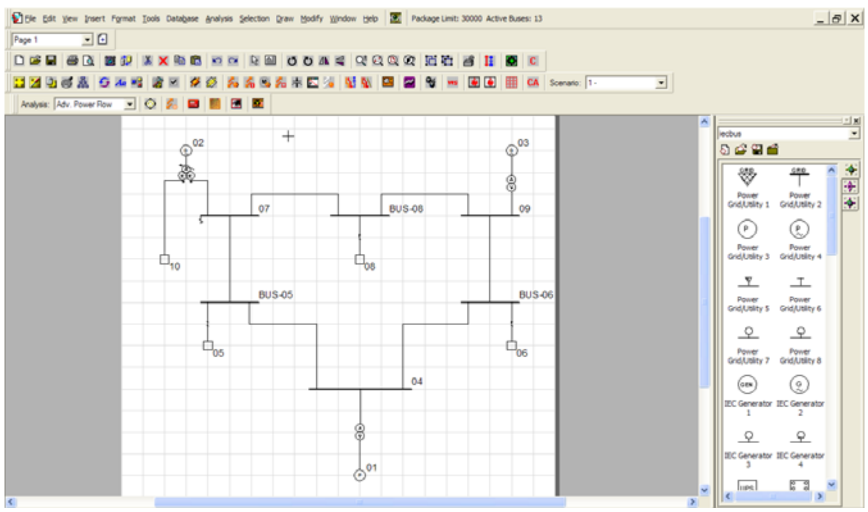
ADVANCED POWER FLOW



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

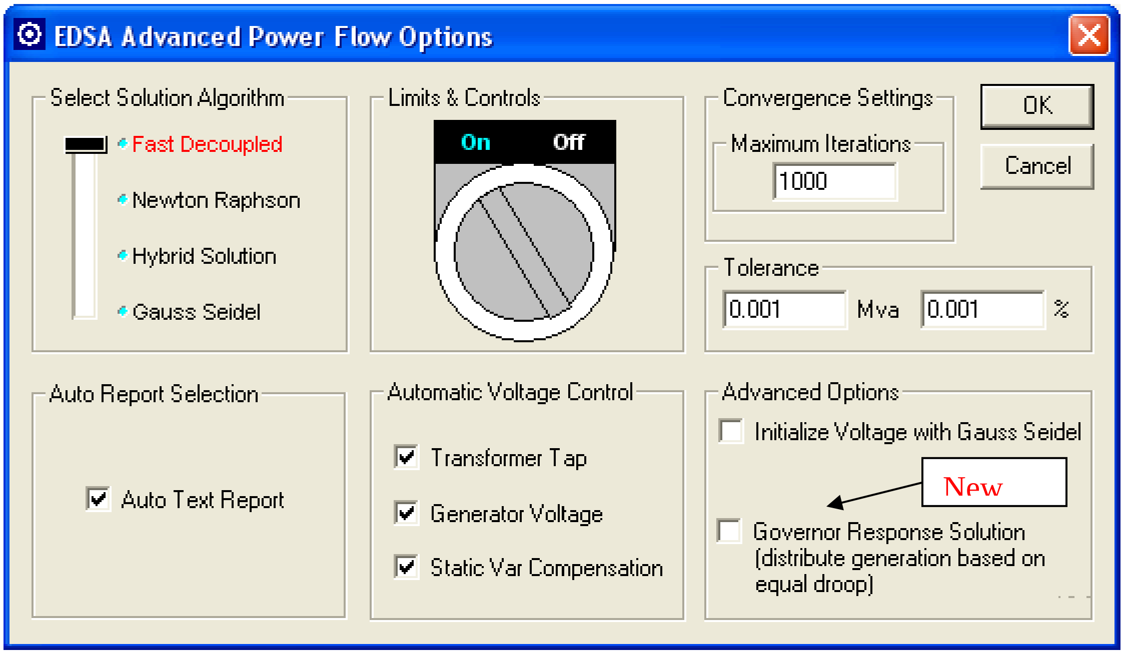
- Advanced Power Flow   Adv_Power_Flow.pdf

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

- 🗀 **Designbase\Samples\ADPF   =   Advanced Power Flow**

Test Files: 2wxfmrvc, 3wxfmrvc, areacont, genvc, svcvc, T14bus, T9bus, T14bus-DC, T9bus-DC

1. What is New in this Release



We have added "Governor Response Solution (distribute generation based on equal droop)" choice in the power flow options dialog box as shown in the above. By default this option is disabled (unchecked).

In power flow solution, the active power generation for each generator in the system is given (specified) by the user except for the swing (reference) bus. Selecting "Governor Response Solution" implies that the program should assume that all generators in the system have the same governor droop. This means that any load changes in the system will be distributed among generators in proportion to their KVA rating. The program first solves power flow (finds system voltages and the swing generation) without "Governor Response Solution". Then, the program redistributes the total generations (from all units and swing) to all units including swing in proportion to their KVA rating and solves power flow one more time. For example, if in a system there are five identical generators, when this option is selected, regardless of the user given generation assigned to each unit, the program distribute the total required generation among five equally.

2. Program Description and Capabilities

The EDSA Advanced Power Flow (EAPF) program is one of the most powerful, fast, and efficient power flow programs with excellent graphical user interface. EAPF supports advanced plotting, numerous options and modeling features. The EAPF program is based on advanced and robust solution algorithms, which incorporates state-of-the-art solution techniques applicable to large and complex systems. The program is equipped with an easy to use and intelligent graphical interface. The program's modeling capabilities include:

- ✓ Support full models of DC lines
- ✓ Unlimited Number of power sources
- ✓ Real and Reactive Power Losses
- ✓ Power Factor Correction and Automatic Temperature Adjustment
- ✓ Newton Raphson, Fast Decoupled, and Accelerated Gauss Seidel

- ✓ Double Precision Newton Raphson
- ✓ Advanced Solution Techniques for Fast Convergence
- ✓ Load Forecasting
- ✓ Overload and violation warnings for bus and branch equipment
- ✓ Option to select any scenario or loading category
- ✓ Global and individual bus diversity factors
- ✓ Phase Shifting Transformer
- ✓ Simulate single-phase networks tapped from 3phase network
- ✓ Voltage Profile
- ✓ Single Phase local and remote voltage control
- ✓ Local and Remote Bus Voltage Control via Static Var Compensation
- ✓ Local and Remote Bus Voltage control 1, 2 and 3 winding Transformers
- ✓ Combined SVC, Generator and Transformer Voltage Control
- ✓ Local and Remote Bus voltage control through Generation Kvar
- ✓ Unlimited physical load connections to a bus
- ✓ Area Interchange Control
- ✓ Transformer Impedance Adjustment based on Transformer Taps
- ✓ Hybrid Simulation Method
- ✓ Transformer ULTC simulation and auto voltage control
- ✓ Relaxed Generator limits simulation technique
- ✓ SVC, Shunt and Reactor compensation
- ✓ Variable voltage initialization techniques
- ✓ Simulate Power Flow inside Schedules
- ✓ Load Analysis by Voltage
- ✓ Load Analysis by Category
- ✓ True Analog/Digital Scope with Built-in Triggering Mechanism
- ✓ IEEE Common Format Output
- ✓ Professional Report Writer with intelligent wizard
- ✓ Detailed reporting in Text, HTML, MS Word, graphical and Excel Formats
- ✓ Custom Report Template Designer for Professional Custom Reporting
- ✓ Governor Response solution – Distribute Generation based on Equal Droop

The Program output includes:

- ✓ Bus voltage and voltage angle;
- ✓ Reactive power, terminal voltage and remotely controlled bus (if any), power factor for generators;
- ✓ Current, active power, reactive power flows and flow power factor through branches;
- ✓ Branch losses and system losses in zone, area, or in entire system;
- ✓ Total Generation, Load, Losses, and System Power Mismatch;
- ✓ Voltage Violations report vs. user-defined threshold;
- ✓ Branch Loading Violations vs. user-defined threshold;

In Addition, all of the solution quantities (voltages and flows) are exportable to Excel, and can be used to Customize reports using Professional Report Writer.

