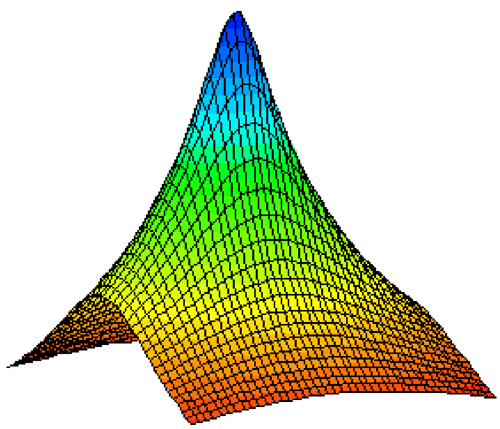
Power System Optimization (PSO)



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Note: You can view this manual from your CD as an Adobe Acrobat PDF file. The file name is:

- Power System Optimization **PSO.pdf**

You will find the Test/Job files used in this tutorial in the following location:

- C:\DesignBase\Samples**PSO** = **Power System Optimization**

Test Files: PSO, Pso_14node_MinControls, PSO_14node_MinGenCost2

1 Overview of DesignBase Power System Optimization

The *Power System Optimization* (**PSO**) is an advanced security constrained optimal powerflow (SCOPF) software that is also a tool for optimal sizing and placement of reactive power resources (reactors, capacitors, and SVCs). The control settings such as generators active power, transformer taps, scheduled voltages of generators are optimized not only for the basecase system configuration but also for up to fifty different system configurations!

PSO in the SCOPF mode finds an operating point that optimizes a given objective function and satisfies a set of physical and operating constraints for the base network configuration and contingency situations. In the reactive power planning mode of operation, PSO determines a minimum cost reactive power expansion plan in VAr equipment which ensures feasible system operation simultaneously for the normal state (basecase) and under contingency situations.

The **PSO** utilizes the state-of-the art in optimization techniques to assist engineers to minimize system losses, perform economic dispatch, minimize load shedding, plan reactive power resources, and optimize system voltage profile with minimum control setting movements.

The present release of PSO supports the following power system optimization functions:

- ✓ **Minimization of Total System Losses**: PSO finds the optimum control settings for the generators scheduled voltages, active power generations, transformer taps, SVCs scheduled voltages such that total system active power losses is minimized. PSO at the same time makes sure that all system voltages are within user defined range, power flows through lines and transformers are within limits, active power generations are within minimum and maximum generators limits, and transformer taps are within their upper and lower bounds.
- ✓ **Minimization of Total Generation Cost:** (also known as economic dispatch) PSO will allocate active power generations to different generators in the system such that total generation cost is minimized. Again PSO will make sure that all system constraints are met (i.e. system voltages are within user defined range, power flows through lines and transformers are within limits, etc.).
- ✓ **Minimization of Controls Movements:** PSO finds minimum controls movements (generators scheduled voltages, active power generations, transformer taps, SVCs scheduled voltages) such that all system voltages are within user defined range, power flows through lines and transformers are within limits, active power generations are within minimum and maximum generators limits, and transformer taps are within their upper and lower bounds.
- ✓ **Minimization of Load Shedding:** PSO will determine the minimum amount of load shedding (including locations) required such that all system constraints are met (i.e. system voltages are within user defined range, power flows through lines and transformers are within limits, etc.)
- ✓ **Minimization of Reactive Power Resource Allocation Cost:** PSO minimizes the cost of addition of new reactive resources (i.e., capacitors/inductors) such that all system constraints are met. The user can select the locations of reactive power resources or PSO program will identify the most effective sites.

The following optimization functions will be supported in the next release of the PSO (these functions are already implemented and at the present time they are in the V&V stage):

- **Maximization of Active Power Flow Across an Interface:** PSO maximizes active power flow across an interface (set of circuits) while at the same time maintaining feasibility in the contingency configurations and basecase (i.e., all system constraints are met). This function is of paramount importance in determination of “Available Transfer Capability” (ATC).
- **Maximization of Loads at a Group of Buses:** PSO maximizes the load at a group of buses while maintaining the same load power factor and feasibility in the basecase and contingency configurations. PSO can also determine the optimal direction of load increase. Candidate sites for load increase can be specified individually, by area, or by zone. This objective function can be used in the computation of voltage stability margins (voltage collapse) capability in a given area.
- **Maximization of Active Power Transfer between two Groups of Buses:** PSO maximizes the active power transfer between any pair of network buses while insuring system feasibility in the basecase and contingency configurations. This function can also be used to determine the “Available Transfer Capability” (ATC).
- **Minimization of Swing Bus Generation:** PSO will re-allocate the power generation at the swing bus(es) to all other generators in the system such that all system constraints are met.

PSO is capable of handling power systems comprising thousands of buses and has been successfully used to optimize the planning and operation of large number of complex power systems. This user guide will highlight the practical aspects of using **PSO** and provides examples.

1.1 V&V for Inclusion Of Feeder/Transformer Loading Constraints

To show that this new feature is working as expected, we first define the feeders/transformers loading limits to be large (e.g. 500% of their rating), as shown below:

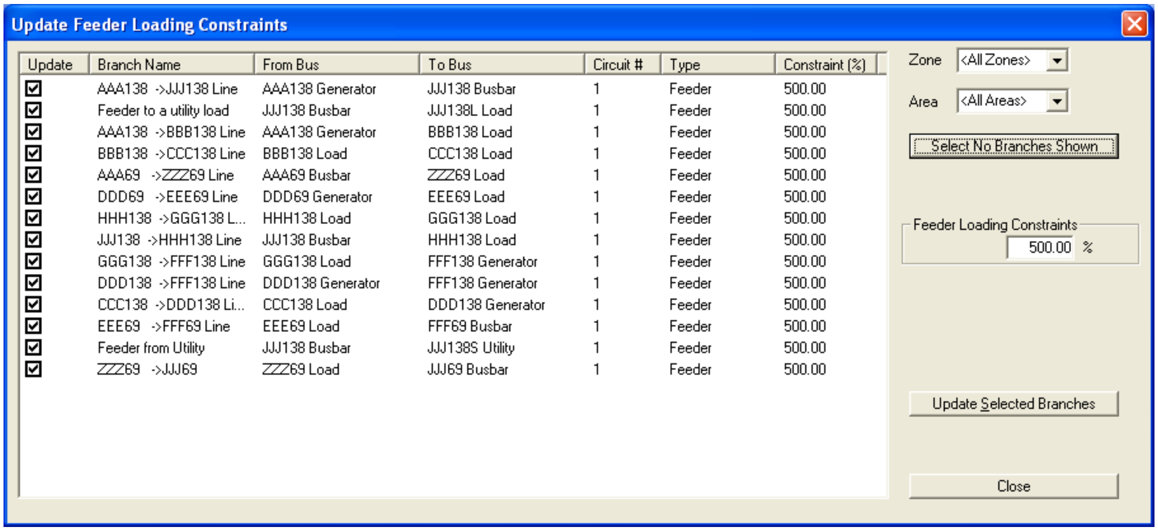


Figure 1: Defining Large Feeder Loading Constraints

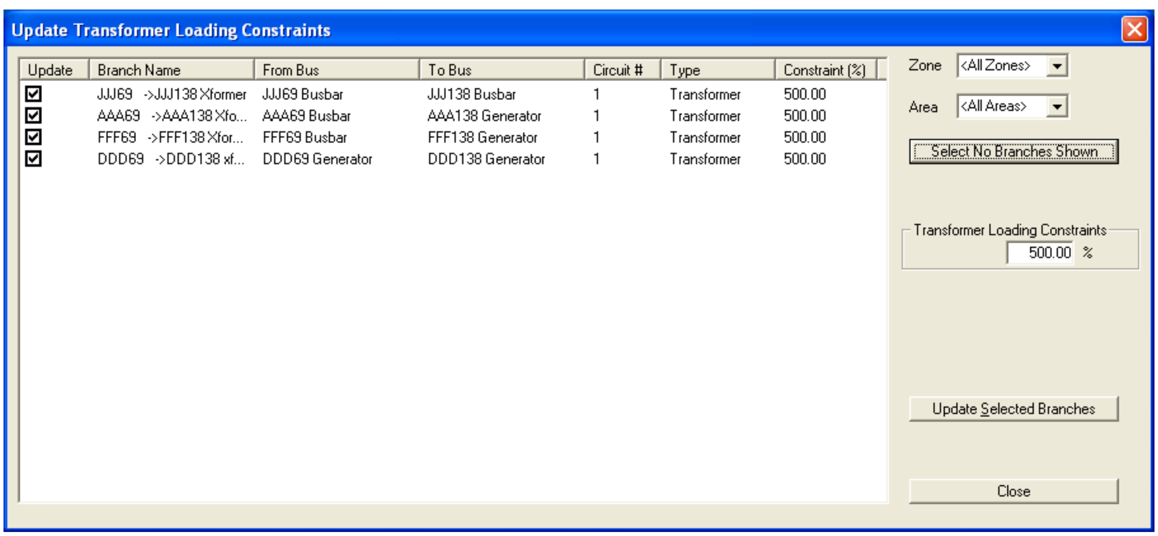


Figure 2: Defining Large Transformer Loading Constraints

The result of optimization is shown below which are exactly the same as those obtained for loss minimization in version 2.00.00 of program (see section 20) where feeder/transformer loading constraints were not imposed:

EDSA Power System Optimization v3.10.00

Project No.	: 12345-1	Page	: 1
Project Name:	PSO Testing	Date	:
Title	: a 14 bus system	Time	:
Drawing No.	: 12345-2	Company	: Edsa
Revision No.:	12345-3	Engineer	: Edsa
Jobfile Name:	pso	Check by	:
Scenario	: 1 -	Date	:

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's Faulted Power Systems

Optimization Objective: Minimization of System Losses
Optimization is SUCCESSFUL.

Economical Impact of Optimization

Total System Losses Before Optimization	=	12982.60 Kilo Watts
Total System Losses After Optimization	=	7809.67 Kilo Watts
System Loss Reduction	=	5172.93 Kilo Watts

Bus Voltage Constraints

Bus Name	System kV	Before(%)	After(%)	Vmin(%)	Vmax(%)
JJJ138S Utility	138.000	104.0	102.0	95.0	105.0
AAA138 Generator	138.000	102.0	103.2	95.0	105.0
DDD138 Generator	138.000	101.3	103.1	95.0	105.0
DDD69 Generator	69.000	100.0	103.4	95.0	105.0
FFF138 Generator	138.000	102.0	102.4	95.0	105.0
AAA69 Busbar	69.000	100.7	101.7	95.0	105.0
BBB138 Load	138.000	97.5	99.1	95.0	105.0
CCC138 Load	138.000	97.3	99.2	95.0	105.0
EEE69 Load	69.000	92.6*	96.4	95.0	105.0
FFF69 Busbar	69.000	99.8	102.9	95.0	105.0
GGG138 Load	138.000	98.2	98.3	95.0	105.0
HHH138 Load	138.000	98.8	98.1	95.0	105.0
JJJ138 Busbar	138.000	104.0	102.0	95.0	105.0
JJJ138L Load	138.000	104.0	102.0	95.0	105.0
JJJ69 Busbar	69.000	99.9	103.6	95.0	105.0
ZZZ69 Load	69.000	93.0*	95.8	95.0	105.0

Optimized Generator Active Power

Bus Name	Before(MW)	After(MW)	Generation Cost ($/MW)
JJJ138S Utility	62.961	149.37	100.00
AAA138 Generator	200.00	155.14	300.00
DDD138 Generator	200.00	172.20	100.00
DDD69 Generator	0.0000	0.99894	100.00
FFF138 Generator	200.00	180.10	100.00

Optimized Generator/SVC Scheduled Voltage

Bus Name	System KV	Before(%)	After(%)
JJJ138S Utility	138.000	104.0	102.0
AAA138 Generator	138.000	102.0	103.2
DDD69 Generator	69.000	100.0	103.4
FFF138 Generator	138.000	102.0	102.4

Optimized Transformer Tap Setting

From Bus Name	To Bus Name	Before(p.u.)	After(p.u.)
FFF69 Busbar	FFF138 Generator	0.98600	1.0113
JJJ69 Busbar	JJJ138 Busbar	0.97200	1.0249

Feeders Loading Constraints

From Bus Name	To Bus Name	Before AMP	After AMP	Limit KA	Ampacity KA	Loading Contraints(%)	Violated
AAA138 Generator	BBB138 Load	123.3	170.7	1.28	0.26	500.0	
AAA138 Generator	JJJ138 Busbar	246.3	17.0	2.75	0.55	500.0	
AAA69 Busbar	ZZZ69 Load	173.9	107.3	1.27	0.25	500.0	
BBB138 Load	CCC138 Load	106.4	46.2	1.28	0.26	500.0	
CCC138 Load	DDD138 Generator	316.2	268.9	1.28	0.26	500.0	
DDD138 Generator	FFF138 Generator	53.4	12.8	1.28	0.26	500.0	

DDD69 Generator	EEE69 Load	130.1	121.5	1.27	0.25	500.0	
EEE69 Load	FFF69 Busbar	108.9	112.2	1.27	0.25	500.0	
JJJ138 Busbar	JJJ138S Utility	537.9	667.9	2.75	0.55	500.0	
JJJ138 Busbar	JJJ138L Load	467.8	467.8	2.75	0.55	500.0	
GGG138 Load	FFF138 Generator	394.8	279.1	1.28	0.26	500.0	
HHH138 Load	GGG138 Load	200.4	55.6	1.28	0.26	500.0	
JJJ138 Busbar	HHH138 Load	99.2	160.4	1.28	0.26	500.0	
ZZZ69 Load	JJJ69 Busbar	102.1	125.8	1.27	0.25	500.0	

Transformers Loading Constraints
================================

From Bus Name	To Bus Name	Before KVA	After KVA	Limit KVA	Capacity KVA	Loading Contraints(%)	Violated
AAA69 Busbar	AAA138 Generator	20762.0	12829.5	500000.0	100000.0	500.0	
DDD69 Generator	DDD138 Generator	14819.1	17419.5	500000.0	100000.0	500.0	
FFF69 Busbar	FFF138 Generator	13683.7	14063.7	500000.0	100000.0	500.0	
JJJ69 Busbar	JJJ138 Busbar	13683.7	15929.2	500000.0	100000.0	500.0	

Figure 3: Improved Optimization Reporting: Optimization Result - Loading Constraints not considered

The result of optimization when loading limits are imposed is reported below. As expected, if the feeder/transformer loading constraints are taken into account, the saving in the system losses are smaller than when loading limits are not considered (3191.29 kW versus 5172.93 kW):

```
                    EDSA Power System Optimization v3.10.00
                    =======================================

Project No. : 12345-1                         Page     : 1
Project Name: PSO Testing                     Date     :
Title       : a 14 bus system                 Time     :
Drawing No. : 12345-2                         Company  : Edsa
Revision No.: 12345-3                         Engineer : Edsa
Jobfile Name: pso                             Check by :
Scenario    : 1 -                             Date     :

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's
Faulted Power Systems


             Optimization Objective: Minimization of System Losses
                          Optimization is SUCCESSFUL.


                       Economical Impact of Optimization
                       =================================

Total System Losses Before Optimization   =  12982.60 Kilo Watts
Total System Losses After Optimization    =   9791.31 Kilo Watts
System Loss Reduction                     =   3191.29 Kilo Watts
```

Bus Voltage Constraints
=======================

Bus Name	System kV	Before(%)	After(%)	Vmin(%)	Vmax(%)
JJJ138S Utility	138.000	104.0	101.0	95.0	105.0
AAA138 Generator	138.000	102.0	104.5	95.0	105.0
DDD138 Generator	138.000	101.3	103.2	95.0	105.0
DDD69 Generator	69.000	100.0	103.6	95.0	105.0
FFF138 Generator	138.000	102.0	101.3	95.0	105.0
AAA69 Busbar	69.000	100.7	103.1	95.0	105.0
BBB138 Load	138.000	97.5	99.8	95.0	105.0
CCC138 Load	138.000	97.3	99.6	95.0	105.0
EEE69 Load	69.000	92.6*	96.3	95.0	105.0
FFF69 Busbar	69.000	99.8	102.8	95.0	105.0
GGG138 Load	138.000	98.2	97.1	95.0	105.0
HHH138 Load	138.000	98.8	96.9	95.0	105.0
JJJ138 Busbar	138.000	104.0	101.0	95.0	105.0
JJJ138L Load	138.000	104.0	101.0	95.0	105.0
JJJ69 Busbar	69.000	99.9	102.4	95.0	105.0
ZZZ69 Load	69.000	93.0*	95.8	95.0	105.0

Optimized Generator Active Power

Bus Name	Before(MW)	After(MW)	Generation Cost ($/MW)
JJJ138S Utility	62.961	115.95	100.00
AAA138 Generator	200.00	213.79	300.00
DDD138 Generator	200.00	181.99	100.00
DDD69 Generator	0.0000	0.98951	100.00
FFF138 Generator	200.00	147.08	100.00

Optimized Generator/SVC Scheduled Voltage

Bus Name	System KV	Before(%)	After(%)
JJJ138S Utility	138.000	104.0	101.0
AAA138 Generator	138.000	102.0	104.5
DDD69 Generator	69.000	100.0	103.6
FFF138 Generator	138.000	102.0	101.3

Optimized Transformer Tap Setting

From Bus Name	To Bus Name	Before(p.u.)	After(p.u.)
FFF69 Busbar	FFF138 Generator	0.98600	1.0229
JJJ69 Busbar	JJJ138 Busbar	0.97200	1.0238

Feeders Loading Constraints

From Bus Name	To Bus Name	Before AMP	After AMP	Limit KA	Ampacity KA	Loading Contraints(%)	Violated
AAA138 Generator	BBB138 Load	123.3	236.3	0.26	0.26	100.0	
AAA138 Generator	JJJ138 Busbar	246.3	166.1	0.55	0.55	100.0	
AAA69 Busbar	ZZZ69 Load	173.9	153.7	0.25	0.25	100.0	
BBB138 Load	CCC138 Load	106.4	17.6	0.26	0.26	100.0	
CCC138 Load	DDD138 Generator	316.2	215.3	0.26	0.26	100.0	Yes
DDD138 Generator	FFF138 Generator	53.4	84.9	0.26	0.26	100.0	
DDD69 Generator	EEE69 Load	130.1	139.1	0.25	0.25	100.0	
EEE69 Load	FFF69 Busbar	108.9	100.2	0.25	0.25	100.0	
JJJ138 Busbar	JJJ138S Utility	537.9	542.7	0.55	0.55	100.0	
JJJ138 Busbar	JJJ138L Load	467.8	467.8	0.55	0.55	100.0	
GGG138 Load	FFF138 Generator	394.8	253.4	0.26	0.26	100.0	Yes
HHH138 Load	GGG138 Load	200.4	23.4	0.26	0.26	100.0	
JJJ138 Busbar	HHH138 Load	99.2	193.5	0.26	0.26	100.0	
ZZZ69 Load	JJJ69 Busbar	102.1	98.0	0.25	0.25	100.0	

Transformers Loading Constraints

From Bus Name	To Bus Name	Before KVA	After KVA	Limit KVA	Capacity KVA	Loading Contraints(%)	Violated
AAA69 Busbar	AAA138 Generator	20762.0	18367.1	100000.0	100000.0	100.0	
DDD69 Generator	DDD138 Generator	14819.1	19605.5	100000.0	100000.0	100.0	
FFF69 Busbar	FFF138 Generator	13683.7	12373.2	100000.0	100000.0	100.0	
JJJ69 Busbar	JJJ138 Busbar	13683.7	12002.9	100000.0	100000.0	100.0	

Figure 4: Optimization Result - Loading Constraints are taken into Account

2 Solution Algorithm of the PSO program

The methodology implemented in PSO to solve the reactive power resource optimization problem alone or together with the security constrained optimal powerflow, is based on a hierarchical decomposition of the original problem into two parts:

- The reactive power planning problem, where the location and size of new reactive sources are determined
- The security constrained optimal powerflow problem in which the reactive power resources are used to optimize system operation.

