, where the program detail name, version, and sponsor information are presented. Specifically, the development of BSI-SuperOPF is sponsored by the U.S. Department of Energy in partnership with Lawrence Berkeley National Laboratory / CERTS, Bigwood Systems Inc. and Cornell University.

Figure: SuperOPF splash screen prior to loading the main window

The main window of the SuperOPF program will be started by clicking the button "Start BSI SuperOPF" on the splash screen. The main window of the SuperOPF consists of two major parts, namely the running message console window and the program main form.

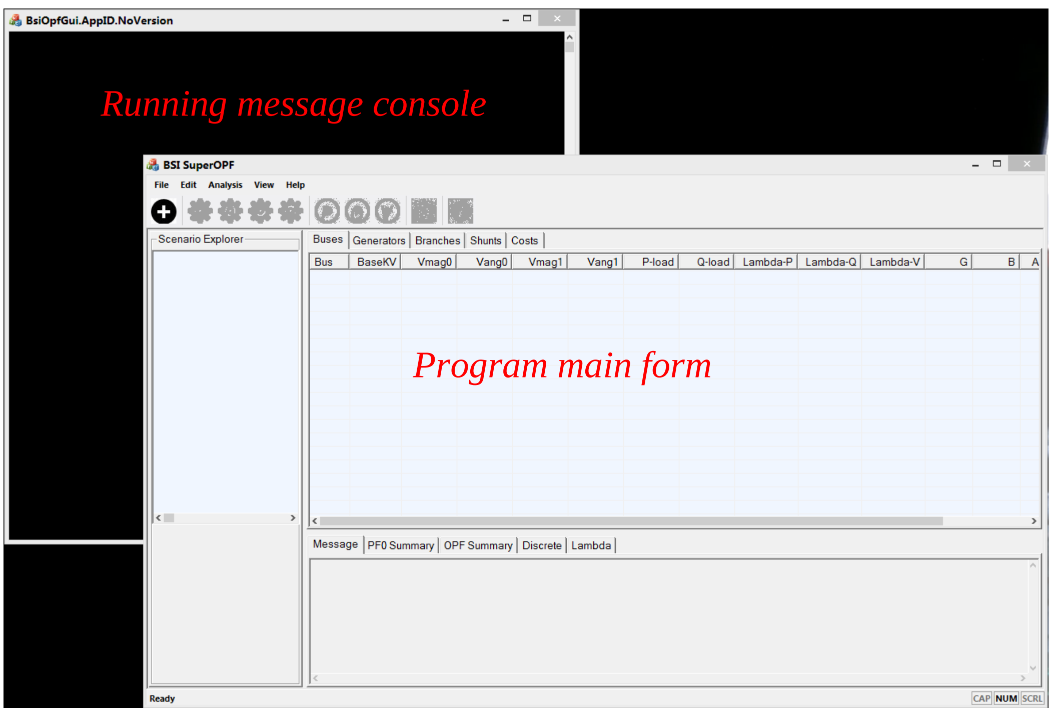


Figure: SuperOPF Main Window prior to loading a case

C. *Top-level (Main) Menu Bar*

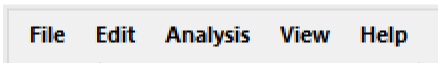


Figure: Menu Bar

The top-level (main) menu bar contains the following menus:

- File
- Edit
- Analysis
- View
- Help

Section 3. FILE Menu

These menu selections provide access to the BSI-SuperOPF run and data initialization functions.

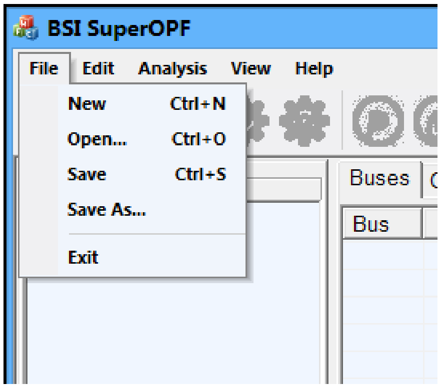


Figure: File menu

3.1 File New

The “File New” selection creates a new user window allowing the user to create an OPF study case directly through the BSI-SuperOPF user-interface.

3.2 File Open

The “File Open” selection brings up a sub-menu window. By default, the dialog allows you to browse your computer’s file system and open the Case Power Flow File, Case OPF Specification File, Case Cost File, Case Scenario Specification File, and Case Voltage Stability Analysis (VSA) configuration files for creating a new SuperOPF study you wish to analyze.

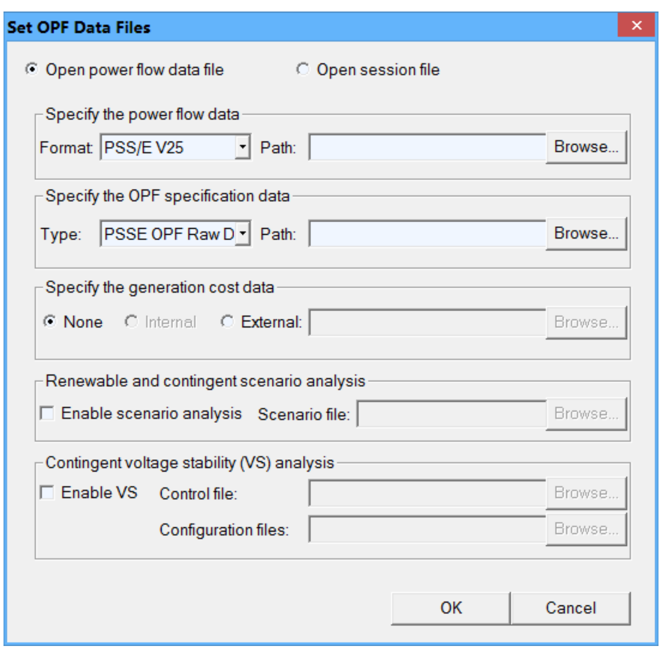


Figure: Set OPF data file dialog

The available options for power flow data formats including PSS/E version 25, PSS/E version 30, PSS/E version 33, MATPOWER version 1, MATPOWER version 2, and AMPL data format. OPF related data, such as the adjustable controls, voltage limits, cost functions, and generation constraints, is provided in the OPF specification data. Optionally, the generation cost file, to be used for minimizing system generation costs, can be internally specified in the power flow file (for MATPOWER power flow files) or can be specified as an external cost file. When the browser button for power flow files is clicked, a File Open Window will show up.

File Open Window

In the "File Open" window, first select the format of the system file you are loading and click on the "three-dot browse" icon to bring up a typical Microsoft Windows file open panel. From this window, you can browse the system file folder on your computer.

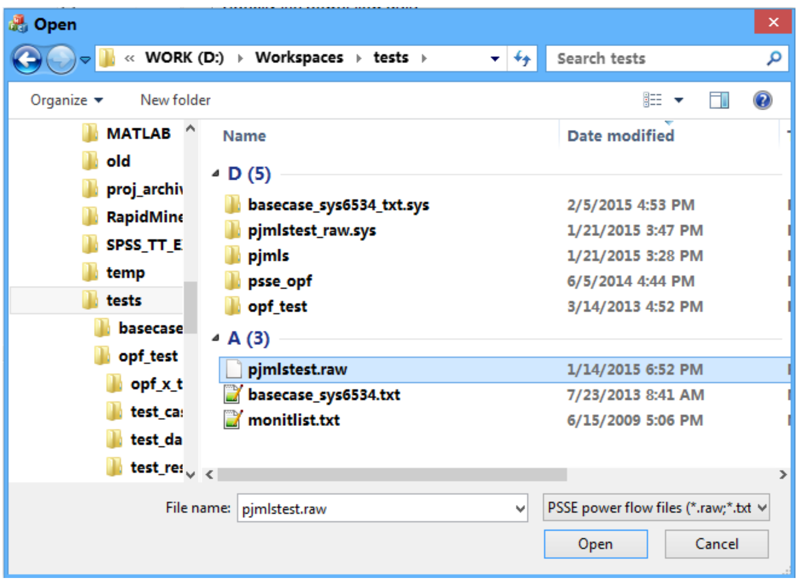


Figure: Select power flow data file dialog

Once you have located the system file you wish to use, select it and click the "open" button. To dismiss the window without creating a new OPF study case, click the "Cancel" button.

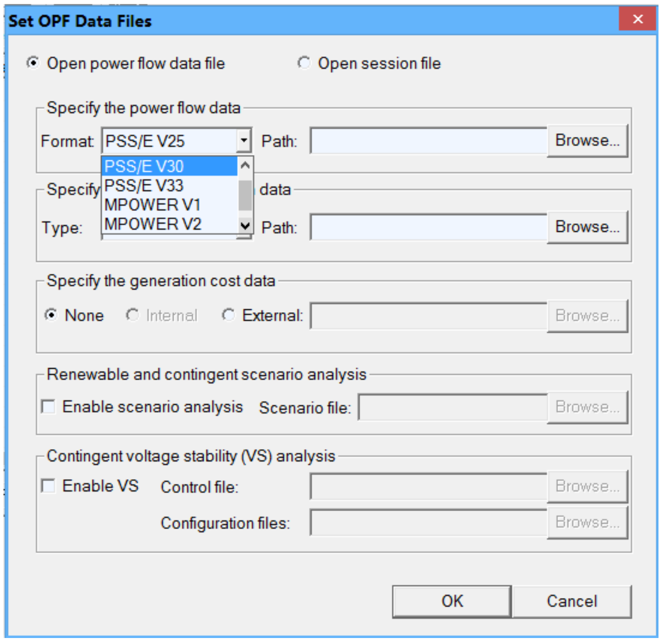


Figure: Select power flow file format

In a similar fashion locate and open the OPF specification data file. The OPF specification data file can be in the PSS/E OPF raw data file format, which is a comprehensive OPF data file. An exemplar PSS/E OPF raw data file is presented in the appendix. The OPF specification data can also be in the format of the system monitor list. This file only specifies the bus voltage limits and branches to be monitored (to be enforced with thermal limit constraints). An exemplar system monitor list file is presented in the appendix.

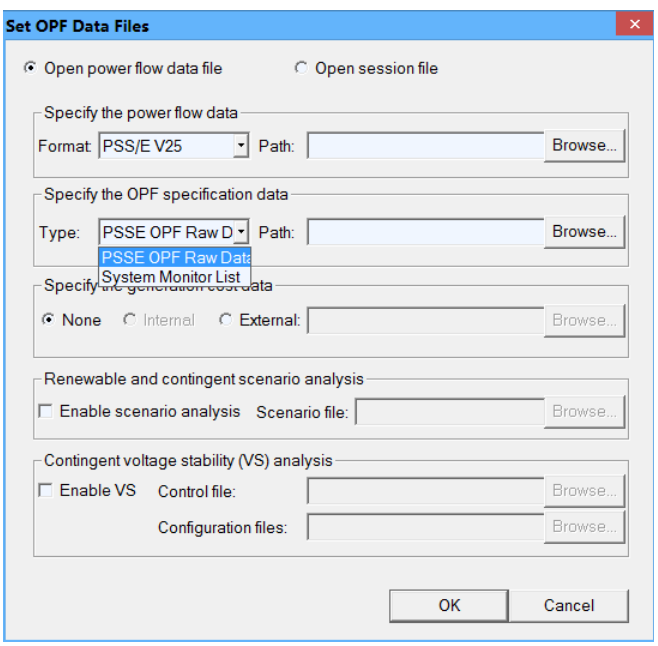


Figure: Select OPF specification file format

The generation cost file can be specified in the PSS/E OPF raw data file. It can also be specified in a separate Cost file. In a similar fashion locate and open the Cost file for the analysis. Click "OK" to load the file and populate the main window with the analysis case.

Instead of opening power flow and/or cost data files for creating a new OPF study case, an OPF study case can also be loaded by opening a session file. A previously performed OPF study will be restored by loading an associated session file.

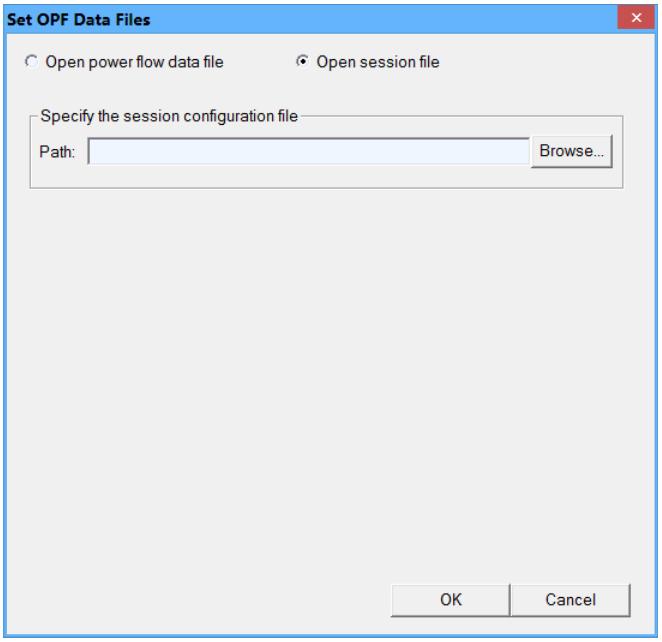


Figure: Open session file

An OPF study session file is used to record all configurations and status for an OPF study case, including the input data files (with their full paths), computation settings, status of the study, and output files (with their full paths). A session file is stored in background automatically when a new OPF study case is created after loading the power flow and/or cost data files and is updated whenever changes have been made on the settings for the OPF study. Therefore, a session file provides a snapshot for the final states of a previously-performed OPF study. When the browser button for session files is clicked, a File Open Window will show up.

File Open Window

In the "File Open" window, click on the "three-dot browse" icon to bring up a typical Microsoft Windows file open panel. From this window, you can browse the system file folder on your computer. By default, an OPF session file is of extension .ses.

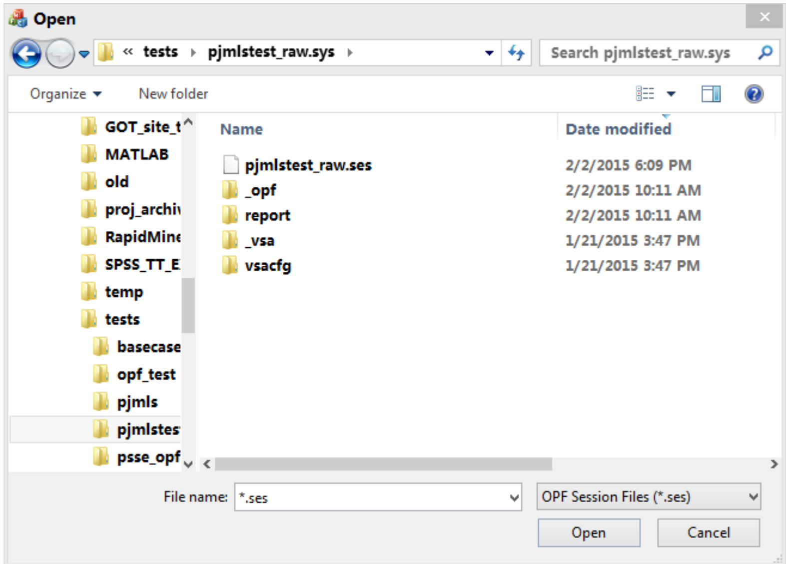


Figure: Open session file dialog

Once you have located the OPF session file you wish to use, select it and click the "open" button. To dismiss the window without loading the OPF study case, click the "Cancel" button.

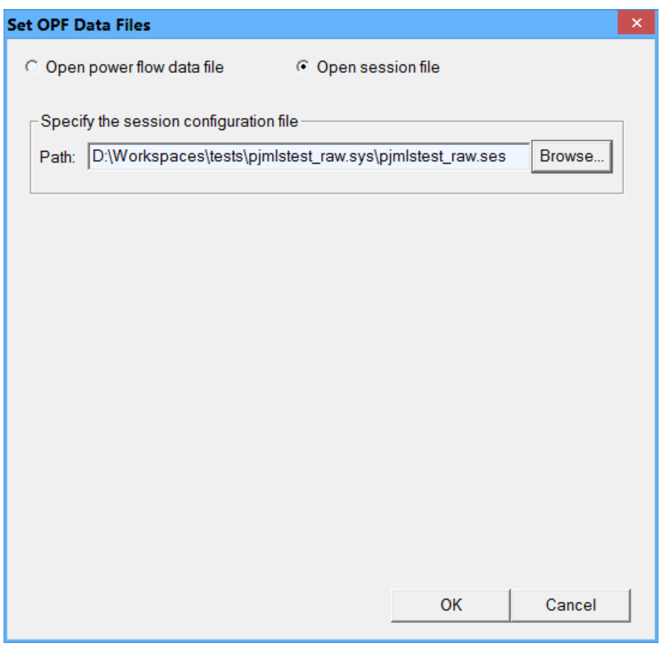


Figure: Set session file dialog

3.3 Case Display

After opening and loading the case, the case definition is displayed in the BSI-SuperOPF main window.

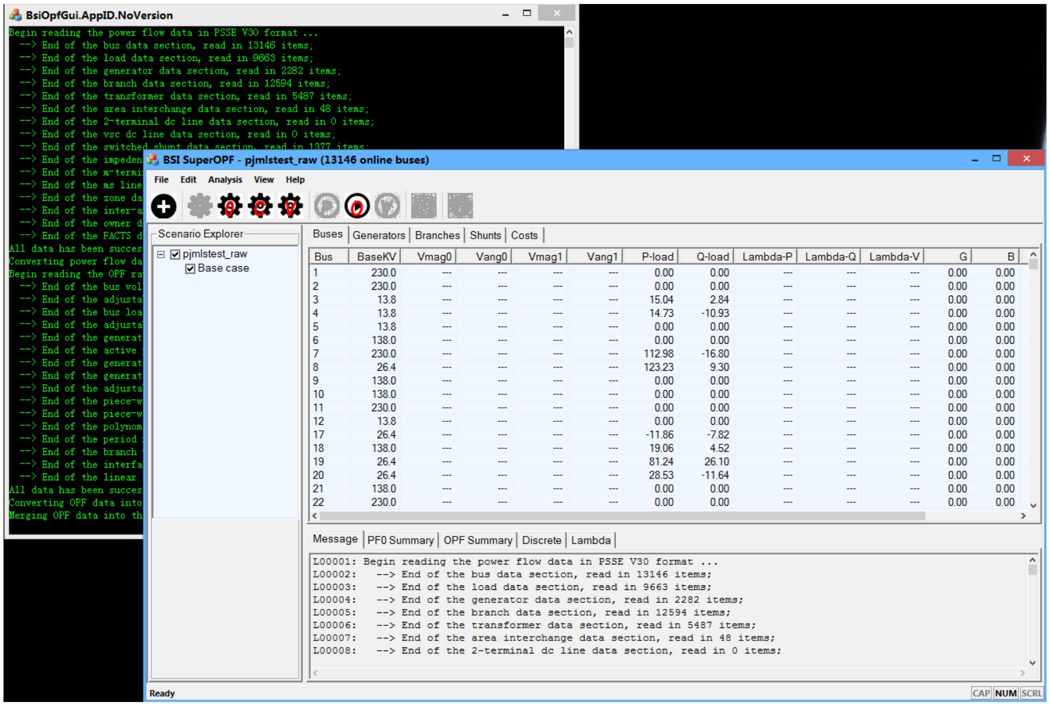


Figure: SuperOPF main window after loading a case

The title bar of the main window shows the case name and the size of the system (i.e., the number of buses in the system).

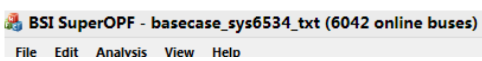


Figure: SuperOPF main window title after loading a case

Messages showing the process of loading the case data files are populated to the console window in a real-time manner.

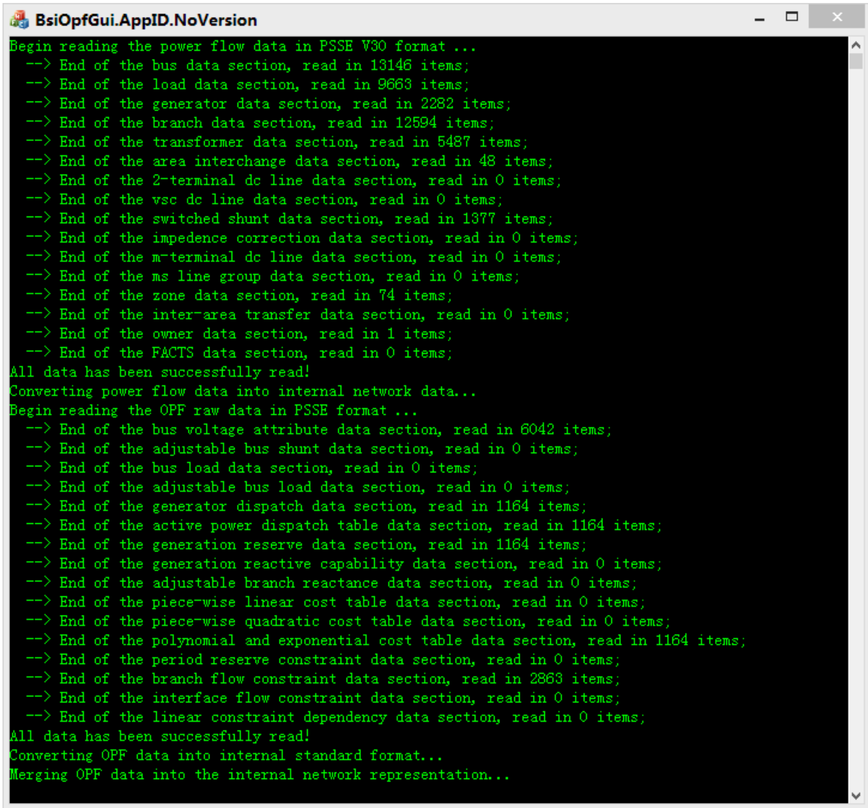


Figure: Console window with real-time running messages

After the case data files have been successfully read by the program, scenarios that are involved in the study will be presented in a tree display for manipulation by the user, including:

- Selection of active scenario(s) to be involved in the computation.
- Selection of the scenario data to be displayed in the data tables.

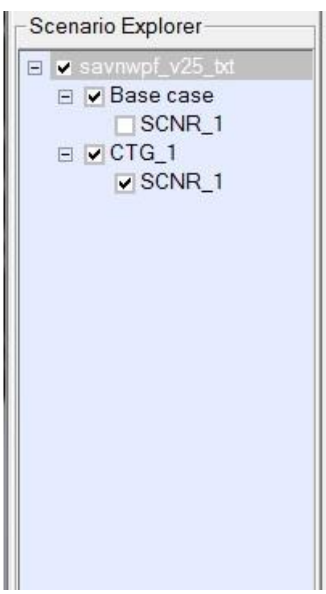


Figure: Study case scenario tree

After the case data files have been successfully read by the program, each section of the power flow case will be presented in a tabbed display for review by the user. The following sections show sample figures for each of the case data tabs.

Buses | Generators | Branches | Shunts | Costs

Bus	BaseKV	Vmag0	Vang0	Vmag1	Vang1	P-load	Q-load	Lambda-P	Lambda-Q	Lambda-V	G	B	Area	Zone	Status
1	230.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
2	230.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
3	13.8	---	---	---	---	15.04	2.84	---	---	---	0.00	0.00	1	1	on
4	13.8	---	---	---	---	14.73	-10.93	---	---	---	0.00	0.00	1	1	on
5	13.8	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
6	138.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
7	230.0	---	---	---	---	112.98	-16.80	---	---	---	0.00	0.00	1	1	on
8	26.4	---	---	---	---	123.23	9.30	---	---	---	0.00	0.00	1	1	on
9	138.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
10	138.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
11	230.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
12	13.8	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
17	26.4	---	---	---	---	-11.86	-7.82	---	---	---	0.00	0.00	1	1	on
18	138.0	---	---	---	---	19.06	4.52	---	---	---	0.00	0.00	1	1	on
19	26.4	---	---	---	---	81.24	26.10	---	---	---	0.00	0.00	1	1	on
20	26.4	---	---	---	---	28.53	-11.64	---	---	---	0.00	0.00	1	1	on
21	138.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
22	230.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
23	230.0	---	---	---	---	49.40	-7.94	---	---	---	0.00	0.00	1	1	on

Figure: Main form with tabbed case data and message display

3.3.1 Case Display – Buses Tab

By default, the bus data tab is shown to the user. In this tab, data values, including bus number, base KV, initial power flow voltage magnitude (Vmag0), initial power flow voltage phase angle (Vang0), optimal power flow voltage magnitude (Vmag1), optimal power flow voltage phase angle (Vang1), real load (P-load), reactive load (Q-load), bus real-power related Lagrange multiplier (Lambda-P), bus reactive-power related Lagrange multiplier (Lambda-Q), bus voltage related Lagrange multiplier (Lambda-V) conductance (G), susceptance (B), area, zone and bus online/offline status, of all buses retrieved from the power flow file and the OPF computation results are displayed in a grid table. It needs to be noted that the data values, namely real and reactive loads, G and B, Vmag0 and Vmag1, displayed in this tab are the associated values after the per-unit conversion.