3. Solution Methods

To cope with the unique features of different power systems, such as transmission, distribution and industrial power systems, or a mix of these systems, EAPF supports a number of solution techniques. The solution methods are **Newton Raphson, Fast Decoupled, Hybrid Solution**, and the **Gauss Seidel**. The latter offers better convergence for the networks having branches with high **R/X.** This situation may arise especially in a power system with predominately cable installations. The users may select the Fast

Decoupled method with limits and controls turned off when experiencing non-convergence. In this solution technique, transformer taps will not be adjusted and the generators are assumed able to deliver/absorb reactive power beyond their reactive power capabilities. This solution technique is particularly useful when the user wishes to determine the reactive power requirements in a new installation, or sometimes with a power system having data errors.

If the Fast Decoupled method does not converge even when you deactivate the constraints, the user should use the Gauss Seidel method. Since this method is inherently slow in convergence, user should allow more iterations.

Hybrid Solution is a very powerful technique suitable when systems with a diverse voltage, load sizes and impedances are modeled. This method utilizes both Newton Raphson and Gauss Seidel techniques. The active power mismatch is solved using Newton Raphson and reactive power mismatch is solved using Gauss Seidel.

4. Generator Modeling

The generator can be modeled using any of the following options:

- Fixed generation i.e., the user specifies constant active and reactive power generation;
- **Voltage controlled** also referred to as **P-V**, in this case active power and reactive power capability (maximum and minimum reactive power) is specified. In addition, the user specifies a desired controlled voltage for either generator terminal or a remote bus. The EAPF solution will determine how much reactive power is required to maintain the desired controlled voltage;
- Swing generator (sometimes it is also referred to as Utility or Reference generator). In this case, the user only specifies desired controlled voltage and its voltage angle (normally set to zero) at the generator terminal. EAPF will determine the required active and reactive power generation at the swing generator.

The user may connect more than one generator to a bus. The generators do not have to be the same rating and type. The following explains how EAPF divides the power among generators connected at the same bus:

- **Fixed generators** do not participate in the allocation;
- **Swing** generators share the required active and reactive generation equally;
- **Voltage-controlled** generators when each produces its specified active generation. Their share of the reactive power required in the solution is distributed proportionately to their reactive power capability range (without violating their limit).
- **Governor response solution** – If this is selected in power flow options, the active power of a network will be equally shared on the generators in the network.

5. Under Load Tap Changing Transformers (ULTC)

The EAPF program supports three types of ULTC transformers, which are described in the following section:

Voltage Controlling ULTC

This transformer can be used to control the voltage at either side of the transformer, or alternatively, it may control the voltage at the bus remote from the transformer terminals. For the latter case, to be practical, the remote bus should be in close proximity of the transformer. The required input data are:

- Transformer leakage impedance and ratings;
- Available tap range, maximum and minimum tap and number of taps;
- The range of controlled voltage (maximum and minimum voltage);
- The controlled bus identification. This may be either one of the transformer's terminals or a valid remote bus in the network.

For example, in Figure 1, a voltage regulating ULTC is connected between buses: BUSA and BUSB. The transformer tap can be on BUSA or BUSB and the voltage may be controlled at BUSA or BUSB or a remote bus such as BUSC. The power flow program will adjust the transformer tap to maintain the voltage at the controlled bus between the maximum and minimum specified voltage. In cases where the program is unable to control the voltage within the specified range, the transformer tap will be at either minimum or maximum tap position. The position is also user defined and can be either one of the transformer's terminals.

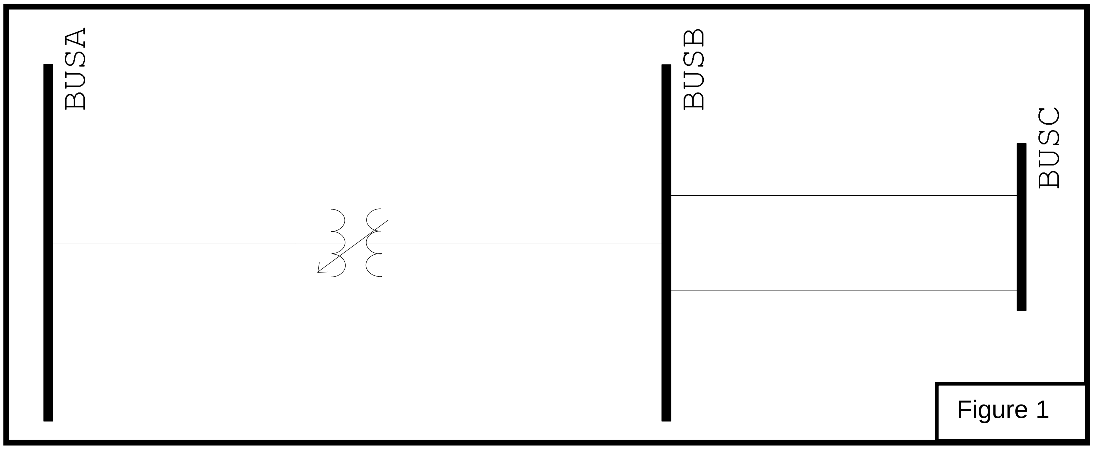


Figure 1: ULTC Voltage Control Transformer Controlling its Own Terminal or Remote Bus

Phase Shifting/Active Power Controlling ULTC

This type of transformer can be used to control the flow of active power through the transformer. It is also known as phase shifting transformer. The required input data are:

- Transformer leakage impedance and rating;
- Available phase shift range (maximum and minimum phase shift and number of taps);
- The range of controlled active power through the transformer.

The EAPF program will automatically adjust the transformer phase shift within its controlled range until the desired active power flow through transformer is obtained. If unable to control active power flow to the prescribed value, the phase shift will be set at either maximum or minimum allowable values.

Reactive Power Controlling ULTC.

This transformer controls the flow of reactive power flow through the transformer by adjusting its tap. The required input data are:

- Transformer leakage impedance and ratings;
- Available tap range (maximum and minimum tap and number of taps);
- The range of controlled reactive power flow through transformer;

The EAPF program will automatically adjust the transformer tap within its controlled range until the desired reactive power through transformer is obtained. If unable to control reactive power flow to the prescribed values, the transformer tap will be set at either maximum or minimum allowable values.