The overall solution is achieved in an iterative method of the investment and operation sub-problems. The investment sub problem initially produces trial values for reactive resources. The effect of addition of these resources in terms of operating feasibility is evaluated by the operating sub problem. If operational constraints are not violated, then, the optimal solution has been found. Otherwise, information about problem infeasibility is fed back to the investment sub problem to obtain a revised reactive resources planning. This process continues until a feasible solution is found. When the option for optimizing a base case objective function along with reactive resources investment cost is considered, both feasibility and the optimality criterions are tested before the iterative process is terminated. PSO solves the reactive power resource planning sub problem by a mixed integer programming method and the operation sub problem by an advanced nonlinear primal-dual interior point method.

If contingencies are to be considered, then, the operation sub problem itself is further subdivided into basecase and contingency operation sub problems making the entire process a three level hierarchical structure. To solve the pure SCOPF problem a two level hierarchical structure is used consisting only of the operation sub problem.

The PSO finds the optimal operation of a power system by adjusting controllable quantities such that physical and operational constraints are satisfied. Mathematically it can be expressed as follows:

$$\begin{aligned} \text{Minimize} \quad & g(z) \\ \text{subject to} \quad & h(z) = 0 \qquad (1) \\ & \mathrm{L} \le \mathrm{z} \le \mathrm{U} \end{aligned}$$

g(z) is the objective function and h(z) is the equality constraints. z is a vector that includes the independent (x) and control variables (u), i.e. z=[x,u]. The power flow equations are given by h(z) and equipment limits and system operating limits are specified by L and U.

There are many standard OPF objective functions that are commonly in use. Some of the more classical ones that are also supported by PSO are minimization of:

- System Active Losses
- Generation Cost (also known as economic dispatch)
- Minimum System Adjustments to meet acceptable operating conditions (e.g. voltage profile, equipment overloading, etc.)
- Minimization of Load Shedding
- Minimization of Cost of Reactive Power Resources

Equation (1) above, is general form of OPF in which the objective functions is minimized by adjusting the available controls. The constraints in OPF include the followings:

- Maximum and minimum voltage limits
- Equipments loading limits
- Maximum and minimum active and reactive power generation
- Maximum and minimum transformer tap positions
- Etc.

Optimization of a power system when outage of network equipments is allowed is known as a security constrained OPF.

In most optimization software the inequality constraints are converted into equality constraints. In linear programming, slack variables are used to convert any inequality constraints to equality constraints. **PSO** uses a nonlinear optimization technique that employs barrier method (primal and dual) to convert inequalities to equalities. Equation (1), then, is reformulated as follows in the **PSO** implementation:

$$\text{Minimize}\left\{ g(z) - \mu \sum_j \log(z_j - l_j) - \mu \sum_j \log(u_j - z_j) \right\}$$

$$\begin{aligned} \text{subject to} \quad & h(z) = 0 \\ & z - S_1 = L \\ & z - S_2 = U \end{aligned}$$

Where S_1 and S_2 are slack variables representing system and equipments constraints. PSO will optimize the objective function by adjusting the control setting of the equipments (i.e., generator active power and voltage set-points, transformers tap positions, and voltage set-points of switchable shunts). These controls can be optimized separately or in any combination.

It should be noted that a powerflow program solves equality constraints, h(z), defined in equation (1) above and keep the equipment settings within their acceptable ranges (e.g. generator reactive power is in between maximum and minimum reactive power generation). PSO solves complete system of equations defined in (1) respecting constraints on system variables (e.g. bus voltages, power flows, etc.).

3 Objective Functions Supported by PSO

The following objective functions are implemented in the present version of PSO software:

Economic Dispatch, Minimum Generation Cost

One of the most important objective functions supported by PSO is determination of minimum active power generation cost also known as economic dispatch (ED). PSO will assign the active power of each generator such that the total cost of generation is minimized while ensuring feasible system operation simultaneously for the normal state (base case) and under contingency situations. It is important that realistic cost coefficient (cost of generation, $/MW) for each of the generators are specified. Generation costs are considered to be piece-wise linear in PSO.

Minimization of Active Power Losses

In this mode, PSO computes optimal settings of the controls so that system active power losses are minimized and at the same time ensure feasibility in the normal state (base case) and under contingency situations (maintaining acceptable voltage profile and alleviating over loading situations).

Minimization of Controls Movement

In this option, PSO program finds a minimum number of controls that should be readjusted in order to alleviate the operational constraint violations. The violations include circuit overloads and voltage problems in the basecase and contingency configurations.

Minimization of Load Shedding

PSO minimizes load shedding in order to correct operational constraint violations such as circuit overloads and voltage problems. Candidate sites for load shedding may be specified individually by buses, by area or by zone. Alternatively, **PSO** can find the most effective load shedding sites yielding the minimum load curtailment to ensure feasible system operation simultaneously for the normal state (basecase) and under contingency situations (maintaining acceptable voltage profile and alleviating over loading situations) by adjusting the control settings.

Optimal Reactive Power Resource Allocation

The PSO program can efficiently be used to optimize reactive power resources in complex power systems. The reactive power resource investment cost is assumed to be a linear function of equipment size. Total investment cost associated with addition of capacitors/inductors is represented by a combination of fixed and variable components cost. Site-specific fixed cost is incurred if any resource is installed in the associated location (bus). The variable cost is assumed to vary linearly with the reactive power size of the equipment. In addition, PSO can model the situations where the reactive power equipment (e.g. capacitor) is composed of several cans (modules) with user defined minimum and maximum size.

The user can specify candidate buses for shunt compensation to be used for optimization of reactive power resource planning. The selection of candidate buses at which shunt VAr source additions can be placed is a very critical step in the planning process. A poorly selected candidate set may lead to infeasibility of the problem or to an economically unattractive solution. The candidate buses can be determined by the user or the PSO program itself can be used to help to identify.

4 Power Systems Controls in PSO

The aforementioned objective functions are optimized using allowable controls specified by the user (e.g. generators scheduled voltages, active power outputs, transformer taps, etc.). The result of **PSO** is very sensitive to the selection and assignments of controls that are to be used in the optimization. The following controls are supported and can be specified:

- **Voltage schedule of Variable shunts/SVC**
- **Transformer taps**

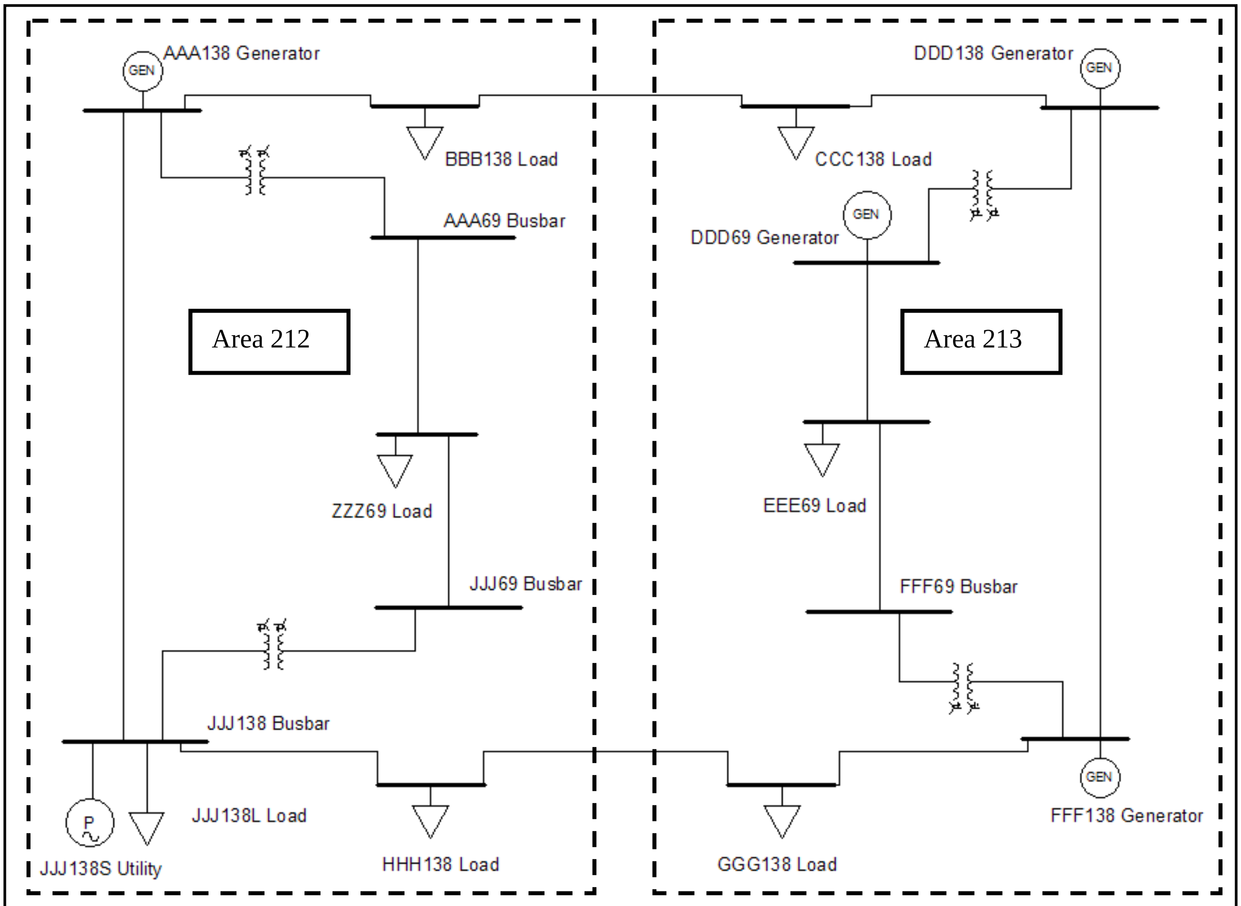
- **Generator terminal voltages**
- **Generation active power output**

5 Constraint Modeling in PSO

The following constraints may be specified in **PSO**:

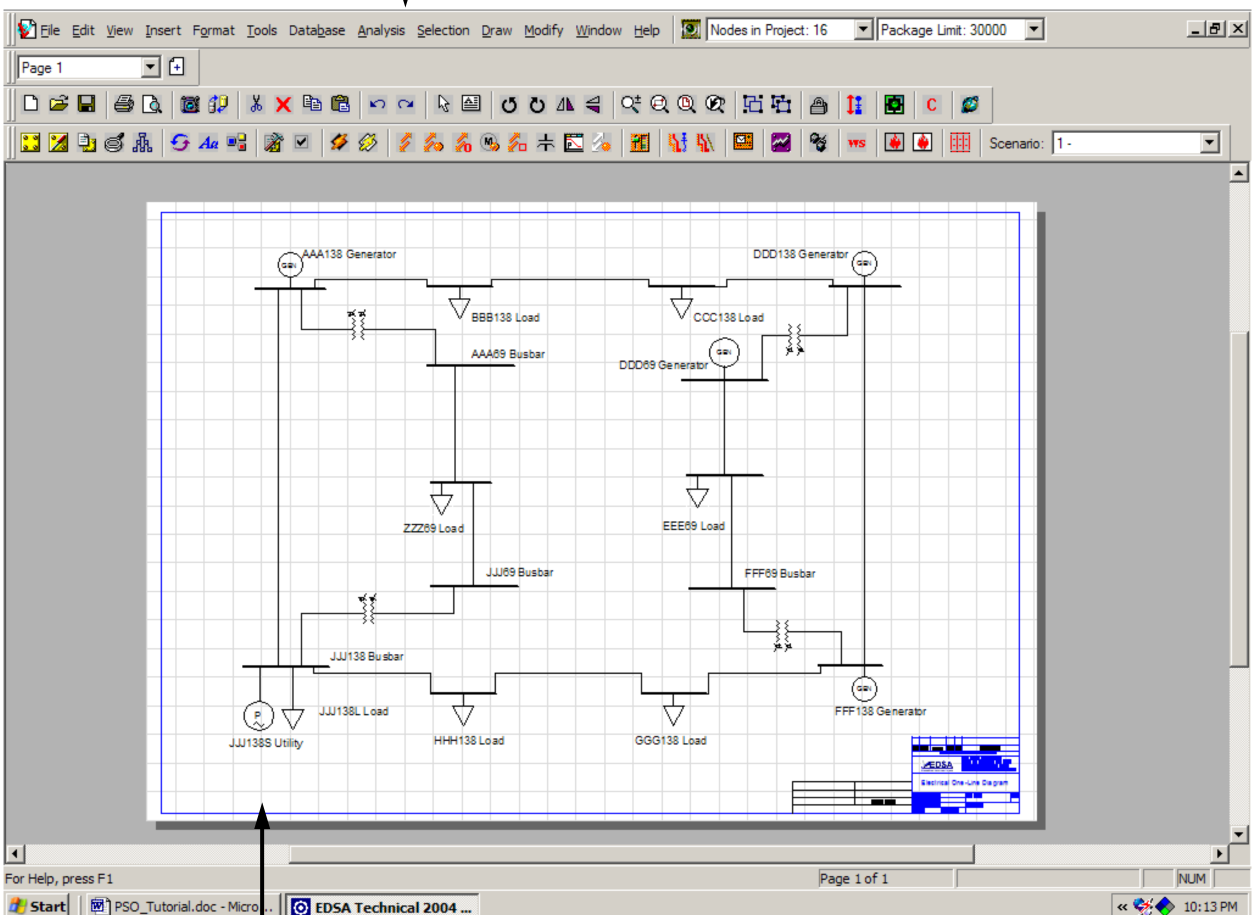
- **Acceptable bus voltage limits in the normal and emergency operation**
- **Branch flow limits (MW/MVAr)**
- **Transformer tap limits**
- **Generator MW and MVAr limits**
- **Phase Shifter Angles (controlling MW flow)**

6 Power System Optimization Tutorial



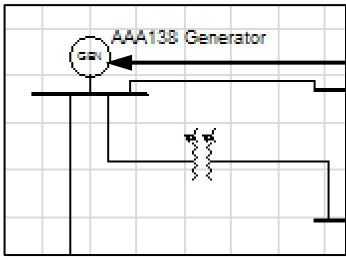
This tutorial will be based on the EDSA project file called “PSO.epr” shown in this figure. Notice that all the buses in the network are subdivided into two areas, namely, Area 212 and Area 213.

Step 1.
Start the EDSA program, and from the samples folder, open the drawing file called "PSO.axd" or the project file "PSO.epr".



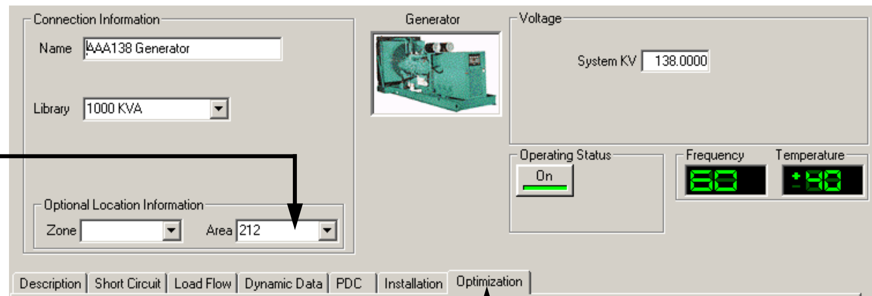
Step 2.
Proceed to define the "Optimization" settings required for Utilities, Generators, Lines, Transformers, Buses and Loads. Follow the instructions in the next sections of this tutorial.

Optimization Settings for Generator Buses



Step 1.
To illustrate how to define the Optimization settings for a typical generator, we will use the generator bus "AAA138" as an example. Proceed to double click on this bus in order to access its editor.

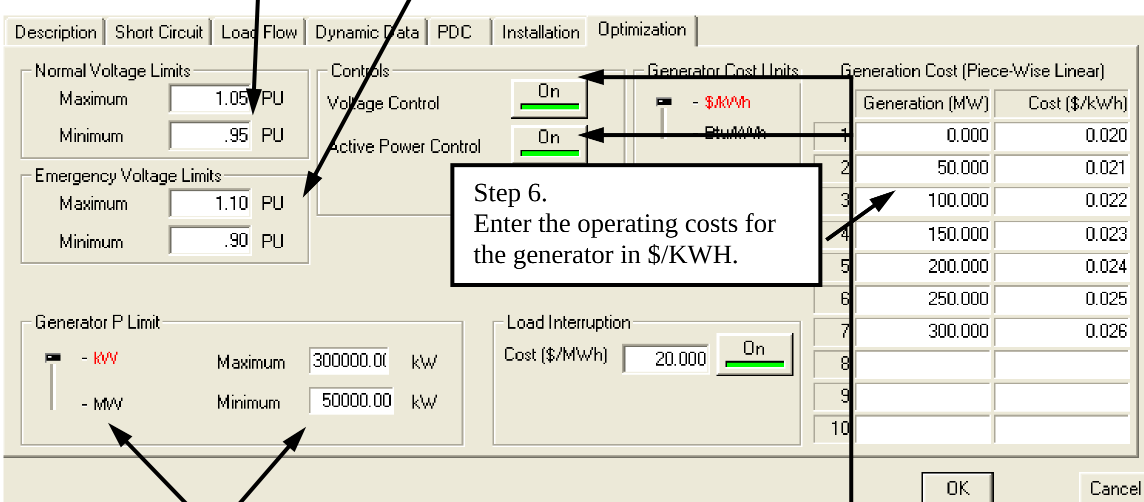
Step 2.
Proceed to assign the "Area" designation for this bus. In this case the area will be typed in as "212".



Step 4.
Define the "Normal" operating voltage limits.

Step 5.
Define the "Emergency" operating voltage limits.

Step 3.
Select the "Optimization" tab.

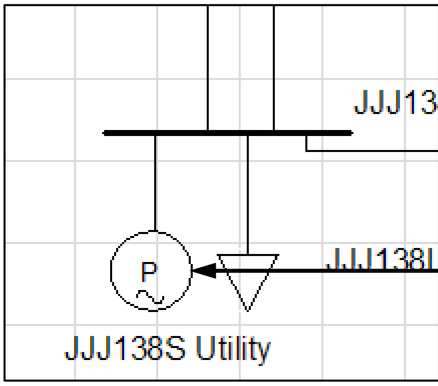


Step 6.
Enter the operating costs for the generator in $/KWH.

Step 7.
Enter the "Minimum" and "Maximum" active power limits for the generator in either KW or MW.