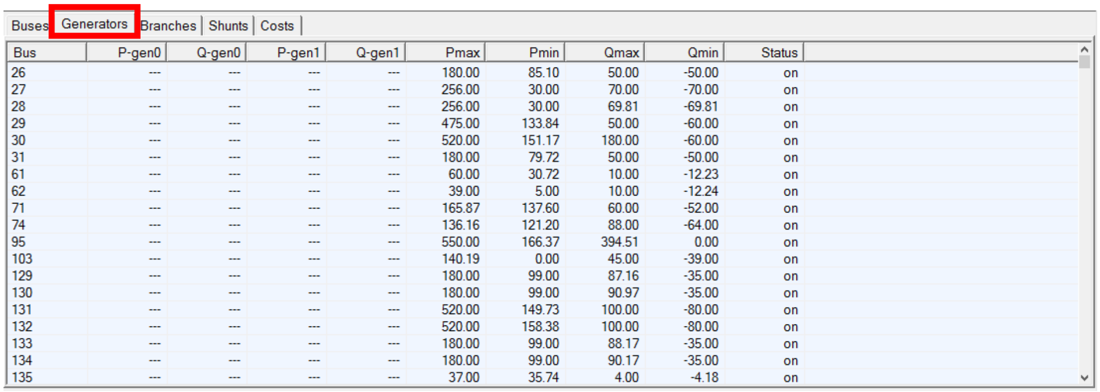
Buses | Generators | Branches | Shunts | Costs

Bus	BaseKV	Vmag0	Vang0	Vmag1	Vang1	P-load	Q-load	Lambda-P	Lambda-Q	Lambda-V	G	B	Area	Zone	Status
1	230.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
2	230.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
3	13.8	---	---	---	---	15.04	2.84	---	---	---	0.00	0.00	1	1	on
4	13.8	---	---	---	---	14.73	-10.93	---	---	---	0.00	0.00	1	1	on
5	13.8	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
6	138.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
7	230.0	---	---	---	---	112.98	-16.80	---	---	---	0.00	0.00	1	1	on
8	26.4	---	---	---	---	123.23	9.30	---	---	---	0.00	0.00	1	1	on
9	138.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
10	138.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
11	230.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
12	13.8	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
17	26.4	---	---	---	---	-11.86	-7.82	---	---	---	0.00	0.00	1	1	on
18	138.0	---	---	---	---	19.06	4.52	---	---	---	0.00	0.00	1	1	on
19	26.4	---	---	---	---	81.24	26.10	---	---	---	0.00	0.00	1	1	on
20	26.4	---	---	---	---	28.53	-11.64	---	---	---	0.00	0.00	1	1	on
21	138.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
22	230.0	---	---	---	---	0.00	0.00	---	---	---	0.00	0.00	1	1	on
23	230.0	---	---	---	---	49.40	-7.94	---	---	---	0.00	0.00	1	1	on

Figure: Bus data tab

3.3.2 Case Display – Generators Tab

In the generator data tab, data values, including generator bus number, initial power flow real power generation (P-gen0), initial power flow reactive power generation (Q-gen0), optimal power flow real power generation (P-gen1), optimal power flow reactive power generation (Q-gen1), maximum real power generation (Pmax), minimum real power generation (Pmin), maximum reactive power generation (Qmax), minimum reactive power generation (Qmin), and generator online/offline status, of all generators retrieved from the power flow file and the OPF computation results are displayed in a grid table.



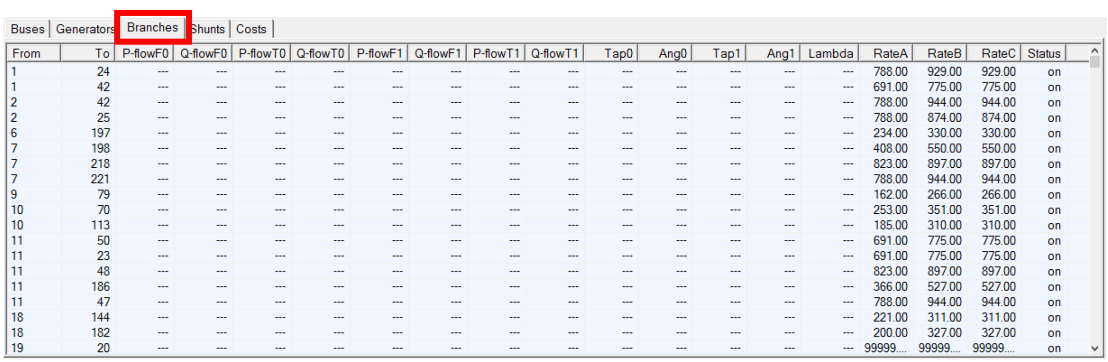
Buses | Generators | Branches | Shunts | Costs

Bus	P-gen0	Q-gen0	P-gen1	Q-gen1	Pmax	Pmin	Qmax	Qmin	Status
26	---	---	---	---	180.00	85.10	50.00	-50.00	on
27	---	---	---	---	256.00	30.00	70.00	-70.00	on
28	---	---	---	---	256.00	30.00	69.81	-69.81	on
29	---	---	---	---	475.00	133.84	50.00	-60.00	on
30	---	---	---	---	520.00	151.17	180.00	-60.00	on
31	---	---	---	---	180.00	79.72	50.00	-50.00	on
61	---	---	---	---	60.00	30.72	10.00	-12.23	on
62	---	---	---	---	39.00	5.00	10.00	-12.24	on
71	---	---	---	---	165.87	137.60	60.00	-52.00	on
74	---	---	---	---	136.16	121.20	88.00	-64.00	on
95	---	---	---	---	550.00	166.37	394.51	0.00	on
103	---	---	---	---	140.19	0.00	45.00	-39.00	on
129	---	---	---	---	180.00	99.00	87.16	-35.00	on
130	---	---	---	---	180.00	99.00	90.97	-35.00	on
131	---	---	---	---	520.00	149.73	100.00	-80.00	on
132	---	---	---	---	520.00	158.38	100.00	-80.00	on
133	---	---	---	---	180.00	99.00	88.17	-35.00	on
134	---	---	---	---	180.00	99.00	90.17	-35.00	on
135	---	---	---	---	37.00	35.74	4.00	-4.18	on

Figure: Generator data tab

3.3.3 Case Display – Branches Tab

In the branch data tab, of all branches retrieved from the power flow file and the OPF computation results are displayed in a grid table. All transformers in the system are also treated as branches and their data values are also populated in this grid table with a unified presentation.



Buses | Generators | Branches | Shunts | Costs

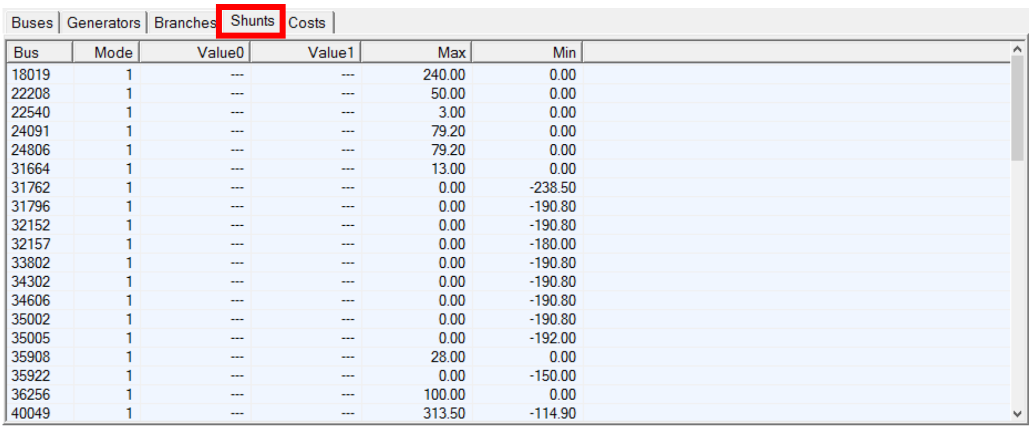
From	To	P-flowF0	Q-flowF0	P-flowT0	Q-flowT0	P-flowF1	Q-flowF1	P-flowT1	Q-flowT1	Tap0	Ang0	Tap1	Ang1	Lambda	RateA	RateB	RateC	Status
1	24	---	---	---	---	---	---	---	---	---	---	---	---	---	788.00	929.00	929.00	on
1	42	---	---	---	---	---	---	---	---	---	---	---	---	---	691.00	775.00	775.00	on
2	42	---	---	---	---	---	---	---	---	---	---	---	---	---	788.00	944.00	944.00	on
2	25	---	---	---	---	---	---	---	---	---	---	---	---	---	788.00	874.00	874.00	on
6	197	---	---	---	---	---	---	---	---	---	---	---	---	---	234.00	330.00	330.00	on
7	198	---	---	---	---	---	---	---	---	---	---	---	---	---	408.00	550.00	550.00	on
7	218	---	---	---	---	---	---	---	---	---	---	---	---	---	823.00	897.00	897.00	on
7	221	---	---	---	---	---	---	---	---	---	---	---	---	---	788.00	944.00	944.00	on
9	79	---	---	---	---	---	---	---	---	---	---	---	---	---	162.00	266.00	266.00	on
10	70	---	---	---	---	---	---	---	---	---	---	---	---	---	253.00	351.00	351.00	on
10	113	---	---	---	---	---	---	---	---	---	---	---	---	---	185.00	310.00	310.00	on
11	50	---	---	---	---	---	---	---	---	---	---	---	---	---	691.00	775.00	775.00	on
11	23	---	---	---	---	---	---	---	---	---	---	---	---	---	691.00	775.00	775.00	on
11	48	---	---	---	---	---	---	---	---	---	---	---	---	---	823.00	897.00	897.00	on
11	186	---	---	---	---	---	---	---	---	---	---	---	---	---	366.00	527.00	527.00	on
11	47	---	---	---	---	---	---	---	---	---	---	---	---	---	788.00	944.00	944.00	on
18	144	---	---	---	---	---	---	---	---	---	---	---	---	---	221.00	311.00	311.00	on
18	182	---	---	---	---	---	---	---	---	---	---	---	---	---	200.00	327.00	327.00	on
19	20	---	---	---	---	---	---	---	---	---	---	---	---	---	99999....	99999....	99999....	on

Figure: Branch data tab

This grid table displays branch and transformer data values, including from- and to-end bus numbers, initial power flow from-end real power flow injection (P-flowF0), initial power flow from-end reactive power flow injection (Q-flowF0), initial power flow to-end real power flow injection (P-flowT0), initial power flow to-end reactive power flow injection (Q-flowT0), optimal power flow from-end real power flow injection (P-flowF1), optimal power flow from-end reactive power flow injection (Q-flowF1), optimal power flow to-end real power flow injection (P-flowT1), optimal power flow to-end reactive power flow injection (Q-flowT1), the initial power flow tap ratio (Tap0) if the branch is a tap-changing transformer, the initial power flow phase angle (Ang0) if the branch is a phase-shifting transformer, the optimal power flow tap ratio (Tap1), the optimal power flow phase angle (Ang1), branch-flow related Lagrange-multiplier (Lambda), first loading rating (RateA), second loading rating (RateB), third loading rating (RateC), and branch online/offline status, of all branches (and transformer) retrieved from the power flow file and the OPF computation results are displayed in a grid table.

3.3.4 Case Display – Shunts Tab

In the branch data tab, of all switchable shunt data retrieved from the power flow file are displayed in a grid table. This grid table displays switchable shunt data values, including the bus number, the shunt device mode, the initial power flow shunt value (Value0), the optimal power flow shunt value (Value1), maximum shunt value (Max), and minimum shunt value (Min) are displayed in a grid table.


Buses | Generators | Branches | Shunts | Costs

Bus	Mode	Value0	Value1	Max	Min
18019	1	---	---	240.00	0.00
22208	1	---	---	50.00	0.00
22540	1	---	---	3.00	0.00
24091	1	---	---	79.20	0.00
24806	1	---	---	79.20	0.00
31664	1	---	---	13.00	0.00
31762	1	---	---	0.00	-238.50
31796	1	---	---	0.00	-190.80
32152	1	---	---	0.00	-190.80
32157	1	---	---	0.00	-180.00
33802	1	---	---	0.00	-190.80
34302	1	---	---	0.00	-190.80
34606	1	---	---	0.00	-190.80
35002	1	---	---	0.00	-190.80
35005	1	---	---	0.00	-192.00
35908	1	---	---	28.00	0.00
35922	1	---	---	0.00	-150.00
36256	1	---	---	100.00	0.00
40049	1	---	---	313.50	-114.90

Figure: Shunt data tab

3.3.5 Case Display – Costs Tab

In the cost data tab, of all generation cost data retrieved from the power flow data (for MATPOWER formats) or from the external cost data file are displayed in a grid table. This grid table displays cost data values, including the generator bus number, generator type (Type), cost model (Model), generator start-up cost (Start-up), generator shut-down cost (Shut-down), and cost model parameters (c0-c7, p0-p7, adaptively showed) are displayed in a grid table.

Gen	Type	Model	Start-up	Shut-down	c0	c1	c2
39	COAL	POLY	0.0000	0.0000	0.0000	24.6179	0.0000
10318	COAL	POLY	0.0000	0.0000	0.0000	0.0000	0.0000
10319	COAL	POLY	0.0000	0.0000	0.0000	255.5858	0.0000
10320	COAL	POLY	0.0000	0.0000	0.0000	27.7871	0.0000
10321	COAL	POLY	0.0000	0.0000	0.0000	14.8690	0.0000
10486	COAL	POLY	0.0000	0.0000	0.0000	293.7534	0.0000
10999	COAL	POLY	0.0000	0.0000	0.0000	0.0000	0.0000
11214	COAL	POLY	0.0000	0.0000	0.0000	28.5384	0.0000
11215	COAL	POLY	0.0000	0.0000	0.0000	34.9892	0.0000
11216	COAL	POLY	0.0000	0.0000	0.0000	0.0000	0.0000
12058	COAL	POLY	0.0000	0.0000	0.0000	22.5331	0.0000
14800	COAL	POLY	0.0000	0.0000	0.0000	33.2302	0.0000
14801	COAL	POLY	0.0000	0.0000	0.0000	22.8057	0.0000
14802	COAL	POLY	0.0000	0.0000	0.0000	57.9661	0.0000
14803	COAL	POLY	0.0000	0.0000	0.0000	11.0000	0.0000
14804	COAL	POLY	0.0000	0.0000	0.0000	38.8081	0.0000
14805	COAL	POLY	0.0000	0.0000	0.0000	19.0995	0.0000
14806	COAL	POLY	0.0000	0.0000	0.0000	35.1257	0.0000
14807	COAL	POLY	0.0000	0.0000	0.0000	412.5436	0.0000

Figure: Cost data table

The generator types include:

- COAL: generators using coal as the energy source
- OIL: generators using fossil oil as the energy source
- NGAS: generators using natural gas as the energy source
- HYDR: hydraulic generators
- NCLR: nuclear generators
- WIND: wind generators

Currently, two types of production costs are supported by SuperOPF program:

- POLY: the cost of the generator is formatted in a polynomial model, where parameters c0 through c7 are used as the coefficients for orders 0 through 7; therefore, the maximum allowed order of a polynomial cost is 7.
- PLNR: the cost of the generator is formatted in a piece-wise linear model, where parameters c0 through c7 and p0 through p7 are used as the turning points to define the line segments for generation-cost in the piece-wise linear cost model; therefore, the maximum allowed line segments in the piece-wise linear cost model is 7.

3.4 Information Display

After the case data files have been successfully read, or the session file with recorded OPF study case has been loaded, or an OPF computation has been carried out, contents in several files generated in the background, storing information including running messages and computation results, will be presented in a tabbed display for review by the user. The following sections show sample figures for each of the information tabs.

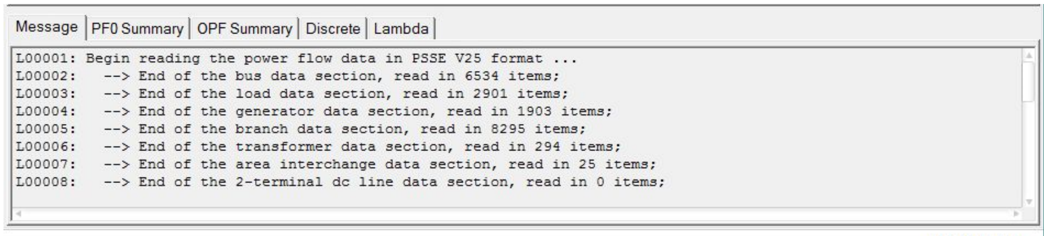


Figure: Information display tabs

3.4.1 Information Display – Message Tab

In the message tab, all running messages since program startup are displayed. The label Lxxxxx at the header of each line is the line number of the corresponding message.

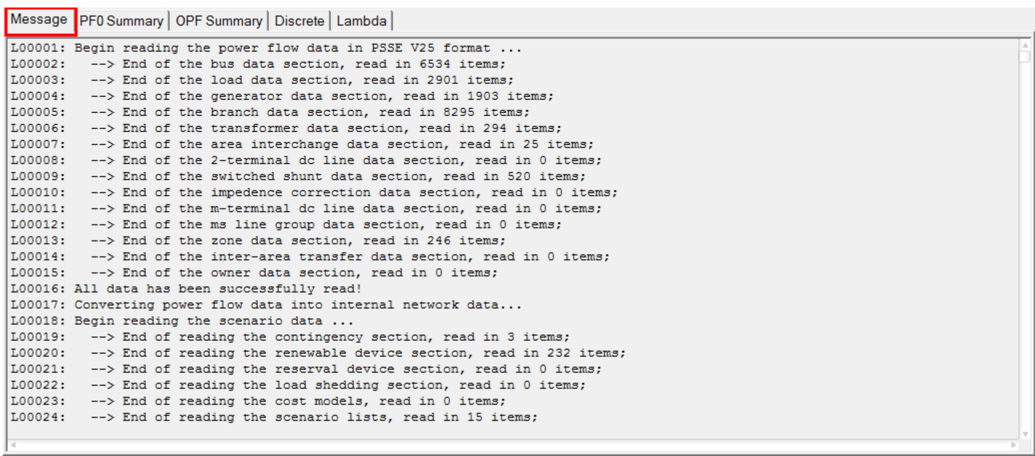
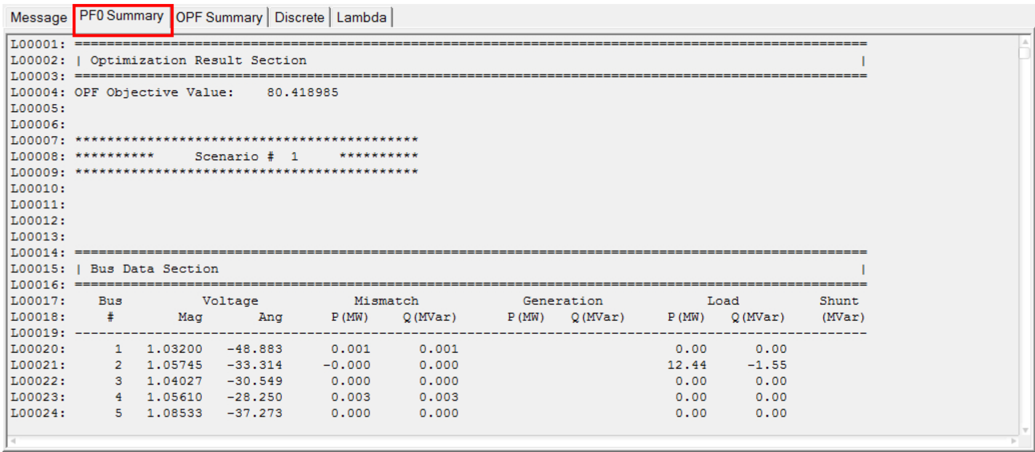


Figure: Running message

3.4.2 Information Display – PF0 Summary Tab

In the PF0 summary tab, the initial states of the power system used as the initial point for the OPF computation are displayed. The label Lxxxxx at the header of each line is the line number of the summary file. Organization of the contents displayed in the summary tab is showed in appendix A.

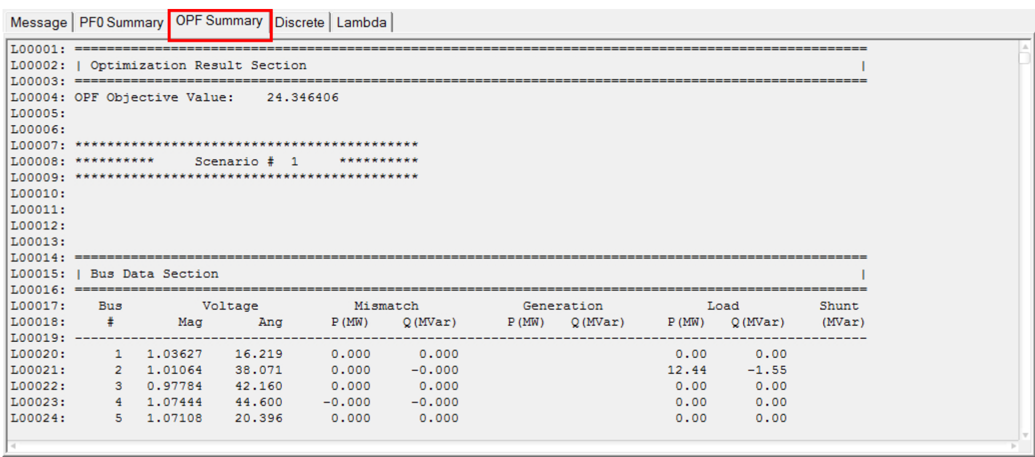


```
Message | PF0 Summary | OPF Summary | Discrete | Lambda |
L00001: ====================================================================================================
L00002: | Optimization Result Section                                                                      |
L00003: ====================================================================================================
L00004: OPF Objective Value:    80.418985
L00005:
L00006:
L00007: ********************************************
L00008: **********     Scenario #  1     **********
L00009: ********************************************
L00010:
L00011:
L00012:
L00013:
L00014: ====================================================================================================
L00015: | Bus Data Section                                                                                 |
L00016: ====================================================================================================
L00017:    Bus          Voltage            Mismatch            Generation            Load          Shunt
L00018:     #        Mag       Ang      P(MW)    Q(MVar)     P(MW)   Q(MVar)     P(MW)   Q(MVar)    (MVar)
L00019: ----------------------------------------------------------------------------------------------------
L00020:      1   1.03200   -48.883    0.001     0.001                            0.00      0.00
L00021:      2   1.05745   -33.314   -0.000     0.000                           12.44     -1.55
L00022:      3   1.04027   -30.549    0.000     0.000                            0.00      0.00
L00023:      4   1.05610   -28.250    0.003     0.003                            0.00      0.00
L00024:      5   1.08533   -37.273    0.000     0.000                            0.00      0.00
```

Figure: Initial power flow summary

3.4.3 Information Display – OPF Summary Tab

In the OPF summary tab, the optimal states of the power system used as the optimal solution found as the result of the OPF computation are displayed. The label Lxxxxx at the header of each line is the line number of the summary file. The content of the summary is organized in the same way as that for initial power flow summary.



```
Message | PF0 Summary | OPF Summary | Discrete | Lambda |
L00001: ====================================================================================================
L00002: | Optimization Result Section                                                                      |
L00003: ====================================================================================================
L00004: OPF Objective Value:    24.346406
L00005:
L00006:
L00007: ********************************************
L00008: **********     Scenario #  1     **********
L00009: ********************************************
L00010:
L00011:
L00012:
L00013:
L00014: ====================================================================================================
L00015: | Bus Data Section                                                                                 |
L00016: ====================================================================================================
L00017:    Bus          Voltage            Mismatch            Generation            Load          Shunt
L00018:     #        Mag       Ang      P(MW)    Q(MVar)     P(MW)   Q(MVar)     P(MW)   Q(MVar)    (MVar)
L00019: ----------------------------------------------------------------------------------------------------
L00020:      1   1.03627    16.219    0.000     0.000                            0.00      0.00
L00021:      2   1.01064    38.071    0.000    -0.000                           12.44     -1.55
L00022:      3   0.97784    42.160    0.000     0.000                            0.00      0.00
L00023:      4   1.07444    44.600   -0.000    -0.000                            0.00      0.00
L00024:      5   1.07108    20.396    0.000     0.000                            0.00      0.00
```

Figure: Optimal power flow summary

3.4.4 Information Display – Discrete Tab

In the discrete tab, all solution values for discrete control variables, namely tap ratios for tap-changing transformers, phase angles for phase-shifting transformers, shunts for switchable shunts, are displayed. The label Lxxxxx at the header of each line is the line number of the information file. Organization of the contents displayed in the discrete tab is showed in appendix B.