6. Area Interchange Control

This modeling of EAPF program can be used to simulate power transactions between utilities or areas of a power network. To illustrate this modeling concept, consider the following example based on Figure 2:

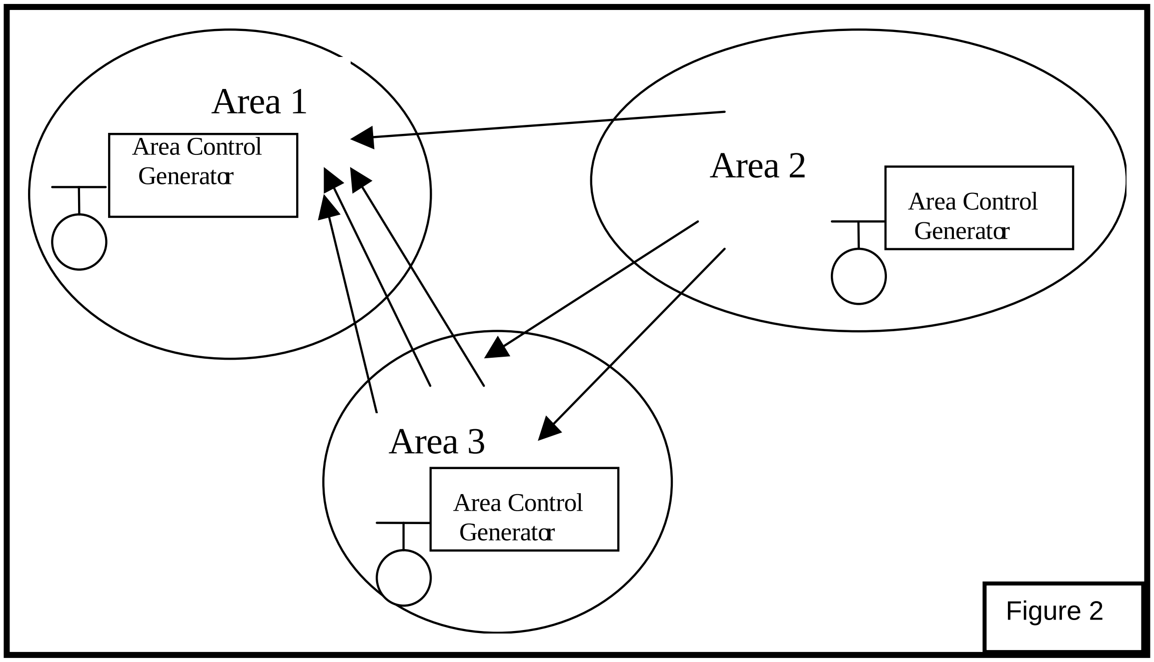


Figure 2: Area Interchange Control

Let's assume that there are three areas in the network, as shown in the figure. Area 2 is exporting power to areas 1 and 3. Area 1 is only importing power from areas 2 and 3. However, area 3 is both importing and exporting power to areas 1 and 2. The following data are the required for each area:

- Area name;
- Bus identification of the area control generator;
- Net exchange value of Active Power. This number could be positive or negative. If the exchange is positive, then, it is considered to be exporting power.
- Tolerance of MW Exchange;
- Maximum and Minimum active generation of the area control generator;
- "Zones" per "Area" assignment, many zones can be assigned to one area.

Tie lines are branches that link system areas and are entered like any other lines. The metering point for a tie line is the "From bus". Losses on the tie line are accounted for in the area of the "To bus". The power flow program automatically determines (using network connectivity information and zones in areas) the associated area tie lines. For example, in Figure 2, there is one tie line between area 1 and area 2. There are three tie lines between areas 3 and 1 and finally two tie lines between areas 2 and 3. For each of iterations the program will try to adjust the area control active power generation (within its specified maximum and minimum) such that the desired amount of import and export within each area is achieved.

Note that each area should have unique zones assigned to it. For example if there are 10 zones, then:

Area 1 can have zones 3,5,9.
Area 2 can have 1,2,7
Area 3 can have 4,6,8 and 10

7. Three Winding Transformers

Three winding transformers are modeled as three 2-winding transformers. The required data are as follows:

- Primary, secondary, and tertiary bus identification;
- Transformer rating;
- Primary to secondary impedance;
- Primary to tertiary impedance;
- Secondary to tertiary impedance;
- Primary, secondary, and tertiary overload capabilities;
- Identification of the voltage controlled bus;
- Primary, secondary, tertiary tap information (maximum tap, minimum tap, number of taps, range of voltage control).

The EAPF program will automatically create three two-winding transformers. Then, each of the two-winding transformers will be treated as either a fixed-tap or ULTC depending on the data provided.

8. Autotransformers

The Autotransformer is a special type of power transformer. It consists of a single, continuous winding that is tapped on one side to provide either a step-up or step-down function. This is different from a conventional two-winding transformer, which has the primary and secondary completely insulated from each other, but magnetically linked by a common core. The autotransformer's windings are both electrically and magnetically interconnected.

An autotransformer is initially cheaper than a similarly rated two-winding transformer. It also has better regulation (smaller voltage drops) and greater efficiency. Furthermore, it can be used to obtain the neutral wire of a three-wire system, just like the secondary of a two-winding transformer. It is commonly used to transform between two high-voltage circuits. But, the autotransformer is considered unsafe for use on ordinary distribution circuits. This is because the high-voltage primary circuit is connected directly to the low-voltage secondary circuit. The capacity of the Autotransformer is:

$$S_1' = \left(V_1 + V_2\right) \cdot I_1 = I_1 V_1 (1 + \frac{1}{a}) = S_1 (1 + \frac{1}{a})$$

The transformation ratio of the Autotransformer is:

$$a' = \frac{\left(V_1 + V_2\right)}{V_2} = a + 1$$

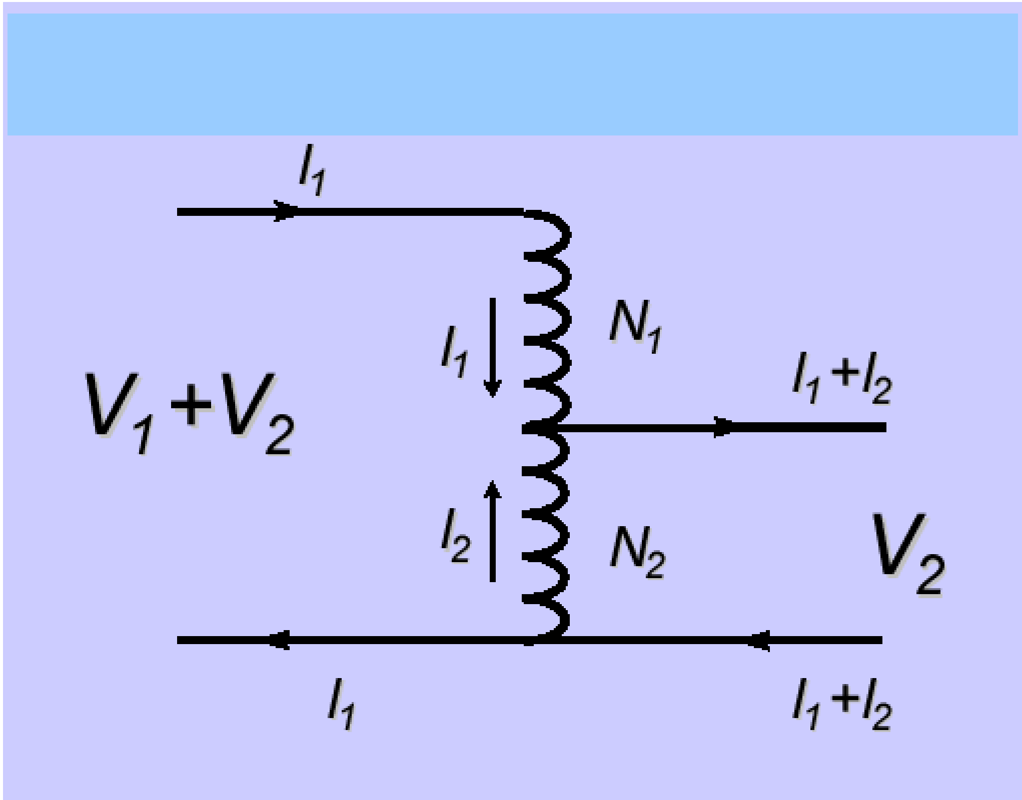


Figure 3: Schematic of an Autotransformer Circuit

For example, if a=1, the capacity has been doubled! The advantages of autotransformers include:

- No “galvanic” isolation between primary and secondary windings;
- More power transformation capacity with the same size of the transformer;
- Possibilities to control voltage and reactive power flow;
- Widespread applications in power systems.