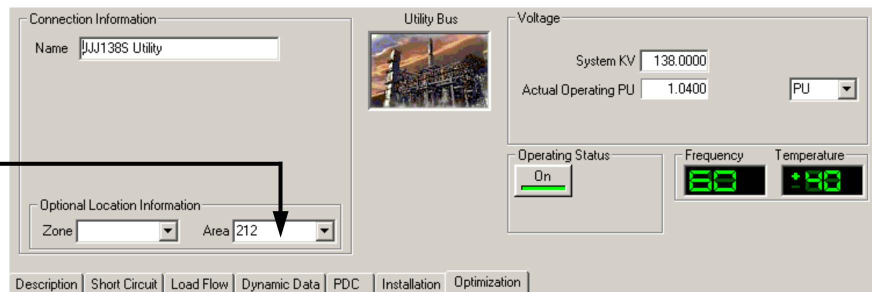
Step 8.
Enable Voltage and/or Active Power Control capabilities for this generator, by selecting the "On" functions as required.
Select "OK" when finished.

7 Optimization Settings for Utility Buses



Step 1.
To illustrate how to define the Optimization settings for a typical utility bus, we will use bus “JJJ138S Utility” as an example. Proceed to double click on this bus in order to access its editor.

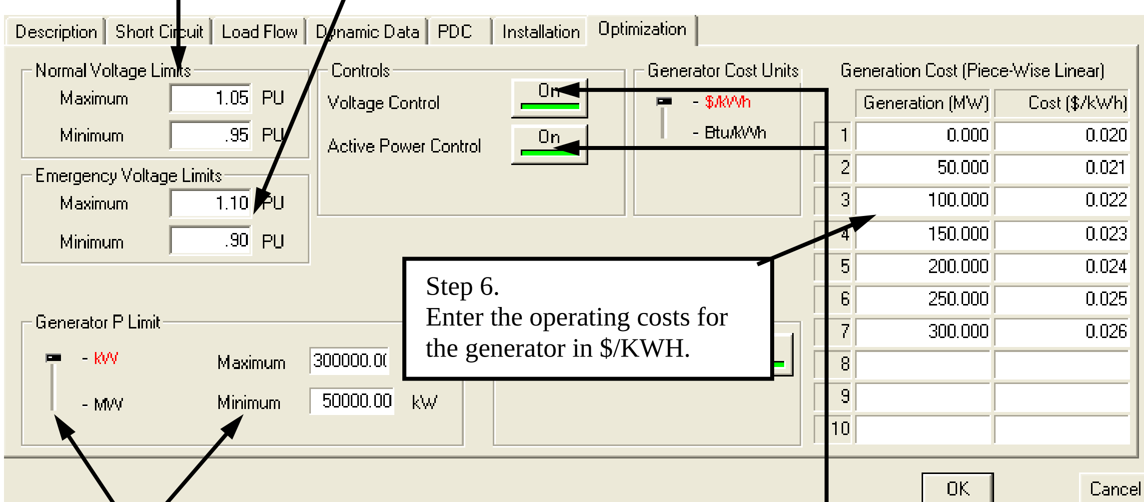
Step 2.
Proceed to assign the “Area” designation for this bus. In this case the area will be typed in as “212”.



Step 4.
Define the “Normal” operating voltage limits.

Step 5.
Define the “Emergency” operating voltage limits.

Step 3.
Select the “Optimization” tab.

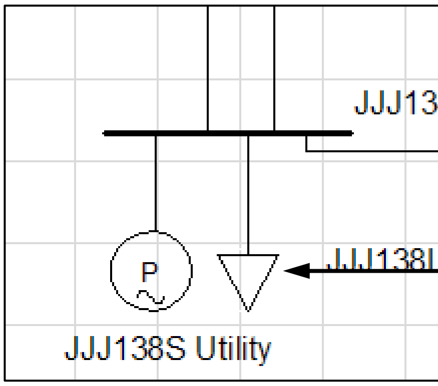


Step 6.
Enter the operating costs for the generator in $/KWH.

Step 7.
Enter the “Minimum” and “Maximum” active power limits for the generator in either KW or MW.

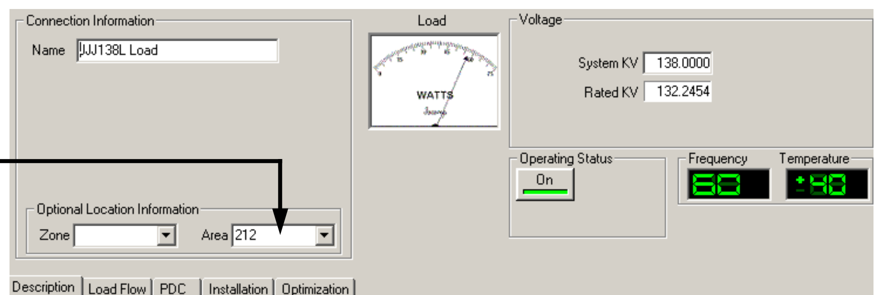
Step 8.
Enable Voltage and/or Active Power Control capabilities for this utility bus, by selecting the “On” functions as required.
Select “OK” when finished.

8 Optimization Settings for Load Buses, Bus Bars & Nodes

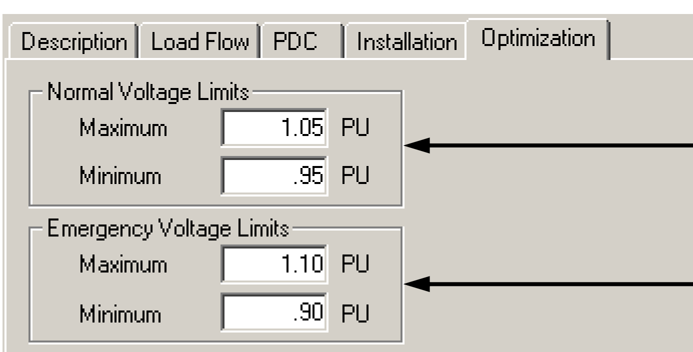


Step 1.
To illustrate how to define the Optimization settings for a typical bus, we will use bus “JJJ138L Load” as an example. Proceed to double click on this bus in order to access its editor.

Step 2.
Proceed to assign the “Area” designation for this bus. In this case the area will be typed in as “212”.



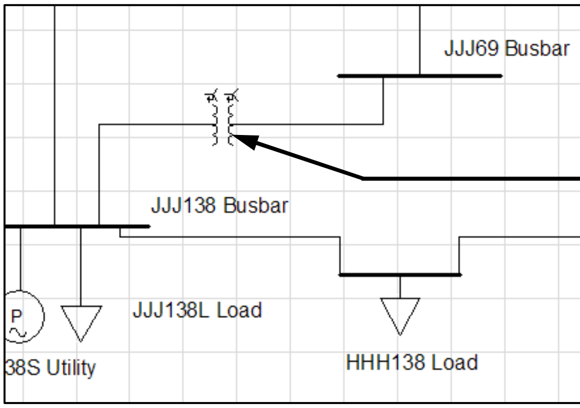
Step 3.
Select the “Optimization” tab.



Step 4.
Define the “Normal” operating voltage limits.

Step 5.
Define the “Emergency” operating voltage limits. Select “OK” when finished.

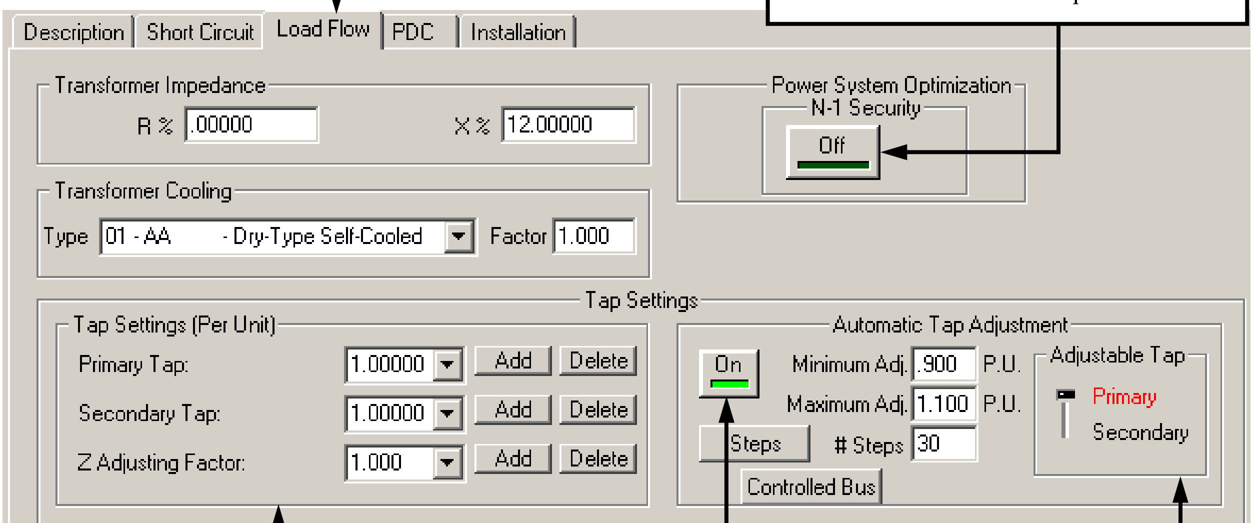
9 Optimization Settings for Transformers



Step 1.
To illustrate how to define the Optimization settings for a transformer, we will use transformer "JJJ69 Busbar – JJJ138 Busbar" as an example. Proceed to double click on this branch in order to access its editor.

Step 2.
Select the "Load Flow" tab.

Step 3.
To assign "N-1 Security" constraint, select "On" or "Off" as required.



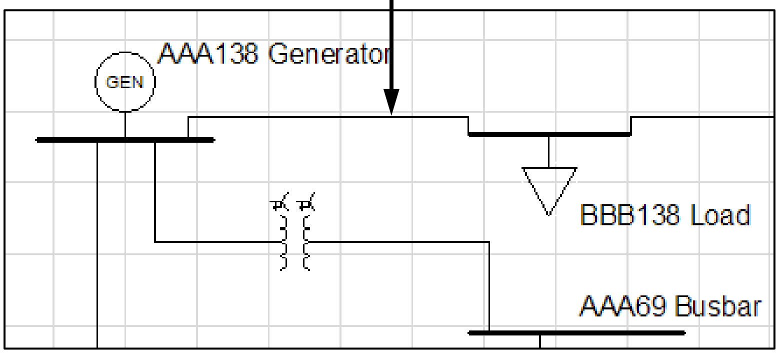
Step 5.
If this transformer will be used as a control transformer in the optimization calculations, select "On". Otherwise the transformer will retain (throughout the optimization analysis) the same fixed settings entered in the "Tap Settings (Per Unit)" section.

Step 6.
Select "OK" to continue.

Step 4.
Select the winding in which the adjustable taps are located (Primary or Secondary).

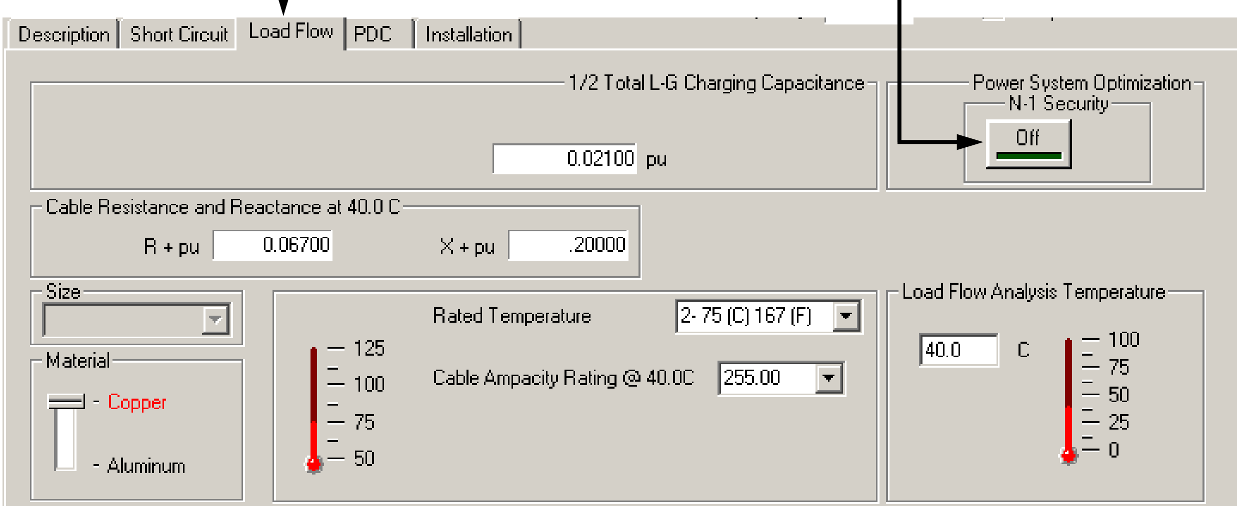
10 Optimization Settings for Feeders

Step 1.
To illustrate how to define the Optimization settings for a typical feeder, we will use feeder “AAA138 Generator – BBB138 Load” as an example. Proceed to double click on this branch in order to access its editor.

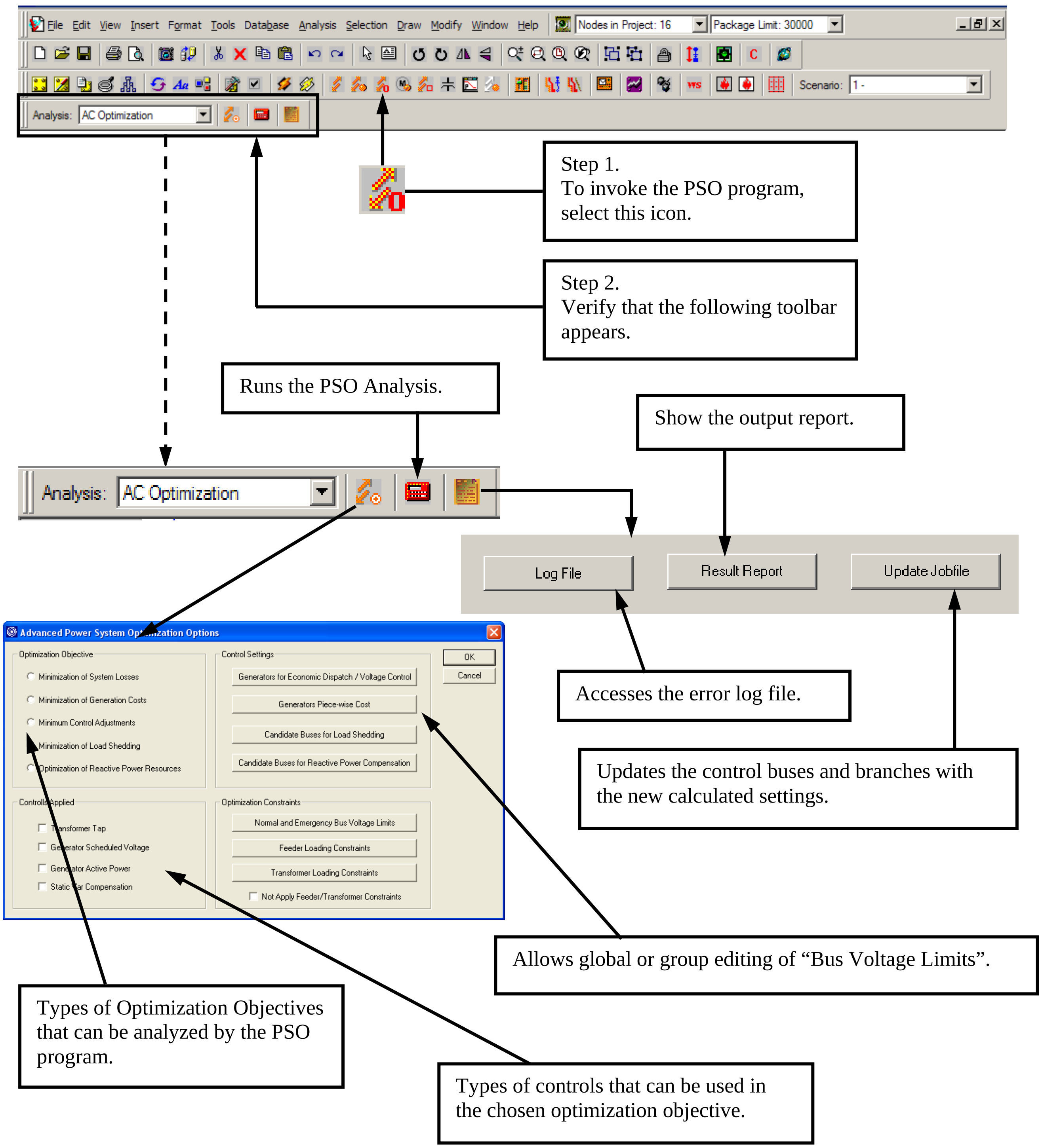


Step 2.
Select the “Load Flow” tab”

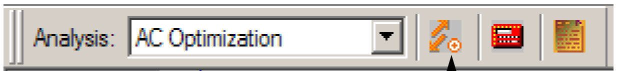
Step 3.
Assign the appropriate “N-1 Security” constraint status to the branch by selecting “On” or “Off” as required. Select “OK” when finished.



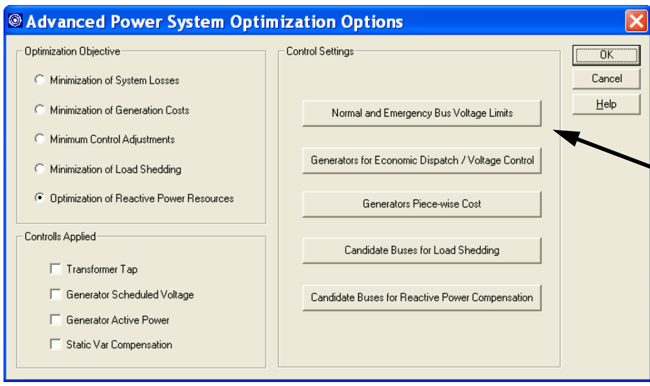
11 The Power System Optimization Program Interface



12 Changing Bus Voltage Limits

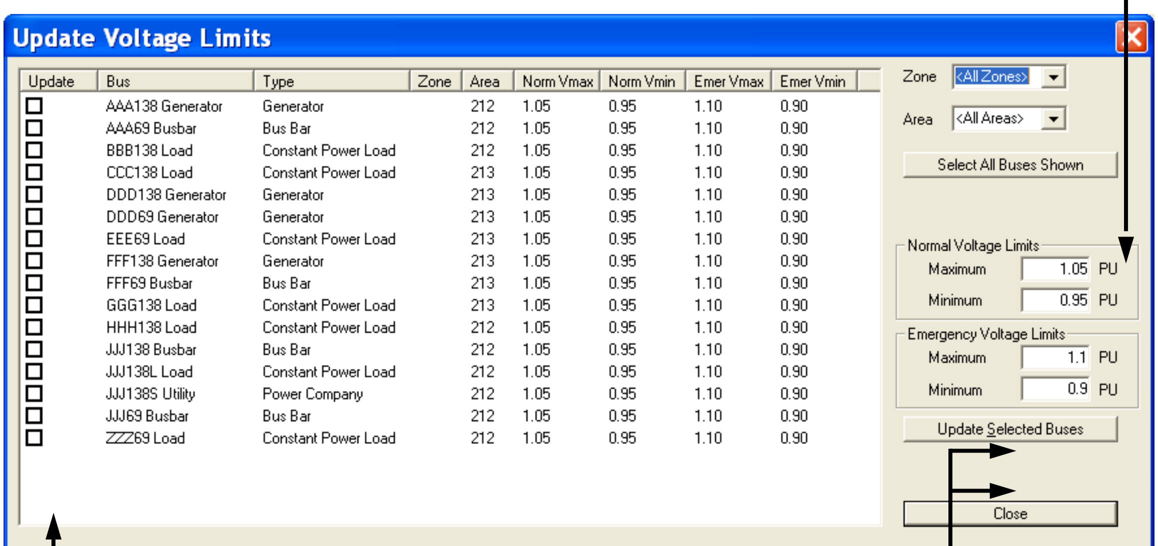


Step 1.
To change bus voltage limits individually or in groups, select the "Options" icon.