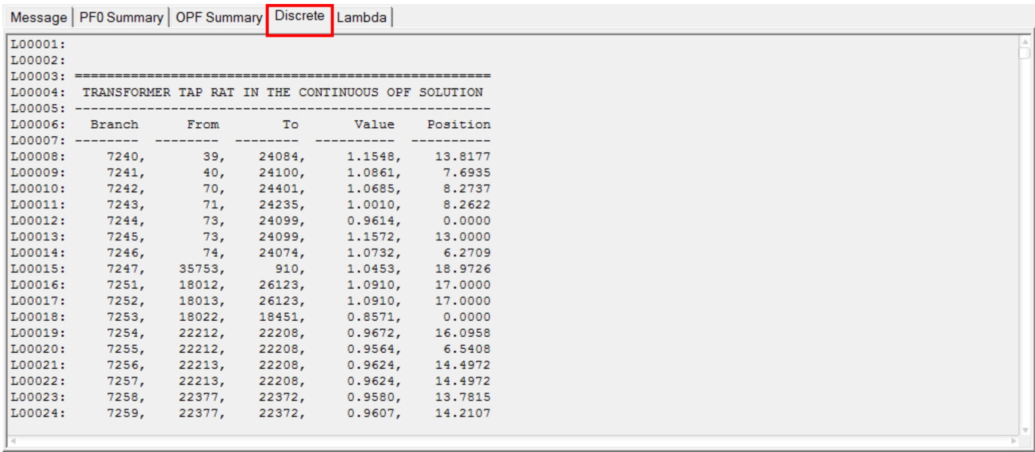


Figure: Discrete control values

3.4.5 Information Display – Lambda Tab

In the message tab, all running messages since program startup are displayed. The label Lxxxxx at the header of each line is the line number of the corresponding message. Organization of the contents displayed in the lambda tab is showed in appendix C.

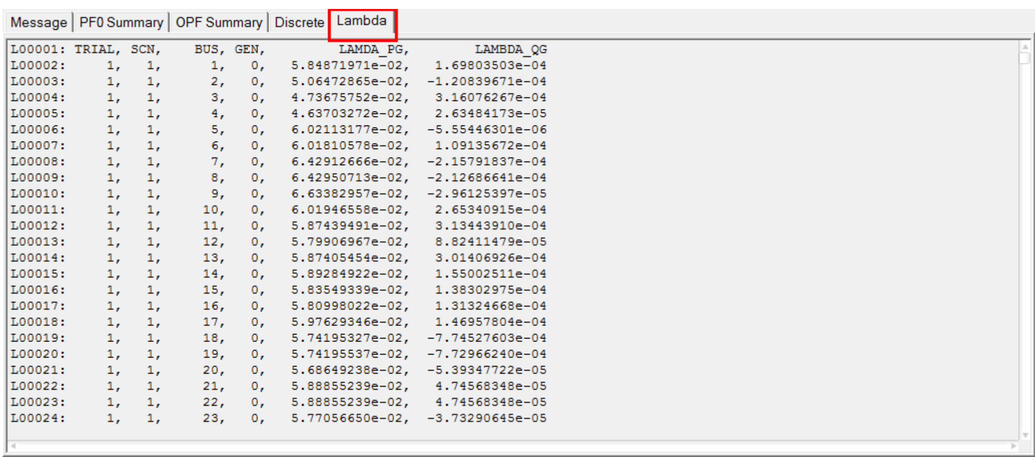


Figure: Marginal prices

3.5 File Save (Save As)

Brings up a sub-menu window that allows you to browse your computer's file system to a location chosen to select or create a folder to save all files associated with the currently open case. Enter a file name and click "save" to store the file.

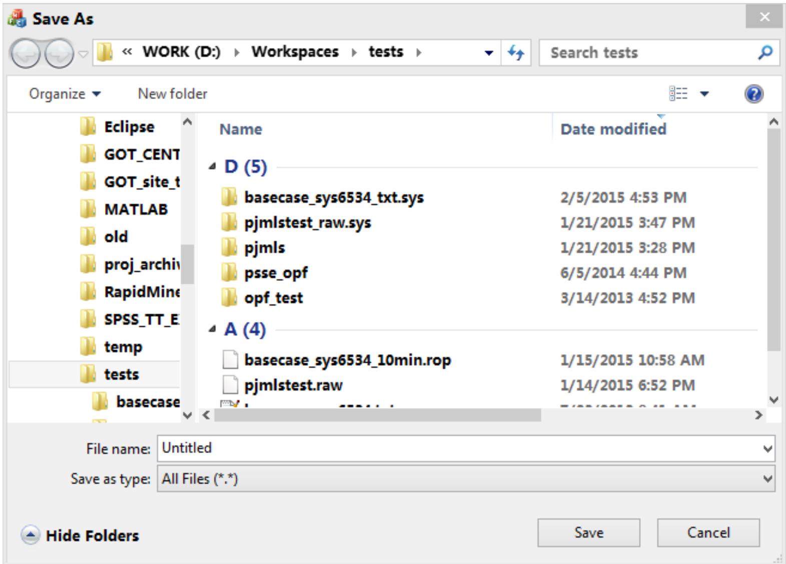


Figure: Save as window

3.6 File Exit

The “File Exit” selection is used to exit the program and close the program window.

Section 4. EDIT MENU

These menu selections provide access to the BSI-SuperOPF data preparation and edit functions.

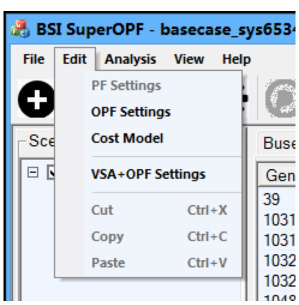


Figure: Edit menu

4.1 Edit PF Settings

Power flow settings edit functions are not implemented in this version.

4.2 Edit OPF Settings

The “Edit OPF Settings” selection displays the following tabbed panel for configuring the OPF computation by modifying the system default values for:

- Basic computation settings
- Computation stopping criteria
- Computational constraint settings
- Discrete control handling settings
- Output settings
- Miscellaneous settings

Buttons, namely First Tab (“|<”), Previous Tab (“<<”), Next Tab (“>>”) and Last Tab (“>|”), are provided to navigate between the setting tabs. The “Reset” button is used to restore the settings to the initial values, while the “Default” button is used to restore the settings to their default values. Click “OK” to accept your changes, “Cancel” to dismiss the panel without updating or “Restore” to display the default settings in the panel.

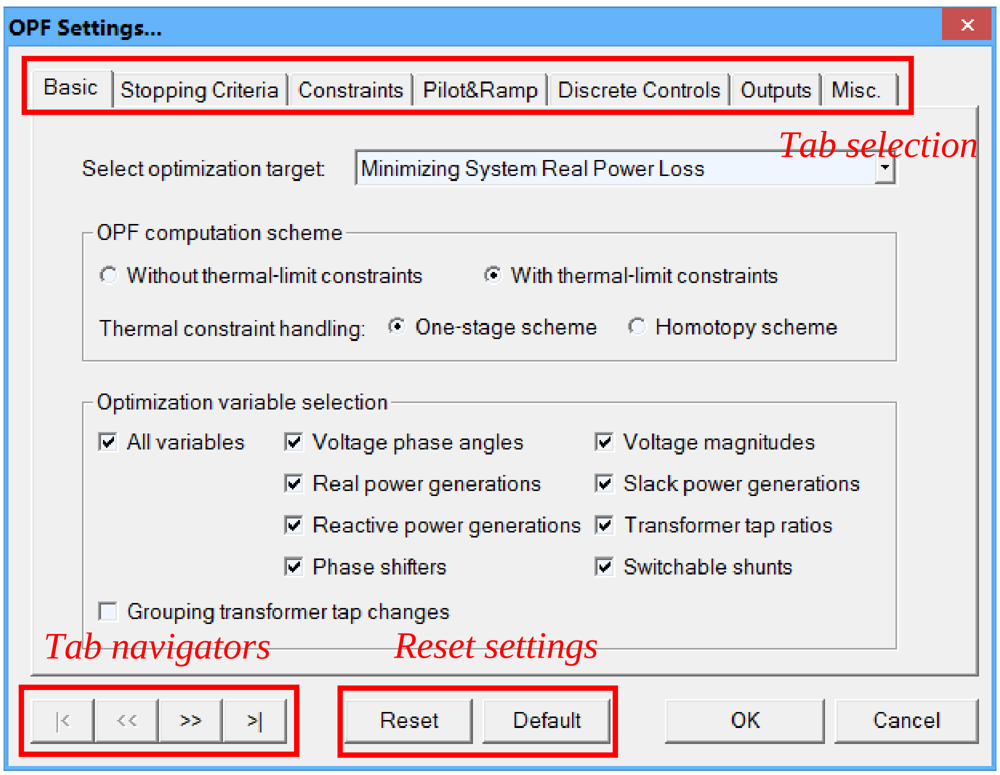


Figure: OPF settings panel

4.2.1 Basic computation settings

This tab presents the basic parameters for an OPF computation case, including the type of optimization objective, the OPF solution method, and the categories of variables involved in optimization.

Currently, the following objective functions are available for choice in an OPF study:

- Minimizing system real power loss

- Minimizing system reactive power loss
- Minimize system real power generation
- Minimize system reactive power generation
- Minimize system generation cost
- Minimize system load cost
- Minimize system voltage relaxations

There are seven categories of optimization variables available for choice, part or all categories can be selected and adjustable for optimizing the specified OPF objective:

- Bus voltage phase angles
- Bus voltage magnitudes
- Real power generations
- Slack bus real power generations
- Reactive power generations
- Tap ratios for tap-changing transformers
- Phase angles for phase-shifting transformers
- Switchable shunts

Only the selected variables will be adjusted during the OPF computation, while those unselected ones are spared and will keep fixed values as their initial values.

An option is also provided for grouping transformer tap changes. If this option is enabled, adjustments of transformers of a same group (by default, a transformer group is defined internally as the transformers with the same phase-1 terminal bus) will be synchronized; in other words, the tap changes for the transformers in a same group will be enforced to be the same value.

Two OPF computation schemes are available for choice, namely,

- OPF computation without thermal limit constraints
- OPF computation with thermal limit constraints

For the OPF computation with thermal limit constraints, two solution methods are provided, namely,

- The one-stage solution method
- The multi-stage homotopy solution method

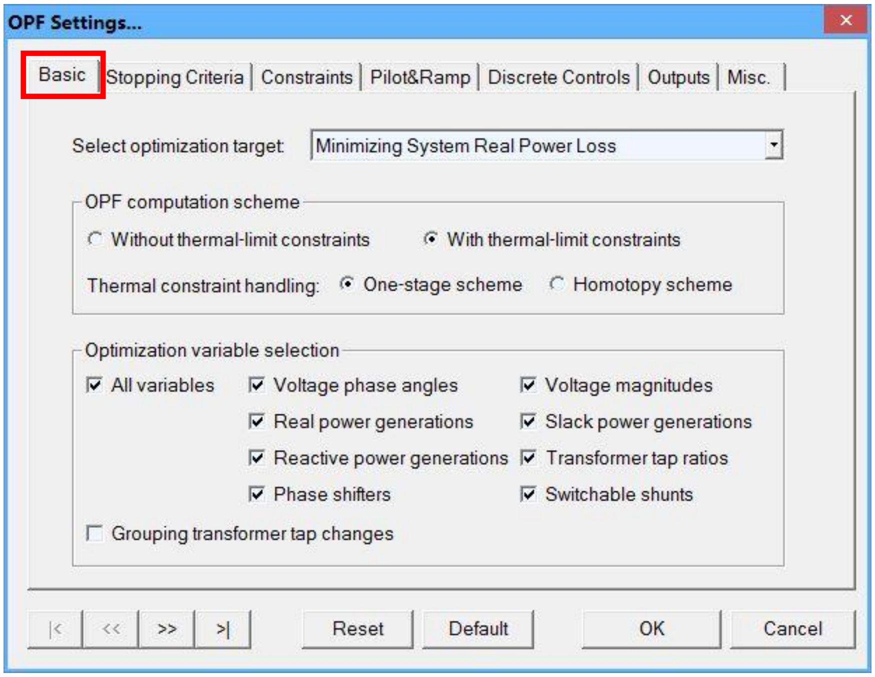


Figure: Basic settings tab

4.2.2 Stopping criteria

This tab sets values of the stopping criteria for the OPF computation. The stopping criteria available for adjusting include:

- The maximum allowed number of iterations for the internal solution method
- The maximum allowed Lagrange multiplier magnitude
- The power flow mismatch tolerance
- The thermal violation tolerance
- The voltage violation tolerance
- The generation violation tolerance
- The first-order KKT optimality tolerance
- Other general computation tolerance

The either of the first two criteria is satisfied, it indicates that the OPF computation fails to converge. An OPF solution is reached only if all the latter six criteria are satisfied simultaneously.

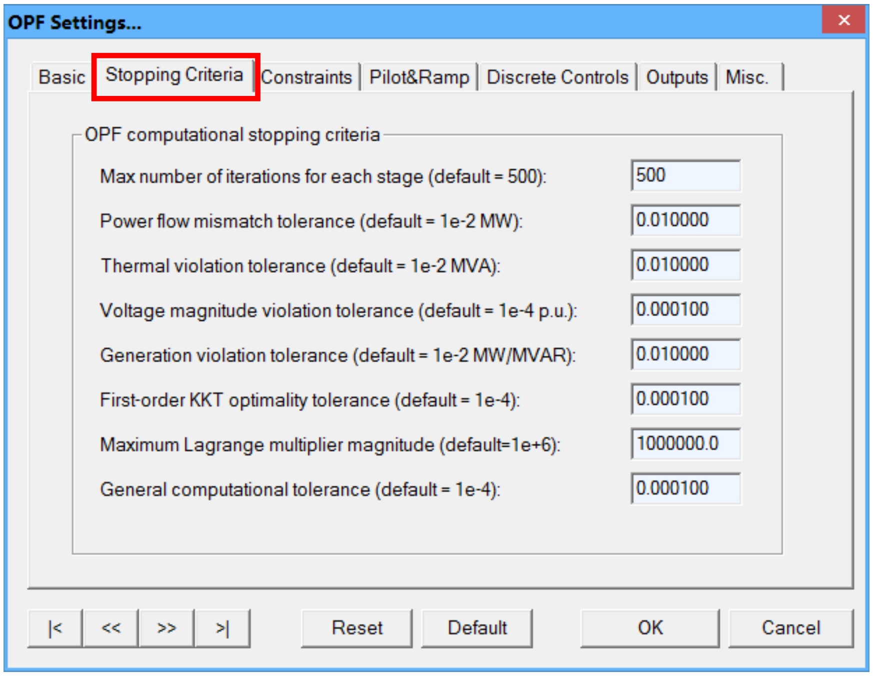


Figure: Stopping criteria tab

4.2.3 Constraint settings

This tab sets parameter values for handling constraints in the OPF computation. The parameters available for adjusting include:

- The system voltage magnitude lower and upper bounds
- The parameters for constraint feasibility analysis, including
  - The solution method for constraint handling, the one-staged scheme or the homotopy scheme
  - The number of homotopy steps and step sizes
- The choice of interface flow limit constraints, including
  - Whether interface-flow limits will be enforced in computation or not?
  - The involved interface-flow limits if enforced

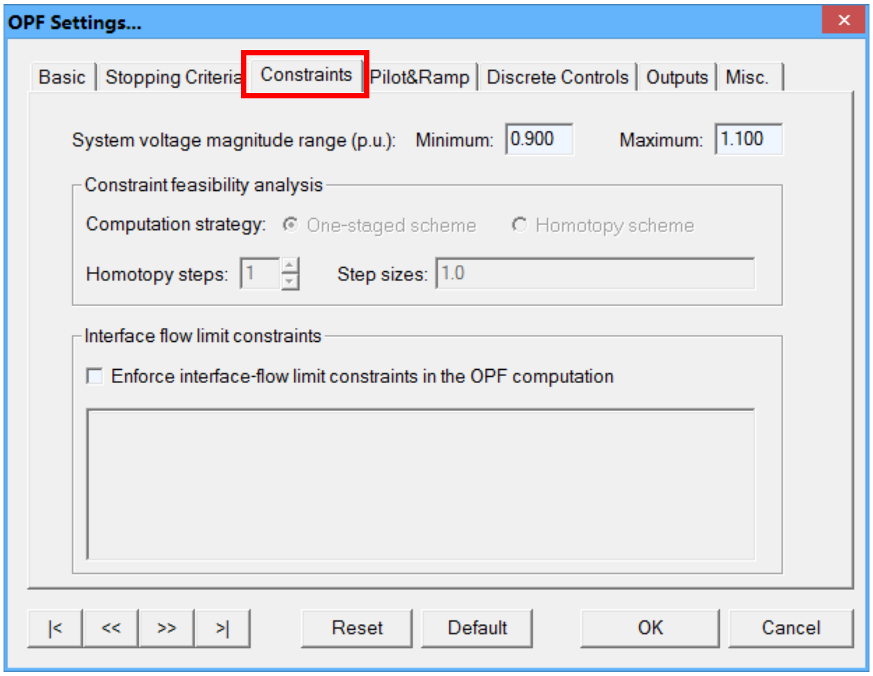


Figure: Constraint settings tab

4.2.4 Pilot&Ramp control settings

This tab sets parameter values for handling pilot controls and/or ramping constraints in the OPF computation. The parameters available for adjusting include:

- The system loading parameter. This value is multiplied to the base value of all system loads, which can be used simulate the changing system loading conditions. Default value of this parameter is 1.00.
- The option to use dynamic integration method for initialization. If this option is enforced, a dynamic integration process will be performed to find an initial point close to the desired OPF solution. This option can be used to improve the convergence of OPF computation under some situations.
- The choice of handling real power generations for a multi-scenario co-optimized OPF computation, including
  - All sync with basecase: If this option is enforced, all real power generations will be synchronized with the corresponding basecase values for all involved scenarios.
  - All sync except slack: If this option is enforced, all real power generations, except the slack generation(s), will be synchronized with the corresponding basecase values for all involved scenarios.
  - None sync with basecase: If this option is enforced, all involved scenarios, including the basecase, will have their own set of real power generations.
- The option to enforce ramping constraints. The ramping rates or up- and down-ramping limits are specified in the OPF raw data file. If this option is

enabled and the ramping rates are provided in values of MW/min, the ramping period can also be adjusted, with the unit being minute. In other words, the up- and down-ramping limits will be internally calculated as the products of ramping rates and the length of ramping period.

- The option to enforce pilot controls. This option specifies extra constraints defined by the pilot devices. Control values of the specified pilot devices will be fixed at the specified values during OPF computation. If this option is enabled,
  - The user is enabled to specify the pilot file for defining the pilot controls.
  - A pilot file may contain multiple-level pilot devices; up to 3 levels are supported by the program. The user can select the level of pilot controls.
  - The user can also specify a global relaxation value imposed on the pilot controls, which may improve the convergence of the OPF computation.

An exemplar pilot file is presented in the appendix.

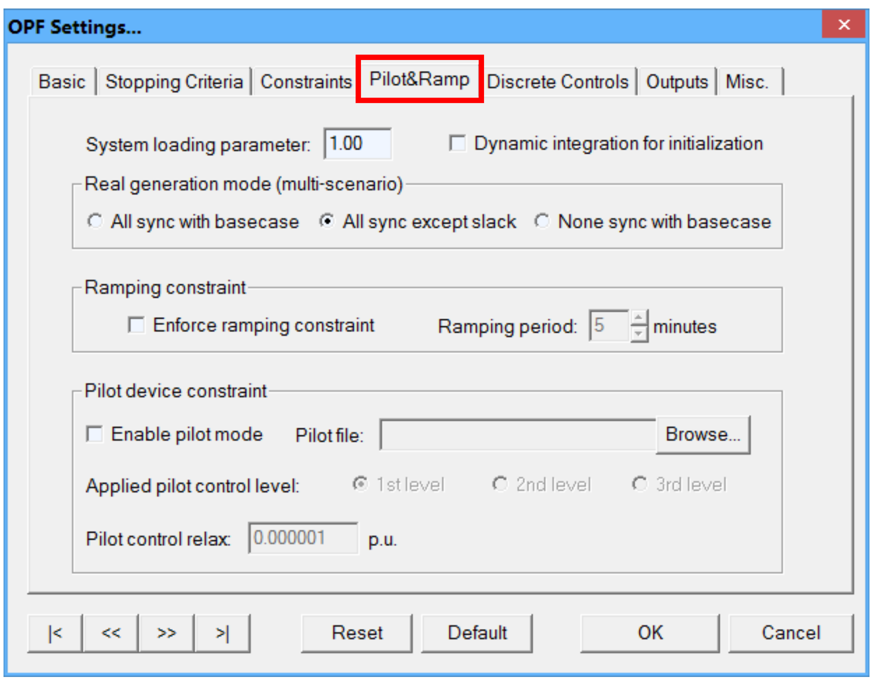


Figure: Pilot&Ramp settings tab

4.2.5 Discrete control settings

This tab sets parameters for handling discrete control variables in the OPF computation. The parameters available for adjusting include:

- Discrete variable handling options
  - Enforce discrete control variables in the OPF computation or not?

- Strategy for discretization: 1) nearest rounding-off, or 2) Iterative adjustment
- Number of steps for iterative adjustment
- Step sizes for iterative adjustment

- Thermal limit constraint parameters if homotopy scheme is selected
  - The starting homotopy relaxation factor
  - The thermal violation threshold for full constraint inclusion
  - The number of homotopy steps
  - The homotopy step sizes.

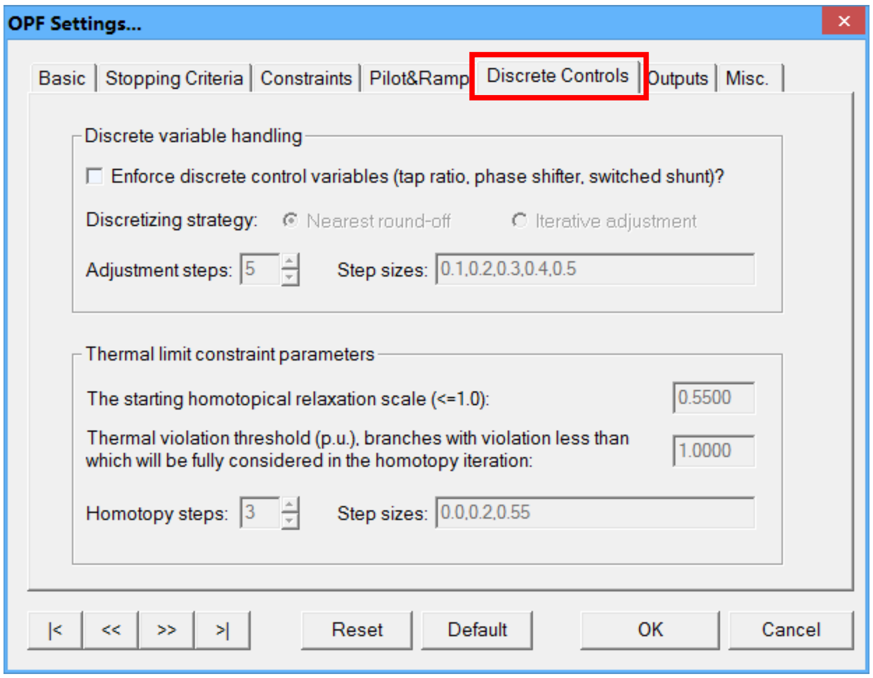


Figure: Discrete control tab

4.2.6 Output settings

This tab sets options for handling OPF computation result outputs. The available configurations include:

- The working folder to store intermediate files produced in computation

- The computation result reporting settings
  - The number of top-changed variables to be reported
  - The result report exporting directory
  - The formats for exporting result reports

- The result optimal power flow file output
  - Whether a copy of the initial power flow file will be backed up in the working folder?
  - The file format for saving the initial and optimal power flow files

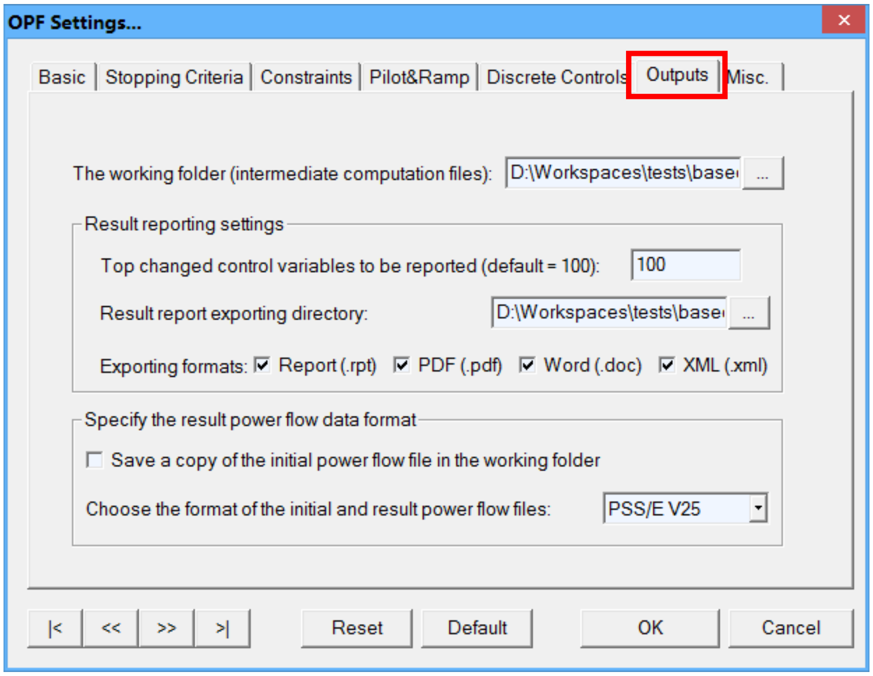


Figure: Output settings tab

4.2.7 Miscellaneous settings

This tab sets remained miscellaneous parameters the OPF computation. These parameters available for adjusting include:

- The coordinate representation for bus voltages
  - Polar voltage representation; or
  - Rectangular voltage representation
- The scheme for deriving objective and constraint function 1st and 2nd order derivatives
  - Hard-coded analytical function derivatives; or
  - Automated differentiation (AD) for function derivatives
- The initial point used for the OPF computation
  - The input initial power flow solution; or
  - The middle values within the variable bounds
- Whether a network data analysis will be performed or not prior to the OPF computation, so as to identify, report, and correct improper generation bounds and thermal limits retrieved from the data file
- Whether a full OPF constraint feasibility analysis will be carried out or not prior to the OPF computation, so as to identify, report, and correct constraints that cause infeasibility for an infeasible OPF study.