The mathematical model of an autotransformer is similar to a two-winding transformer and the EAPF treats an autotransformer the same as a voltage-controlled transformer but with simplified data requirements.

9. Line Voltage Regulator (LVR)

The line voltage regulator normally uses several-tap autotransformer to control the voltage to a precise set point. The Voltage Regulator circuitry monitors the incoming line voltage and compares it to a voltage reference set point. If a voltage fluctuation requires that a different tap be selected, the new tap is electronically switched (normally at the zero-crossing, to avoid distorting the AC waveform). In some design, if necessary, it can switch taps as often as once each cycle. Most commercial voltage regulators using multiple-tapped transformers switch taps at uncontrolled times, thereby creating voltage spikes.

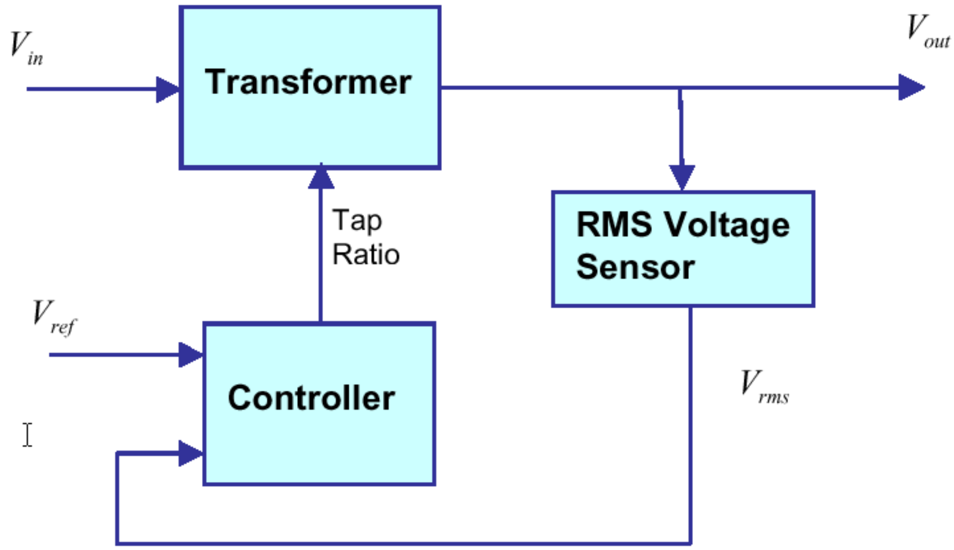


Figure 4: Line Voltage Regulator (LVR)

Again, the LVR is modeled similarly to voltage controlled ULTC, but with simplified data entry. The function of LVR can be either boost or buck of the secondary voltage.

10. Power Flow Solution Options and Controls

The EAPF program solution options and control parameters are shown in Figure 5. With these options user can select:

- Solution Method (Newton, Gauss, etc.);
- Convergence tolerance;
- Select Automatic Adjustments (ULTC's, Generator, and SVC);
- Limits & Controls On/Off;
- Governor Response Solution (default is unchecked);
- Auto Text Report;

The solution options were described in the previous sections. EAPF also allows the user to initialize the power flow solution by Gauss Seidel method. This is shown in Figure 6 where the number of initial iteration is specified as 20.

The Governor Response Solution (distribute generation based on equal droop) is unchecked in default. If this selection is checked, the power flow calculation will equally distribute the total active power of a network to all the generators. It's convenient for this type of application.