Step 2.
Select the "Setting Bus Voltage Limits" button.

Step 3.
Specify the new voltage settings for "Normal" and/or "Emergency" operation.



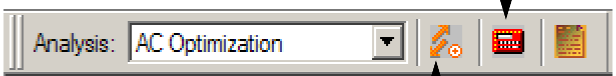
Step 4.
Select the buses that are to be updated with the new limits by either of the following methods:

1. By placing a check mark next to the bus or buses.
2. By selecting buses in specific Zones/Areas
3. By selecting all buses if the changes are global.

Step 5.
Select the "Update" function as shown here. Repeat steps 1-5 as necessary. Select "Done" to complete the operation.

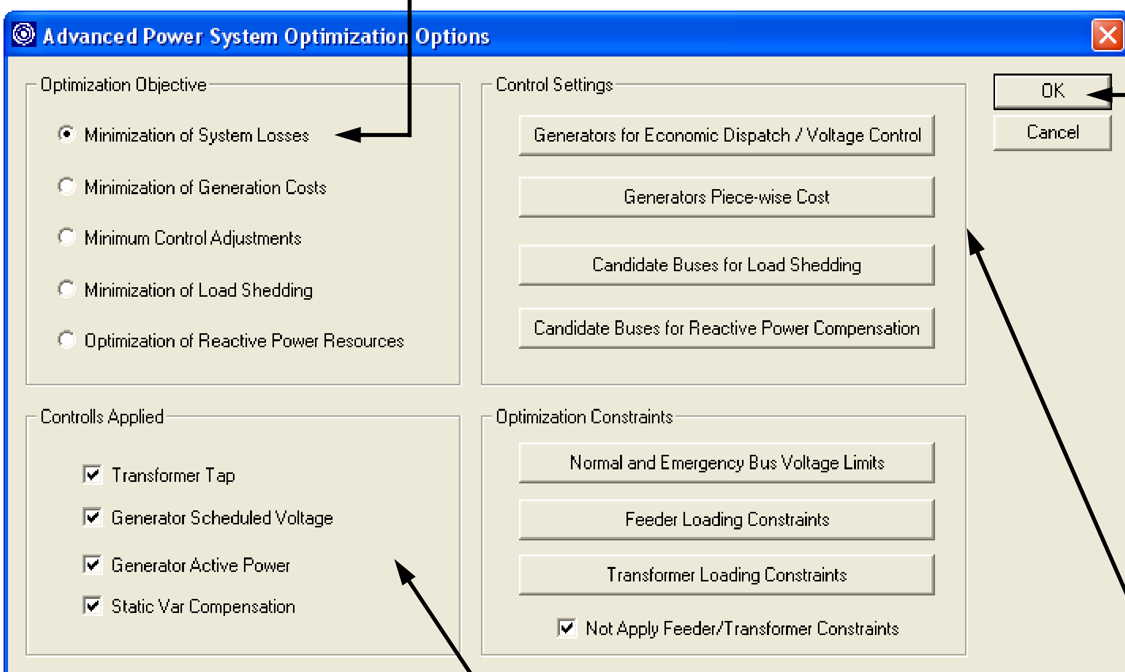
13 Minimization of System Losses

Step 6.
Select the "Analyze" icon.



Step 1.
From the PSO toolbar, select the "Options" icon.

Step 2.
From the "Objectives" menu, select "Minimization of System Losses".



Step 5.
Select "OK".

Step 3.
From the "Controls" menu, select the type or types of control strategies that are to be used in the optimization process. For this example, select all of them.

Step 4.
If required, modify these settings.

Step 7.
Once the calculation is completed, a dialog box will indicate whether the analysis was successful or not. If the analysis was successful, an output report will appear as indicated in the next two pages. If the analysis was unsuccessful, select the "Log File" command to troubleshoot and rectify the problems. The "Log File" button can be accessed as indicated in section 7.11 this tutorial.

```
                         Power System Optimization
                         =========================

Project No.  : 12345-1                             Page       : 1
Project Name: PSO Testing                          Date       :
Title        : a 14 bus system                     Time       :
Drawing No.  : 12345-2                             Company    :
Revision No.: 12345-3                              Engineer   :
Jobfile Name: pso                                  Check by   :
Scenario     : 1 -                                 Date       :

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's
Faulted Power Systems

             Optimization Objective: Minimization of System Losses
                          Optimization is SUCCESSFUL.
```

The net reduction of system losses is shown here.

```
                    Economical Impact of Optimization
                    =================================

Total System Losses Before Optimization    =  12982.60 Kilo Watts
Total System Losses After Optimization     =   7809.67 Kilo Watts
System Loss Reduction                      =   5172.93 Kilo Watts
```

Bus Voltage Change

Bus Name	System kV	Before(%)	After(%)	Vmin(%)	Vmax(%)
JJJ138S Utility	138.000	104.0	102.0	95.0	105.0
AAA138 Generator	138.000	102.0	103.2	95.0	105.0
DDD138 Generator	138.000	101.3	103.1	95.0	105.0
DDD69 Generator	69.000	100.0	103.4	95.0	105.0
FFF138 Generator	138.000	102.0	102.4	95.0	105.0
AAA69 Busbar	69.000	100.7	101.7	95.0	105.0
BBB138 Load	138.000	97.5	99.1	95.0	105.0
CCC138 Load	138.000	97.3	99.2	95.0	105.0
EEE69 Load	69.000	92.6*	96.4	95.0	105.0
FFF69 Busbar	69.000	99.8	102.9	95.0	105.0
GGG138 Load	138.000	98.2	98.3	95.0	105.0
HHH138 Load	138.000	98.8	98.1	95.0	105.0
JJJ138 Busbar	138.000	104.0	102.0	95.0	105.0
JJJ138L Load	138.000	104.0	102.0	95.0	105.0
JJJ69 Busbar	69.000	99.9	103.6	95.0	105.0
ZZZ69 Load	69.000	93.0*	95.8	95.0	105.0

The voltage correction report is shown here. The buses marked with an asterisk, indicate values that were outside the acceptable limits prior to the optimization process

Step 8.
Select “Done” to exit.

This section of the report shows the control-generator settings before and after the optimization analysis.

Optimized Generator Active Power

Bus Name	Before(MW)	After(MW)	Generation Cost ($/MW)
JJJ138S Utility	62.961	149.37	100.00
AAA138 Generator	200.00	155.14	300.00
DDD138 Generator	200.00	172.20	100.00
DDD69 Generator	0.0000	0.99894	100.00
FFF138 Generator	200.00	180.10	100.00

Optimized Generator Scheduled Voltage

Bus Name	System KV	Before(%)	After(%)
JJJ138S Utility	138.000	104.0	102.0
AAA138 Generator	138.000	102.0	103.2
DDD69 Generator	69.000	100.0	103.4
FFF138 Generator	138.000	102.0	102.4

Optimized Transformer Tap Setting

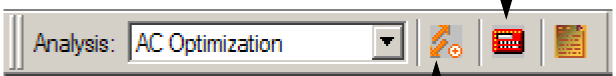
From Bus Name	To Bus Name	Before(p.u.)	After(p.u.)
FFF69 Busbar	FFF138 Generator	0.98600	1.0113
JJJ69 Busbar	JJJ138 Busbar	0.97200	1.0249

This section shows the tap settings for the two control transformers, before and after the optimization process.

This section shows the generators output voltage change, before and after the optimization analysis.

14 Minimization of Generation Costs

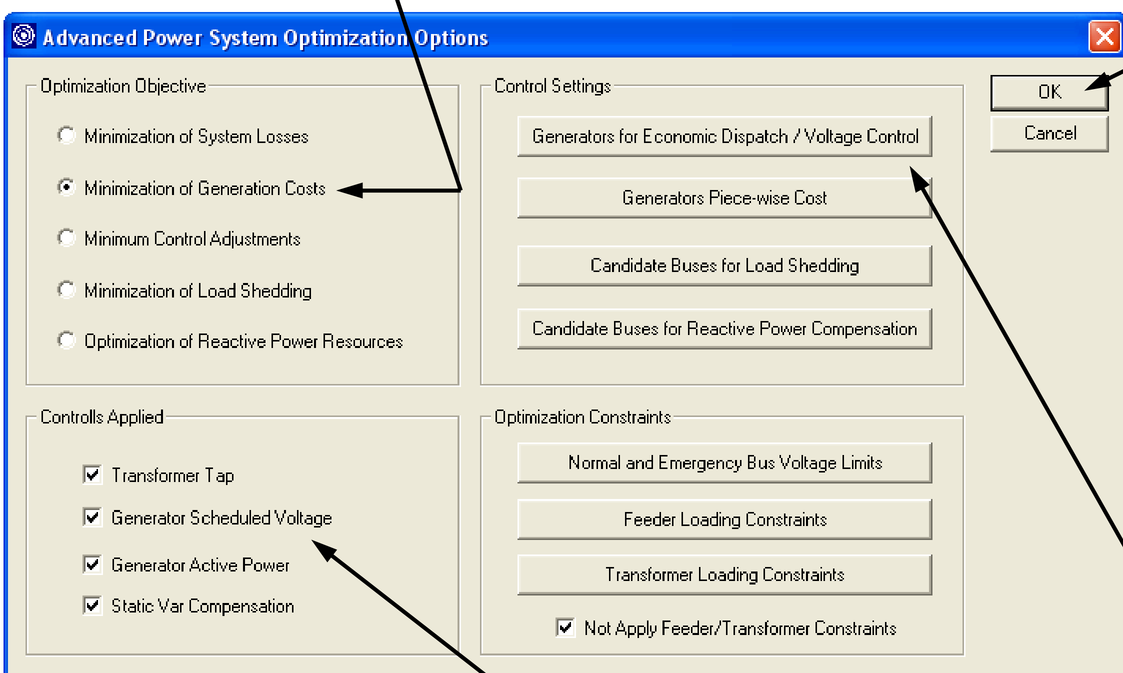
Step 6.
Select the "Analyze" icon.



Step 2.
From the "Objectives" menu, select "Minimization of Generation Costs".

Step 1.
From the PSO toolbar, select the "Options" icon.

Step 5.
Select "OK".



Step 3.
From the "Controls" menu, select the type or types of control strategies that are to be used in the optimization process. For this example, select all of them.

Step 4.
If required, modify these settings.

Step 7.
Once the calculation is completed, a dialog box will indicate whether the analysis was successful or not. If the analysis was successful, an output report will appear as indicated in the next two pages. If the analysis was unsuccessful, select the "Log File" command to troubleshoot and rectify the problems. The "Log File" button can be accessed as indicated in section 7.11 this tutorial.

```
                         Power System Optimization
                         =========================

Project No.  : 12345-1                        Page      : 1
Project Name: PSO Testing                     Date      :
Title        : a 14 bus system                Time      :
Drawing No.  : 12345-2                        Company   :
Revision No.: 12345-3                         Engineer  :
Jobfile Name: pso                             Check by  :
Scenario     : 1 -                            Date      :

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's
Faulted Power Systems


            Optimization Objective: Minimization of Generation Costs
                         Optimization is SUCCESSFUL.


                    Economical Impact of Optimization
                    =================================
Total System Losses Before Optimization    =  12982.60 Kilo Watts
Total System Losses After Optimization     =  11948.05 Kilo Watts
System Loss Reduction                      =   1034.54 Kilo Watts

Total Generation cost before optimization = 106296.10 dollars
Total Generation cost after  optimization =  76195.08 dollars
Saving in generation cost                 =  30101.02 dollars
```

The net reduction of system generation costs and losses are shown here.

```
                              Bus Voltage Change
                              ==================

        Bus Name            System kV  Before(%)  After(%)   Vmin(%)   Vmax(%)
------------------------   ---------  ---------  --------  ---------  -------
JJJ138S Utility               138.000     104.0     105.0       95.0    105.0
AAA138 Generator              138.000     102.0     101.9       95.0    105.0
DDD138 Generator              138.000     101.3     105.0       95.0    105.0
DDD69 Generator                69.000     100.0     105.0       95.0    105.0
FFF138 Generator              138.000     102.0     105.0       95.0    105.0
AAA69 Busbar                   69.000     100.7     100.0       95.0    105.0
BBB138 Load                   138.000      97.5      99.4       95.0    105.0
CCC138 Load                   138.000      97.3     100.1       95.0    105.0
EEE69 Load                     69.000      92.6*     98.4       95.0    105.0
FFF69 Busbar                   69.000      99.8     105.0       95.0    105.0
GGG138 Load                   138.000      98.2     101.2       95.0    105.0
HHH138 Load                   138.000      98.8     101.2       95.0    105.0
JJJ138 Busbar                 138.000     104.0     105.0       95.0    105.0
JJJ138L Load                  138.000     104.0     105.0       95.0    105.0
JJJ69 Busbar                   69.000      99.9     105.0       95.0    105.0
ZZZ69 Load                     69.000      93.0*     95.5       95.0    105.0
```

The voltage correction report is shown here. The buses marked with an asterisk, indicate values that were outside the acceptable limits prior to the optimization process

Step 8.
Select “Done” to exit.

This section of the report shows the control-generator settings before and after the optimization analysis.

Optimized Generator Active Power

Bus Name	Before(MW)	After(MW)	Generation Cost ($/MW)
JJJ138S Utility	62.961	224.35	100.00
AAA138 Generator	200.00	50.001	300.00
DDD138 Generator	200.00	210.20	100.00
DDD69 Generator	0.0000	0.73825	100.00
FFF138 Generator	200.00	176.65	100.00

Optimized Generator Scheduled Voltage

Bus Name	System KV	Before(%)	After(%)
JJJ138S Utility	138.000	104.0	105.0
AAA138 Generator	138.000	102.0	101.9
DDD69 Generator	69.000	100.0	105.0
FFF138 Generator	138.000	102.0	105.0

Optimized Transformer Tap Setting

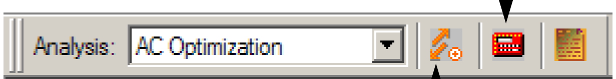
From Bus Name	To Bus Name	Before(p.u.)	After(p.u.)
FFF69 Busbar	FFF138 Generator	0.98600	1.0059
JJJ69 Busbar	JJJ138 Busbar	0.97200	1.0053

This section shows the tap settings for the two control transformers, before and after the optimization process.

This section shows the generators output voltage change, before and after the optimization analysis.

15 Minimization of Controls Movements

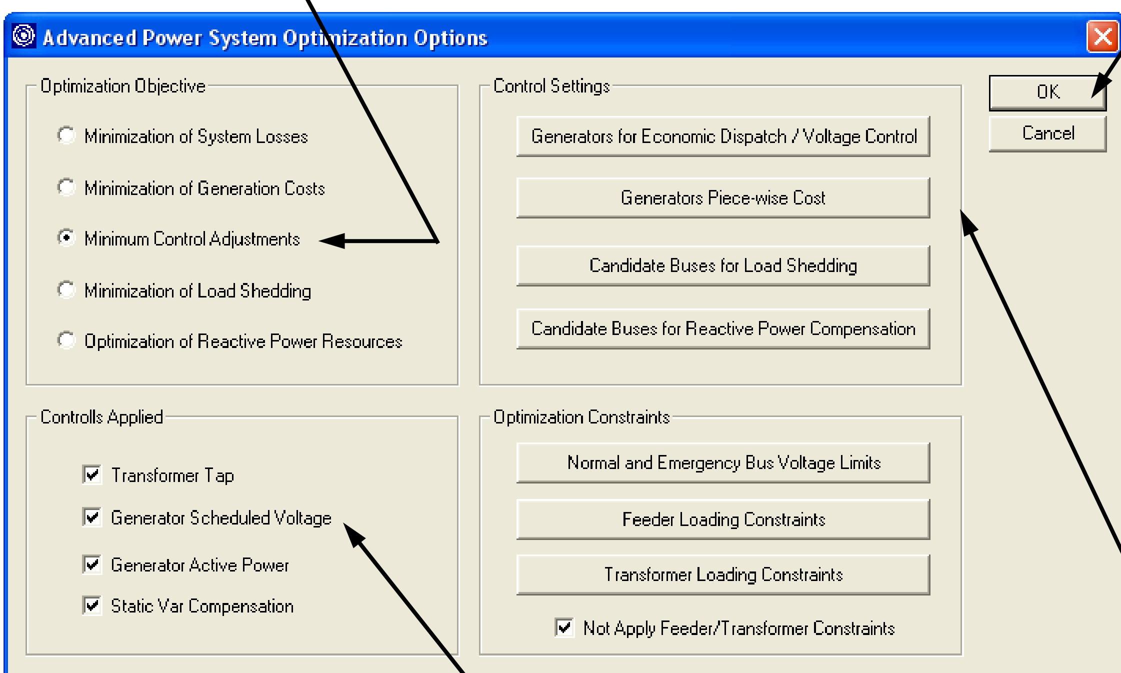
Step 6.
Select the “Analyze” icon.



Step 2. Select the “Minimum Control Adjustments” function.

Step 1.
From the PSO toolbar, select the “Options” icon.

Step 5.
Select “OK”.



Step 3.
From the “Controls” menu, select the type or types of control strategies that are to be used in the optimization process. For this example, select all of them.

Step 4.
If required, modify these settings.

Step 7.
Once the calculation is completed, a dialog box will indicate whether the analysis was successful or not. If the analysis was successful, an output report will appear as indicated in the next two pages. If the analysis was unsuccessful, select the “Log File” command to troubleshoot and rectify the problems. The “Log File” button can be accessed as indicated in section 7.11 this tutorial.

Power System Optimization
=========================

Project No.	: 12345-1	Page	: 1
Project Name	: PSO Testing	Date	:
Title	: a 14 bus system	Time	:
Drawing No.	: 12345-2	Company	:
Revision No.	: 12345-3	Engineer	:
Jobfile Name	: pso	Check by	:
Scenario	: 1 -	Date	:

The net reduction of system losses after the optimization is shown here.

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's Faulted Power Systems

Optimization Objective: Optimal Bus Voltage Profile
Optimization is SUCCESSFUL.