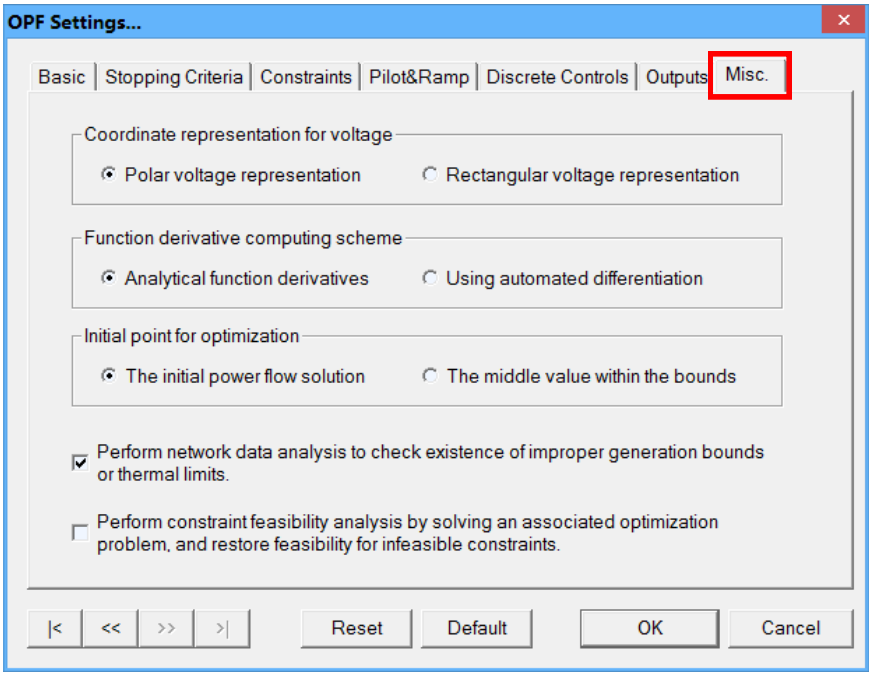


Figure: Miscellaneous settings tab

4.3 Edit VSA+OPF Settings

The "Edit VSA+OPF Settings" sets options for handling SuperOPF+VS computation for optimal power flow ensuring voltage stability associated with a list of credible contingencies. The available configurations include:

- The path to the file containing the contingency list
- The available preventive controls for VSA
  - Check box for enabling all available controls
  - Check box for enabling reactive power generation control
    - Value of the weighting factor for reactive power generation control
  - Check box for enabling switchable shunt control
    - Value of the weighting factor for switchable shunt control
  - Check box for enabling tap-changing transformer control
    - Value of the weighting factor for tap-ratio control
  - Check box for enabling phase-shifting transformer control
    - Value of the weighting factor for phase-shifting control
  - Check box for enabling real power generation control
    - Value of the weighting factor for real power generation control
    - Value of maximum allowed control range
  - Check box for enabling adding new shunt devices
    - Value of weighting factor for new shunt device
    - Value of maximum allowed single new shunt device

    - Check box for enabling load shedding
        - Value of weighting factor for load shedding
        - Value for maximum allowed load shedding percentage
        - Value for Q-ratio change in load shedding
- The stopping criteria for the SuperOPF+VS procedure
    - The maximum number of allowed iterations for the SuperOPF+VS analysis procedure
    - The tolerance of ratio of change of the OPF objective value between consecutive iterations.

Buttons are provided for convenient user interaction. The "Reset" button is used to restore the settings to the initial values, while the "Default" button is used to restore the settings to their default values. Click "OK" to accept your changes, "Cancel" to dismiss the panel without updating or "Restore" to display the default settings in the panel.

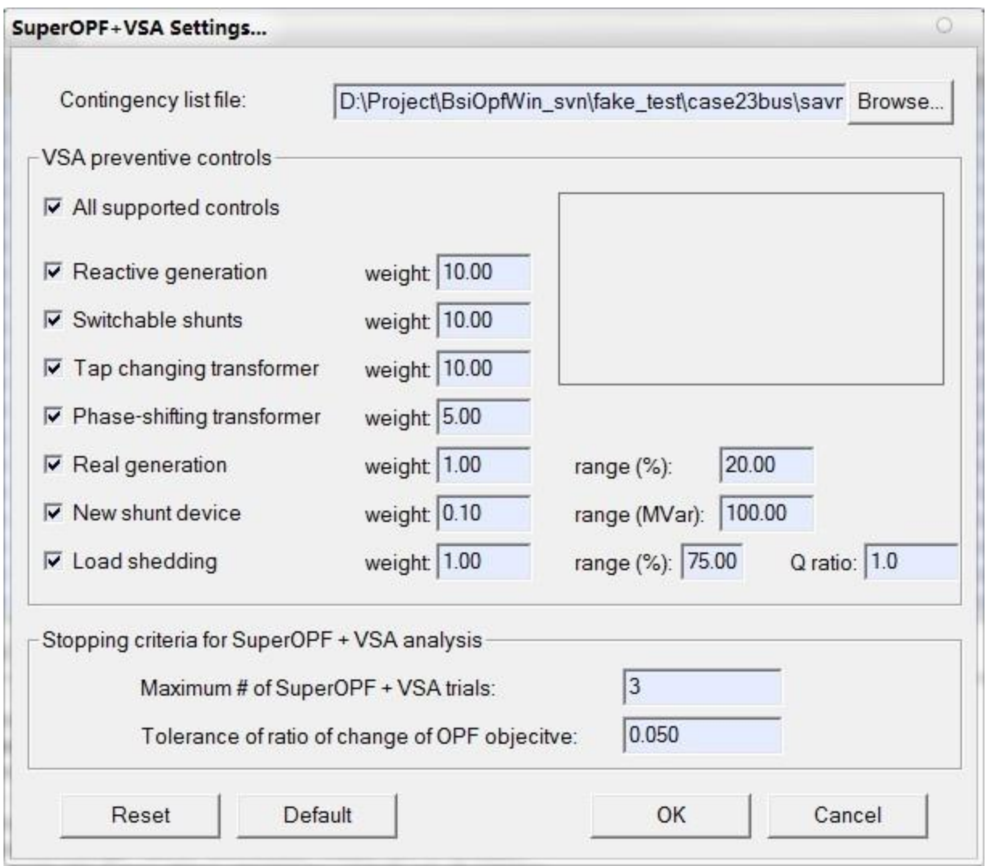


Figure: VSA + OPF settings dialog

4.3 Edit Cost Model

The “Edit Cost Model” selection display the following panel to allow the user to select the generation cost model representation and set the model parameters.

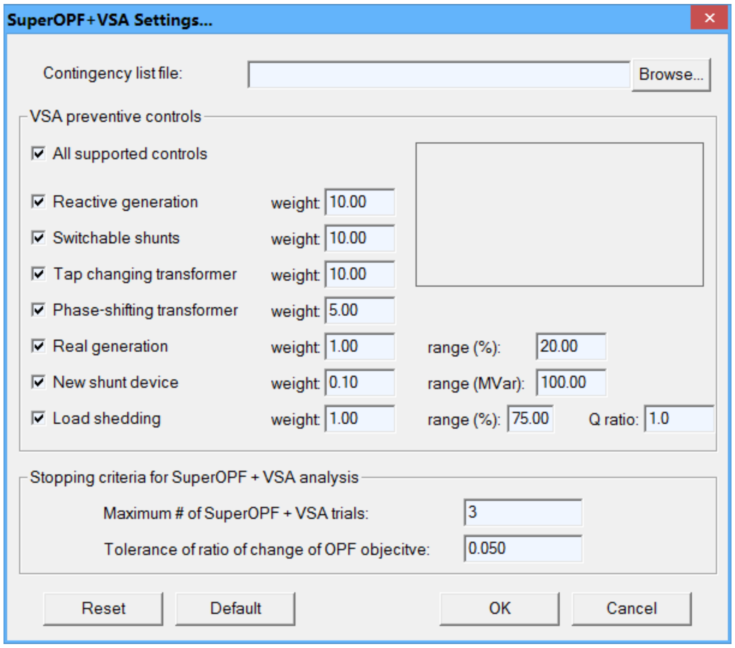


Figure: Generation cost model editing dialog panel

Click “OK” to accept your changes, “Cancel” to dismiss the panel without updating or “Restore” to display the default settings in the panel.

Section 5. ANALYSIS MENU

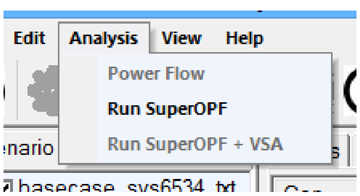


Figure: Analysis menu

5.1 Analysis – Run Power Flow

The power flow analysis feature is disabled in this version.

5.2 Analysis – SuperOPF

The Analysis SuperOPF selection brings a panel displaying the current OPF settings for the user to review. Click, “Cancel,” to dismiss the panel and return to the Edit OPF Settings function to modify the setting or click, “Run OPF,” to accept the current settings and execute the optimal power flow.

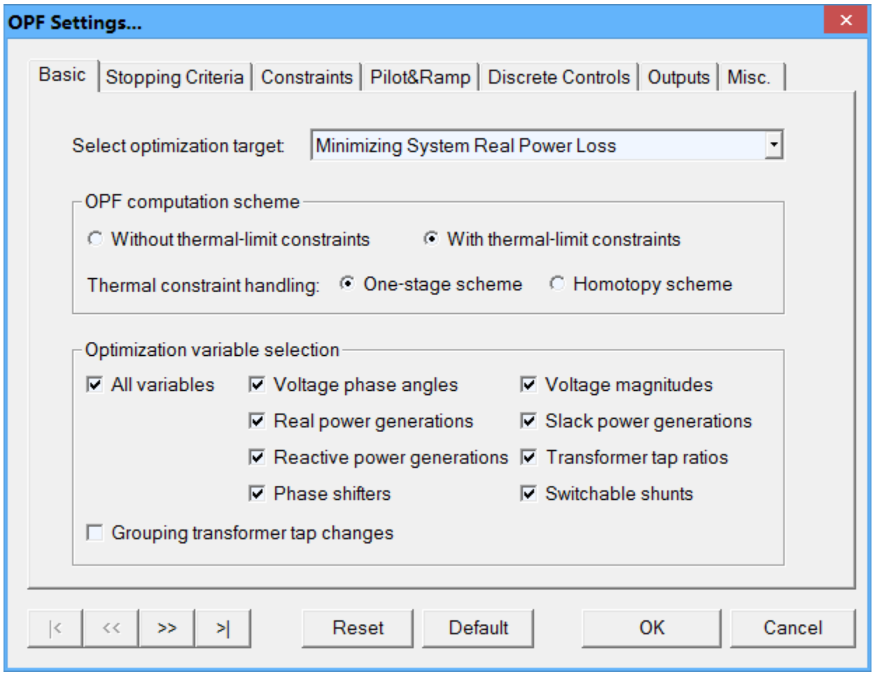


Figure: Confirm OPF settings and run panel

At the conclusion of the OPF run the following message panel is displayed to indicate the analysis completion. Click “OK” to dismiss.

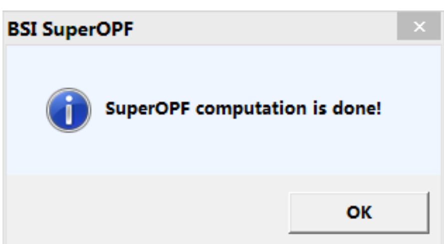


Figure: OPF done panel

The OPF console window display log messages of the OPF run.

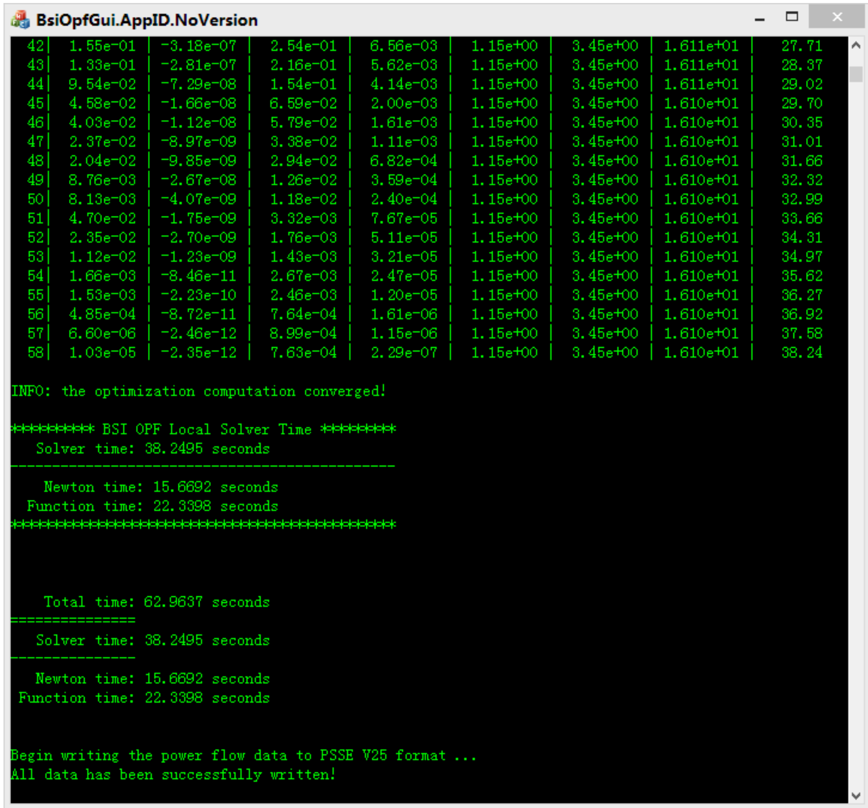


Figure: OPF console logging

5.2.1 Optimal Power Flow Run Log Example

```
***** Begin Log *****
Open a new OPF case files.
Open a new OPF case files.
Begin reading the power flow data in PSSE V25 format ...
  --> End of the bus data section, read in 13183 items;
  --> End of the load data section, read in 9691 items;
  --> End of the generator data section, read in 2304 items;
  --> End of the branch data section, read in 18168 items;
  --> End of the transformer data section, read in 1410 items;
  --> End of the area interchange data section, read in 48 items;
  --> End of the 2-terminal dc line data section, read in 0 items;
  --> End of the switched shunt data section, read in 1404 items;
  --> End of the impedence correction data section, read in 0 items;
  --> End of the m-terminal dc line data section, read in 0 items;
  --> End of the ms line group data section, read in 0 items;
  --> End of the zone data section, read in 74 items;
  --> End of the inter-area transfer data section, read in 0 items;
  --> End of the owner data section, read in 0 items;
All data has been successfully read!
Converting power flow data into internal network data...
ERROR: the active generation limit is invalid!
ERROR: the active generation limit is invalid!
ERROR: the active generation limit is invalid!
ERROR: the active generation limit is invalid!

Iter|   Max Eq     |   Max Iq |  Max Grad    |  P-D Gap   |  Max Lam |   Max Mu  | Objective  | Time(s)
==  | =======   |=======|==========  |========|=========|=========|=========|======
   0| 2.35e+001 | 1.68e+000 | 2.33e+001 | 3.99e+004 | 0.00e+000 | 1.00e+000 |5.589e+001 |     0.74
   1| 5.19e+000 | 2.07e-001 | 3.68e+000 | 2.02e+004 | 1.58e+000 | 2.06e+000 |5.274e+001 |     2.27
```

```
   2| 2.93e+000 | 1.20e-001 | 1.68e+000 | 1.17e+004 | 1.04e+001 | 9.12e+000 |5.122e+001 |     3.77
   3| 2.05e+000 | 7.56e-002 | 2.34e+000 | 7.05e+003 | 1.59e+001 | 3.10e+001 |4.975e+001 |     5.26
   4| 1.22e+000 | 4.41e-002 | 2.08e+000 | 3.96e+003 | 2.14e+001 | 3.47e+001 |4.768e+001 |     6.66
   5| 8.30e-001 | 2.00e-002 | 7.10e-001 | 2.03e+003 | 2.60e+001 | 3.28e+001 |4.491e+001 |     8.03
   6| 7.19e-001 | 9.22e-003 | 4.40e-001 | 9.94e+002 | 2.44e+001 | 2.53e+001 |4.257e+001 |     9.39
   7| 8.17e-001 | 2.37e-004 | 1.57e+000 | 5.86e+002 | 1.84e+001 | 1.88e+001 |3.914e+001 |    10.75
   8| 8.42e-001 | 1.06e-004 | 9.36e-001 | 3.50e+002 | 1.18e+001 | 1.24e+001 |3.808e+001 |    12.12
   9| 5.93e-001 | 2.29e-005 | 6.39e-001 | 1.56e+002 | 6.37e+000 | 8.01e+000 |3.680e+001 |    13.47
  10| 2.17e-001 | 2.40e-006 | 7.47e-001 | 7.62e+001 | 4.26e+000 | 8.27e+000 |3.539e+001 |    14.81
  11| 2.20e-001 | -1.58e-005 | 8.31e-001 | 5.64e+001 | 3.78e+000 | 7.19e+000 |3.459e+001 |    16.16
  12| 2.00e-001 | 4.22e-007 | 5.04e-001 | 3.75e+001 | 3.33e+000 | 5.72e+000 |3.413e+001 |    17.51
  13| 2.77e-001 | -2.71e-007 | 4.01e-001 | 2.38e+001 | 3.04e+000 | 4.28e+000 |3.337e+001 |    18.87
  14| 2.52e-001 | 2.42e-007 | 2.85e-001 | 1.96e+001 | 2.98e+000 | 3.69e+000 |3.323e+001 |    20.21
  15| 2.25e-001 | 5.41e-008 | 1.18e-001 | 1.22e+001 | 2.89e+000 | 3.43e+000 |3.288e+001 |    21.57
  16| 1.95e-001 | -2.13e-007 | 2.11e-001 | 7.82e+000 | 2.88e+000 | 3.46e+000 |3.262e+001 |    22.93
  17| 1.70e-001 | 1.18e-007 | 3.44e-001 | 5.90e+000 | 2.88e+000 | 3.53e+000 |3.248e+001 |    24.28
  18| 1.37e-001 | 8.12e-008 | 4.88e-001 | 3.91e+000 | 2.87e+000 | 3.76e+000 |3.232e+001 |    25.64
  19| 9.47e-002 | 5.22e-009 | 5.16e-001 | 2.49e+000 | 2.82e+000 | 4.07e+000 |3.214e+001 |    27.00
  20| 7.11e-002 | -2.27e-007 | 5.48e-001 | 1.59e+000 | 2.75e+000 | 4.27e+000 |3.204e+001 |    28.36
  21| 6.24e-002 | -2.12e-008 | 4.66e-001 | 8.93e-001 | 2.71e+000 | 4.38e+000 |3.191e+001 |    29.71
  22| 6.21e-002 | 8.24e-009 | 4.08e-001 | 5.05e-001 | 2.68e+000 | 4.40e+000 |3.183e+001 |    31.07
  23| 5.77e-002 | 2.14e-008 | 3.69e-001 | 2.71e-001 | 2.66e+000 | 4.38e+000 |3.179e+001 |    32.44
  24| 5.61e-002 | -4.31e-008 | 3.58e-001 | 2.64e-001 | 2.66e+000 | 4.38e+000 |3.178e+001 |    33.80
  25| 4.73e-002 | -1.52e-007 | 2.84e-001 | 1.76e-001 | 2.65e+000 | 4.36e+000 |3.175e+001 |    35.17
  26| 4.15e-002 | -2.75e-008 | 2.63e-001 | 1.38e-001 | 2.64e+000 | 4.36e+000 |3.174e+001 |    36.53
  27| 3.90e-002 | -3.54e-007 | 2.89e-001 | 9.26e-002 | 2.63e+000 | 4.35e+000 |3.173e+001 |    37.89
  28| 7.67e-002 | -6.12e-007 | 2.64e-001 | 8.46e-002 | 2.63e+000 | 4.35e+000 |3.173e+001 |    39.25
  29| 7.62e-002 | -3.56e-007 | 1.39e-001 | 4.95e-002 | 2.63e+000 | 4.35e+000 |3.170e+001 |    40.62
  30| 4.22e-002 | -1.45e-007 | 8.74e-002 | 2.45e-002 | 2.63e+000 | 4.34e+000 |3.169e+001 |    41.97
  31| 2.64e-002 | -2.64e-008 | 6.44e-002 | 1.23e-002 | 2.63e+000 | 4.34e+000 |3.169e+001 |    43.33
  32| 1.65e-002 | -2.78e-008 | 4.33e-002 | 6.78e-003 | 2.63e+000 | 4.34e+000 |3.168e+001 |    44.71
  33| 8.38e-003 | -5.03e-008 | 2.21e-002 | 3.29e-003 | 2.63e+000 | 4.34e+000 |3.168e+001 |    46.07
  34| 4.95e-003 | -2.49e-008 | 1.34e-002 | 1.65e-003 | 2.63e+000 | 4.34e+000 |3.168e+001 |    47.44
  35| 2.48e-003 | -2.68e-008 | 6.82e-003 | 7.69e-004 | 2.63e+000 | 4.34e+000 |3.168e+001 |    48.80
  36| 2.29e-003 | -1.05e-008 | 2.83e-003 | 3.14e-004 | 2.63e+000 | 4.34e+000 |3.168e+001 |    50.16
  37| 1.60e-003 | -5.79e-009 | 1.76e-003 | 1.66e-004 | 2.63e+000 | 4.34e+000 |3.168e+001 |    51.52
  38| 1.72e-003 | -8.37e-010 | 1.32e-003 | 7.48e-005 | 2.63e+000 | 4.34e+000 |3.168e+001 |    52.88
  39| 2.07e-003 | -9.17e-011 | 4.46e-004 | 2.08e-005 | 2.63e+000 | 4.34e+000 |3.168e+001 |    54.25
  40| 1.17e-003 | -2.23e-010 | 2.98e-004 | 6.30e-006 | 2.63e+000 | 4.34e+000 |3.168e+001 |    55.61
  41| 1.40e-003 | -5.43e-012 | 9.61e-005 | 6.50e-007 | 2.63e+000 | 4.34e+000 |3.168e+001 |    56.97
  42| 3.05e-004 | -4.17e-013 | 3.06e-005 | 6.56e-008 | 2.63e+000 | 4.34e+000 |3.168e+001 |    58.34

DONE: the IPM computation converged!
==============================================
    Newton time: 30.017 seconds
  Function time: 27.9314 seconds
==============================================


    Total time: 69.938 seconds
===============
   Solver time: 58.3476 seconds
---------------
   Newton time: 30.017 seconds
 Function time: 27.9314 seconds

***** End Log *****
```

5.3 Analysis – SuperOPF + VSA

The Analysis SuperOPF + VSA selection brings a panel displaying the current VSA settings for the user to review. Click, “Cancel,” to dismiss the panel and return to the Edit VSA+OPF Settings function to modify the setting or click “Proceed” to accept the current settings and selection brings a panel displaying the current OPF settings for the user to review.