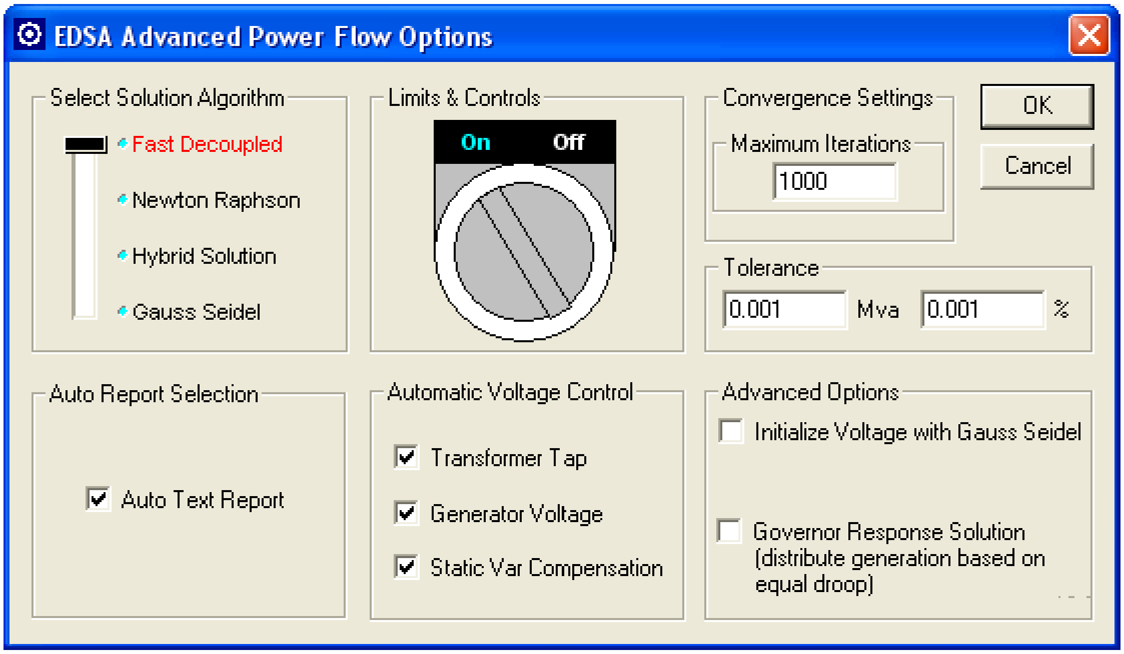


Figure 5: Advanced Power Flow Solution Options

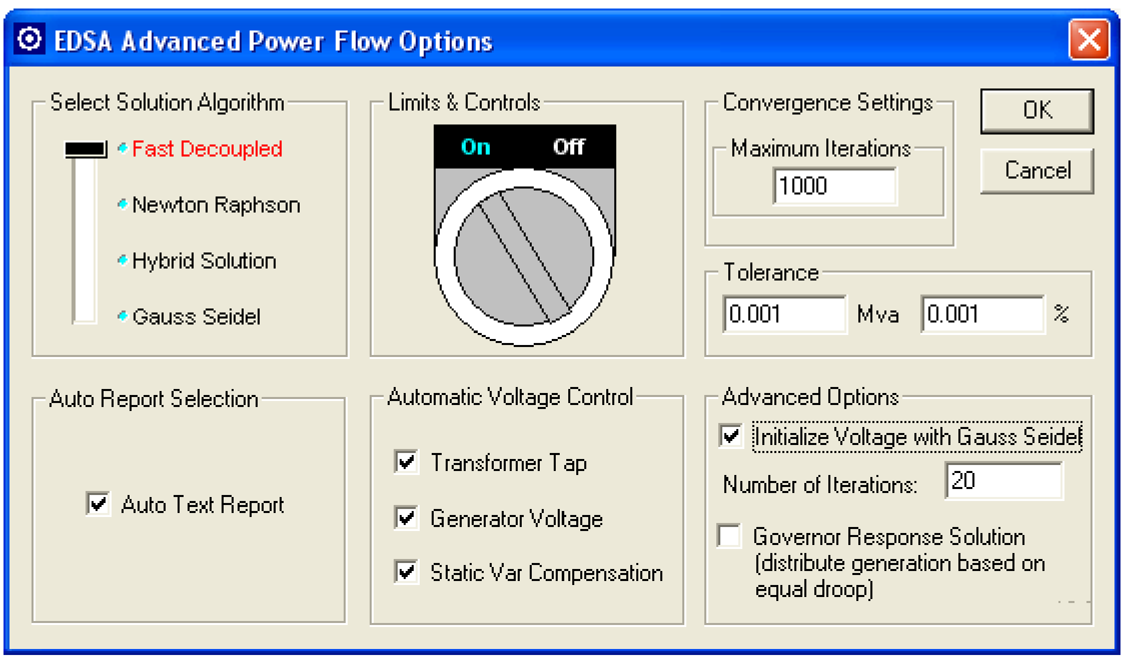


Figure 6: Initializing the Power Flow Solution with Preliminary Gauss Seidel Iterations

11. Customizing the EAPF Report, Setting Units and Exporting Facilities

The EAPF supports a number of standard reports that are commonly accepted by the power industry load flow report formats. In addition to these reports, the result of power flow solution, i.e., voltages and power flows can be exported to Excel program. The reports can also be customized by advance “Professional Report Writer Wizard”.

The units for reporting voltages and flows can be selected as shown in Figure 7. The voltages can be reported in p.u, volts, or kV. The unit of current report can be p.u., Amps, or kA. Finally, the active and reactive powers are reported in p.u., KW/KVAR, or MW/MVAR.

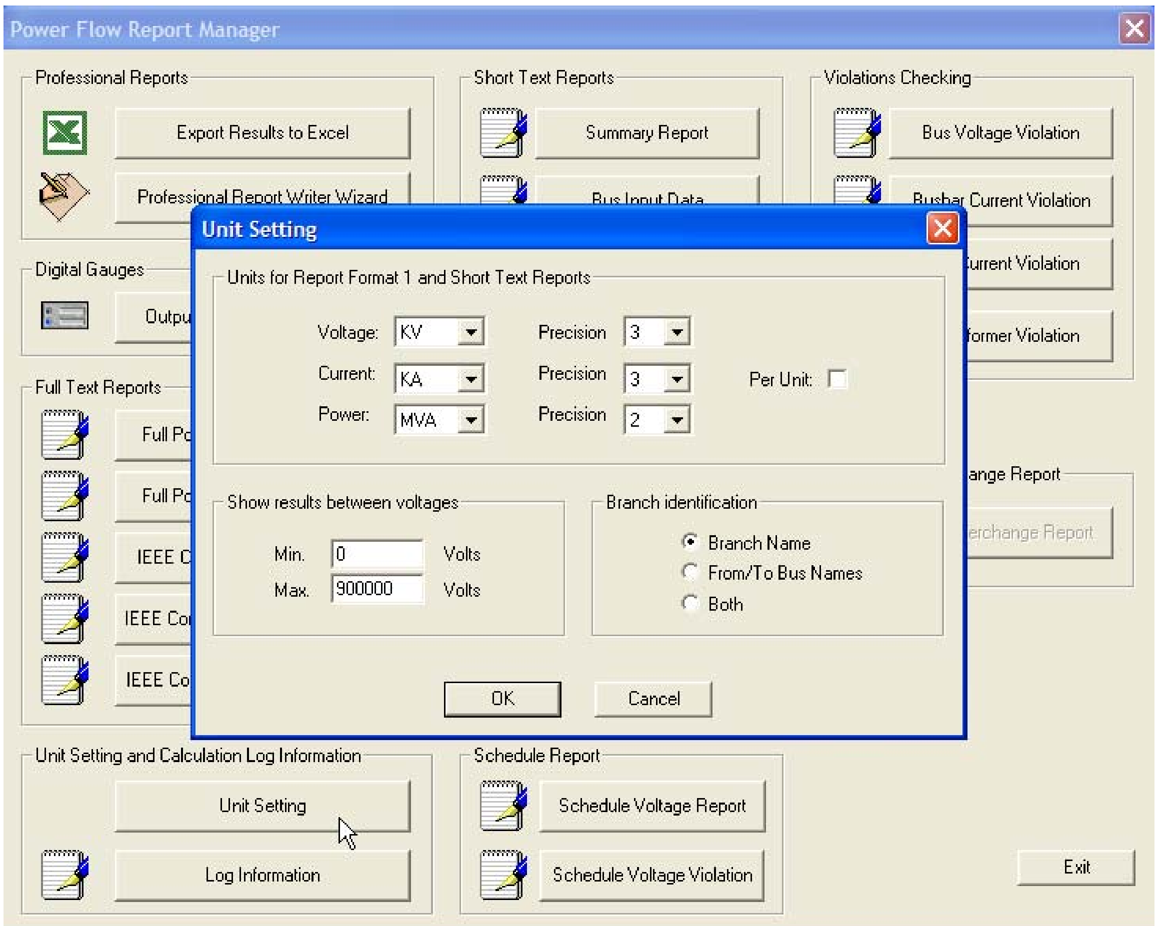


Figure 7: Setting Report Units in the Advanced Power Flow Program

Figure 8 shows how different report options can be accessed in the Advanced Power Flow Program. The “Area Interchange Report” button will be active if area power interchange is selected in the master file editor.