Economical Impact of Optimization
==================================

Total System Losses Before Optimization	=	12982.60 Kilo Watts
Total System Losses After Optimization	=	11549.25 Kilo Watts
System Loss Reduction	=	1433.35 Kilo Watts

Bus Voltage Change
==================

Bus Name	System kV	Before(%)	After(%)	Vmin(%)	Vmax(%)
JJJ138S Utility	138.000	104.0	103.9	50.0	150.0
AAA138 Generator	138.000	102.0	106.0	50.0	150.0
DDD138 Generator	138.000	101.3	104.3	95.0	105.0
DDD69 Generator	69.000	100.0	102.7	50.0	150.0
FFF138 Generator	138.000	102.0	104.6	50.0	150.0
AAA69 Busbar	69.000	100.7	104.4	95.0	105.0
BBB138 Load	138.000	97.5	101.4	95.0	105.0
CCC138 Load	138.000	97.3	100.9	95.0	105.0
EEE69 Load	69.000	92.6*	95.7	95.0	105.0
FFF69 Busbar	69.000	99.8	102.4	95.0	105.0
GGG138 Load	138.000	98.2	100.3	95.0	105.0
HHH138 Load	138.000	98.8	100.2	95.0	105.0
JJJ138 Busbar	138.000	104.0	103.9	95.0	105.0
JJJ138L Load	138.000	104.0	103.9	95.0	105.0
JJJ69 Busbar	69.000	99.9	100.2	95.0	105.0
ZZZ69 Load	69.000	93.0*	95.3	95.0	105.0

The voltage correction report is shown here. The buses marked with an asterisk, indicate values that were outside the acceptable limits prior to the optimization process

Step 8.
Select "Done" to exit.

This section of the report shows the control-generator settings before and after the optimization analysis.

```
                    Optimized Generator Active Power
                    ================================

        Bus Name                 Before(MW)   After(MW)  Generation Cost ($/MW)
------------------------------  ----------  ----------  ----------------------
JJJ138S Utility                    62.961      61.544          100.00
```

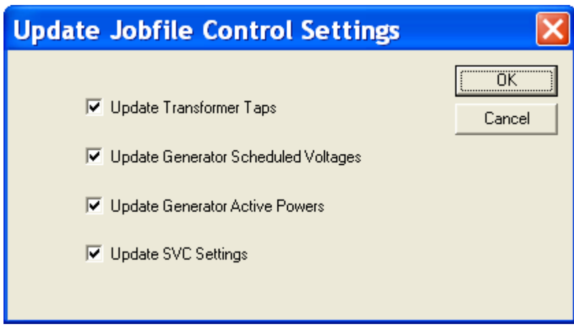
```
                 Optimized Generator Scheduled Voltage
                 =====================================

        Bus Name                 System KV   Before(%)   After(%)
------------------------------  ----------  ----------  ----------
JJJ138S Utility                    138.000      104.0       103.9
AAA138 Generator                   138.000      102.0       106.0
DDD69 Generator                     69.000      100.0       102.7
FFF138 Generator                   138.000      102.0       104.6
```

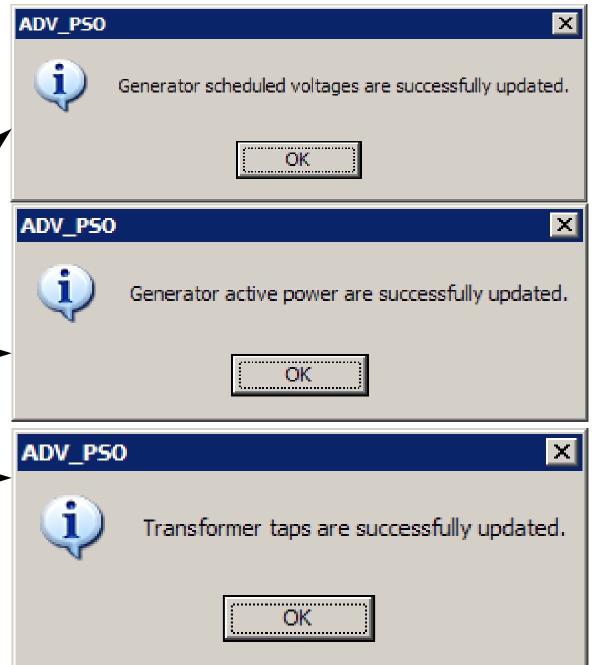
```
                   Optimized Transformer Tap Setting
                   =================================

   From Bus Name              To Bus Name            Before(p.u.)  After(p.u.)
------------------------  ------------------------  ------------  -----------

*** No changes were required by optimization for this control
```

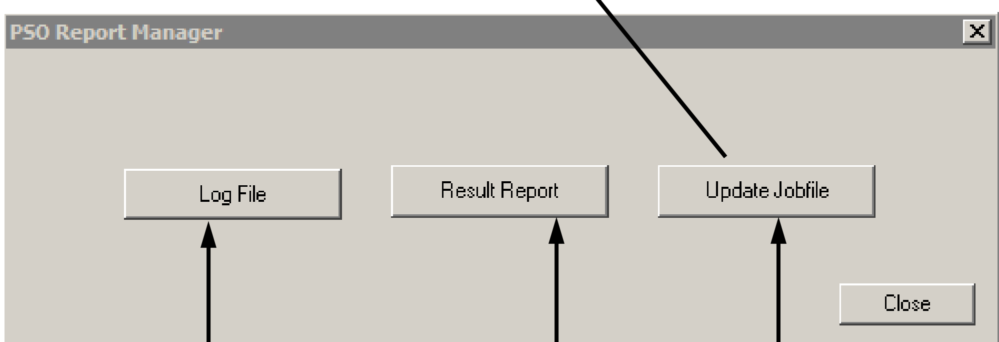
This section shows the tap settings for the two control transformers, before and after the optimization process. Notice that in this case no adjustments are required.

This section shows the generators output voltage change, before and after the optimization analysis.

16 The PSO Report Manager







Select the “Log File” to view important convergence data generated during the analysis. This feature can assist the user in troubleshooting unsuccessful PSO calculations.

The “Update Jobfile” command allows the user to update all the control devices with settings calculated by the last optimization analysis.

The “Result Report” command, is used to re-display (if necessary) the output report for the last performed analysis, after having closed it using the “Done” command.

17 How to Perform Minimization of Active Power Generation

The jobfile used to demonstrate this optimization option is named “pso_14node_MinGenCost2” which is in the DesignBase\Samples\PSO directory. This sample case is also used in the validation and verification of the PSO for this optimization function. The system one line diagram is shown below:

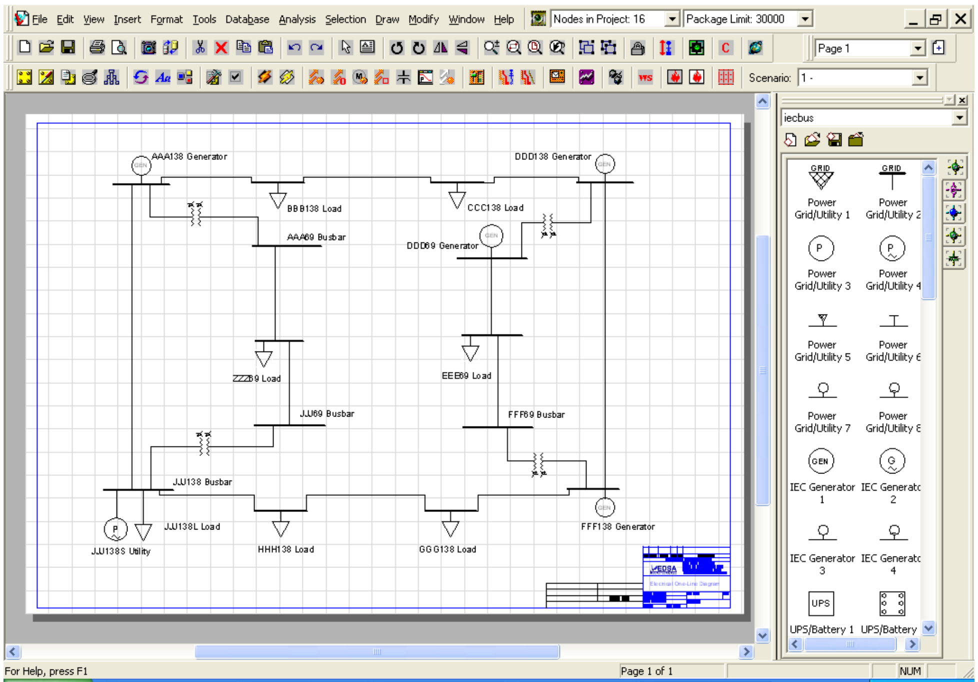


Figure 5: Single Line Diagram of the Sample Jobfile used in V&V of the “Minimization of Generation Cost”

The optimization control setting for this jobfile is shown below:

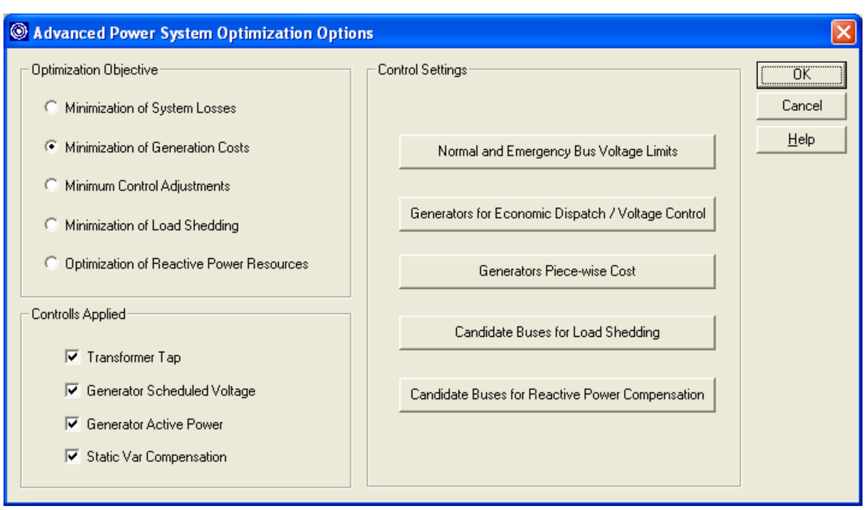


Figure 6: Control Settings used in V&V of the “Minimization of Generation Cost”

Here we select all the controls, i.e., Transformer tap adjustment, generator scheduled voltage, generator active power, and static var compensator scheduled voltage. In this example we have used a piece-wise linear cost function for several of the units in this jobfile.

The PSO program accepts both constant generation cost or user defined piece-wise linear generation cost function. A piece-wise generation cost for the generator at bus "AAA138 Generator" is shown below:

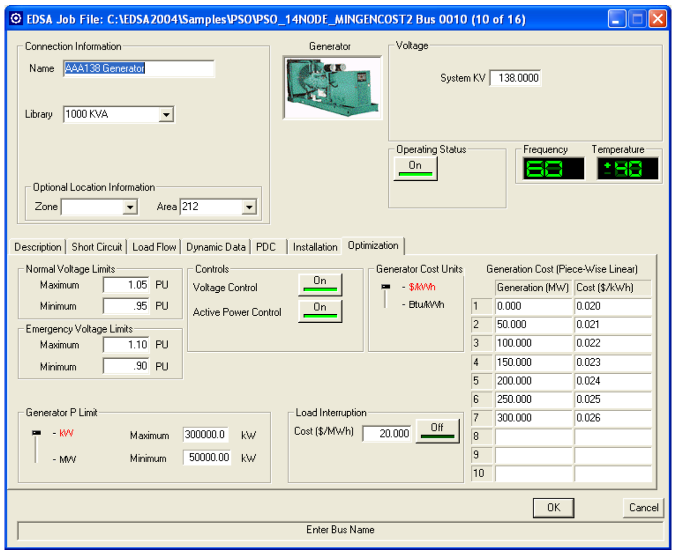
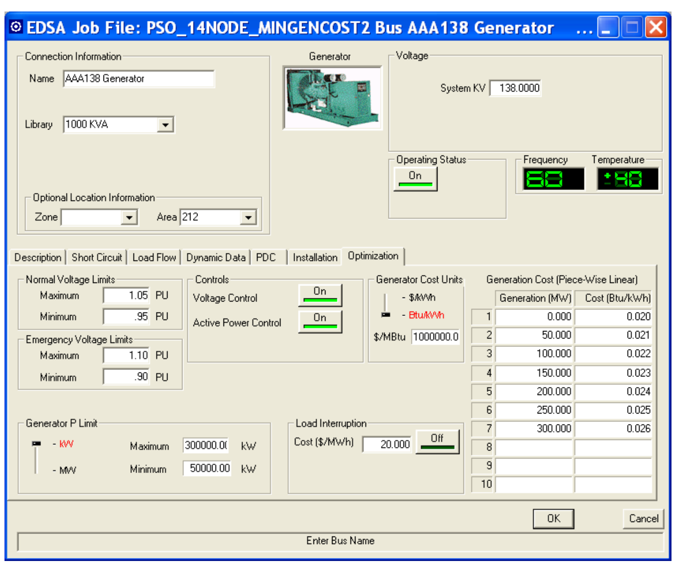


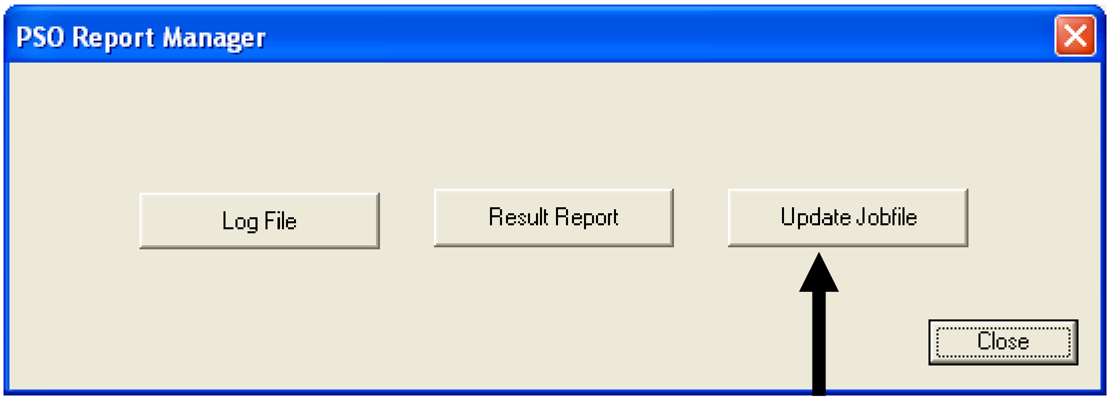
Figure 7: Piece-Wise Generation Cost for bus "AAA138 Generator" used in V&V of the "Minimization of Generation Cost"

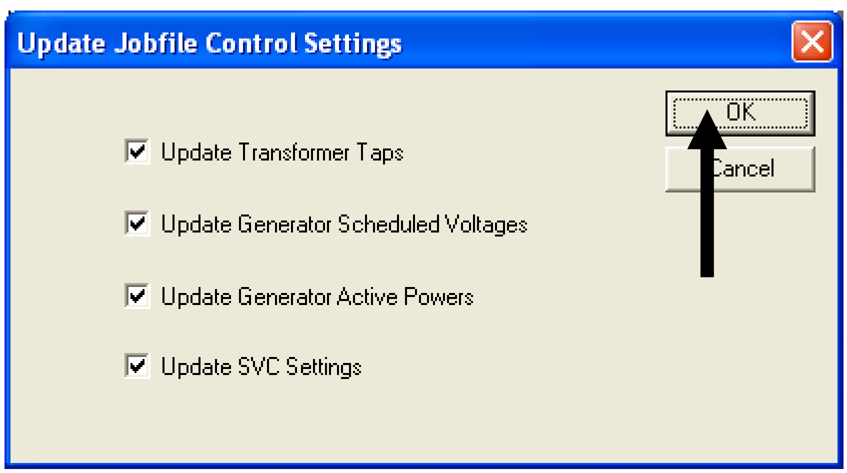
As seen in the above dialog, the user can specify the generation cost coefficient in either $/kWh or alternatively, provide cost in $/million Btu as shown below:



To complete the V&V, perform the following steps:

- Run optimization program, the results include bus voltages before and after optimized control settings
- Set the controls (generator scheduled voltages and active powers, and the transformer taps) according to the result obtained by the Optimization program as follows:





- After updating the control settings, run advanced power flow program for pso_14node_MinGenCost2. The bus voltage result should be the same as the result obtained by PSO program.

- The following table gives a summary comparison showing excellent match

	Voltage in % by PSO		Voltage in % by ADVPF		Difference in %	
Bus NAme	**Before**	**after**	**Before**	**After**	**Before**	**After**
JJJ138S Utility	104.0	105.0	104.0	105.0	0	0
AAA138 Generator	102.0	105.0	102.0	105.0	0	0
DDD138 Generator	101.3	99.9	101.3	100.0	0	0.1
DDD69 Generator	100.0	105.0	100.0	105.0	0	0

	Voltage in % by PSO		Voltage in % by ADVPF		Difference in %	
FFF138 Generator	102.0	101.4	102.0	101.4	0	0
AAA69 Busbar	100.7	103.2	100.8	103.2	0.1	0
BBB138 Load	97.5	95.0	97.5	95.0	0	0
CCC138 Load	97.3	95.1	97.3	95.2	0	0.1
EEE69 Load	92.6	98.1	92.6	98.0	0	0.1
FFF69 Busbar	99.8	104.4	99.8	104.3	0	0.1
GGG138 Load	98.2	96.9	98.2	96.9	0	0
HHH138 Load	98.8	96.8	98.8	96.8	0	0
JJJ138 Busbar	104.0	105.0	104.0	105.0	0	0
JJJ138L Load	104.0	105.0	104.0	105.0	0	0
JJJ69 Busbar	99.9	101.0	99.9	101.1	0	0.1
ZZZ69 Load	93.0	95.2	93.0	95.2	0	0

Note: The bus voltages achieved in optimizations are all within defined limits.