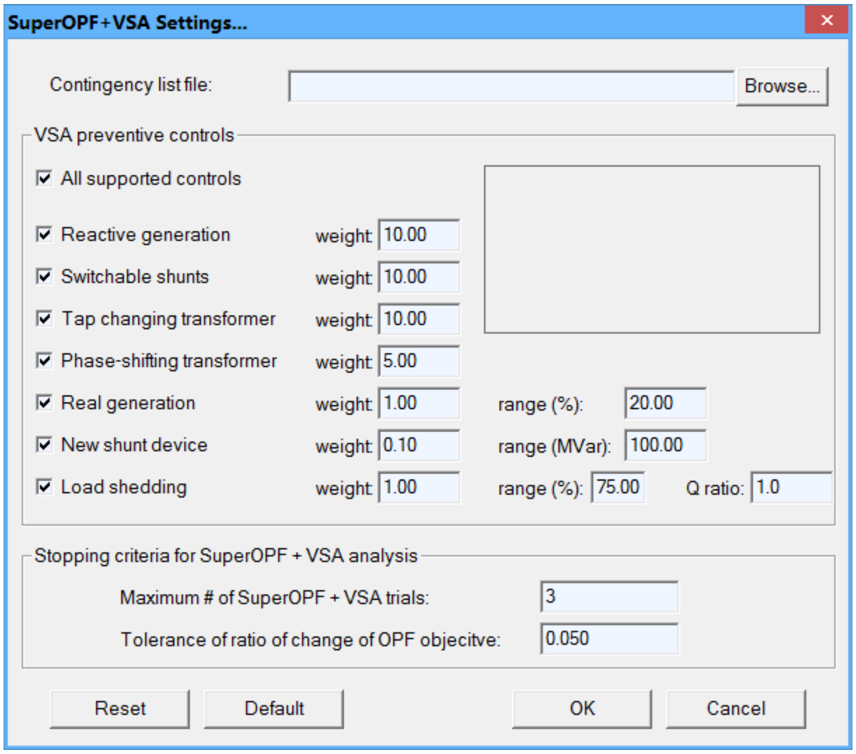


Figure: Confirm VSA settings and proceed panel

Click, “Cancel,” to dismiss the panel and return to the Edit OPF Settings function to modify the setting or click, “Run Analysis,” to accept the current settings and execute the optimal power flow with contingent voltage stability analysis.

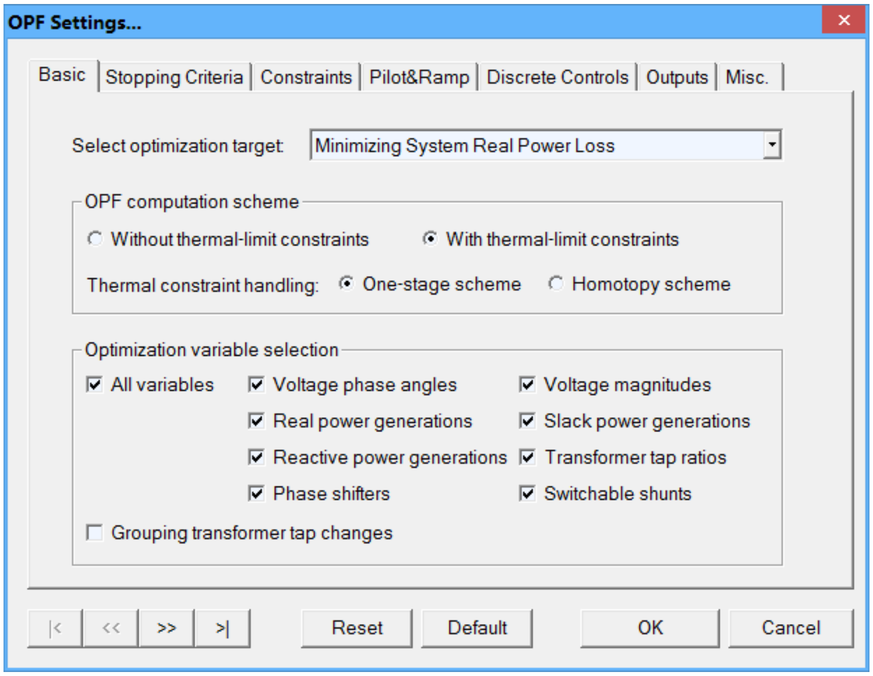


Figure: Confirm OPF settings and run panel

At the conclusion of the OPF run the following message panel is displayed to indicate the analysis completion. Click "OK" to dismiss. The OPF console window display log messages of the OPF run.

Section 6. **VIEW MENU**

The View Menu commands provide user control of the optional user interface features.

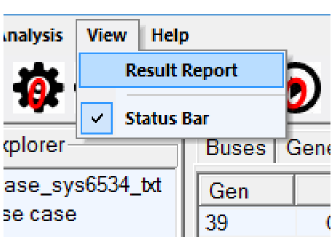


Figure: View menu

6.1 View Result Report

The “View Result Report” selection performs report processing for the OPF run. The follow popup window is displayed to present the OPF result reports.

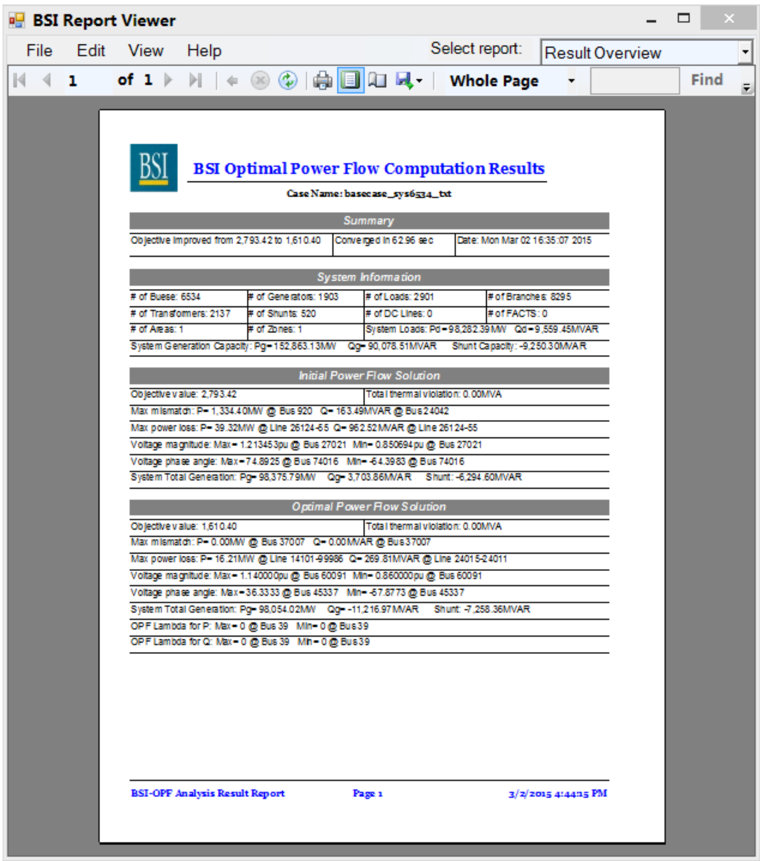


Figure: Report window

The following reports can be selected via the drop-down menu on the upper-right corner of the report window:

- Result overview report.
- Top changed voltages
- Top changed generators
- Top changed transformers
- Top changed shunts

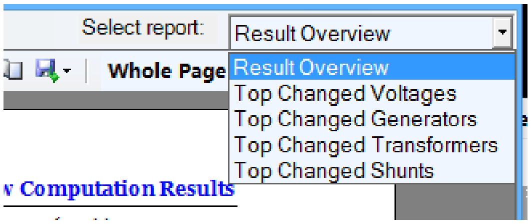


Figure: Report selection

6.1.1 Report: Optimal Power Flow Computation Summary

In this report, a summary of the OPF computation result is formatted. More specifically, the content of the report consists of the following sections:

- Summary: this section contains
  1) the OPF objective values for the initial power flow solution and the optimal power flow solution;
  2) the CPU time consumed by the computation; and
  3) the date and time of the computation.

- System information: this section contains dimensions of the system and basic system information, including
  1) numbers of different devices, namely, buses, generators, loads, branches, transformers, shunts, DC lines, and FACTS in the system;
  2) numbers of areas and zones in the system;
  3) the system real and reactive loads;
  4) the system real and reactive power generation capacities; and
  5) the system switchable shunt capacity.

- Initial power flow solution: this section contains system status overview for the initial power flow solution used as the starting point for the OPF study. Specifically, information displayed in this section includes:
  1) the OPF objective value;
  2) the system total thermal violation;
  3) the maximum real and reactive power flow mismatches and the associated buses;
  4) the maximum real and reactive power losses and the associated branches;
  5) the maximum and minimum voltage magnitudes and the associated buses;
  6) the maximum and minimum voltage phase angles and the associated buses;
  7) the system total real and reactive power generations; and
  8) the system total shunts.

- Optimal power flow solution: this section contains system status overview for the optimal power flow solution as the computation result of the OPF study. Specifically, information displayed in this section includes:

1) the OPF objective value;
2) the system total thermal violation;
3) the maximum real and reactive power flow mismatches and the associated buses;
4) the maximum real and reactive power losses and the associated branches;
5) the maximum and minimum voltage magnitudes and the associated buses;
6) the maximum and minimum voltage phase angles and the associated buses;
7) the system total real and reactive power generations;
8) the system total shunts;
9) the maximum and minimum marginal prices (Lambda values) for real power generations and associated buses; and
10) the maximum and minimum marginal prices (Lambda values) for reactive power generations and associated buses.

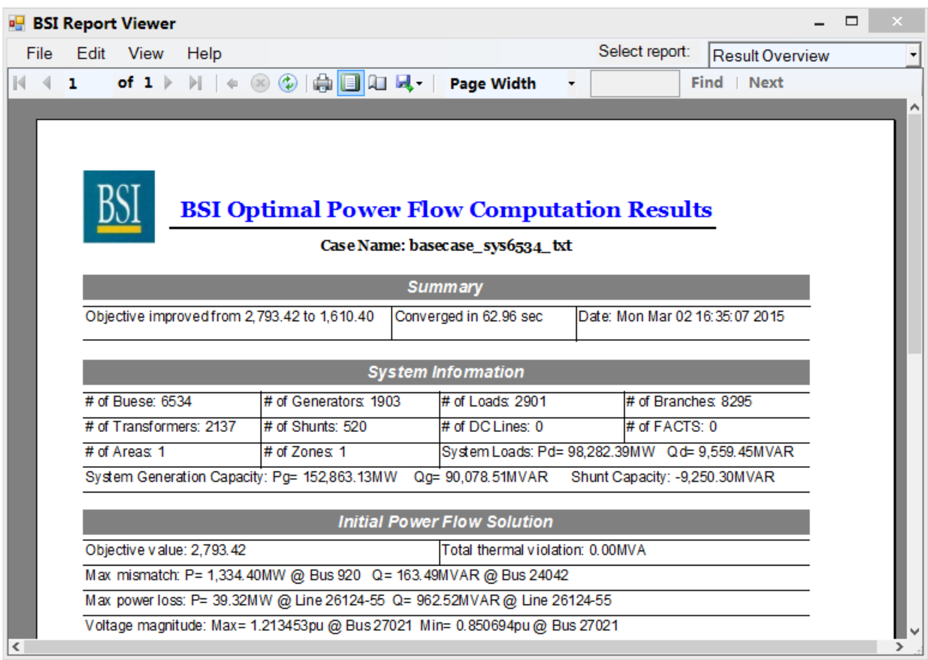


Figure: Computation summary

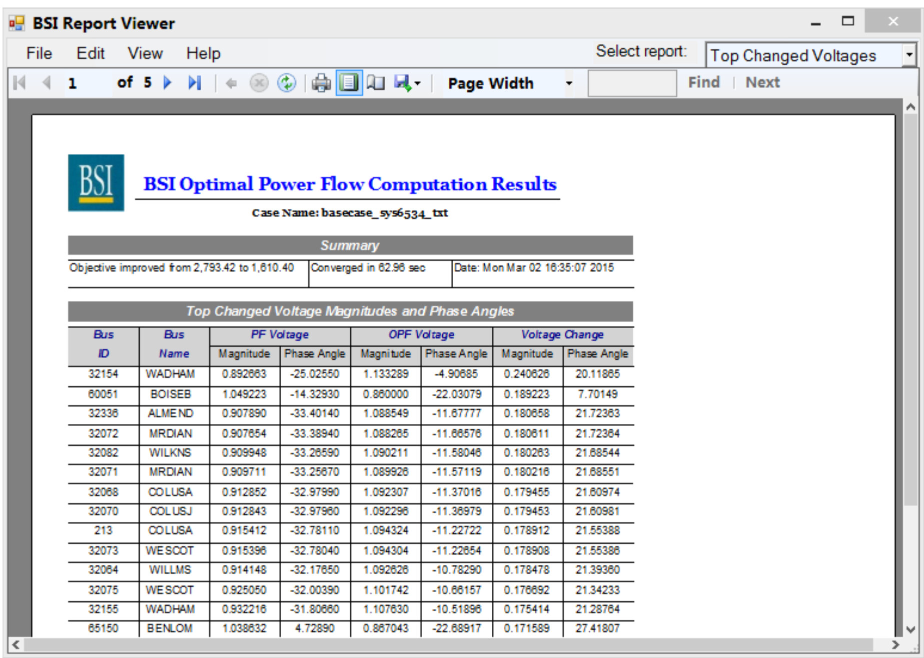
6.1.2 Report: Top Changed Voltage Magnitudes and Phase Angles

In this report, the list of buses with largest changes of voltage from the initial state (initial power flow solution) to the optimal state (optimal power flow solution) is presented. More specifically, the content of the report consists of the following sections

- Summary: this section contains

1) the OPF objective values for the initial power flow solution and the optimal power flow solution;
2) the CPU time consumed by the computation; and
3) the date and time of the computation.

- Top changed voltage magnitudes and phase angles, each row has eight items, including
  1) The bus number or ID,
  2) the bus name,
  3) the voltage magnitude (per-unit value) and the phase angle of the bus in the initial power solution;
  4) the voltage magnitude (per-unit value) and the phase angle of the bus in the optimal power flow solution; and
  5) the changes in the voltage magnitude (per-unit value) and the phase angle.



Summary		
Objective improved from 2,793.42 to 1,610.40	Converged in 62.96 sec	Date: Mon Mar 02 16:35:07 2015

Top Changed Voltage Magnitudes and Phase Angles

Bus ID	Bus Name	PF Voltage		OPF Voltage		Voltage Change	
		Magnitude	Phase Angle	Magnitude	Phase Angle	Magnitude	Phase Angle
32154	WADHAM	0.892663	-25.02550	1.133289	-4.90685	0.240626	20.11865
60051	BOISEB	1.049223	-14.32930	0.860000	-22.03079	0.189223	7.70149
32336	ALMEND	0.907890	-33.40140	1.088549	-11.67777	0.180658	21.72363
32072	MRDIAN	0.907654	-33.38940	1.088265	-11.66576	0.180611	21.72364
32082	WILKNS	0.909948	-33.26590	1.090211	-11.58046	0.180263	21.68544
32071	MRDIAN	0.909711	-33.25670	1.089926	-11.57119	0.180216	21.68551
32068	COLUSA	0.912852	-32.97990	1.092307	-11.37016	0.179455	21.60974
32070	COLUSJ	0.912843	-32.97960	1.092296	-11.36979	0.179453	21.60981
213	COLUSA	0.915412	-32.78110	1.094324	-11.22722	0.178912	21.55388
32073	WESCOT	0.915396	-32.78040	1.094304	-11.22654	0.178908	21.55386
32064	WILLMS	0.914148	-32.17650	1.092626	-10.78290	0.178478	21.39360
32075	WESCOT	0.925050	-32.00390	1.101742	-10.66157	0.176692	21.34233
32155	WADHAM	0.932216	-31.80660	1.107630	-10.51896	0.175414	21.28764
65150	BENLOM	1.038632	4.72890	0.867043	-22.68917	0.171589	27.41807

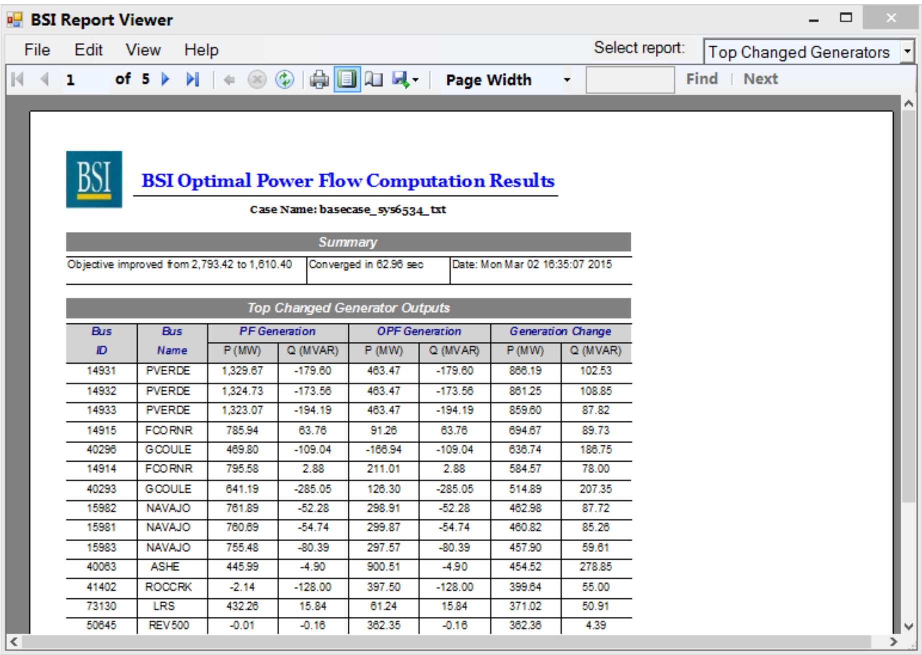
Figure: Top changed voltage magnitudes and phase angles

6.1.3 Report: Top Changed Generator Outputs

In this report, the list of generators with largest changes from the initial state (initial power flow solution) to the optimal state (optimal power flow solution) is presented. More specifically, the content of the report consists of the following sections

- Summary: this section contains
  4) the OPF objective values for the initial power flow solution and the optimal power flow solution;
  5) the CPU time consumed by the computation; and
  6) the date and time of the computation.

- Top changed generators, each row has eight items, including
  6) The bus number or ID,
  7) the bus name,
  8) the real and reactive power generation of the generator in the initial power solution;
  9) the real and reactive power generation of the generator in the optimal power solution; and
  10) the changes in the real and reactive power generation of the generator.



Bus ID	Bus Name	PF Generation		OPF Generation		Generation Change	
		P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
14931	PVERDE	1,329.67	-179.60	463.47	-179.60	866.19	102.53
14932	PVERDE	1,324.73	-173.56	463.47	-173.56	861.25	108.85
14933	PVERDE	1,323.07	-194.19	463.47	-194.19	859.60	87.82
14915	FCORNR	785.94	63.76	91.26	63.76	694.67	89.73
40296	GCOULE	469.80	-109.04	-166.94	-109.04	636.74	186.75
14914	FCORNR	795.58	2.88	211.01	2.88	584.57	78.00
40293	GCOULE	641.19	-285.05	126.30	-285.05	514.89	207.35
15982	NAVAJO	761.89	-52.28	298.91	-52.28	462.98	87.72
15981	NAVAJO	760.69	-54.74	299.87	-54.74	460.82	85.26
15983	NAVAJO	755.48	-80.39	297.57	-80.39	457.90	59.61
40063	ASHE	445.99	-4.90	900.51	-4.90	454.52	278.85
41402	ROCCRK	-2.14	-128.00	397.50	-128.00	399.64	55.00
73130	LRS	432.26	15.84	61.24	15.84	371.02	50.91
50645	REV500	-0.01	-0.16	362.35	-0.16	362.36	4.39

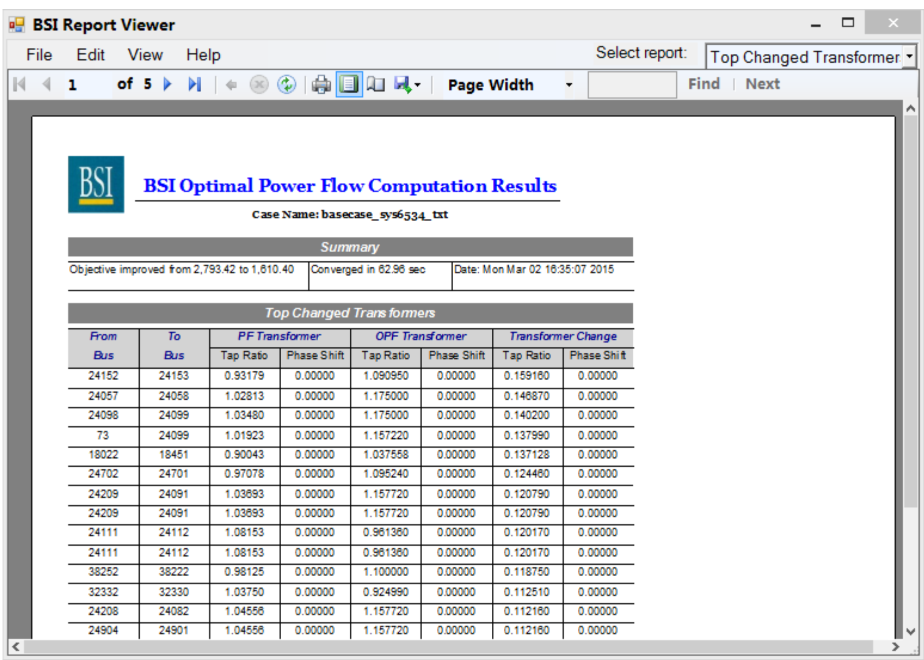
Figure: Top changed generators

6.1.4 Report: Top Changed Transformers

In this report, the list of transformers with largest changes from the initial state (initial power flow solution) to the optimal state (optimal power flow solution) is presented. More specifically, the content of the report consists of the following sections

- Summary: this section contains
  1) the OPF objective values for the initial power flow solution and the optimal power flow solution;
  2) the CPU time consumed by the computation; and
  3) the date and time of the computation.

- Top changed transformers, each row has eight items, including
  1) the from-end bus number or ID,
  2) the to-end bus number or ID,
  3) the tap ratio and phase angle of the transformer in the initial power solution;
  4) the tap ratio and phase angle of the transformer in the optimal power solution; and
  5) the changes in the tap ratio and phase angle of the transformer.