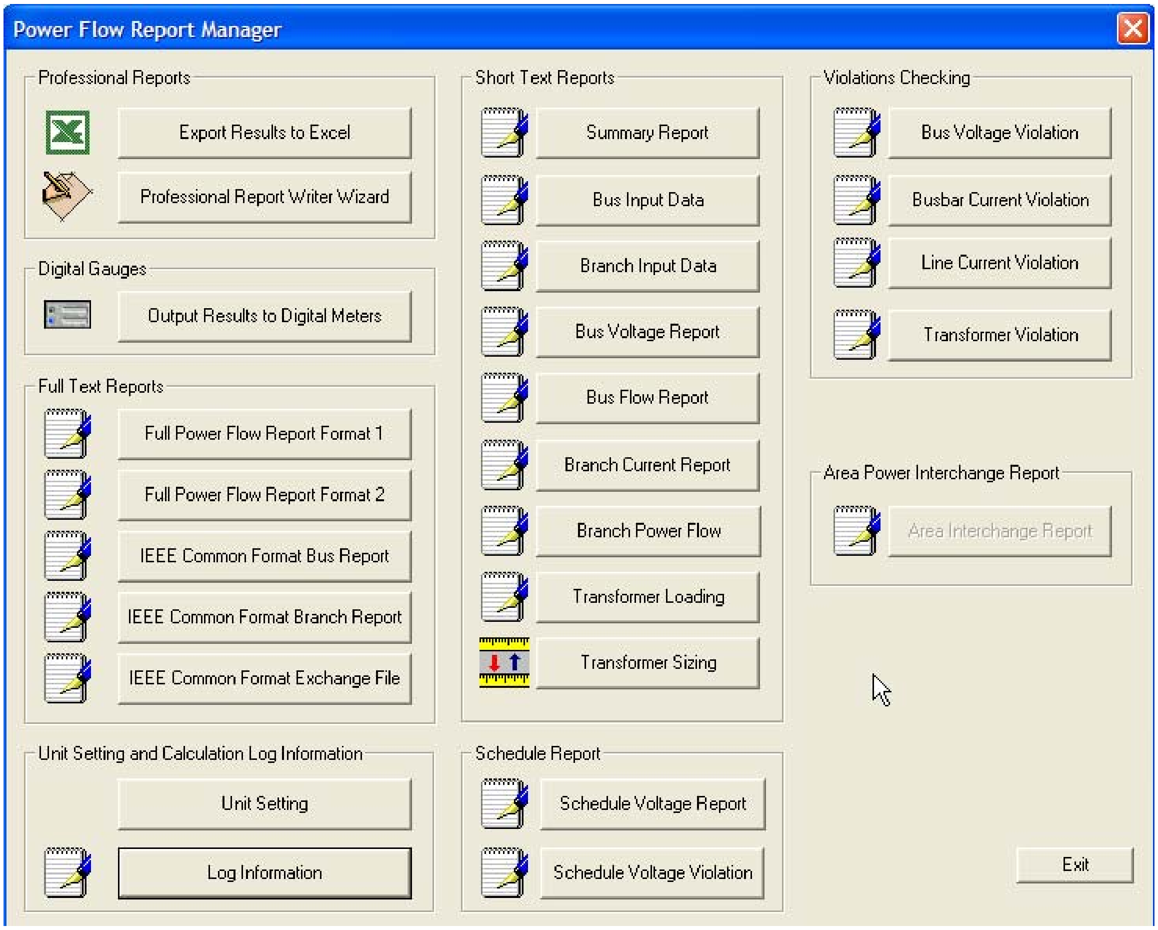


Figure 8: Selection of Reports, Units, Customizing, and Exporting Power Flow Results

12. Violation and Summary Reports

The violation report identifies undesirable conditions in the network (overloaded equipment and unacceptably high or low voltages). It contains only those transformers, lines and cables that are loaded beyond the limits specified by the user. It also lists only those buses whose voltages fall outside the user-defined acceptable range. The program allows the user to adjust these limits before or even after the load flow calculation.

The summary report provides totals of generation, load, losses and mismatches[1] in the network. (Losses are the difference between generation and load.) Active and reactive quantities are listed separately. Motor load and static load are identified by separate totals. The solution method, base power, calculation tolerance and mismatches are also listed.

It is possible to show the power flows and the bus voltages directly on the one-line diagram.

[1] If reported mismatches are not small as compared to the other quantities reported (for example a few percent of the total system load), consider running the load flow again with a smaller tolerance.

13. Important Notes

Selection of Base Power "BASE MVA/KVA"

This is the common power base to which all impedances will be referred (per unitized). Choose a value midway between the largest and smallest power rating of the equipment in the network. Convenient values are 0.1, 1, 10 or 100 MVA.

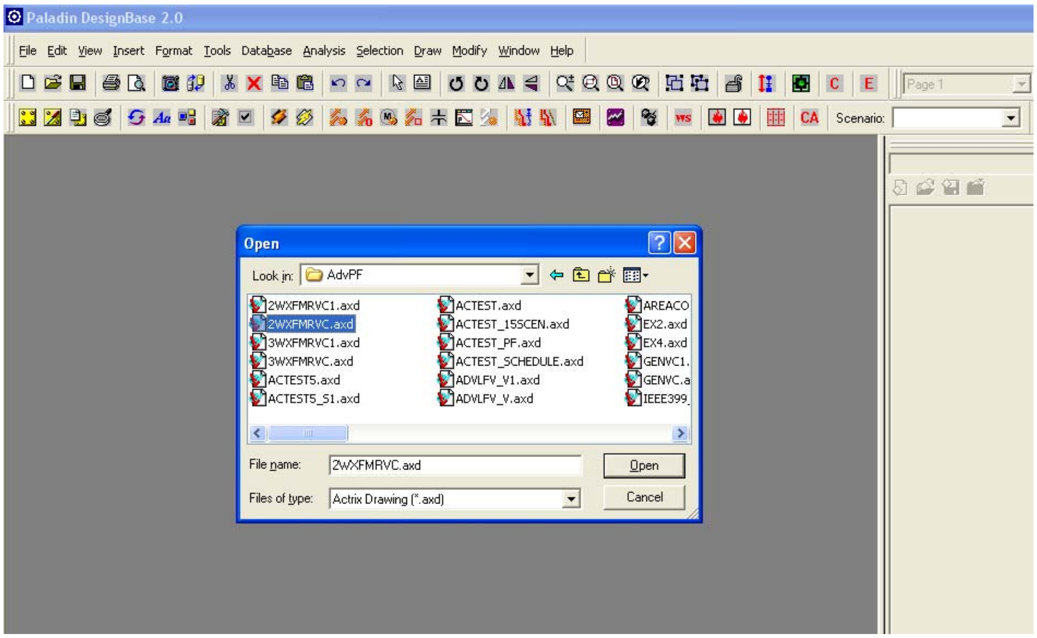
What to do if the Load Flow does not converge

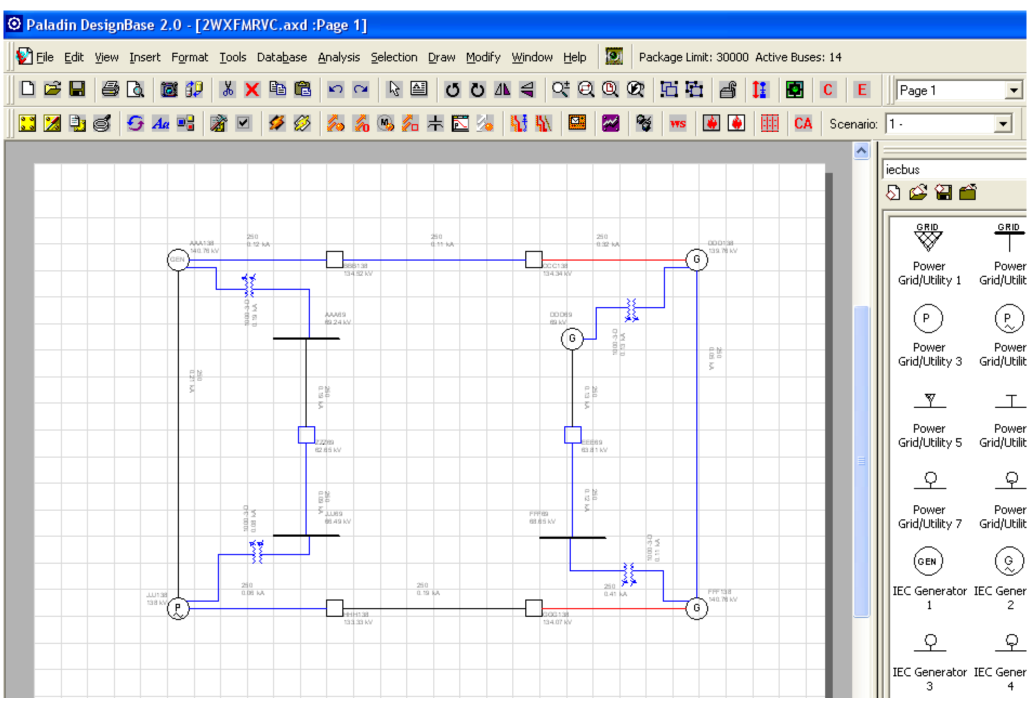
EAPF generates a file named "ErrorLog", where all the warnings and error messages are logged. The power flow iterations are also reported in this file. Log file gives the user the information about the convergence of the power flow solution process. Also, if the power system component data are in error, the program will issue messages related to the erroneous data.