Optimization Result for "Minimization of Generation Cost" is summarized below:

```
                    EDSA Power System Optimization
                    ==============================

Project No. : 12345-1                          Page     : 1
Project Name: PSO Min Gen Cost                 Date     :
Title       : a 14 bus system                  Time     :
Drawing No. : 12345-2                          Company  : Edsa
Revision No.: 12345-3                          Engineer : Edsa
Jobfile Name: pso_14node_mingencost2           Check by :
Scenario    : 1 -                              Date     :

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's
Faulted Power Systems


            Optimization Objective: Minimization of Generation Costs
                          Optimization is SUCCESSFUL.

                       Economical Impact of Optimization
                       =================================

Total System Losses Before Optimization    =  13009.88 Kilo Watts
Total System Losses After Optimization     =  38539.25 Kilo Watts
System Loss Reduction                      = -25529.36 Kilo Watts

Total Generation cost before optimization =  35996.49 dollars
Total Generation cost after  optimization =  25097.91 dollars
Saving in generation cost                 =  10898.59 dollars

                               Bus Voltage Change
                               ==================

        Bus Name              System kV  Before(%)  After(%)   Vmin(%)   Vmax(%)
------------------------     ---------  ---------  --------  ---------  -------
JJJ138S Utility                138.000      104.0     105.0       95.0    105.0
AAA138 Generator               138.000      102.0     105.0       95.0    105.0
DDD138 Generator               138.000      101.3      99.9       95.0    105.0
DDD69 Generator                 69.000      100.0     105.0       95.0    105.0
FFF138 Generator               138.000      102.0     101.4       95.0    105.0
AAA69 Busbar                    69.000      100.7     103.2       95.0    105.0
BBB138 Load                    138.000       97.5      95.0       95.0    105.0
CCC138 Load                    138.000       97.3      95.1       95.0    105.0
EEE69 Load                      69.000       92.6*     98.1       95.0    105.0
FFF69 Busbar                    69.000       99.8     104.4       95.0    105.0
```

GGG138 Load	138.000	98.2	96.9	95.0	105.0
HHH138 Load	138.000	98.8	96.8	95.0	105.0
JJJ138 Busbar	138.000	104.0	105.0	95.0	105.0
JJJ138L Load	138.000	104.0	105.0	95.0	105.0
JJJ69 Busbar	69.000	99.9	101.0	95.0	105.0
ZZZ69 Load	**69.000**	**93.0***	**95.2**	**95.0**	**105.0**

Optimized Generator Active Power

Bus Name	Before(MW)	After(MW)	Generation Cost ($/MW)
JJJ138S Utility	63.591	236.17	29.170
AAA138 Generator	200.00	284.87	25.697
DDD138 Generator	200.00	50.001	100.00
FFF138 Generator	200.00	117.77	50.000

Optimized Generator/SVC Scheduled Voltage

Bus Name	System KV	Before(%)	After(%)
JJJ138S Utility	138.000	104.0	105.0
AAA138 Generator	138.000	102.0	105.0
DDD69 Generator	69.000	100.0	105.0
FFF138 Generator	138.000	102.0	101.4

Optimized Transformer Tap Setting

From Bus Name	To Bus Name	Before(p.u.)	After(p.u.)
FFF69 Busbar	FFF138 Generator	0.98600	1.0325
JJJ69 Busbar	JJJ138 Busbar	0.97200	0.96766

Bus voltages using advanced power flow program before optimization:

EDSA Advanced Power Flow Program

```
Project No. : 12345-1                        Page     : 1
Project Name: PSO Testing                    Date     :
Title       : a 14 bus system                Time     : 02
Drawing No. : 12345-2                        Company  : Edsa
Revision No.: 12345-3                        Engineer : Edsa
Jobfile Name: pso_14node_mingencost2         Check by :
Scenario    : 1 -                            Date     :
```

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's Faulted Power Systems

Bus Voltage Results

Bus Name	Type		V (PU)	DROP (%)	ANG (DEG)	P (PU)	Q (PU)	PF (%)
JJJ138S Utility	Swing		1.0400	-4.00	0.0	0.6359	1.1206	49.36
AAA138 Generator	Gen	*	1.0200	-2.00	6.6	1.0000	-0.1179	99.31
DDD138 Generator	Gen	*	1.0126	-1.26	9.8	1.0000	0.0584	99.83
DDD69 Generator	Gen	*	1.0000	0.00	8.8	0.0000	0.0317	0.00
FFF138 Generator	Gen	*	1.0200	-2.00	8.5	1.0000	0.1779	98.45
AAA69 Busbar	None		1.0075	-0.75	5.2	0.0000	0.0000	
BBB138 Load	P_Load		0.9746	2.54	4.1	-0.5000	-0.0600	99.29

CCC138 Load	P_Load		0.9733	2.67	5.7	-0.5000	-0.2500	89.44
EEE69 Load	P_Load		0.9264	7.36	6.2	-0.2500	-0.1142	90.96
FFF69 Busbar	None	*	0.9979	0.21	7.7	0.0000	0.0000	
GGG138 Load	P_Load		0.9823	1.77	3.1	-0.5000	-0.2500	89.44
HHH138 Load	P_Load		0.9875	1.25	0.1	-0.5000	-0.0550	99.40
JJJ138 Busbar	None		1.0400	-4.00	0.0	0.0000	0.0000	
JJJ138L Load	P_Load		1.0400	-4.00	0.0	-1.0000	-0.5000	89.44
JJJ69 Busbar	None	*	0.9990	0.10	-0.4	0.0000	0.0000	
ZZZ69 Load	P_Load		0.9298	7.02	0.3	-0.2500	-0.1135	91.05

** : Voltage Controlled Buses*

Bus voltages using advanced power flow program after optimization:

```
                  EDSA Advanced Power Flow Program
                  =================================

Project No. : 12345-1                        Page     : 1
Project Name: PSO Testing                    Date     :
Title       : a 14 bus system                Time     :
Drawing No. : 12345-2                        Company  : Edsa
Revision No.: 12345-3                        Engineer : Edsa
Jobfile Name: pso_14node_mingencost2         Check by :
Scenario    : 1 -                            Date     :

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's
Faulted Power Systems
```

Bus Voltage Results

Bus Name	Type	V (PU)	DROP (%)	ANG (DEG)	P (PU)	Q (PU)	PF (%)
JJJ138S Utility	Swing	1.0500	-5.00	0.0	2.3695	0.6884	96.03
AAA138 Generator	Gen	1.0500	-5.00	1.5	1.8501	0.2041	99.40
DDD138 Generator	Gen	1.0000	0.00	-25.6	-0.5000	0.0709	99.01
DDD69 Generator	Gen	1.0500	-5.00	-26.3	0.0000	0.6193	0.00
FFF138 Generator	Gen	1.0140	-1.40	-22.8	0.1779	0.4951	33.81
AAA69 Busbar	None	1.0323	-3.23	0.5	0.0000	0.0000	
BBB138 Load	P_Load	0.9504	4.96	-15.9	-0.5000	-0.0693	99.05
CCC138 Load	P_Load	0.9517	4.83	-22.2	-0.5000	-0.2500	89.44
EEE69 Load	P_Load	0.9804	1.96	-27.1	-0.2500	-0.1039	92.34
FFF69 Busbar	None	1.0434	-4.34	-23.9	0.0000	0.0000	
GGG138 Load	P_Load	0.9693	3.07	-20.4	-0.5000	-0.2500	89.44
HHH138 Load	P_Load	0.9677	3.23	-15.2	-0.5000	-0.0627	99.22
JJJ138 Busbar	None	1.0500	-5.00	-0.0	0.0000	0.0000	
JJJ138L Load	P_Load	1.0500	-5.00	-0.0	-1.0000	-0.5000	89.44
JJJ69 Busbar	None	1.0106	-1.06	-0.7	0.0000	0.0000	
ZZZ69 Load	P_Load	0.9521	4.79	-2.1	-0.2500	-0.1094	91.62

Conclusions

a. The voltages at buses “EEE69 Load” and “ZZZ69 Load” were low and out of the normal voltage limits before optimization and were corrected after optimization.

b. The optimal scheduled generator voltages and active powers can easily be reflected in the jobfile using the “Update” facility. The bus voltage result obtained by the Advanced

Powerflow (after the optimal settings found by PSO were reflected in the jobfile) agrees very well with the result obtained by PSO

c. PSO can efficiently be used to perform secure economic dispatch

18 How to Perform Minimization of Load Shedding Analysis

The jobfile used in this sample case is named "**`PSO-Min-Load-Shedding`**" which is in the DesignBase\Samples\PSO directory. The one line diagram for this network is shown below:

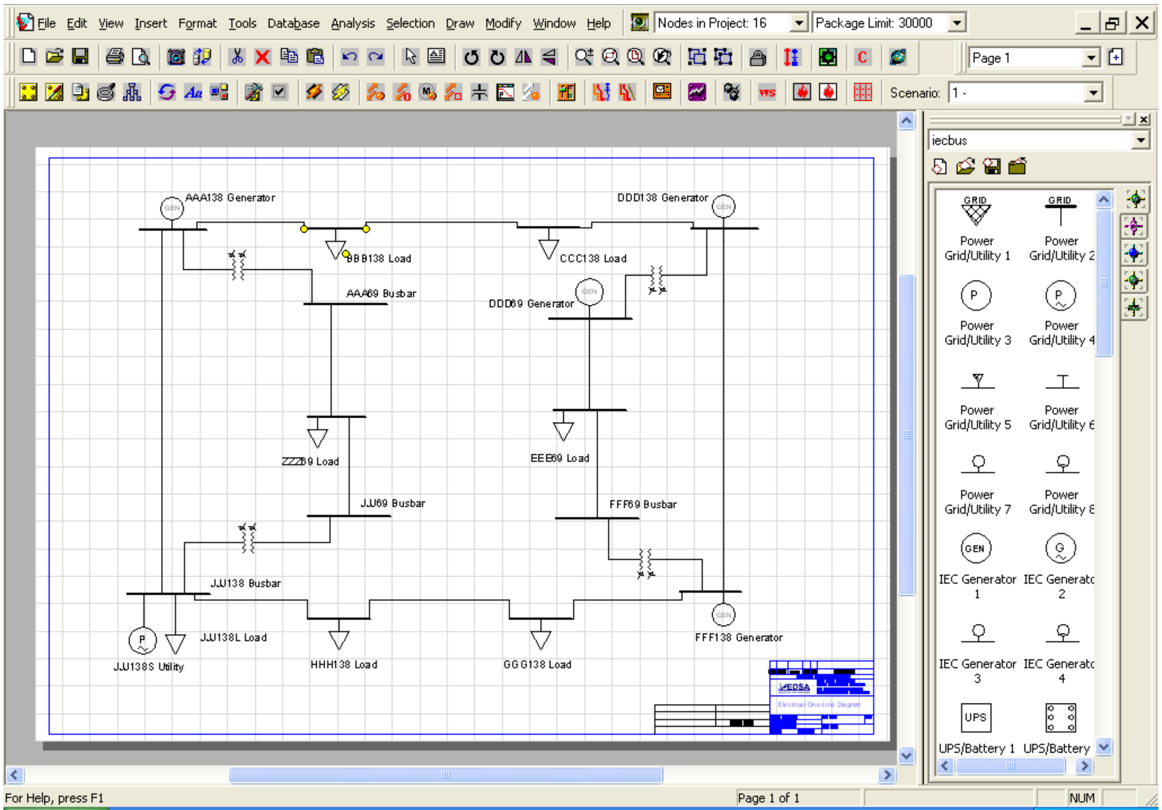


Figure 8: Single Line Diagram of the Sample Jobfile used in V&V of the "Minimization of Load Shedding"

The optimization control setting for this jobfile is shown below:

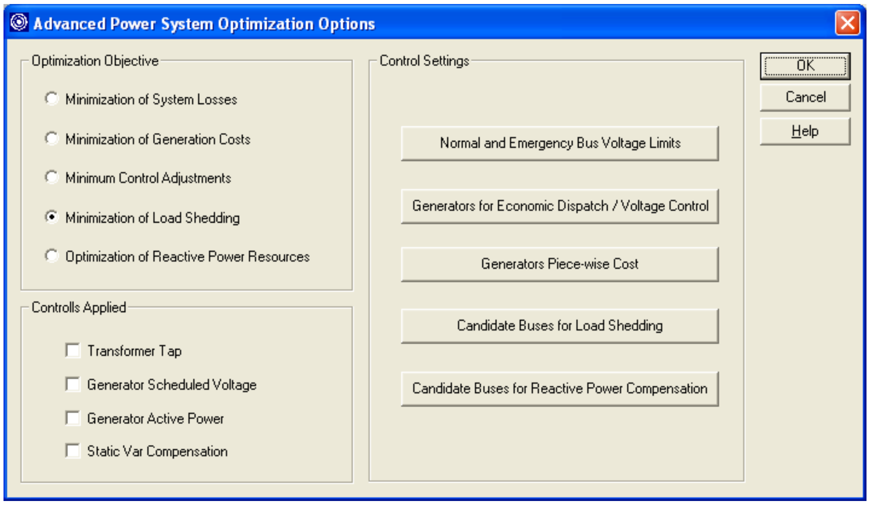
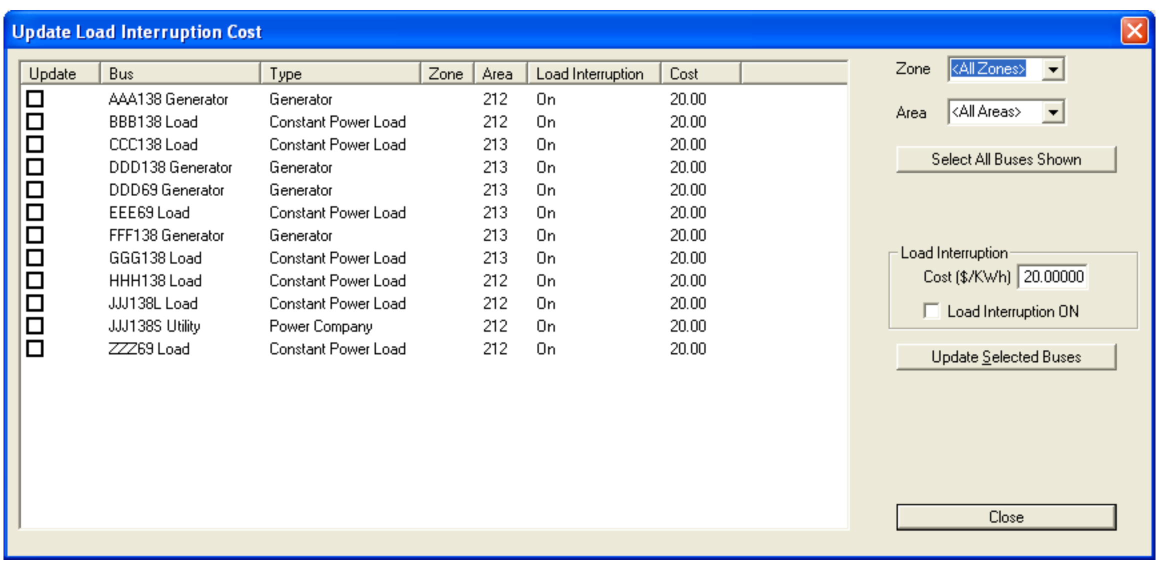


Figure 9: Control Settings used in V&V of the "Minimization of Load Shedding"

We have intentionally disabled all the controls to see how much load shedding is required to alleviate the low voltages in the sample jobfile. It is important that the user assigns appropriate load interruption costs to each of the system loads. If the load interruption cost is not of main concern, then, the user can assign high interruption cost to the critical loads and lower cost to the non-essential loads.

The following load buses were selected as candidate buses for load shedding:



Update	Bus	Type	Zone	Area	Load Interruption	Cost
☐	AAA138 Generator	Generator		212	On	20.00
☐	BBB138 Load	Constant Power Load		212	On	20.00
☐	CCC138 Load	Constant Power Load		213	On	20.00
☐	DDD138 Generator	Generator		213	On	20.00
☐	DDD69 Generator	Generator		213	On	20.00
☐	EEE69 Load	Constant Power Load		213	On	20.00
☐	FFF138 Generator	Generator		213	On	20.00
☐	GGG138 Load	Constant Power Load		213	On	20.00
☐	HHH138 Load	Constant Power Load		212	On	20.00
☐	JJJ138L Load	Constant Power Load		212	On	20.00
☐	JJJ138S Utility	Power Company		212	On	20.00
☐	ZZZ69 Load	Constant Power Load		212	On	20.00

Figure 10: Candidate Buses for the Load Shedding used in V&V of the "Minimization of Load Shedding"

To complete the V&V, perform the following steps:

- Run optimization program, the results include bus voltages before and after optimized control settings
- Run advanced power flow program, the calculated bus voltages should match the results obtained by optimization program

- Shed the same amount of loads indicated by the result of PSO and then re-run advanced power flow program. The bus voltage results should be the same as the results obtained by optimization program.
- The following table gives a summary comparison showing a good match

	Voltage in % by PSO		Voltage in % by ADVPF		Difference in %	
Bus NAme	**Before**	**after**	**Before**	**After**	**Before**	**After**
JJJ138S Utility	104.0	104.0	104.0	104.0	0	0
AAA138 Generator	102.0	102.0	102.0	102.0	0	0
DDD138 Generator	101.3	101.3	101.3	101.3	0	0
DDD69 Generator	100.0	100.0	100.0	100.0	0	0
FFF138 Generator	102.0	102.0	102.0	102.0	0	0
AAA69 Busbar	100.7	101.1	100.8	101.1	0.1	0
BBB138 Load	97.5	97.5	97.5	97.5	0	0
CCC138 Load	97.3	97.3	97.3	97.3	0	0
EEE69 Load	**92.6**	**95.0**	**92.6**	**95.1**	**0**	**0.1**
FFF69 Busbar	**99.8**	**100.0**	**99.8**	**100.1**	**0**	**0.1**
GGG138 Load	98.2	98.1	98.2	98.1	0	0
HHH138 Load	98.8	98.6	98.8	98.6	0	0
JJJ138 Busbar	104.0	104.0	104.0	104.0	0	0
JJJ138L Load	104.0	104.0	104.0	104.0	0	0
JJJ69 Busbar	**99.9**	**100.0**	**99.9**	**100.1**	**0**	**0.1**
ZZZ69 Load	**93.0**	**95.0**	**93.0**	**95.0**	**0**	**0**

Optimization Result for "Minimization of Load Shedding" is summarized below:

```
                    EDSA Power System Optimization
                    ==============================

Project No. : 12345-1                         Page     : 1
Project Name: PSO Min Load Shedding           Date     :
Title       : a 14 bus system                 Time     :
Drawing No. : 12345-2                         Company  : Edsa
Revision No.: 12345-3                         Engineer : Edsa
Jobfile Name: pso-min-load-shedding           Check by :
Scenario    : 1 -                             Date     :

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's
Faulted Power Systems


             Optimization Objective: Minimization of Load Shedding
                          Optimization is SUCCESSFUL.


                       Economical Impact of Optimization
                       =================================

Total System Losses Before Optimization    =  13009.88 Kilo Watts
Total System Losses After Optimization     =  13527.97 Kilo Watts
System Loss Reduction                      =   -518.09 Kilo Watts

                               Bus Voltage Change
                               ==================

        Bus Name          System kV  Before(%)  After(%)    Vmin(%)   Vmax(%)
------------------------  ---------  ---------  --------  ---------  -------
JJJ138S Utility             138.000      104.0     104.0       95.0    105.0
AAA138 Generator            138.000      102.0     102.0       95.0    105.0
DDD138 Generator            138.000      101.3     101.3       95.0    105.0
DDD69 Generator              69.000      100.0     100.0       95.0    105.0
FFF138 Generator            138.000      102.0     102.0       95.0    105.0
AAA69 Busbar                 69.000      100.7     101.1       95.0    105.0
```

BBB138 Load	138.000	97.5	97.5	95.0	105.0
CCC138 Load	138.000	97.3	97.3	95.0	105.0
EEE69 Load	**69.000**	**92.6***	**95.0**	**95.0**	**105.0**
FFF69 Busbar	**69.000**	**99.8***	**100.0**	**100.0**	**100.0**
GGG138 Load	138.000	98.2	98.1	95.0	105.0
HHH138 Load	138.000	98.8	98.6	95.0	105.0
JJJ138 Busbar	138.000	104.0	104.0	95.0	105.0
JJJ138L Load	138.000	104.0	104.0	95.0	105.0
JJJ69 Busbar	**69.000**	**99.9***	**100.0**	**100.0**	**100.0**
ZZZ69 Load	**69.000**	**93.0***	**95.0**	**95.0**	**105.0**

Optimized Generator Active Power

Bus Name	Before(MW)	After(MW)	Generation Cost ($/MW)
JJJ138S Utility	63.591	45.836	0.0000

Optimized Generator/SVC Scheduled Voltage

Bus Name	System KV	Before(%)	After(%)
JJJ138S Utility	138.000	104.0	104.0
AAA138 Generator	138.000	102.0	102.0
DDD69 Generator	69.000	100.0	100.0
FFF138 Generator	138.000	102.0	102.0

Optimized Transformer Tap Setting

From Bus Name	To Bus Name	Before(p.u.)	After(p.u.)
FFF69 Busbar	FFF138 Generator	0.98600	0.98503
JJJ69 Busbar	JJJ138 Busbar	0.97200	0.97157

Report of Load Shedding

Bus Name	Initial Load(KVA)	PowerFactor(%)	Percent Load Shed	Interruption Cost($)
EEE69 Load	32015.6	78.09	21.57	20.
FFF138 Generator	111803.4	89.44	7.96	20.
ZZZ69 Load	32015.6	78.09	17.28	20.