From Bus	To Bus	PF Transformer Tap Ratio	PF Transformer Phase Shift	OPF Transformer Tap Ratio	OPF Transformer Phase Shift	Transformer Change Tap Ratio	Transformer Change Phase Shift
24152	24153	0.93179	0.00000	1.090950	0.00000	0.159160	0.00000
24057	24058	1.02813	0.00000	1.175000	0.00000	0.146870	0.00000
24098	24099	1.03480	0.00000	1.175000	0.00000	0.140200	0.00000
73	24099	1.01923	0.00000	1.157220	0.00000	0.137990	0.00000
18022	18451	0.90043	0.00000	1.037558	0.00000	0.137128	0.00000
24702	24701	0.97078	0.00000	1.095240	0.00000	0.124460	0.00000
24209	24091	1.03693	0.00000	1.157720	0.00000	0.120790	0.00000
24209	24091	1.03693	0.00000	1.157720	0.00000	0.120790	0.00000
24111	24112	1.08153	0.00000	0.961360	0.00000	0.120170	0.00000
24111	24112	1.08153	0.00000	0.961360	0.00000	0.120170	0.00000
38252	38222	0.98125	0.00000	1.100000	0.00000	0.118750	0.00000
32332	32330	1.03750	0.00000	0.924990	0.00000	0.112510	0.00000
24208	24082	1.04556	0.00000	1.157720	0.00000	0.112160	0.00000
24904	24901	1.04556	0.00000	1.157720	0.00000	0.112160	0.00000

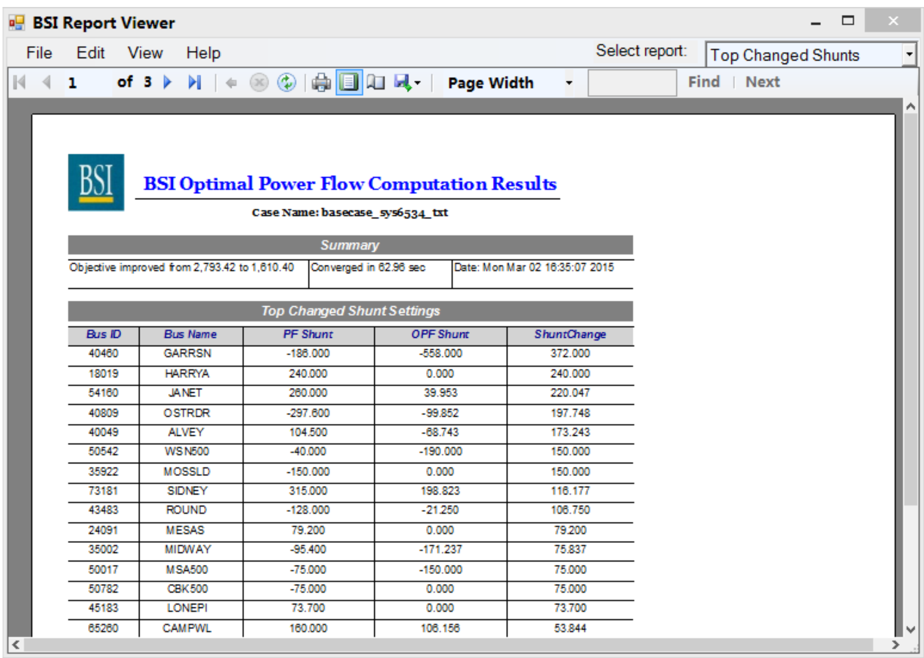
Figure: Top changed transformers

6.1.5 Report: Top Changed Shunts

In this report, the list of shunts with largest changes from the initial state (initial power flow solution) to the optimal state (optimal power flow solution) is presented. More specifically, the content of the report consists of the following sections

- Summary: this section contains
  1) the OPF objective values for the initial power flow solution and the optimal power flow solution;
  2) the CPU time consumed by the computation; and
  3) the date and time of the computation.

- Top changed shunts, each row has five items, including
  1) the bus number or ID,
  2) the bus name,
  3) the shunt setting in the initial power solution;
  4) the shunt setting in the optimal power flow solution; and
  5) the changes in the shunt setting.



Bus ID	Bus Name	PF Shunt	OPF Shunt	ShuntChange
40460	GARRSN	-186.000	-558.000	372.000
18019	HARRYA	240.000	0.000	240.000
54160	JANET	260.000	39.953	220.047
40809	OSTRDR	-297.600	-99.852	197.748
40049	ALVEY	104.500	-68.743	173.243
50542	WSN500	-40.000	-190.000	150.000
35922	MOSSLD	-150.000	0.000	150.000
73181	SIDNEY	315.000	198.823	116.177
43483	ROUND	-128.000	-21.250	106.750
24091	MESAS	79.200	0.000	79.200
35002	MIDWAY	-95.400	-171.237	75.837
50017	MSA500	-75.000	-150.000	75.000
50782	CBK500	-75.000	0.000	75.000
45183	LONEPI	73.700	0.000	73.700
65260	CAMPWL	160.000	106.156	53.844

Figure: Top changed shunts

6.1.6 Report: Optimal Power Flow + VSA Computation Summary

In this report, a summary of the OPF with voltage stability analysis computation result is formatted. More specifically, the content of the report consists of the following sections:

- Summary: this section contains
  1) the OPF objective values for the initial power flow solution and the optimal power flow solution;
  2) the CPU time consumed by the computation; and
  3) the date and time of the computation.

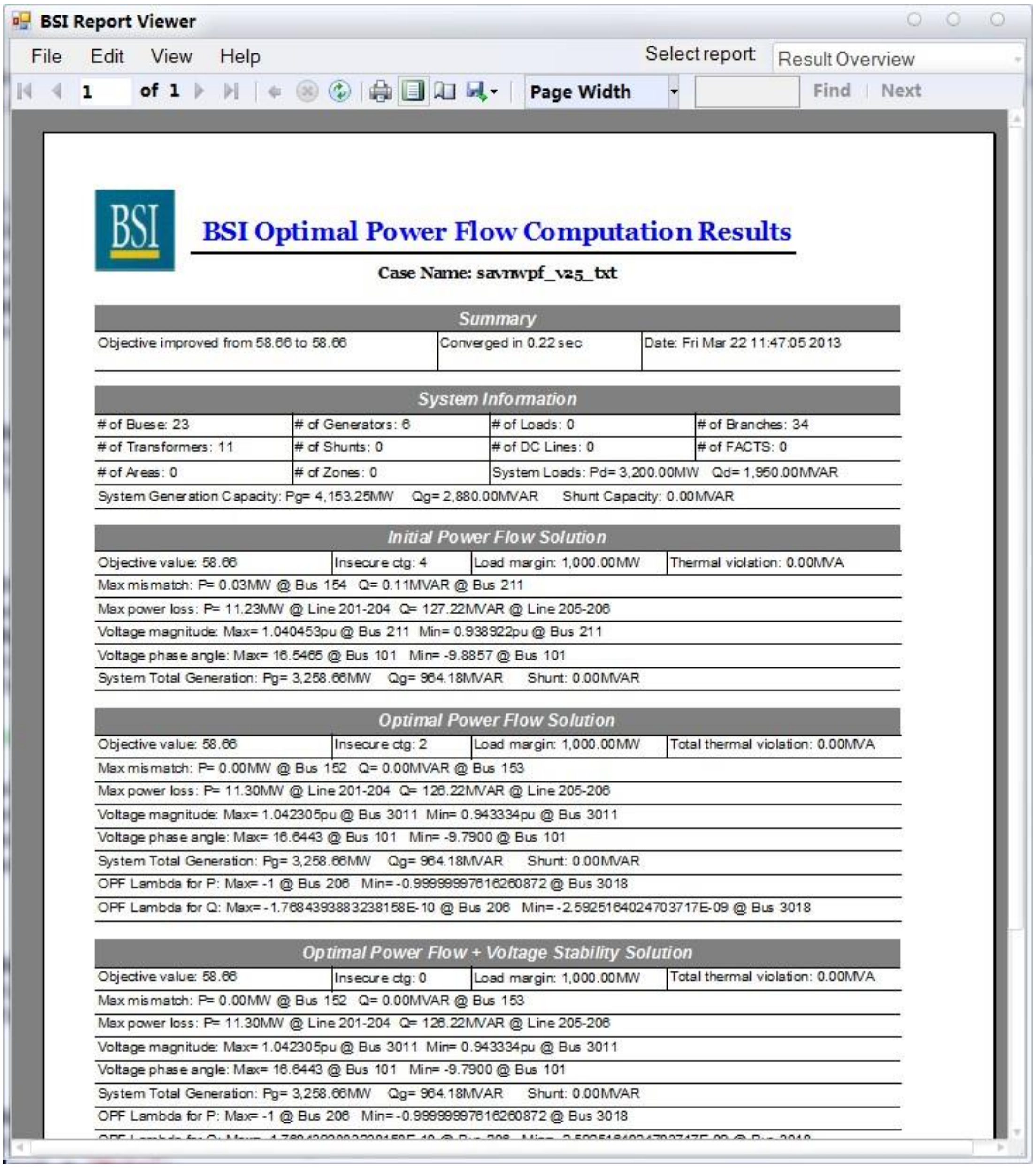
- System information: this section contains dimensions of the system and basic system information, including
  1) numbers of different devices, namely, buses, generators, loads, branches, transformers, shunts, DC lines, and FACTS in the system;
  2) numbers of areas and zones in the system;
  3) the system real and reactive loads;
  4) the system real and reactive power generation capacities; and
  5) the system switchable shunt capacity.

- Initial power flow solution: this section contains system status overview for the initial power flow solution used as the starting point for the OPF study. Specifically, information displayed in this section includes:
  1) the OPF objective value;
  2) the number of insecure contingencies;
  3) the system real load margin;
  4) the system total thermal violation;
  5) the maximum real and reactive power flow mismatches and the associated buses;
  6) the maximum real and reactive power losses and the associated branches;
  7) the maximum and minimum voltage magnitudes and the associated buses;
  8) the maximum and minimum voltage phase angles and the associated buses;
  9) the system total real and reactive power generations; and
  10) the system total shunts.

- Optimal power flow (before VSA) solution: this section contains system status overview for the base-line optimal power flow solution before VSA as the computation result of the OPF+VS study. Specifically, information displayed in this section includes:
  1) the OPF objective value;
  2) the number of insecure contingencies;
  3) the system real load margin;
  4) the system total thermal violation;
  5) the maximum real and reactive power flow mismatches and the associated buses;

6) the maximum real and reactive power losses and the associated branches;
7) the maximum and minimum voltage magnitudes and the associated buses;
8) the maximum and minimum voltage phase angles and the associated buses;
9) the system total real and reactive power generations;
10) the system total shunts;
11) the maximum and minimum marginal prices (Lambda values) for real power generations and associated buses; and
12) the maximum and minimum marginal prices (Lambda values) for reactive power generations and associated buses.

- Optimal power flow (after VSA) solution: this section contains system status overview for the final optimal power flow solution after VSA as the computation result of the OPF+VS study. Specifically, information displayed in this section includes:
  1) the OPF objective value;
  2) the number of insecure contingencies;
  3) the system real load margin;
  4) the system total thermal violation;
  5) the maximum real and reactive power flow mismatches and the associated buses;
  6) the maximum real and reactive power losses and the associated branches;
  7) the maximum and minimum voltage magnitudes and the associated buses;
  8) the maximum and minimum voltage phase angles and the associated buses;
  9) the system total real and reactive power generations;
  10) the system total shunts;
  11) the maximum and minimum marginal prices (Lambda values) for real power generations and associated buses; and
  12) the maximum and minimum marginal prices (Lambda values) for reactive power generations and associated buses.



BSI Optimal Power Flow Computation Results

Case Name: savnwpf_v25_txt

Summary		
Objective improved from 58.66 to 58.66	Converged in 0.22 sec	Date: Fri Mar 22 11:47:05 2013

System Information			
# of Buese: 23	# of Generators: 6	# of Loads: 0	# of Branches: 34
# of Transformers: 11	# of Shunts: 0	# of DC Lines: 0	# of FACTS: 0
# of Areas: 0	# of Zones: 0	System Loads: Pd= 3,200.00MW Qd= 1,950.00MVAR	
System Generation Capacity: Pg= 4,153.25MW Qg= 2,880.00MVAR Shunt Capacity: 0.00MVAR			

Initial Power Flow Solution			
Objective value: 58.66	Insecure ctg: 4	Load margin: 1,000.00MW	Thermal violation: 0.00MVA
Max mismatch: P= 0.03MW @ Bus 154 Q= 0.11MVAR @ Bus 211			
Max power loss: P= 11.23MW @ Line 201-204 Q= 127.22MVAR @ Line 205-206			
Voltage magnitude: Max= 1.040453pu @ Bus 211 Min= 0.938922pu @ Bus 211			
Voltage phase angle: Max= 16.5465 @ Bus 101 Min= -9.8857 @ Bus 101			
System Total Generation: Pg= 3,258.66MW Qg= 964.18MVAR Shunt: 0.00MVAR			

Optimal Power Flow Solution			
Objective value: 58.66	Insecure ctg: 2	Load margin: 1,000.00MW	Total thermal violation: 0.00MVA
Max mismatch: P= 0.00MW @ Bus 152 Q= 0.00MVAR @ Bus 153			
Max power loss: P= 11.30MW @ Line 201-204 Q= 126.22MVAR @ Line 205-206			
Voltage magnitude: Max= 1.042305pu @ Bus 3011 Min= 0.943334pu @ Bus 3011			
Voltage phase angle: Max= 16.6443 @ Bus 101 Min= -9.7900 @ Bus 101			
System Total Generation: Pg= 3,258.66MW Qg= 964.18MVAR Shunt: 0.00MVAR			
OPF Lambda for P: Max= -1 @ Bus 206 Min= -0.999999997616260872 @ Bus 3018			
OPF Lambda for Q: Max= -1.7684393883238158E-10 @ Bus 206 Min= -2.5925164024703717E-09 @ Bus 3018			

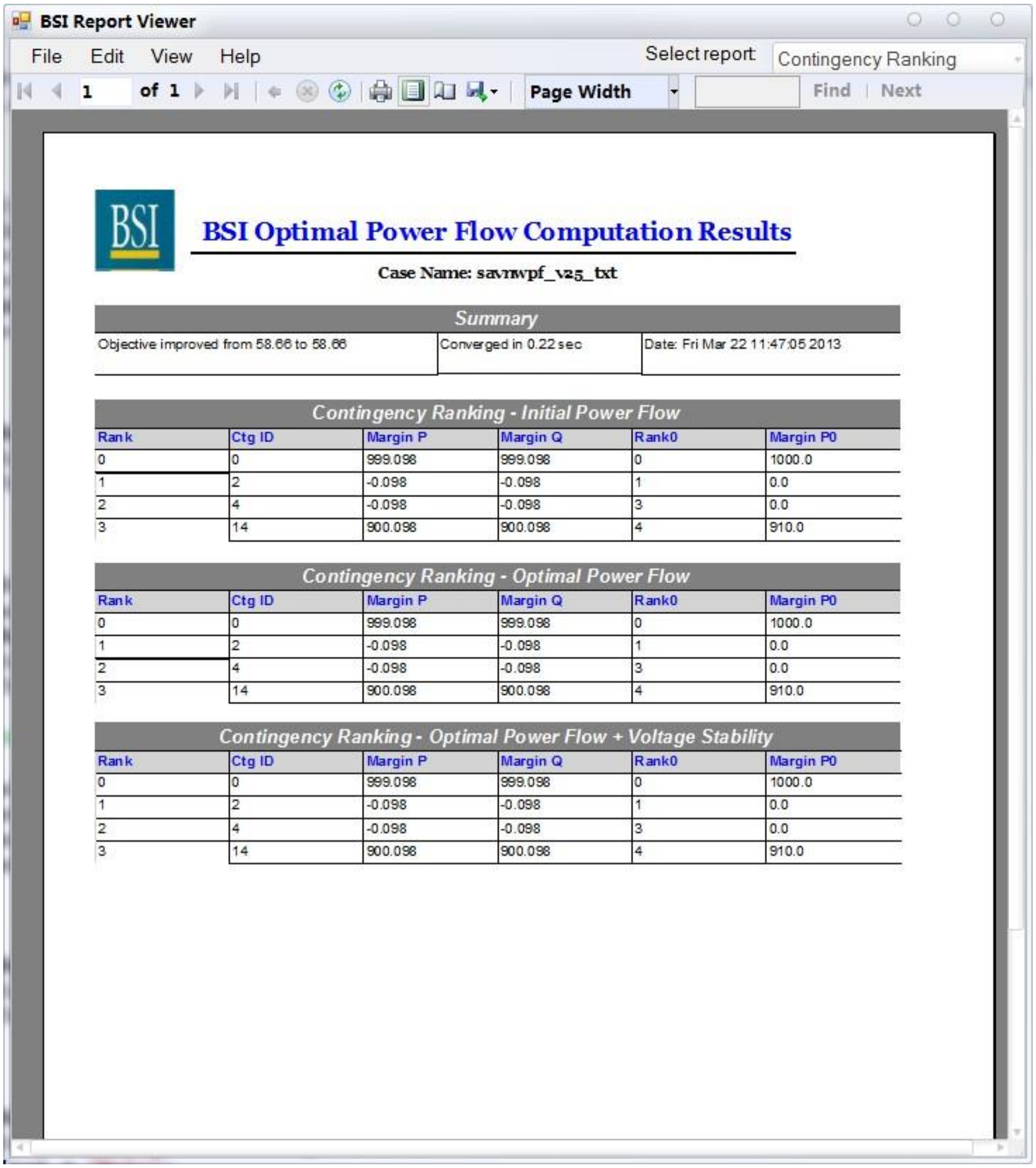
Optimal Power Flow + Voltage Stability Solution			
Objective value: 58.66	Insecure ctg: 0	Load margin: 1,000.00MW	Total thermal violation: 0.00MVA
Max mismatch: P= 0.00MW @ Bus 152 Q= 0.00MVAR @ Bus 153			
Max power loss: P= 11.30MW @ Line 201-204 Q= 126.22MVAR @ Line 205-206			
Voltage magnitude: Max= 1.042305pu @ Bus 3011 Min= 0.943334pu @ Bus 3011			
Voltage phase angle: Max= 16.6443 @ Bus 101 Min= -9.7900 @ Bus 101			
System Total Generation: Pg= 3,258.66MW Qg= 964.18MVAR Shunt: 0.00MVAR			
OPF Lambda for P: Max= -1 @ Bus 206 Min= -0.999999997616260872 @ Bus 3018			

Figure: Optimal power flow + VS result summary

6.1.7 Report: Contingency Rankings

In this report, the contingency rankings for the initial state (initial power flow solution), the optimal state (optimal power flow solution) before VSA, and the optimal state (optimal power flow solution) after VSA are presented. More specifically, the content of the report consists of the following sections

- Summary: this section contains
  1) the OPF objective values for the initial power flow solution and the optimal power flow solution;
  2) the CPU time consumed by the computation; and
  3) the date and time of the computation.
- Contingency ranking for the initial state, each row has six items, including
  1) the rank ID (0 for base case),
  2) the contingency ID (0 for base case),
  3) the system real load margin;
  4) the system reactive load margin;
  5) the estimated contingency rank ID (0 for base case); and
  6) the estimated system real load margin.
- Contingency ranking for the optimal state before VSA, each row has six items, including
  1) the rank ID (0 for base case),
  2) the contingency ID (0 for base case),
  3) the system real load margin;
  4) the system reactive load margin;
  5) the estimated contingency rank ID (0 for base case); and
  6) the estimated system real load margin.
- Contingency ranking for the optimal state after VSA, each row has six items, including
  1) the rank ID (0 for base case),
  2) the contingency ID (0 for base case),
  3) the system real load margin;
  4) the system reactive load margin;
  5) the estimated contingency rank ID (0 for base case); and
  6) the estimated system real load margin.



BSI

BSI Optimal Power Flow Computation Results

Case Name: savnwpf_v25_txt

Summary		
Objective improved from 58.66 to 58.66	Converged in 0.22 sec	Date: Fri Mar 22 11:47:05 2013

Contingency Ranking - Initial Power Flow

Rank	Ctg ID	Margin P	Margin Q	Rank0	Margin P0
0	0	999.098	999.098	0	1000.0
1	2	-0.098	-0.098	1	0.0
2	4	-0.098	-0.098	3	0.0
3	14	900.098	900.098	4	910.0

Contingency Ranking - Optimal Power Flow

Rank	Ctg ID	Margin P	Margin Q	Rank0	Margin P0
0	0	999.098	999.098	0	1000.0
1	2	-0.098	-0.098	1	0.0
2	4	-0.098	-0.098	3	0.0
3	14	900.098	900.098	4	910.0

Contingency Ranking - Optimal Power Flow + Voltage Stability

Rank	Ctg ID	Margin P	Margin Q	Rank0	Margin P0
0	0	999.098	999.098	0	1000.0
1	2	-0.098	-0.098	1	0.0
2	4	-0.098	-0.098	3	0.0
3	14	900.098	900.098	4	910.0

Figure: Contingency rankings

6.2 View Status Bar

Use check box toggle to display or hide the Status Bar that is displayed at the bottom of the BSI-OPF main window.

Figure: Status bar example

6.3 View Toolbars and Docking Windows

Use check box toggle to display or hide the Standard or Customized Toolbar displayed in the BSI=OPF main window just below the top-level menu.

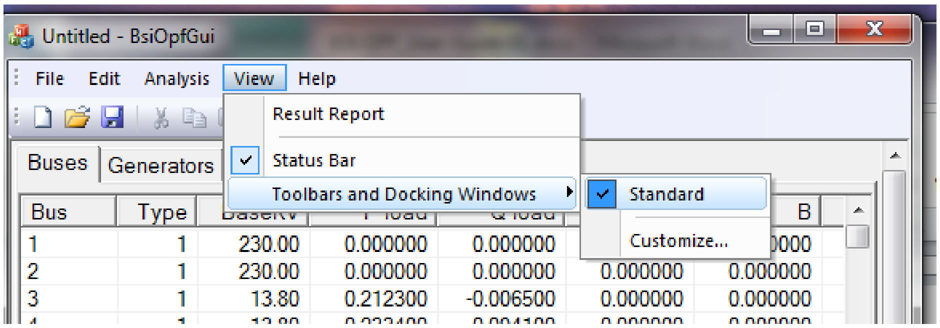


Figure: View Toolbar menu selection

Section 7. **CONSOLE PROGRAM**

Besides the GUI program, a console program is also developed in the SuperOPF suite. This console program eliminates all graphical interactions and can only be run in a command line environment. However, the user still has a full control over the computation scenarios through specifying the parameters to the SuperOPF console program via the following command-line option values.

```
NAME:
    bsiopf - BSI optimal power flow (OPF) computation program.

USAGE:
  Mode 1: by specifying the session/configuration file:
    bsiopf -C cfg_file

  Mode 2: by specifying individual parameter values:
    bsiopf -f pf_file -g gc_file -R rop_file -w work_dir -m msg_file -o out_file
           -t [ploss|qloss|pgall|qgall|pcost|vmvio] -c [polar|rect]
           -p [psse|mpwr] -v version [25|30|33] -S snr_file
           -i max_iter -j rlx_iter -s vmag_erlx -G vmag_crlx -q 0.1,0.2,0.5 -u 1111111
           -e [no|yes] -a [no|yes] -b homot_rlx0 -d tvio_thr -k homot_step -I [no|yes]
           -n [yes|no] -r [yes|no] -h [no|yes] -x [yes|no] -y [no|yes] -z [no|yes]
           -T [no|yes] -P [0|1|...] -D 0.01 -M [yes|no]
           -A [no|yes] -B pilot_file -E [no|yes] -H [no|yes] -F 1,2,3,4

DESCRIPTION:
    -a  Specify if homotopy-type scheme is used for thermal-limit handling?
    -b  Specify the homotopy starting violation relaxation factor
    -c  Specify the coordinate system for voltages.
    -d  Specify the thermal violation suppressing threshold
    -e  Specify the middle-value initialization for computation.
    -f  Specify the power flow file for computation.
    -g  Specify the generation cost file for computation.
```

```
    -h  Specify the homotopy scheme in constraint analysis/relaxation.
    -i  Specify the maximum number of iterations for each solution trial.
    -j  Specify the maximum number of iterations for each relaxation trial.
    -k  Specify the maximum number of homotopy steps for thermal violation handling
    -m  Specify the running message output file name.
    -n  Specify if discrete variables will be processed or not.
    -o  Specify the optimal power flow result file.
    -p  Specify the power flow file specification type.
    -q  Specify the discrete variable adjusting thresholds (e.g. -q 0.1,0.2,0.5 or -q 3).
    -r  Specify the branch thermal-limit checking status.
    -s  Specify the network-wise global voltage relaxation value (external).
    -t  Specify the type of objective for optimal power flow computation.
    -u  Specify the active status of each category of variables (e.g. -u 1111111).
    -v  Specify the version of the power flow file format.
    -w  Specify the working folder path with writable permission.
    -x  Specify if network analysis is carried out or not.
    -y  Specify if constraint analysis is carried out or not.
    -z  Specify if automated differentiation is used or not.
    -A  Specify if output files with case surffix.
    -B  Specify the pilot device spec data (AVC mode).
    -C  Specify the session/configuration file (will ignor other parameters).
    -D  Specify the generation deviation cost coefficient.
    -E  Specify if AVC mode will be active or not (pilot file needs to be valid)
    -F  Specify the list of central areas (other areas will be regarded as external)
    -G  Specify the network-wise global voltage relaxation value (central).
    -H  Specify if secondary pilot devices are enabled for AVC computation.
    -I  Specify if system trajectory integration is enabled for initialization.
    -M  Specify if the co-optimization problem will be treated as the master problem.
    -P  Specify the scenario sub-problem to be solved.
    -R  Specify the OPF raw data file path.
    -S  Specify the scenario bundle specification file.
    -T  Specify if multi-scenario analysis is enabled or not.

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    Copyright (c) 2010-2015 Bigwood Systems Inc.
    All rights reserved.
```

This results in a stand-alone, lightweight SuperOPF program suitable for low-end hardware environments. Moreover, such command-line based execution of the SuperOPF program provides the user a convenient way to effectively cooperate with other computation and management programs. For example, the user can include the call of the SuperOPF console program in a script to automate the analysis tasks of sequential execution of multiple programs or the task of analyzing a batch of scenarios.