If the ErrorLog shows that the calculation does not converge, inspect to see what buses have high power mismatches. If from iteration to iteration, the mismatches increase steadily, check the input data for components connected to the indicated buses. Look for very high or very low line/cable/transformer impedances. Make sure line and cable lengths are consistent with the length unit used for defining the impedance. If the mismatches increase and decrease and devices are being adjusted on every iteration, try solving without constraints. If that calculation converges, you may be able to see from the results what is wrong. Perhaps two devices have been asked to control the voltage at the same bus. If the convergence seems to be going up and down, this is an indication that some transformers/generators devices are continually being adjusted. If so, you may also try changing the settings of one or more of these devices before re-attempting another run. If the mismatches steadily decrease but remain higher than the specified tolerance as the permitted number of iterations is exhausted, try increasing the number of iterations before solving again.

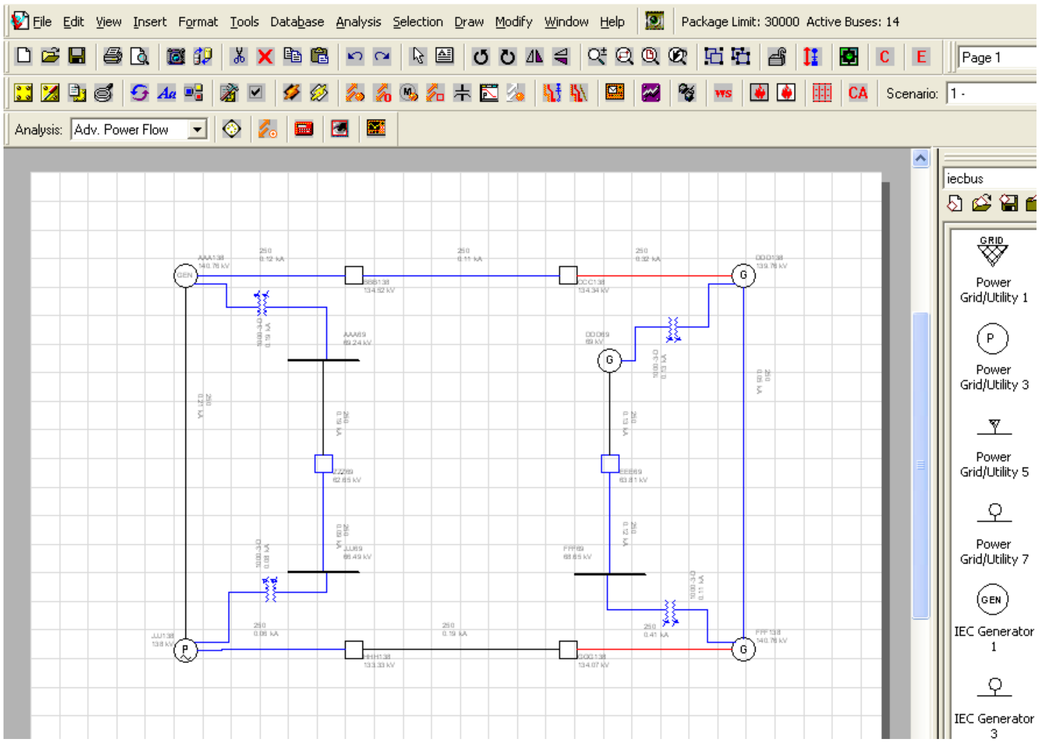
14. Tutorial: ULTC using Two-Winding Transformers

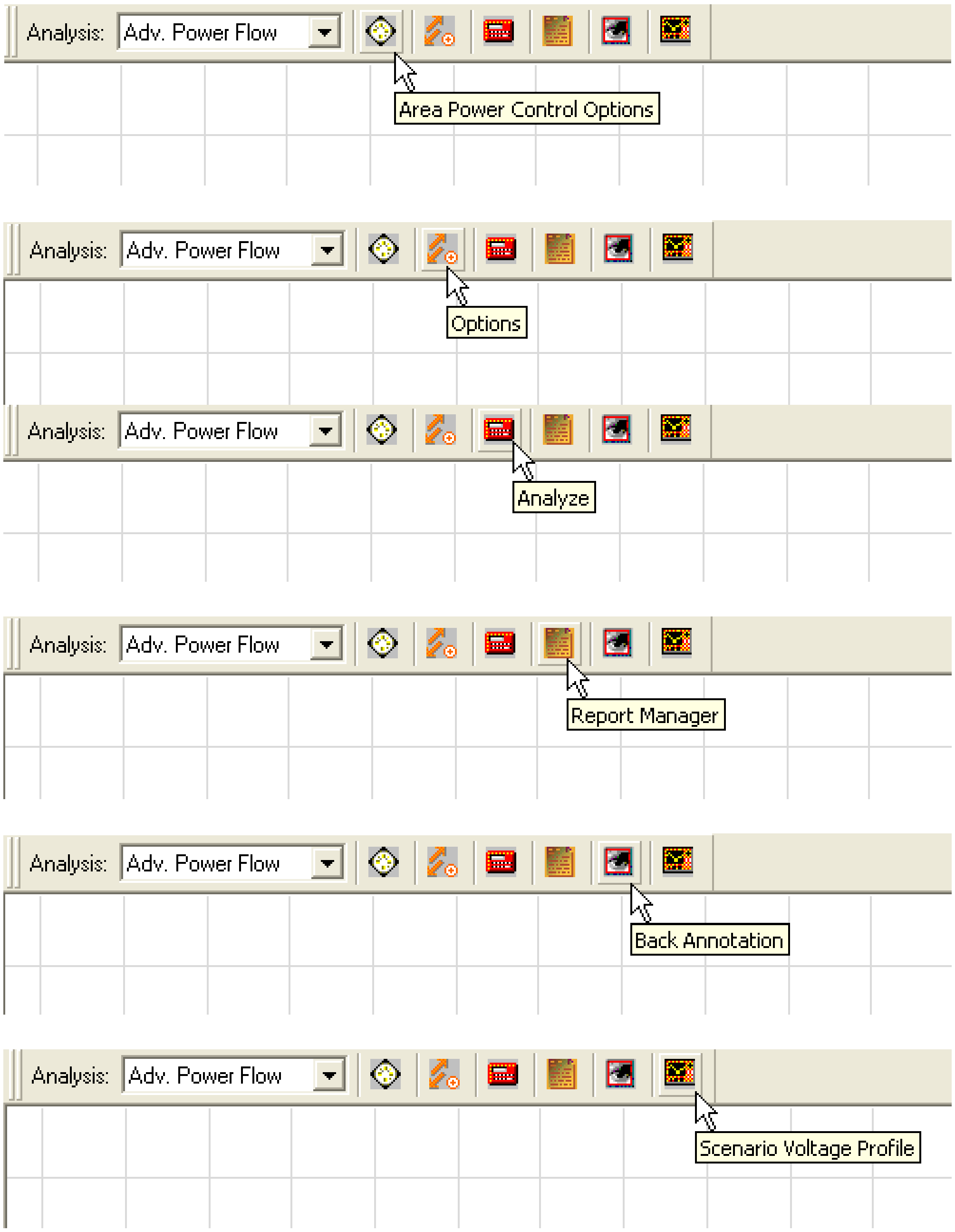
1. Invoke the EDSA Graphical Interface, and proceed to open the file called "**2WXFMRVC**" as indicated in the following screen captures.