Total Cost of Load Interruption($)= 353.4

Bus voltages using Advanced Powerflow program before load shedding

EDSA Advanced Power Flow Program

```
Project No. : 12345-1                        Page     : 1
Project Name: PSO Min Load Shedding          Date     :
Title       : a 14 bus system                Time     :
Drawing No. : 12345-2                        Company  : Edsa
Revision No.: 12345-3                        Engineer : Edsa
Jobfile Name: pso-min-load-shedding          Check by :
Scenario    : 1 -                            Date     :
```

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's Faulted Power Systems

Bus Voltage Results
===================

Bus Name	Type		V (PU)	DROP (%)	ANG (DEG)	P (PU)	Q (PU)	PF (%)
JJJ138S Utility	Swing		1.0400	-4.00	0.0	0.6359	1.1206	49.36
AAA138 Generator	Gen	*	1.0200	-2.00	6.6	1.0000	-0.1179	99.31
DDD138 Generator	Gen	*	1.0126	-1.26	9.8	1.0000	0.0584	99.83
DDD69 Generator	Gen	*	1.0000	0.00	8.8	0.0000	0.0317	0.00
FFF138 Generator	Gen	*	1.0200	-2.00	8.5	1.0000	0.1779	98.45
AAA69 Busbar	None		1.0075	-0.75	5.2	0.0000	0.0000	
BBB138 Load	P_Load		0.9746	2.54	4.1	-0.5000	-0.0600	99.29
CCC138 Load	P_Load		0.9733	2.67	5.7	-0.5000	-0.2500	89.44
EEE69 Load	P_Load		0.9264	7.36	6.2	-0.2500	-0.1142	90.96
FFF69 Busbar	None	*	0.9979	0.21	7.7	0.0000	0.0000	
GGG138 Load	P_Load		0.9823	1.77	3.1	-0.5000	-0.2500	89.44
HHH138 Load	P_Load		0.9875	1.25	0.1	-0.5000	-0.0550	99.40
JJJ138 Busbar	None		1.0400	-4.00	0.0	0.0000	0.0000	
JJJ138L Load	P_Load		1.0400	-4.00	0.0	-1.0000	-0.5000	89.44
JJJ69 Busbar	None	*	0.9990	0.10	-0.4	0.0000	0.0000	
ZZZ69 Load	P_Load		0.9298	7.02	0.3	-0.2500	-0.1135	91.05

** : Voltage Controlled Buses*

Bus voltages using Advanced Powerflow program after load shedding

EDSA Advanced Power Flow Program
================================

Project No.	: 12345-1	Page	: 1
Project Name	: PSO Min Load Shedding	Date	:
Title	: a 14 bus system	Time	:
Drawing No.	: 12345-2	Company	: Edsa
Revision No.	: 12345-3	Engineer	: Edsa
Jobfile Name	: pso-min-load-shedding	Check by	:
Scenario	: 1 -	Date	:

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's Faulted Power Systems

Bus Voltage Results
===================

Bus Name	Type		V (PU)	DROP (%)	ANG (DEG)	P (PU)	Q (PU)	PF (%)
JJJ138S Utility	Swing		1.0400	-4.00	0.0	0.4647	1.1674	36.99
AAA138 Generator	Gen	*	1.0200	-2.00	7.3	1.0000	-0.1446	98.97
DDD138 Generator	Gen	*	1.0128	-1.28	11.8	1.0000	0.0582	99.83
DDD69 Generator	Gen	*	1.0000	0.00	11.0	0.0000	-0.0004	0.00
FFF138 Generator	Gen	*	1.0200	-2.00	10.7	1.0796	0.1376	99.20
AAA69 Busbar	None		1.0108	-1.08	6.0	0.0000	0.0000	
BBB138 Load	P_Load		0.9745	2.55	5.4	-0.5000	-0.0601	99.29
CCC138 Load	P_Load		0.9730	2.70	7.3	-0.5000	-0.2500	89.44
EEE69 Load	P_Load		0.9505	4.95	8.7	-0.1961	-0.0665	94.70
FFF69 Busbar	None	*	1.0011	-0.11	10.1	0.0000	0.0000	
GGG138 Load	P_Load		0.9807	1.93	4.7	-0.5000	-0.2500	89.44
HHH138 Load	P_Load		0.9860	1.40	1.2	-0.5000	-0.0556	99.39
JJJ138 Busbar	None		1.0400	-4.00	0.0	0.0000	0.0000	
JJJ138L Load	P_Load		1.0400	-4.00	0.0	-1.0000	-0.5000	89.44

```
JJJ69 Busbar             None  *   1.0009  -0.09  -0.2    0.0000    0.0000
ZZZ69 Load               P_Load    0.9503   4.97   1.0   -0.2068   -0.0751   93.99

                    * : Voltage Controlled Buses
```

Conclusions

a. The voltages at buses “EEE69 Load” and “ZZZ69 Load” were low and out of the normal voltage limits before optimization and were corrected after optimization.

b. The bus voltage result obtained by the Advanced Powerflow (after the minimum load shedding scheme found by PSO were reflected in the jobfile) agrees very well with the result obtained by PSO

c. PSO can efficiently be used to design load shedding schemes in order to maintain power system security

19 How to Perform Optimization of Reactive Power Resources

The jobfile used for this analysis option is named "**`PSO-Reactive-Optimization`**" which is in the DesignBase\Samples\PSO directory. The one line diagram of the system is shown below:

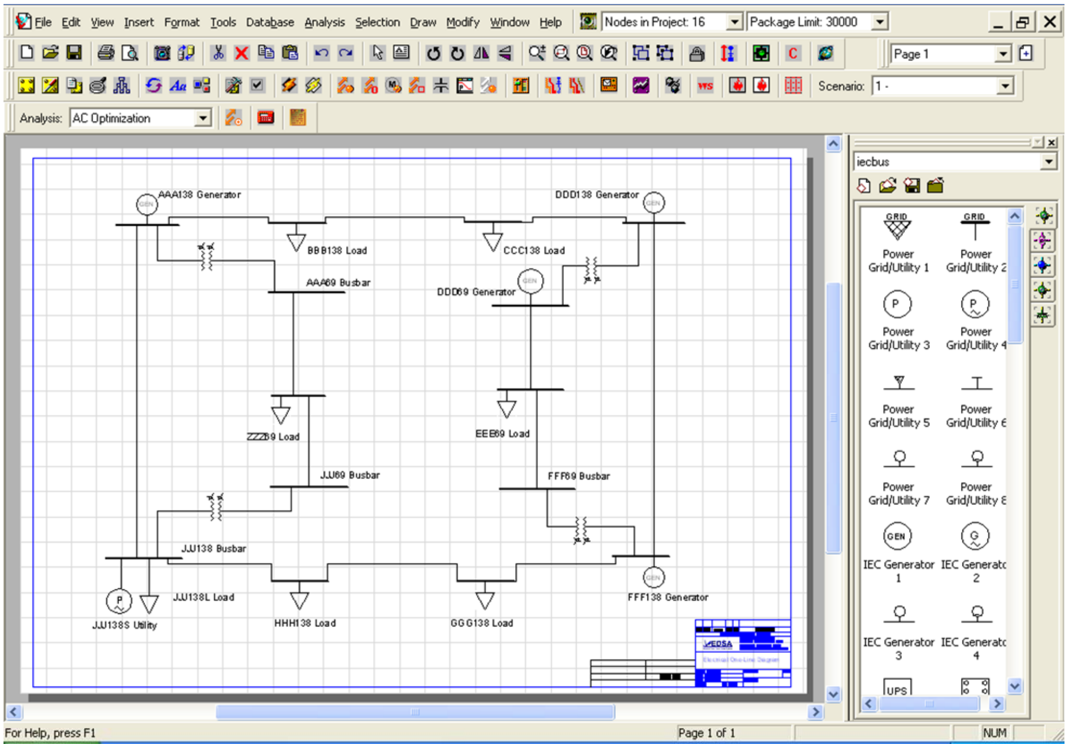


Figure 11: Single Line Diagram of the Sample Jobfile used in V&V of the "Optimization of Reactive Power Resources"

The optimization control setting for this jobfile is shown below:

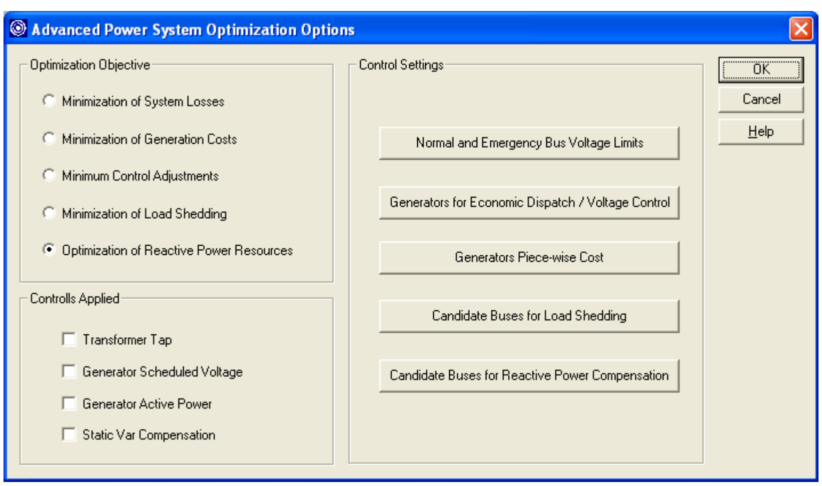


Figure 12: Control Settings used in V&V of the "Optimization of Reactive Power Resources"

Again, we have intentionally disabled all the control to see how much and where reactive power resources (i.e. capacitors and/or inductors) are required to alleviate the low/high voltages in the sample jobfile.

In this example, all the system buses were selected as candidate buses for reactive power resources having the same cost as shown below:

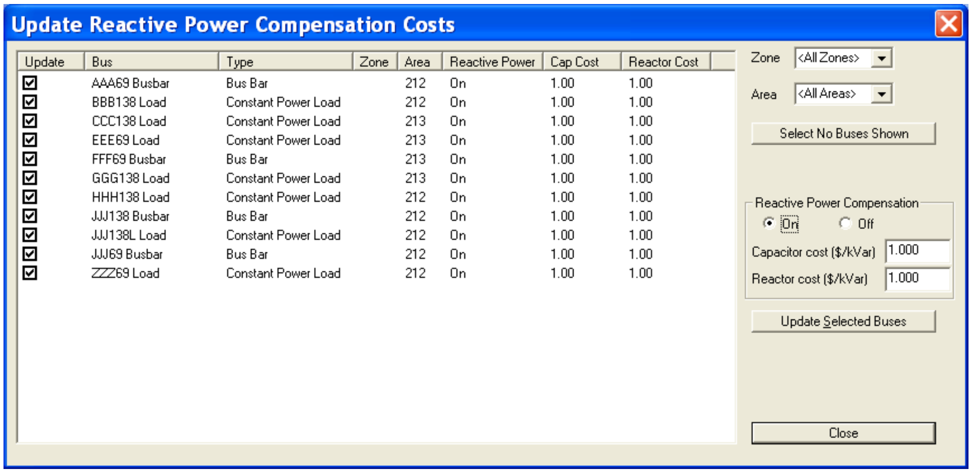


Figure 13: Candidate Buses for reactive power resources used in V&V of the "Optimization of Reactive Power Resources"

To complete the V&V, perform the following steps:

- Run optimization program, the results include bus voltages before and after optimized control settings
- Run advanced power flow program, the calculated bus voltages should match the results obtained by optimization program
- Set the reactive powers indicated by PSO and then re-run advanced power flow program. The bus voltage results should be the same as the results obtained by optimization program
- The following table gives a summary comparison showing a good match

	Voltage in % by PSO		Voltage in % by ADVPF		Difference in %	
Bus NAme	**Before**	**after**	**Before**	**After**	**Before**	**After**
JJJ138S Utility	104.0	104.0	104.0	104.0	0	0
AAA138 Generator	102.0	102.0	102.0	102.0	0	0
DDD138 Generator	101.3	101.0	101.3	101.1	0	0.1
DDD69 Generator	100.0	100.0	100.0	100.0	0	0
FFF138 Generator	102.0	102.0	102.0	102.0	0	0
AAA69 Busbar	100.7	101.2	100.8	101.2	0.1	0
BBB138 Load	97.5	97.0	97.5	97.1	0	0.1
CCC138 Load	97.3	96.7	97.3	96.8	0	0.1
EEE69 Load	**92.7**	**95.0**	**92.7**	**95.0**	**0**	**0**
FFF69 Busbar	**99.8**	**100.0**	**99.8**	**100.3**	**0**	**0.3**
GGG138 Load	98.2	98.2	98.2	98.2	0	0
HHH138 Load	98.8	98.7	98.8	98.8	0	0.1
JJJ138 Busbar	104.0	104.0	104.0	104.0	0	0
JJJ138L Load	104.0	104.0	104.0	104.0	0	0
JJJ69 Busbar	**99.9**	**100.0**	**99.9**	**100.3**	**0**	**0.3**
ZZZ69 Load	**93.0**	**95.0**	**93.0**	**95.0**	**0**	**0**

Note: the bus voltages after optimization are all within defined limits.

Optimal result on Optimization of Reactive Power Resources

```
                    EDSA Power System Optimization
                    =======================================

Project No. : 12345-1                              Page     : 1
Project Name: PSO Testing                          Date     :
Title       : a 14 bus system                      Time     :
Drawing No. : 12345-2                              Company  : Edsa
Revision No.: 12345-3                              Engineer : Edsa
Jobfile Name: pso-reactive-optimization            Check by :
Scenario    : 1 -                                  Date     :

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's
Faulted Power Systems


        Optimization Objective: Optimization of Reactive Power Resources
                          Optimization is SUCCESSFUL.


                       Economical Impact of Optimization
                       =================================

Total System Losses Before Optimization    =  12979.39 Kilo Watts
Total System Losses After Optimization     =  12546.50 Kilo Watts
System Loss Reduction                      =    432.89 Kilo Watts


                               Bus Voltage Change
                               ==================

        Bus Name          System kV  Before(%)  After(%)   Vmin(%)   Vmax(%)
------------------------  ---------  ---------  --------  ---------  -------
JJJ138S Utility             138.000      104.0     104.0       95.0    105.0
AAA138 Generator            138.000      102.0     102.0       95.0    105.0
DDD138 Generator            138.000      101.3     101.0       95.0    105.0
DDD69 Generator              69.000      100.0     100.0       95.0    105.0
FFF138 Generator            138.000      102.0     102.0       95.0    105.0
AAA69 Busbar                 69.000      100.7     101.2       95.0    105.0
BBB138 Load                 138.000       97.5      97.0       95.0    105.0
CCC138 Load                 138.000       97.3      96.7       95.0    105.0
EEE69 Load                   69.000       92.7*     95.0       95.0    105.0
FFF69 Busbar                 69.000       99.8*    100.0      100.0    100.0
GGG138 Load                 138.000       98.2      98.2       95.0    105.0
HHH138 Load                 138.000       98.8      98.7       95.0    105.0
JJJ138 Busbar               138.000      104.0     104.0       95.0    105.0
JJJ138L Load                138.000      104.0     104.0       95.0    105.0
JJJ69 Busbar                 69.000       99.9*    100.0      100.0    100.0
ZZZ69 Load                   69.000       93.0*     95.0       95.0    105.0


                        Optimized Generator Active Power
                        ================================

            Bus Name       Before(MW)   After(MW)  Generation Cost ($/MW)
------------------------  ----------  ----------  ----------------------
JJJ138S Utility             62.979       62.545        0.0000
```

Optimized Generator/SVC Scheduled Voltage

Bus Name	System KV	Before(%)	After(%)
JJJ138S Utility	138.000	104.0	104.0
AAA138 Generator	138.000	102.0	102.0
DDD69 Generator	69.000	100.0	100.0
FFF138 Generator	138.000	102.0	102.0

Optimized Transformer Tap Setting

From Bus Name	To Bus Name	Before(p.u.)	After(p.u.)
FFF69 Busbar	FFF138 Generator	0.98600	0.98259
JJJ69 Busbar	JJJ138 Busbar	0.97200	0.96897

Optimally Allocated Reactive Power

Bus Name	kVAR	MVAR
CCC138 Load	-4699.7	-4.70
EEE69 Load	9243.1	9.24
ZZZ69 Load	7004.9	7.00

Bus voltages using advanced powerflow program before reactive power adjustment

EDSA Advanced Power Flow Program

```
Project No. : 12345-1                         Page      : 1
Project Name: PSO Testing                     Date      :
Title       : a 14 bus system                 Time      :
Drawing No. : 12345-2                         Company   : Edsa
Revision No.: 12345-3                         Engineer  : Edsa
Jobfile Name: pso-reactive-optimization       Check by  :
Scenario    : 1 -                             Date      :
```

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's Faulted Power Systems

Bus Voltage Results

Bus Name	Type	V (PU)	DROP (%)	ANG (DEG)	P (PU)	Q (PU)	PF (%)
JJJ138S Utility	Swing	1.0400	-4.00	0.0	0.6298	1.1209	48.98
AAA138 Generator	Gen *	1.0200	-2.00	6.6	1.0000	-0.1182	99.31
DDD138 Generator	Gen *	1.0127	-1.27	9.8	1.0000	0.0600	99.82
DDD69 Generator	Gen *	1.0000	0.00	8.8	0.0000	0.0311	0.00
FFF138 Generator	Gen *	1.0200	-2.00	8.5	1.0000	0.1766	98.48
AAA69 Busbar	None	1.0075	-0.75	5.2	0.0000	0.0000	
BBB138 Load	P_Load	0.9747	2.53	4.1	-0.5000	-0.0600	99.29
CCC138 Load	P_Load	0.9734	2.66	5.7	-0.5000	-0.2500	89.44
EEE69 Load	P_Load	0.9265	7.35	6.2	-0.2500	-0.1142	90.96
FFF69 Busbar	None *	0.9979	0.21	7.7	0.0000	0.0000	
GGG138 Load	P_Load	0.9823	1.77	3.1	-0.5000	-0.2500	89.44
HHH138 Load	P_Load	0.9875	1.25	0.2	-0.5000	-0.0550	99.40

JJJ138 Busbar	None	1.0400	-4.00	0.0	0.0000	0.0000	
JJJ138L Load	P_Load	1.0400	-4.00	0.0	-1.0000	-0.5000	89.44
JJJ69 Busbar	None *	0.9991	0.09	-0.4	0.0000	0.0000	
ZZZ69 Load	P_Load	0.9301	6.99	0.3	-0.2500	-0.1135	91.06