Detailed descriptions are provided below:

Option –a

Use option –a if BSI-SuperOPF should use a homotopy-type scheme for thermal-limit handling. This option can improve the program convergence when thermal-limits are causing poor convergence. Option –a can be specified with a “no” or “yes”. The default value of this option is “no”.

Option –b

Use option –b to specify the homotopy starting violation relaxation factor. Values should be between 0.0 and 1.0.

Option –c

Use option –c to specify the coordinate system for voltages. The default coordinate system is the polar coordinate system. Options include the polar coordinate system (specified by the option value "polar") or the rectangular coordinate system (specified by the option value "rect"). The default value of this option is "polar".

Option –d
Use option –d to specify the thermal violation suppressing threshold. This parameter is used in the homotopy scheme for handling thermal limit constraints. During a homotopy step, thermal limit constraints imposed on those branches with thermal violations lower than this threshold value will be treated in full, that is, will not be relaxed by the homotopy step. The default value of this threshold is 1.0 pu.

Option -e
Use option –e to specify the middle-value initialization for the BSI-SuperOPF computation. If this option value is "yes", then the middle value within the allowable ranges of the variables will be used as the starting point for the OPF computation. Otherwise, the system state values specified in the input power flow file will be used as the starting point for the OPF computation. The default value of this option is "no".

Option –f
Use option –f to specify the power flow file for computation. Option –f must be provided to run BSI-SuperOPF.

Option -g
Use option –g to specify the generation cost file. Option –g must be provided to run BSI-SuperOPF if the objective of the OPF computation is to minimize the system generation cost.

Option -h
Use option –h to specify the homotopy scheme in constraint analysis or relaxation computation. Options include "yes" or "no". If this option value is "yes", then the homotopy scheme will be used as the solution method for the OPF computation. Otherwise, the default one-staged method will be used for the OPF computation. The default value of this option is "no".

Option –i
Use option –i to specify the maximum number of iterations for each OPF computation trial. The default value is 500.

Option –j
Use option –j to specify the maximum number of iterations that should be used for each feasibility analysis or relaxation trial. This value is only considered when the constraint analysis is enabled by specifying the option "–y yes". The default value is 500.

Option –k

Use option –k to specify the maximum number of homotopy steps for thermal violation handling. This value is considered only when the homotopy scheme is enabled by specifying the option “-a yes”. The default value is 2.

Option –m
Use option –m to specify the running message output file. The default message file name is “message.txt” in the current folder.

Option –n
Use option –n to specify if discrete variables will be processed or not. Options are “yes” or “no”. If the value is “no”, involved discrete controls will be only treated as continuous variables; therefore, in the output of the computation, a discrete control variable can take any value between its lower and upper bounds. The default value is “no”.

Option –o
Use option –o to specify the location of the result file. If this option is not specified, the computation result will be saved to a default file, whose file name is automatically generated by the program based on the power flow file name.

Option –p
Use option –p to specify the power flow specification type. The current supported power flow file formats include:
- psse: PSS/E formatted power flow file; and
- mpwr: MATPOWER formatted power flow file (both version 1 and version 2).

The default value of this option is “psse”.

Option –q
Use option –q to specify the discrete variable adjusting thresholds. This option is considered only when the option –n for processing discrete variables is enabled (i.e., “-n yes”). The value for this option can be specified in two formats:
- “-q v1,v2,…,vn”: the discrete variable adjusting will be carried out in n steps with ascending threshold values v1, v2, …, vn. Only values within (0.0,0.5] is allowed for the specified thresholds.
- “-q n”: the discrete adjusting will be carried out in n steps, where the threshold values at each step will be automatically determined by the program.

The default value is “0.1,0.2.0.5”.

Option –r
Use option –r to specify the branch thermal-limit checking status. Options include “yes” or “no”. If this option is enabled, thermal-limit constraints will be involved in the OPF computation; therefore, there will be no any thermal-violated branches in the resulted optimal power flow. Since thermal-limit constraints are nonlinear inequality constraint, their involvement in the OPF problem will make the computation considerably more complicated. The default value is “no”.

Option –s
Use option –s to specify the network-wise global voltage relaxation value. This value controls the system-wise lower and upper bounds for bus voltage magnitudes. Specifically, if this option value is set to "-s 0.01", the system-wise range for the allowable bus voltage magnitudes will be within [0.89pu,1.11pu]. The default value is 0.0 pu, that is, the system-wise range for the allowable bus voltage magnitudes is [0.9pu, 1.1pu].

Option –t
Use option –t to specify the type of objective for optimal power flow computation. Options include
- "ploss": the OPF objective is to minimize the system real power losses;
- "qloss": the OPF objective is to minimize the system reactive power losses;
- "pgall": the OPF objective is to minimize the system total real power generation;
- "qgall": the OPF objective is to minimize the system total reactive power generation;
- "pcost": the OPF objective is to minimize the system total generation cost; and
- "mviol": the OPF objective is to minimize the system total voltage violations.

If this option value is not specified, the default OPF objective will be to minimize the system real power losses.

Option –u
Use option –u to specify the active status of the seven categories of variables which are currently supported by the program. The seven categories are
- 1st digit: Bus voltage phase angles;
- 2nd digit: Bus voltage magnitudes;
- 3rd digit: Transformer tap ratios;
- 4th digit: Phase-shifting transformer phase angles;
- 5th digit: Switchable shunts;
- 6th digit: Real power generations;
- 7th digit: Reactive power generations.

The "1" value for a digit means the corresponding category of variables will be involved in the optimization process (i.e., their values will be optimally changed in order to achieve the desired objective). The default value for this option is "1111111", that is, all seven categories of variables will be involved in the OPF computation.

Option –v
Use option –v to specify the powerflow file format. This option is only considered for PSS/E power flow files (with option value "-p psse"). Options include "25" or "30". The default value for this option is "25".

Option –w
Use option –w to specify the working folder path and allow writable permission. All intermediate files generated during the OPF computation will be written to this folder. This option must be specified in order for an OPF computation.

Option –x
Use option –x to specify if network analysis will be carried out. Options include "yes" or "no". If this option is enabled, a set of straightforward scenarios will checked over the input network and power flow data. Existence of these scenarios will cause the OPF computation infeasible. Corrections will be automatically applied in order to eliminate the caused infeasibility; therefore, the proceeding OPF computation can progress to a convergent solution (optimal solution). The default value of this option is "yes".

Option –y
Use option –y to specify if the constraint analysis has been carried out. Options include "yes" or "no". If this option is enabled ("-y yes"), a full constraint analysis will be carried out before OPF computation is carried out. This full constraint analysis is to solve an optimization problem involving only the OPF constraints. This procedure is much more complicated than the straightforward scenarios for the option "-x yes". The default value of this option is "no".

Option –z
Use option –z to specify if automated differentiation is used or not. Options include "yes" or "no". If this option is enabled, the exact first- (Jacobian) and second-order (Hessian) derivatives of the objective and constraint functions of the optimization problem will be computed using the automated differentiation technique, eliminating the need of hard-coded derivative computations. This computation is carried out at the expense of increased computing time. The default value of this option is "no".

Option –A
Use option –A to specify if the output file names will be appended with the case name. Options include "yes" or "no". The default value of this option is "no".

Option –B
Use option –B to specify the pilot control data file. This pilot control file specifies extra constraints to be satisfied by the obtained solution.

Option –C
Use option –C to specify the session configuration file. This session file contains all settings values. If this file is specified, all other parameter values specified through program arguments will be ignored. An exemplar session file is presented in the appendix.

Option –D
Use option –D to specify the generation deviation cost coefficient. This is a penalty cost associated with requesting higher or lower power production from a given generator over the originally planned value (the base-case OPF solution). The coefficient is applied to a quadratic function which adjusts the penalty as a function of power output deviation. The default value is 0.01.

Option –E
Use option –E to specify if the AVC mode will be enforced or not. Options include "yes" or "no". If this option is enabled, and the pilot control file is provided, the AVC mode will be enabled. The default value is "no".

Option –F
Use option –F to specify the list of central areas. The list of central areas is specified in the format "-F a1,a2,a3". If this value is specified, the specified areas will be treated as the central areas; while all other areas in the system will be treated as external areas.

Option –G
Use option –G to specify the network-wise global voltage relaxation value for AVC mode. This option is valid only when the option "–E yes" is also specified.

Option –H
Use option –H to specify if the secondary pilot controls will be enforced or not. Options include "yes" or "no". The default value is "no".

Option –I
Use option –I to specify if the dynamic trajectory integration method will be used for initializing the OPF computation. Options include "yes" or "no". The default value is "no".

Option –M
Use option –M to specify if the co-optimization problem will be treated as the master problem. When this option is selected, the problem will be optimized in two stages. In the first stage, the scenarios will be optimized independently to determine the initial starting point. In the second stage, optimization will be performed on the master problem based on the output from the first stage.

Option –P
Use option – P to solve an individual scenario. The scenario number can be determined according to the following example:

	Base Case	Scenario 1	Scenario 2
Base Case	0	1	2
Renewable 1	3	4	5
Renewable 2	6	7	8

Option –R
Use option –R to specify the PSS/E OPF raw data file.

Option –S

Use option –S to specify the scenario bundle specification file. This file contains detailed information about each of the scenarios and renewable energy possibilities. This file is only considered when the multi-scenario analysis is enabled by specifying "-T yes". On the other hand, if the multi-scenario analysis is expected to be enabled by specifying "-T yes", but the scenario specification file indicated by this option value is not a valid file (e.g., wrong file path, not readable, etc.), the multi-scenario analysis will be automatically disabled.

Option –T
Use option –T to specify if multi-scenario analysis is enabled or not. The default value of this option is "no".

Section 8. **Appendix**

A. The scenario specification file

The scenario specification file, as its name suggests, specifies the scenarios that will be studied or analyzed by the SuperOPF-MS program. A sample scenario specification file is shown in Figure A-1. In the current version of the specification, there are six types of data blocks that can be enclosed in the scenario file, thus interpretable by the SuperOPF-MS program. These data blocks include:

- Contingency list block;
- Renewable energy list block;
- Reserved generation list block;
- Load shedding list block;
- Cost models for reserved generation and load shedding; and
- Renewable energy forecast scenarios.

```
/*****************************************************************************
 * Sample scenario definition file for BSI SuperOPF program.                 *
 *                                                                           *
 * Author: Bin Wang                                                          *
 * Copyright (C) (2010-2013) Bigwood Systems, Inc.                           *

*****************************************************************************/

CONTING_LIST /* this section specifies the list of contingencies */
  // name, type, from-bus, to-bus, ckt, probability, status
  'CTG_1', 'DISCONN_BRANCH', 1, 2, '1', 0.1, 1;  // description of CTG_1
  // name, type, bus, ckt, probability        /* description of CTG_2 */
  'CTG_2', 'REMOVE_MACHINE', 1,  , '1', 0.1, 1;
  // name, type, bus, ckt, probability
  'CTG_3', 'REMOVE_SHUNT',   1,  , '1', 0.1, 1;
END

RENEW_GEN_LIST  /* this section specifies the list of renewable generations */
  // name, type, bus, ckt, pmax, pmin, qmax, qmin, status
  'WG_1', 'WIND', 1, '1', 50.00, -50.00, 25.00, -25.00, 1;
  'WG_2', 'WIND', 2, '1', 50.00, -50.00, 25.00, -25.00, 1;
```

```
END

RESRV_GEN_LIST  /* this section specifies the list of reserved generations */
  // name, type, bus, ckt, pmax, pmin, qmax, qmin, status
  'RS_1', 'BTTR', 1, '1', 50.00, -50.00, 25.00, -25.00, 1;
  'RS_2', 'BTTR', 2, '1', 50.00, -50.00, 25.00, -25.00, 1;
END

LOAD_SHED_LIST  /* this section specifies the list of load shedding */
  // name, type, bus, ckt, max-percent, status
  'LSD_1', 'BUS',  1, '1', 50, 1;        // single load at a single bus
  // name, type, bus, max-percent
  'LSD_2', 'BUS',  1,    , 50, 1;             // all loads at a single bus
  // name, type, buses, max-percent
  'LSD_3', 'GROUP', [1,2,3,4,12-20,22:25], , 50, 0;   // all loads at a group of
buses
  // name, type, zone, max-percent
  'LSD_4', 'ZONE', 1,    , 50, 1;            // all loads in a zone
  // name, type, area, max-percent
  'LSD_5', 'AREA', 1,    , 50, 1;            // all loads in an area
END

COST_LIST   /* this section specifies cost models for different components */
  // name, type, start, stop, c0, ..., c7, p0, ..., p7
  'RS_1',  'POLY', 0.0, 0.0, , , 1e-5;
  'RS_2',  'POLY', 0.0, 0.0, , , 1e-5;
  'LSD_1', 'PLNR', 0.0, 0.0, , , 1e-5;
  'LSD_2', 'PLNR', 0.0, 0.0, , , 1e-5;
  'LSD_3', 'POLY', 0.0, 0.0, , , 1e-5;
  'LSD_4', 'POLY', 0.0, 0.0, , , 1e-5;
  'LSD_5', 'POLY', 0.0, 0.0, , , 1e-5;
END

/* the remained blocks define individual scenarios */
SCENARIO
  NAME: 'SCNR_1';   // name or label of the scenario
  TIME: 0.0;        // time stamp
  PVAL: 0.1;        // scenario probability
  CTGS: ALL;        // applicable contingencies
```

```
  CTRL: ALL;        // applicable controls (reserves, load shedding)
  ROUT: ['WG_1',25.0,10.0],['WG_2',25.0,10.0];    // renewable outputs
  STAT: 1;
END

SCENARIO
  NAME: 'SCNR_2';   // name or label of the scenario
  TIME: 0.0;        // time stamp
  PVAL: 0.1;        // scenario probability
  CTGS: ALL;        // applicable contingencies
  CTRL: ALL;        // applicable controls (reserves, load shedding)
  ROUT: ['WG_1',25.0,10.0],['WG_2',25.0,10.0];    // renewable outputs
  STAT: 1;
END

SCENARIO
  NAME: 'SCNR_3';   // name or label of the scenario
  TIME: 0.0;        // time stamp
  PVAL: 0.1;        // scenario probability
  CTGS: ALL;        // applicable contingencies
  CTRL: ALL;        // applicable controls (reserves, load shedding)
  ROUT: ['WG_1',25.0,10.0],['WG_2',25.0,10.0];    // renewable outputs
  STAT: 1;
END
```

Figure A-1. A sample scenario specification file

A.1 Overall organization

A scenario specification file can contain all or a subset of the six data blocks listed above. At the same time, the order of the data blocks presenting in the file is not restricted to the one shown in the sample file. Moreover, each type of data blocks can have multiple presences (containing specifications for different devices, of course) in the scenario specification file.

A data block starts with a predefined keyword (unique for different data types) and ends with the keyword “END”. A data block is composed of multiple key-value pairs, where the key text and the value text are separated by the character “:”. Each key-value pair spans a logic line in the specification file. A logical line in the file is a text line that will be actually processed by the SuperOPF program, which can be composed of multiple physical text lines written in the file. Each logical line ends with the character ";"; therefore, lengthy value text (such as the renewable generation forecasts when there are many renewable generators defined in the network, which is not uncommon for large power networks) can span multiple physical text lines in the specification file, provided that only the last text line of the value part ends with the character ";".

In processing the text read from the specification file, all text behind "//" or enclosed by the pair "/*" and "*/" will be treated as comments, and thus will be ignored by the program. The block keywords are case insensitive; therefore, both "END" and "eNd" are valid signs of a block ending. However, device names are case sensitive; therefore, "device1" and "Device1" will be recognized by the program as two different devices.

A.2 The Contingency List Block

The first block of the scenario file specifies the list of contingencies to be involved in the OPF computation, starting with the keyword "CONTING_LIST". Multiple contingencies can be defined in this block, each of which spans a logical text line. Only N-1 contingencies are supported, that is, there is only one device in the power network can be involved in a single contingency.

A logical text to define a contingency is formatted in the following way:

```
Name, Type, From-bus, To-bus, Ckt, Probability, Status
```

Text blocks can be defined for the following items:

- Name: the name or label for the contingency. Name for a contingent device must be unique in the whole scenario specification file.
- Type: the type of the contingency. Following three types of contingencies are supported by the current SuperOPF-MS program:
    - DISCONN_BRANCH: disconnecting a single branch from the network.
    - REMOVE_MACHINE: removing a generator (machine) from the network.
    - REMOVE_SHUNT: removing a shunt device from the network.
- From-bus: the from-end bus number for the contingent line of a DISCONNECT_BRANCH contingency, or the bus number that the contingent device is attached to for a REMOVE_MACHINE or REMOVE_SHUNT contingency.
- To-bus: the to-end bus number for the contingent line of a DISCONNECT_BRANCH contingency; it is skipped for the other two types of contingencies.
- Ckt: the ID of the contingent device.
- Probability: the probability for the contingency to occur during the planning horizon.

- Status: the active status of the contingency to be involved in the analysis. If the status is inactive (with value 0), the corresponding contingency will not be involved in the SuperOPF-MS computation.

Text blocks for different items are separated by commas (“,”). Special text blocks including characters, such as commas (“,”), need to be enclosed by a pair of single quote mark (i.e., in the form of ‘aaa,b’).

```
CONTING_LIST /* this section specifies the list of contingencies */
  // name, type, from-bus, to-bus, ckt, probability, status
  ‘CTG_1’, ‘DISCONN_BRANCH’, 1, 2, ‘1’, 0.1, 1;  // description of CTG_1
  // name, type, bus, ckt, probability        /* description of CTG_2 */
  ‘CTG_2’, ‘REMOVE_MACHINE’, 1,  , ‘1’, 0.1, 1;
  // name, type, bus, ckt, probability
  ‘CTG_3’, ‘REMOVE_SHUNT’,   1,  , ‘1’, 0.1, 1;
END
```

Figure A-2. The contingency list block

A.3 The Renewable Generator List Block

The second block of the scenario file specifies the list of renewable generators to be involved in the OPF computation, starting with the keyword “RENEW_GEN_LIST”. Multiple renewable generators can be defined in this block, each of which spans a logical text line.

A logical text to define a contingency is formatted in the following way:

```
Name, Type, Bus, Ckt, Pmax, Pmin, Gmax, Gmin, Status
```

Text blocks can be defined for the following items:

- Name: the name of the renewable generator. Name for a renewable generator must be unique in the whole scenario specification file.
- Type: the type of the renewable generator. Possible types of renewable generators may include wind power, solar power and hydro power.
- Bus: the bus number that the renewable generator is attached to.
- Ckt: the ID of the renewable generator.
- Pmax: the maximum real power output of the renewable generator.

- Pmin: the minimum real power output of the renewable generator.
- Qmax: the maximum reactive power output of the renewable generator.
- Qmax: the minimum reactive power output of the renewable generator.
- Status: the active status of the renewable generator to be involved in the analysis. If the status is inactive (with value 0), the corresponding generator will not be involved in the SuperOPF-MS computation.

Text blocks for different items are separated by commas (“,”). Special text blocks including characters, such as commas (“,”), need to be enclosed by a pair of single quote mark (i.e., in the form of ‘aaa,b’).

```
RENEW_GEN_LIST  /* this section specifies the list of renewable generations
*/
  // name, type, bus, ckt, pmax, pmin, qmax, qmin, status
  'WG_1', 'WIND', 1, '1', 50.00, -50.00, 25.00, -25.00, 1;
  'WG_2', 'WIND', 2, '1', 50.00, -50.00, 25.00, -25.00, 1;
END
```

Figure A-3. The renewable generator list block

A.4 The Reserved Generator List Block

The third block of the scenario file specifies the list of reserved generators to be involved in the OPF computation, starting with the keyword “RESRV_GEN_LIST”. Multiple reserved generators can be defined in this block, each of which spans a logical text line.

A logical text to define a contingency is formatted in the following way:

```
Name, Type, Bus, Ckt, Pmax, Pmin, Gmax, Gmin, Status
```

Text blocks can be defined for the following items:

- Name: the name of the reserved generator. Name for a reserved generator must be unique in the whole scenario specification file.
- Type: the type of the reserved generator. Possible types of renewable generators may include battery.
- Bus: the bus number that the reserved generator is attached to.
- Ckt: the ID of the reserved generator.

- Pmax: the maximum real power output of the reserved generator.
- Pmin: the minimum real power output of the reserved generator.
- Qmax: the maximum reactive power output of the reserved generator.
- Qmax: the minimum reactive power output of the reserved generator.
- Status: the active status of the reserved generator to be involved in the analysis. If the status is inactive (with value 0), the corresponding generator will not be involved in the SuperOPF-MS computation.

Text blocks for different items are separated by commas (“,”). Special text blocks including characters, such as commas (“,”), need to be enclosed by a pair of single quote mark (i.e., in the form of ‘aaa,b’).

```
RESRV_GEN_LIST  /* this section specifies the list of reserved generations */
  // name, type, bus, ckt, pmax, pmin, qmax, qmin, status
  'RS_1', 'BTTR', 1, '1', 50.00, -50.00, 25.00, -25.00, 1;
  'RS_2', 'BTTR', 2, '1', 50.00, -50.00, 25.00, -25.00, 1;
END
```

Figure A-4. The reserved generator list block

A.5 The Load Shedding List Block

The fourth block of the scenario file specifies the list of load shedding to be involved in the OPF computation, starting with the keyword “LOAD_SHED_LIST”. Multiple load shedding definitions can be defined in this block, each of which spans a logical text line.

A logical text to define a contingency is formatted in the following way:

```
Name, Type, Idx, Ckt, Max-perc, Status
```

Text blocks can be defined for the following items:

- Name: the name of the load shedding item. Name for a load shedding item must be unique in the whole scenario specification file.
- Type: the type of the load shedding item. Following four types of load shedding items are supported by the current SuperOPF-MS program:
  - BUS: single or all loads attached to the specified bus will be adjustable.

    - GROUP: all loads attached to the specified group of buses, enclosed in a pair of square brackets ("[" and "]"), will be adjustable.
    - ZONE: all loads within the specified zone will be adjustable.
    - AREA: all loads within the specified area will be adjustable.
- Idx: the bus number for type BUS, the group of buses for type GROUP, the zone number for type ZONE, and the area number for type AREA.
- Ckt: the ID of the load attached to a bus, only valid for type BUS.
- Max-perc: the maximum allowable percentage for load shedding.
- Status: the active status of the load shedding item to be involved in the analysis. If the status is inactive (with value 0), the corresponding load shedding definition will not be involved in the SuperOPF-MS computation.

Text blocks for different items are separated by commas (","). Special text blocks including characters, such as commas (","), need to be enclosed by a pair of single quote mark (i.e., in the form of 'aaa,b').

```
LOAD_SHED_LIST  /* this section specifies the list of load shedding */
  // name, type, bus, ckt, max-percent, status
  'LSD_1', 'BUS',  1, '1', 50, 1;        // single load at a single bus
  // name, type, bus, max-percent
  'LSD_2', 'BUS',  1,    , 50, 1;             // all loads at a single bus
  // name, type, buses, max-percent
  'LSD_3', 'GROUP', [1,2,3,4,12-20,22:25], , 50, 0;   // all loads at a group
of buses
  // name, type, zone, max-percent
  'LSD_4', 'ZONE', 1,    , 50, 1;            // all loads in a zone
  // name, type, area, max-percent
  'LSD_5', 'AREA', 1,    , 50, 1;            // all loads in an area
END
```

Figure A-5. The load shedding list block

A.6 The Cost Model List Block

The fifth block of the scenario file specifies the list of cost models for the reserved generators and load shedding items to be involved in the OPF computation, starting with the keyword "COST_LIST". A cost model for each reserved generator and load shedding item needs to be defined in the scenario specification file. Each cost model spans a logical text line.

A logical text to define a contingency is formatted in the following way:

`Name, Type, Start, Stop, c0-c7, p0-p7`

Text blocks can be defined for the following items:

- Name: the name of the device that the cost model is associated with.
- Type: the type of the cost model. Following two types of cost model are supported by the current SuperOPF-MS program:
  - POLY: the cost model will be in a polynomial form.
  - PLNR: the cost model will be in a piece-wise linear form.
- Start: the start-up cost of the controllable device.
- Stop: the shut-down cost of the controllable device.
- c0-c7: the cost coefficients for the polynomial cost model or the end-point costs for the piece-wise linear cost model, of the unit ($/MWhr).
- p0-p7: the end-points (real power in MW) for the piece-wise linear cost model.