* : Voltage Controlled Buses

Bus voltages using advanced power flow program after reactive power adjustment

EDSA Advanced Power Flow Program
================================

Project No. : 12345-1
Project Name: PSO Testing
Title : a 14 bus system
Drawing No. : 12345-2
Revision No.: 12345-3
Jobfile Name: pso-reactive-optimization
Scenario : 1 -

Page : 1
Date :
Time :
Company : Edsa
Engineer : Edsa
Check by :
Date :

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's
Faulted Power Systems

Bus Voltage Results
===================

Bus Name	Type	V (PU)	DROP (%)	ANG (DEG)	P (PU)	Q (PU)	PF (%)
JJJ138S Utility	Swing	1.0400	-4.00	0.0	0.6256	1.0856	49.93
AAA138 Generator	Gen *	1.0200	-2.00	6.6	1.0000	-0.1346	99.11
DDD138 Generator	Gen *	1.0105	-1.05	9.9	1.0000	0.0600	99.82
DDD69 Generator	Gen *	1.0000	-0.00	8.9	0.0000	0.0000	0.00
FFF138 Generator	Gen *	1.0200	-2.00	8.6	1.0000	0.1466	98.94
AAA69 Busbar	None	1.0116	-1.16	5.2	0.0000	0.0000	
BBB138 Load	P_Load	0.9710	2.90	4.1	-0.5000	-0.0614	99.25
CCC138 Load	P_Load	0.9680	3.20	5.8	-0.5000	-0.2940	86.20
EEE69 Load	P_Load	0.9495	5.05	5.4	-0.2500	-0.0265	99.44
FFF69 Busbar	None *	1.0027	-0.27	7.8	0.0000	0.0000	
GGG138 Load	P_Load	0.9823	1.77	3.2	-0.5000	-0.2500	89.44
HHH138 Load	P_Load	0.9875	1.25	0.2	-0.5000	-0.0550	99.40
JJJ138 Busbar	None	1.0400	-4.00	0.0	0.0000	0.0000	
JJJ138L Load	P_Load	1.0400	-4.00	0.0	-1.0000	-0.5000	89.44
JJJ69 Busbar	None *	1.0031	-0.31	-0.4	0.0000	0.0000	
ZZZ69 Load	P_Load	0.9501	4.99	-0.3	-0.2500	-0.0465	98.31

* : Voltage Controlled Buses

Conclusions

a. The voltages at buses “EEE69 Load” and “ZZZ69 Load” were low and out of the normal voltage limits before optimization and were corrected after optimization.

b. The bus voltage result obtained by the Advanced Powerflow (after the reactive resources identified by PSO were included in the jobfile) agrees very well with the result obtained by PSO

c. PSO can efficiently be used to plan reactive power resources at minimum cost

20 How to Perform Minimum Control Adjustments

The jobfile used for this analysis option is named "Pso_14node_MinControls" which is in the DesignBase\Samples\PSO directory. The one line diagram of the system is shown below:

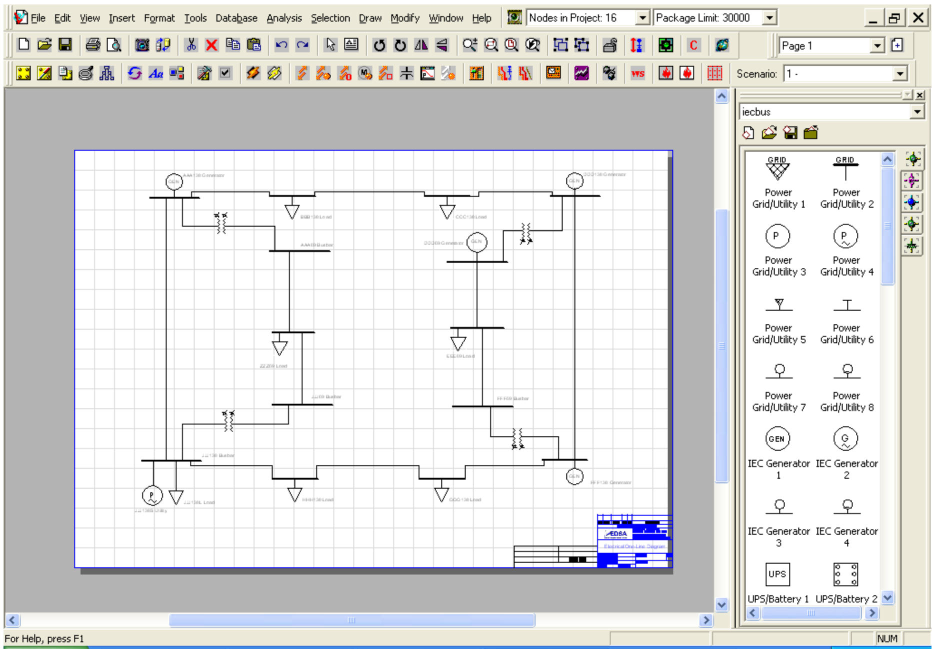


Figure 14: Single Line Diagram of the Sample Jobfile used in V&V of the "Minimum Control Adjustments"

In this analysis option all of the available controls, i.e., transformer taps, generators scheduled voltages, etc. are selected to see how many controls should be adjusted in order to satisfy the constraints (voltages are within prescribed limits, powerflow are within the transformers/cables loading capabilities, etc.). However, normally active power generation is not selected in this type of analysis.

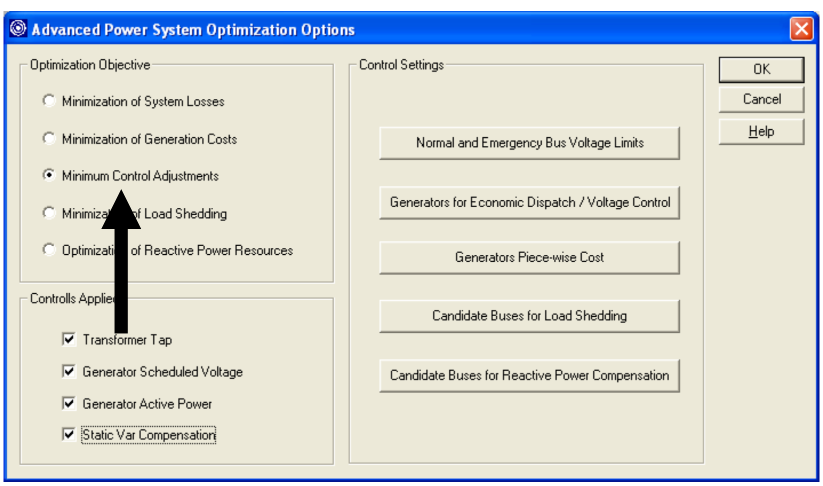
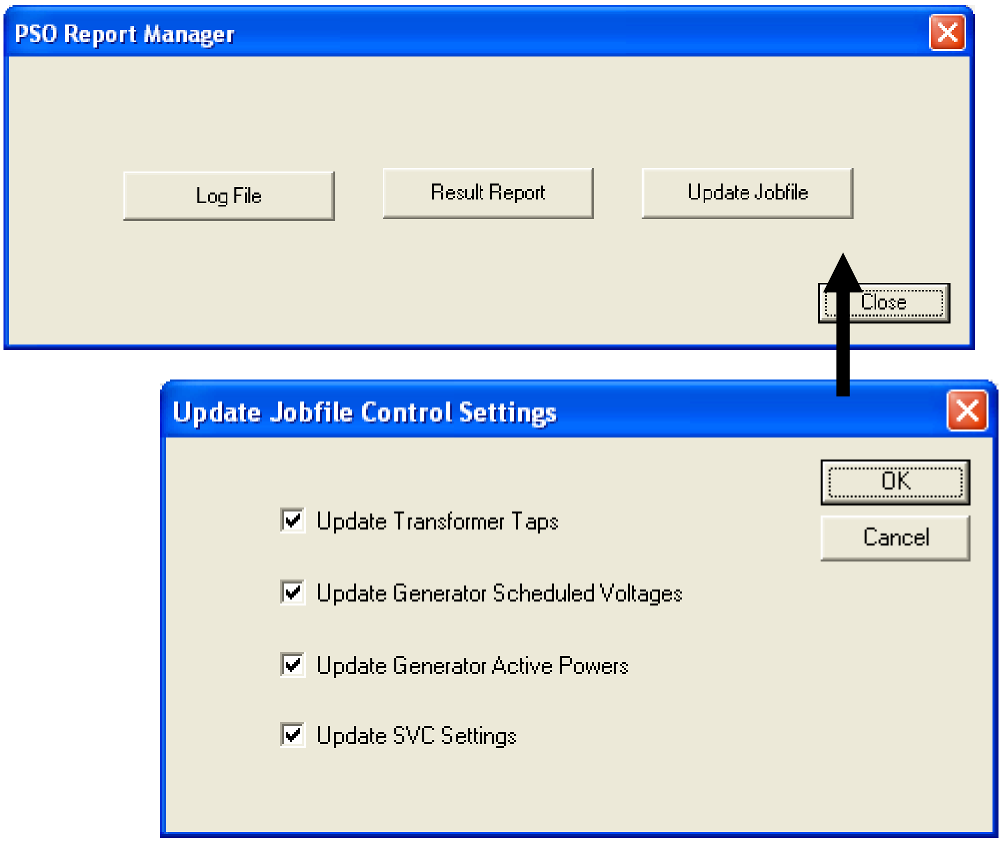


Figure 15: Control Settings used in V&V of the "Minimum Control Adjustments"

To complete this simulation the following steps are performed:

- Run optimization program, to obtain the results including bus voltages before and after optimized control settings.
- Set the controls (generator scheduled voltages, generators active powers, transformer taps and SVC reactive powers) according to the results obtained from PSO as follows:



- Run advanced power flow program, the calculated bus voltages should match the results obtained from PSO.
- The following table gives a summary comparison showing a good match

	Voltage in % by PSO		Voltage in % by ADVPF		Difference in %	
Bus NAme	**Before**	**after**	**Before**	**After**	**Before**	**After**
JJJ138S Utility	104.0	103.1	104.0	103.1	0	0
AAA138 Generator	102.0	104.0	102.0	104.0	0	0
DDD138 Generator	101.3	102.3	101.3	102.3	0	0
DDD69 Generator	100.0	103.7	100.0	103.7	0	0
FFF138 Generator	102.0	102.0	102.0	102.0	0	0
AAA69 Busbar	101.0	102.3	101.0	102.3	0	0
BBB138 Load	97.5	99.0	97.5	99.1	0	0.1
CCC138 Load	97.4	98.8	97.4	98.8	0	0
EEE69 Load	93.4	95.9	93.4	95.9	0	0
FFF69 Busbar	101.1	101.9	101.1	101.9	0	0
GGG138 Load	98.2	98.3	98.2	98.3	0	0
HHH138 Load	98.8	98.5	98.8	98.5	0	0
JJJ138 Busbar	104.0	103.1	104.0	103.1	0	0

JJJ138L Load	104.0	103.1	104.0	103.1	0	0
JJJ69 Busbar	102.5	102.4	102.5	102.4	0	0
ZZZ69 Load	94.6	95.5	94.6	95.5	0	0

Optimal result on Optimization of Reactive Power Resources

```
                    EDSA Power System Optimization
                    ==============================

Project No. : 12345-1                          Page     : 1
Project Name: PSO Testing                      Date     :
Title       : a 14 bus system                  Time     :
Drawing No. : 12345-2                          Company  : Edsa
Revision No.: 12345-3                          Engineer : Edsa
Jobfile Name: pso_14node_mincontrols           Check by :
Scenario    : 1 -                              Date     :

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's
Faulted Power Systems


             Optimization Objective: Minimum Control Adjustments
                         Optimization is SUCCESSFUL.

                       Economical Impact of Optimization
                       =================================

Total System Losses Before Optimization    =  13060.51 Kilo Watts
Total System Losses After Optimization     =   9146.54 Kilo Watts
System Loss Reduction                      =   3913.97 Kilo Watts

                               Bus Voltage Change
                               ==================

        Bus Name          System kV  Before(%)  After(%)   Vmin(%)   Vmax(%)
------------------------  ---------  ---------  --------  ---------  -------
JJJ138S Utility             138.000      104.0     103.1       95.0    105.0
AAA138 Generator            138.000      102.0     104.0       95.0    105.0
DDD138 Generator            138.000      101.3     102.3       95.0    105.0
DDD69 Generator              69.000      100.0     103.7       95.0    105.0
FFF138 Generator            138.000      102.0     102.0       95.0    105.0
AAA69 Busbar                 69.000      101.0     102.3       95.0    105.0
BBB138 Load                 138.000       97.5      99.0       95.0    105.0
CCC138 Load                 138.000       97.4      98.8       95.0    105.0
EEE69 Load                   69.000       93.4*     95.9       95.0    105.0
FFF69 Busbar                 69.000      101.1     101.9       95.0    105.0
GGG138 Load                 138.000       98.2      98.3       95.0    105.0
HHH138 Load                 138.000       98.8      98.5       95.0    105.0
JJJ138 Busbar               138.000      104.0     103.1       95.0    105.0
JJJ138L Load                138.000      104.0     103.1       95.0    105.0
JJJ69 Busbar                 69.000      102.5     102.4       95.0    105.0
ZZZ69 Load                   69.000       94.6*     95.5       95.0    105.0


                        Optimized Generator Active Power
                        ================================

        Bus Name          Before(MW)  After(MW)  Generation Cost ($/MW)
------------------------  ----------  ---------- ----------------------
JJJ138S Utility             63.061      149.53       100.00
AAA138 Generator            200.00      173.46       300.00
DDD138 Generator            200.00      125.97       100.00
FFF138 Generator            200.00      210.19       100.00


                   Optimized Generator/SVC Scheduled Voltage
```

==

Bus Name	System KV	Before(%)	After(%)
JJJ138S Utility	138.000	104.0	103.1
AAA138 Generator	138.000	102.0	104.0
DDD69 Generator	69.000	100.0	103.7
FFF138 Generator	138.000	102.0	102.0

Bus voltages using advanced power flow program before optimization

EDSA Advanced Power Flow Program
================================

```
Project No. : 12345-1                          Page     : 1
Project Name: PSO Testing                      Date     :
Title       : a 14 bus system                  Time     :
Drawing No. : 12345-2                          Company  : Edsa
Revision No.: 12345-3                          Engineer : Edsa
Jobfile Name: pso_14node_mincontrols           Check by :
Scenario    : 1 -                              Date     :
```

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's Faulted Power Systems

Bus Voltage Results
===================

Bus Name	Type	V (PU)	DROP (%)	ANG (DEG)	P (PU)	Q (PU)	PF (%)
JJJ138S Utility	Swing	1.0400	-4.00	0.0	0.6306	1.1456	48.22
AAA138 Generator	Gen	1.0200	-2.00	6.7	1.0000	-0.1446	98.97
DDD138 Generator	Gen	1.0130	-1.30	9.9	1.0000	0.0620	99.81
DDD69 Generator	Gen	1.0000	0.00	8.9	0.0000	0.0169	0.00
FFF138 Generator	Gen	1.0200	-2.00	8.5	1.0000	0.1881	98.28
AAA69 Busbar	None	1.0102	-1.02	5.4	0.0000	0.0000	
BBB138 Load	P_Load	0.9749	2.51	4.2	-0.5000	-0.0599	99.29
CCC138 Load	P_Load	0.9736	2.64	5.8	-0.5000	-0.2500	89.44
EEE69 Load	P_Load	0.9337	6.63	6.3	-0.2500	-0.1128	91.15
FFF69 Busbar	None	1.0106	-1.06	7.7	0.0000	0.0000	
GGG138 Load	P_Load	0.9823	1.77	3.2	-0.5000	-0.2500	89.44
HHH138 Load	P_Load	0.9875	1.25	0.2	-0.5000	-0.0550	99.40
JJJ138 Busbar	None	1.0400	-4.00	0.0	0.0000	0.0000	
JJJ138L Load	P_Load	1.0400	-4.00	0.0	-1.0000	-0.5000	89.44
JJJ69 Busbar	None	1.0251	-2.51	-0.5	0.0000	0.0000	
ZZZ69 Load	P_Load	0.9463	5.37	0.4	-0.2500	-0.1105	91.47

Bus voltages using advanced power flow program after optimization

```
                    EDSA Advanced Power Flow Program
                    ================================

Project No. : 12345-1                        Page     : 1
Project Name: PSO Testing                    Date     :
Title       : a 14 bus system                Time     :
Drawing No. : 12345-2                        Company  : Edsa
Revision No.: 12345-3                        Engineer : Edsa
Jobfile Name: pso_14node_mincontrols         Check by :
Scenario    : 1 -                            Date     :

A 14-bus network shown in Fig.E.3 in Paul M. Anderson's
Faulted Power Systems
```

Bus Voltage Results

Bus Name	Type	V (PU)	DROP (%)	ANG (DEG)	P (PU)	Q (PU)	PF (%)
JJJ138S Utility	Swing	1.0307	-3.07	0.0	1.4952	0.5940	92.94
AAA138 Generator	Gen	1.0401	-4.01	0.2	0.7346	0.1448	98.11
DDD138 Generator	Gen	1.0228	-2.28	-3.8	0.2598	0.0620	97.27
DDD69 Generator	Gen	1.0372	-3.72	-4.5	0.0000	0.3216	0.00
FFF138 Generator	Gen	1.0200	-2.00	-0.0	1.1019	0.0249	99.97
AAA69 Busbar	None	1.0234	-2.34	-0.7	0.0000	0.0000	
BBB138 Load	P_Load	0.9905	0.95	-5.8	-0.5000	-0.0538	99.43
CCC138 Load	P_Load	0.9877	1.23	-6.0	-0.5000	-0.2500	89.44
EEE69 Load	P_Load	0.9589	4.11	-4.8	-0.2500	-0.1080	91.79
FFF69 Busbar	None	1.0186	-1.86	-1.1	0.0000	0.0000	
GGG138 Load	P_Load	0.9829	1.71	-3.3	-0.5000	-0.2500	89.44
HHH138 Load	P_Load	0.9848	1.52	-4.0	-0.5000	-0.0560	99.38
JJJ138 Busbar	None	1.0307	-3.07	-0.0	0.0000	0.0000	
JJJ138L Load	P_Load	1.0307	-3.07	-0.0	-1.0000	-0.5000	89.44
JJJ69 Busbar	None	1.0238	-2.38	-0.8	0.0000	0.0000	
ZZZ69 Load	P_Load	0.9546	4.54	-2.8	-0.2500	-0.1089	91.68

Conclusions

a. The voltages at buses “EEE69 Load” and “ZZZ69 Load” were low and out of the normal voltage limits before optimization and were corrected after optimization found the minimum control adjustments.

b. The bus voltage result obtained by the Advanced Powerflow (after the minimum control adjustments found by PSO were incorporated in the sample network) agrees very well with the result obtained by PSO

c. PSO can efficiently be used to obtain minimum control settings adjustments required to maintain power system security

Salient features of the DesignBase power system optimization software were demonstrated throughout this document when applied to sample power system. It was shown repeatedly that PSO is accurate, fast and efficient software in identifying optimal operation conditions in power systems by optimizing resources to maintain power system security.