Text blocks for different items are separated by commas (“,”). Special text blocks including characters, such as commas (“,”), need to be enclosed by a pair of single quote mark (i.e., in the form of ‘aaa,b’).

```
COST_LIST   /* this section specifies cost models for different components */
  // name, type, start, stop, c0, ..., c7, p0, ..., p7
  'RS_1',  'POLY', 0.0, 0.0, , , 1e-5;
  'RS_2',  'POLY', 0.0, 0.0, , , 1e-5;
  'LSD_1', 'PLNR', 0.0, 0.0, , , 1e-5;
  'LSD_2', 'PLNR', 0.0, 0.0, , , 1e-5;
  'LSD_3', 'POLY', 0.0, 0.0, , , 1e-5;
  'LSD_4', 'POLY', 0.0, 0.0, , , 1e-5;
  'LSD_5', 'POLY', 0.0, 0.0, , , 1e-5;
END
```

Figure A-6. The cost model list block

A.7 The Renewable Scenario List Block

The sixth block of the scenario file specifies the forecast scenario of the renewable generations to be involved in the OPF computation, starting with the keyword "SCENARIO". Each block corresponds to a single forecast scenario. Multiple forecasts can be included in a scenario specification file.

A forecast scenario block can be defined with following key-value pairs:

- NAME: the name of the renewable energy forecast scenario. Name for a forecast scenario must be unique in the whole scenario specification file.
- TIME: the timestamp for the forecast.
- PVAL: the probability of occurrence for the forecast.
- CTGS: the list of applicable contingencies, or ALL for all contingencies defined in the scenario file.
- CTRL: the list of available controls (reserved generations and load shedding definitions), or ALL for all controls defined in the scenario file.
- ROUT: the forecasts of the outputs by the renewable generators. The real and reactive power outputs by a renewable generator is enclosed by a pair of square brackets ("[" and "]") and formed in the following way:

```
ITEM_NAME, REAL_OUTPUT, REACTIVE_OUTPUT
```

- STAT: the active status of the forecast scenario to be involved in the analysis. If the status is inactive (with value 0), the corresponding forecast will not be involved in the SuperOPF-MS computation.

Text blocks for different items are separated by commas (","). Special text blocks including characters, such as commas (","), need to be enclosed by a pair of single quote mark (i.e., in the form of 'aaa,b').

```
SCENARIO
  NAME: 'SCNR_1';   // name or label of the scenario
  TIME: 0.0;        // time stamp
  PVAL: 0.1;        // scenario probability
  CTGS: ALL;        // applicable contingencies
  CTRL: ALL;        // applicable controls (reserves, load shedding)
  ROUT: ['WG_1',25.0,10.0],['WG_2',25.0,10.0];    // renewable outputs
  STAT: 1;
END
```

Figure A-7. The renewable scenario block

B. The solution summary file

The solution summary file contains values for the system states corresponding to the specified solution point. Specifically, state values of the system are presented in seven sections.

Section 1: objective value for the solution point

This section displays the objective value of the solution point, in terms of the specified OPF optimization objective function.

```
=================================================================================================
| Optimization Result Section                                                                   |
=================================================================================================
OPF Objective Value:   167.069240
```

Section 2: the bus data section

This section displays bus data, namely states of the buses in the system running at the states specified by the solution point. Each row contains ten items, namely, the bus number (Bus #), the voltage magnitude (Voltage Mag), the voltage phase angle (Voltage Ang), real power flow mismatch (Mismatch P), the reactive power flow mismatch (Mismatch Q), the real power generation if a generator is attached to the bus (Generation P), the reactive power generation if a generator is attached to the bus (Generation Q), the real load if a load is attached to the bus (Load P), the reactive load if a load is attached to the bus (Load Q), and the shunt value if a shunt device is attached to the bus (Shunt). The total real and reactive power flow mismatches, the total real and reactive power generations, the total real and reactive loads, and the total shunt outputs are summarized and printed in the last two lines of the section.

```
=================================================================================================
| Bus Data Section                                                                              |
=================================================================================================
   Bus          Voltage              Mismatch              Generation              Load          Shunt
    #         Mag        Ang       P(MW)     Q(MVar)      P(MW)    Q(MVar)      P(MW)   Q(MVar)    (MVar)
 ------------------------------------------------------------------------------------------------
     1    1.01992     -2.108      -0.034       0.001                              0.00      0.00
    33    1.02169    -13.315      -0.496       0.358                             72.31     13.09   -100.00
    60    1.01650    -14.068       0.031      -0.004      29.28      -6.95        0.00      0.00
```

```
 ...        ...              ...              ...              ...
=====================================================
Total:  P-mismatch= 22909.33MW    P-generation=257334.26MW    P-load=251745.86MW
        Q-mismatch=  2506.40MVar  Q-generation= 28590.19MVar  Q-load= 52509.89MVar   Shunt= 10290.76MVar
```

Section 3: the branch data section

This section displays branch data, namely states of the branches in the system running at the states specified by the solution point. Each row contains eleven items, namely, the branch number (Branch #), the branch from-end bus number (From Bus), the branch to-end bus number (To Bus), the real power injection to the from-end bus (From-End Inj P), the reactive power injection to the from-end bus (From-End Inj Q), the real power injection to the to-end bus (To-End Inj P), the reactive power injection to the to-end bus (To-End Inj Q), the real power loss over the branch (Loss P), the reactive power loss over the branch (Loss Q), the tap ratio if the branch is a tap-changing transformer (Ratio), and the phase-shifter angle if the branch is a phase-shifting transformer (Phase). The system total real and reactive power losses, namely, the sum of all real and reactive power losses occurred over all branches is displayed in the last line of the section.

```
============================================================================================================
| Branch Data Section                                                                                      |
============================================================================================================
Branch     From      To         From-End Inj            To-End Inj               Loss            Transformer
  #         Bus      Bus       P(MW)    Q(MVar)       P(MW)   Q(MVar)         P(MW)     Q(MVar)     Ratio    Phase
------------------------------------------------------------------------------------------------------------
     1        1       24     -104.17     -11.10      104.22     10.51         0.050      0.537
 12642        1        3       21.27       1.67      -21.23      0.65         0.044      2.320     1.0615    0.000
 ...        ...              ...              ...              ...
                                                                        ==========================
                                                                  Total:       5584.87   81291.39
```

Section 4: the binding bus voltages and shunts data

This section displays binding buses, namely buses with voltage magnitudes or shunt values close to the lower or upper bounds. Each row contains eight items, namely, the bus number (Bus #), the voltage magnitude (Mag), the voltage phase angle (Ang), the minimum allowed voltage magnitude (Vmin), the maximum allowed voltage magnitude (Vmax), the current shunt value (B), the minimum allowed shunt setting (Bmin), and the maximum allowed shunt setting (Bmax). The total number of binding buses and the total number of binding shunts are shown in the last line of the section.

```
==========================================================================
| Binding Bus Voltage Magnitudes and Shunt Capacitors                    |
==========================================================================
   Bus          Voltage        Voltage Bounds          Shunt Data
    #         Mag         Ang     Vmin         Vmax          B      Bmin      Bmax
--------------------------------------------------------------------------
  8873   0.88880    16.266    0.9000    1.1000
 ...         ...                 ...                 ...                 ...
               -----------------------------------------------------------
               Total binding buses:    12      Total binding shunts:     0
```

Section 5: the binding generations

This section displays binding generators, namely generators with real and/or reactive power generations close to the lower or upper bound. Each row contains seven items, namely, the generator bus number (Bus #), the real power generation (P), the minimum allowed real power generation (P Min), the maximum allowed real power generation (P Max), the reactive power generation (Q), the minimum allowed reactive power generation (Q Min), and the maximum allowed reactive power generation (Q Max). The total number of binding generators is shown in the last line of the section.

```
==================================================================
| Binding Power Generations                                      |
==================================================================
   Bus          Real Gen (MW)                 React Gen (MVar)
    #           P       Min       Max          Q        Min       Max
------------------------------------------------------------------
 ...         ...                 ...                 ...
               ---------------------------------------------------
                                        Total binding generators:     0
```

Section 6: the thermal limit violations

This section displays thermal limit violations, namely branches with flows larger than their maximum allowed flows, of the system running at the states represented by the solution point. Each row contains seven items, namely, the branch number (Branch #), the from-end bus number (From Bus), the to-end bus number (To Bus), the from-end power flow injection (From-End Flow), the to-end power flow injection (To-End Flow), the maximum allowed power flow through the branch (Max Flow), and the power flow violation over the thermal limit of the branch (Flow Violation). The system total thermal violation, namely the sum of all thermal violation in the system, is printed in the last line of the section.

```
=================================================================
| Violation Data - Branch Thermal Limit Violations              |
=================================================================
Branch    From     To    From-End    To-End      Max      Flow
  #        Bus     Bus     Flow       Flow       Flow   Violation
-----------------------------------------------------------------
 12946    1279    1276      88.29      89.31     84.00        5.31
 ...        ...               ...                 ...
                               =================================
                               Total thermal violation =    67.87MVA
```

Section 7: area-wise real power losses

This section displays area-wise power losses of the system running at the states represented by the solution point. Each row contains four items, namely, the area number (Area #), the number of branches in the area (# of Branches), the total real power loss in the area (Total P Loss), and the total reactive power loss in the area (Total Q Loss). It needs to be noted that area-crossing branches, that is, branches connecting two buses belonging to different areas are not considered in calculating the area-wise losses.

```
=========================================
| Area-wise Total Loss                  |
=========================================
  Area    # of     Total P    Total Q
    #   Branches  Loss (MW)  Loss (MVar)
-----------------------------------------
     1      381     68.265   1858.554
     2      602     80.249   2272.080
   ...             ...                ...
```

B. The discrete control file

The discrete control file contains values for discrete control variables. Specifically, values for three types of discrete controls are stored, including tap ratios for tap-changing transformers, phase angles for phase-shifting transformers, and switchable shunts.

Section 1: tap ratios

Each row contains five items, namely, the branch number (Branch), the from-end bus number (From), the to-end bus number (To), the tap ratio value (Value), and the tap position (Position).

```
====================================================
 TRANSFORMER TAP RAT IN THE CONTINUOUS OPF SOLUTION
----------------------------------------------------
  Branch      From        To        Value    Position
--------  --------  --------  ----------  ----------
   16758,        6,        7,     0.9250,     0.0000
   16759,        9,       11,     0.9294,     0.0000
   16760,       10,       11,     0.9778,     6.0000
   ...            ...              ...
```

Section 2: phase shifters

Each row contains five items, namely, the branch number (Branch), the from-end bus number (From), the to-end bus number (To), the phase shifting angle (Value), and the tap position (Position).

```
====================================================
 PHASE SHIFTER VALUE IN THE CONTINUOUS OPF SOLUTION
----------------------------------------------------
  Branch      From        To        Value    Position
--------  --------  --------  ----------  ----------
   16776        77        76      0.0000     23.0000
   16782       138       139      0.0000     10.0000
   ...            ...              ...
```

Section 3: switchable shunts

Each row contains five items, namely, the bus number (Bus), the shunt value (Value), the lower closest allowable shunt configuration (Close-L), the upper closest allowable shunt configuration (Close-H), and the relative position (Position). Specifically, when the position equals to 0, the shunt value is configured to be that of Close-L; when the position equals to 1, the shunt value is configured to be that of Close-H.

```
=======================================================
    SWITCHABLE SHUNTS IN THE CONTINUOUS OPF SOLUTION
-------------------------------------------------------
     Bus        Value      Close-L      Close-H    Position
--------  ----------  ----------  ----------  ----------
      33,  -100.0000,  -100.0000,    -50.0000,      0.0000
      35,   200.0000,   100.0000,   200.0000,      1.0000
     ...          ...                 ...
```

C. The marginal price file

The Lagrange multipliers (Lambda), that is, the marginal prices are stored in this file. The content of this file is organized as follows. Specifically, each row contains six items, namely, the trial index (TRIAL), the contingency index (CTG), the bus number (BUS), the flag is a generator or not (GEN), the marginal price for real power injection or generation (LAMBDA_PG), and the marginal price for reactive power injection or generation (LAMBDA_QG).

```
TRIAL, CTG,    BUS, GEN,         LAMDA_PG,        LAMBDA_QG
    0,   0,      1,   0,   0.00000000e+00,   0.00000000e+00
    0,   0,     17,   1,   0.00000000e+00,   0.00000000e+00
    ...           ...              ...
    1,   0,      1,   0,   4.35571289e-02,   1.01677632e-04
    1,   0,     17,   1,   4.70494893e-02,  -2.21044395e-04
    ...           ...              ...
```

D. The PSS/E OPF raw data file

An exemplar PSS/E OPF raw data file is presented as follows. Detailed description of the data format can be found in the Program Operational Manual of PSS/E.

```
0          /  PSS/E-30.0, MON, SEP 20 2004  17:32
     101     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
     102     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
     151     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
     152     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
     153     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
     154     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
     201     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
     202     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
     203     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
     204     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
     205     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
     206     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
     211     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
    3001     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
    3002     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
    3003     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
    3004     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
    3005     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
    3006     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
    3007     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
    3008     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
    3011     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
    3018     1.0500     0.9500  9999.0000 -9999.0000 1       1.0000
 0 / End of Bus Voltage Constraint data, begin Adjustable Bus Shunt data
 0 / End of Adjustable Bus Shunt data, begin Bus Load data
 0 / End of Bus Load data, begin Adjustable Bus Load Tables
 0 / End of Adjustable Bus Load Tables, begin Generator Dispatch data
     206 1       1.000       2
     211 1       1.000       4
    3011 1       1.000       3
    3018 1       1.000       1
 0 / End of Generator Dispatch data, begin Active Power Dispatch Tables
       1    130.000     10.000      1.000 2 1        1
       2   1000.000    100.000      1.000 3 1        2
       3   1000.000    100.000      1.000 3 1        3
       4    725.000     10.000      1.000 3 1        4
 0 / End of Active Power Dispatch Tables, begin Generation Reserve data
     206 1     10.000  1100.000
     211 1    100.000   725.000
 0 / End of Generation Reserve data, begin Generation Reactive Capability data
     101 1      1.760     1.000     0.950     0.950     0.454 1
```

```
    206 1      1.760     1.000     0.950     0.900     0.455 1
    211 1      1.760     1.000     0.950     0.950     0.455 1
   3011 1      1.470     1.000     0.900     0.850     0.544 1
   3018 1      1.760     1.000     0.950     0.900     0.454 4
0 / End of Generation Reactive Capability data, begin Adjustable Branch Reactance data
    201      204 1      1.000     1.000     0.300  1440.000 1 1        0
0 / End of Adjustable Branch Reactance data, begin Piece-wise Linear Cost Tables
       1  'LINEAR 1    '   9
   10.000   200.000
   20.000   420.000
   30.000   649.000
   40.000   885.500
   60.000  1371.500
   80.000  1868.500
   90.000  2121.500
  100.000  2378.500
  130.000  3164.500
0 / End of Piece-wise Linear Cost Tables, begin Piece-wise Quadratic Cost Tables
       2  'QUAD. 2     '    2050.0000   8
  100.000    21.500
  200.000    22.500
  300.000    23.300
  400.000    24.000
  600.000    24.600
  800.000    25.100
  900.000    25.500
 1000.000    25.900
       3  'QUAD. 3     '    1700.0000   6
  100.000    18.100
  200.000    19.100
  400.000    20.700
  600.000    22.000
  800.000    23.100
 1000.000    23.800
       4  'QUAD. 4     '      30.5000   6
   10.000     3.000
   90.000     3.800
  125.001     4.150
  300.000     5.900
  500.000     7.900
  725.000    10.150
0 / End of Piece-wise Quadratic Cost Tables, begin Polynomial Cost Tables
0 / End of Polynomial Cost Tables, begin Period Reserve data
 1    200.000      5.000 1
    206 1
    211 1
0 / End of Participating Reserve Units
0 / End of Period Reserve data, begin Branch Flow Constraint data
    153      154 1  1   200.000     0.000     0.000     0.000 3 1     1.000
```

```
     153      154 2  1   200.000     0.000     0.000     0.000 3 1     1.000
     202      203 1  1   600.000   600.000     0.000     0.000 1 1     1.000
 0 / End of Branch Flow Constraint data, begin Interface Flow data
        1  'AREA 5 TO AREA 1                '   -155.000   -160.000 1 1     0.000
    3004      152 1
    3006      153 1
    3008      154 1
 0 / End of Participating Branches in Interface Flow
 0 / End of Interface Flow data, begin Linear Constraint Equation Dependency data
 0 / End of Linear Constraint Equation Dependency data, begin 2-terminal dc Line Constraint data
 0 / End of 2-terminal dc Line Constraint data
```

E. The System Monitor list file

An exemplar system monitor list data file is presented as follows.

```
MONITOR BRANCHES
     1     24  1 /* ADAMS    230 KV   F         BENNETTS 230 KV   F
     1     42  1 /* ADAMS    230 KV   F         BRUNSWIC 230 KV   230-1
... ...
END
MONITOR VOLTAGE RANGE BUS      1        .9500       1.0522     /* ADAMS    230 KV   F        0000000000
MONITOR VOLTAGE DEVIATION BUS      1        .0500        .0500 /* ADAMS    230 KV   F
MONITOR VOLTAGE RANGE BUS      6        .9203       1.0507     /* ALDENE   138 KV   L-1312   0000000000
MONITOR VOLTAGE DEVIATION BUS      6        .0800        .0800 /* ALDENE   138 KV   L-1312
... ...
END
```

F. The Pilot Control File

An exemplar pilot control file is presented as follows.

```
*36117
BUS    1900    1.10    0.90   1.0094060      1
BUS    2100    1.10    0.90   1.0135283      1
*second batch
BUS    2490    1.10    0.90   1.0420665      1
*third batch
BUS    1750    1.10    0.90   1.0147959      1
```

G. The System Session Configuration File

An exemplar system session configuration file is presented as follows. This file stores all computation settings for a previous OPF study; therefore, it can be loaded to the program to restore a previous OPF study. The file content is organized in a key-value format, where each line corresponding to a key-value pair. A key-value pair is specified in the format “KEY: value”. Comment lines beginning with “#” are skipped by the program.

```
# BSI SuperOPF Session Configuration File
# Saved by BSI SuperOPF on Mon Feb 09 14:57:01 2015

ACTIVE_XCATG: 11111110
APPLY_DISCRETE: no
AVC_2ND_PILOT_DEV: no
AVC_3RD_PILOT_DEV: no
AVC_MODE_ENABLE: no
AVC_PILOT_FILE:
AVC_PILOT_VM_RLX: 1.0e-06
CASE_NAME: basecase_sys6534_txt
CENTR_AREA_LIST:
CONSTR_ANAL_1STG: yes
CONSTR_ANAL_SIZE: 1.0
CONSTR_ANAL_STEP: 1
COST_FILE:
COST_FORMAT: 0
CREATE_DATE: Mon Feb 09 14:56:43 2015
DISCR_NEAR_RNDOFF: yes
DISCR_RNDOFF_SIZE: 0.1,0.2,0.3,0.4,0.5
DISCR_RNDOFF_STEP: 5
FLOW_FILE: F:\Workspaces\test\basecase_sys6534.txt
FLOW_FORMAT: psse
FLOW_VERSION: 25
FORCE_FINAL_PFLOW: no
GEN_VIOL_TOL: 1.000000e-02
HAVE_COST_FILE: no
INTFC_FILE:
KKT_GRAD_TOL: 1.000000e-04
MAX_LAGR_MULT: 1.000000e+06
MAX_RLX_ITER: 500
MAX_SOL_ITER: 500
MODIF_DATE: Mon Feb 09 14:56:43 2015
MONIT_LIST:
OBJ_FUNC: ploss
OPF_FILE_READY: yes
OVERALL_TOL: 1.000000e-04
PF_MISMTCH_TOL: 1.000000e-02
RAMP_PERIOD_LEN: 1.0e+01
```

```
REDC_CTRL_THRESH: 1.0e-02
REDC_CTRL_TYPE: 0
REDUCE_NUM_CTRL: no
REPORT_DIR: F:\Workspaces\test\basecase_sys6534_txt.sys\report
RESULT_READY: no
ROP_FILE: F:\Workspaces\test\basecase_sys6534.rop
RPT_DATA_READY: no
RPT_EXP_DOC: yes
RPT_EXP_PDF: yes
RPT_EXP_RPT: yes
RPT_EXP_XML: yes
RPT_TOP_CHANGE: 100
RSLT_MSG_FILE: F:\Workspaces\test\basecase_sys6534_txt.sys\message.txt
RSLT_PFLOW_FILE:
RSLT_PFLOW_FORMAT: □
RSLT_PFLOW_VERSION: 25
RSLT_SMRY_FILE:
SCNR_ACTIVE_IDX: 1
SCNR_ANAL_ENABLED: yes
SCNR_FILE: F:\Workspaces\test\scenario_sys6534s.txt
SCNR_GENDEV_FACT: 1.0e-02
SCNR_MASTER_TYPE: no
SCNR_PG_CTRL_MODE: 1
SOLV_METHOD: 1
SYNC_TRFM_SAME_BUS: no
SYS_INIT_LOAD_PARAM: 1.0e+00
SYS_MAX_VMAG_CT: 1.100e+00
SYS_MAX_VMAG_EX: 1.100e+00
SYS_MIN_VMAG_CT: 9.000e-01
SYS_MIN_VMAG_EX: 9.000e-01
SYS_TRAJ_INT_CONVG: 0
THRM_HOMOT_SIZE: 0.0,0.2,0.55
THRM_HOMOT_STEP: 3
THRM_INIT_RLX: 5.500e-01
THRM_VIOL_THRESH: 1.000e+00
THRM_VIOL_TOL: 1.000000e-02
USE_AUTO_DIFF: no
USE_CONSTR_ANAL: no
USE_INTFC_LIMIT: no
USE_MID_INIT: no
USE_NETW_ANAL: yes
USE_RAMP_CONSTR: no
USE_RECT_VOLT: no
USE_SYS_TRAJ_INTEG: no
USE_THERM_LIMIT: no
VAR_INIT_TYPE: input
VMAG_VIOL_TOL: 1.000000e-04
VSA_ANAL_ENABLED: no
VSA_CONF_DST_FOLDER: F:\Workspaces\test\basecase_sys6534_txt.sys\vsacfg
```

```
VSA_CONF_SRC_FOLDER:
VSA_CTG_LIST_FILE: F:\Workspaces\test\basecase_sys6534_txt.sys\vsacfg\ctglist.txt
VSA_CTRL_PATH_FILE: F:\Workspaces\test\basecase_sys6534_txt.sys\vsacfg\path.txt
VSA_INTERFACE_FILE: F:\Workspaces\test\basecase_sys6534_txt.sys\vsacfg\interface.txt
VSA_MONIT_BUS_FILE: F:\Workspaces\test\basecase_sys6534_txt.sys\vsacfg\MonitBus.txt
VSA_MONIT_LIST_FILE: F:\Workspaces\test\basecase_sys6534_txt.sys\vsacfg\MonitList.txt
VSA_PCTRL_LDSHED_ON: yes
VSA_PCTRL_LDSHED_QRAT: 1.000e+00
VSA_PCTRL_LDSHED_RNG: 7.500e+01
VSA_PCTRL_LDSHED_WGT: 1.000e+00
VSA_PCTRL_LTC_ON: yes
VSA_PCTRL_LTC_WGT: 1.000e+01
VSA_PCTRL_NEWSHT_ON: yes
VSA_PCTRL_NEWSHT_RNG: 1.000e+02
VSA_PCTRL_NEWSHT_WGT: 1.000e-01
VSA_PCTRL_PAR_ON: yes
VSA_PCTRL_PAR_WGT: 5.000e+00
VSA_PCTRL_PG_ON: yes
VSA_PCTRL_PG_RNG: 2.000e+01
VSA_PCTRL_PG_WGT: 1.000e+00
VSA_PCTRL_QG_ON: yes
VSA_PCTRL_QG_WGT: 1.000e+01
VSA_PCTRL_SHUNT_ON: yes
VSA_PCTRL_SHUNT_WGT: 1.000e+01
VSA_PROC_TIME_OUT: 3600000
VSA_SESSION_FILE: F:\Workspaces\test\basecase_sys6534_txt.sys\vsacfg\session.txt
VSA_SESSION_SOURCE:
VSA_STOP_MAX_ITER: 3
VSA_STOP_OBJ_TOL: 5.000e-02
VSA_STOP_THERM_TOL: 1.0e+01
WORK_DIR: F:\Workspaces\test\basecase_sys6534_txt.sys
WRITE_FINAL_SUMM: yes
WRITE_FINAL_XML: no
WRITE_INIT_PFLOW: no
WRITE_INIT_SUMM: yes
WRITE_OPF_LAMBDA: no
WRITE_VSA_CTRL: no
```