2. Next, proceed to designate the desired transformer, or transformers, that will be used as ULTC Control Transformers. Follow the instructions shown in the next screen capture.





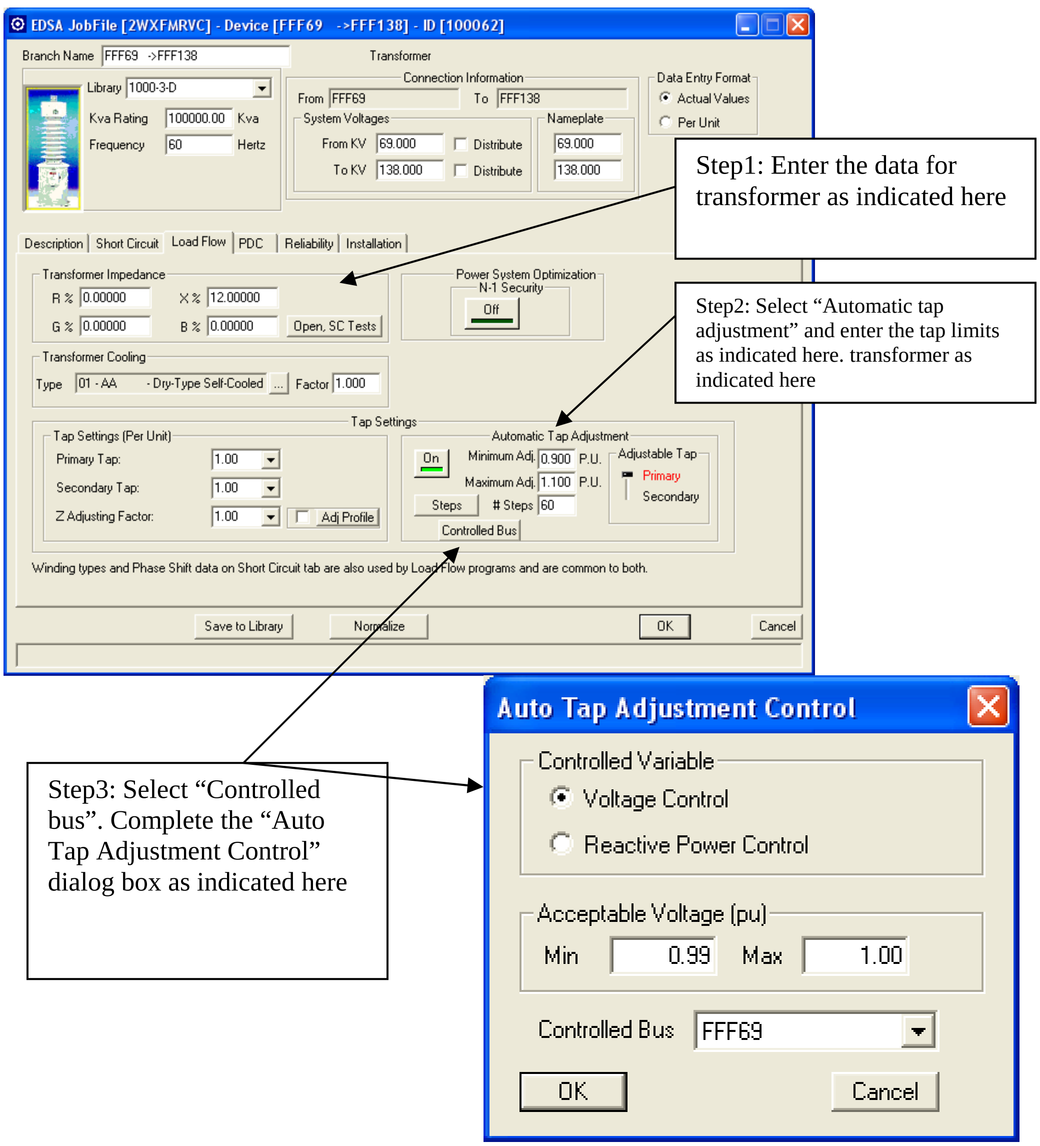
Overview – EDSA Toolbar

3. Proceed to enter the transformer data as well as the Auto Tap Adjustment Control options for this unit. In this example, the type of control will be defined as follows:

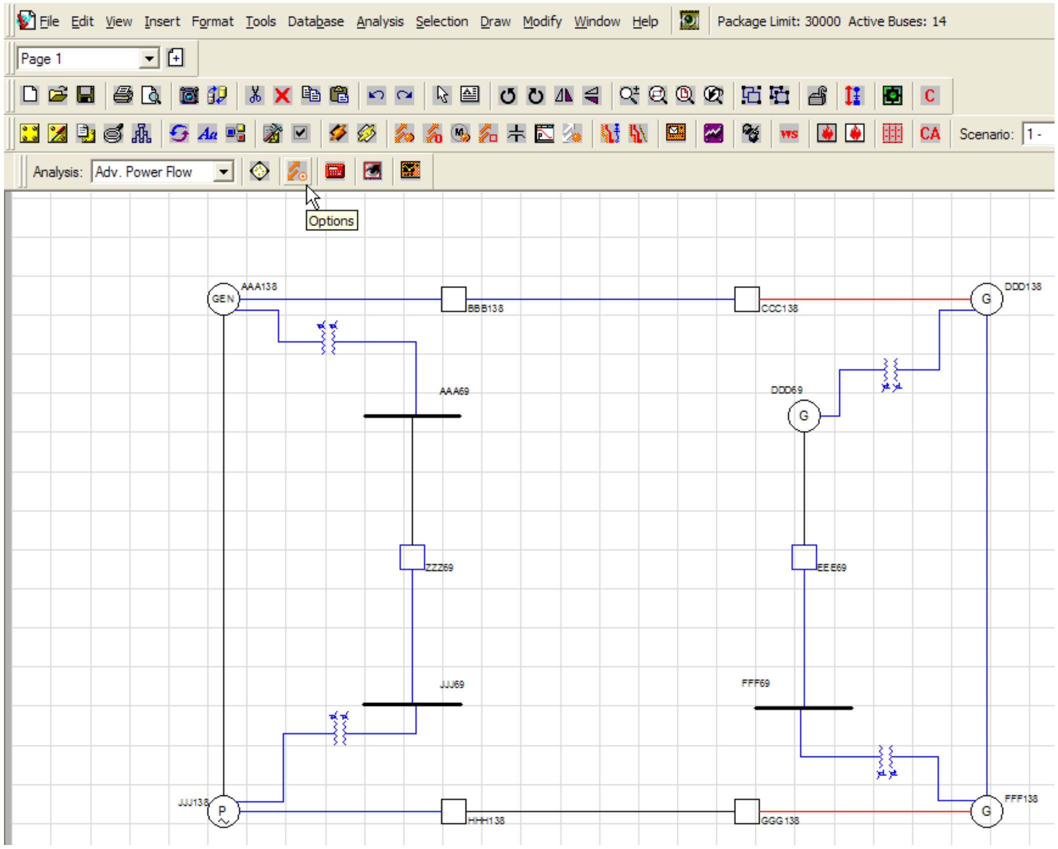
   Control Variable: Voltage
   Controlled Bus: FFF69 (69kV Primary Bus)

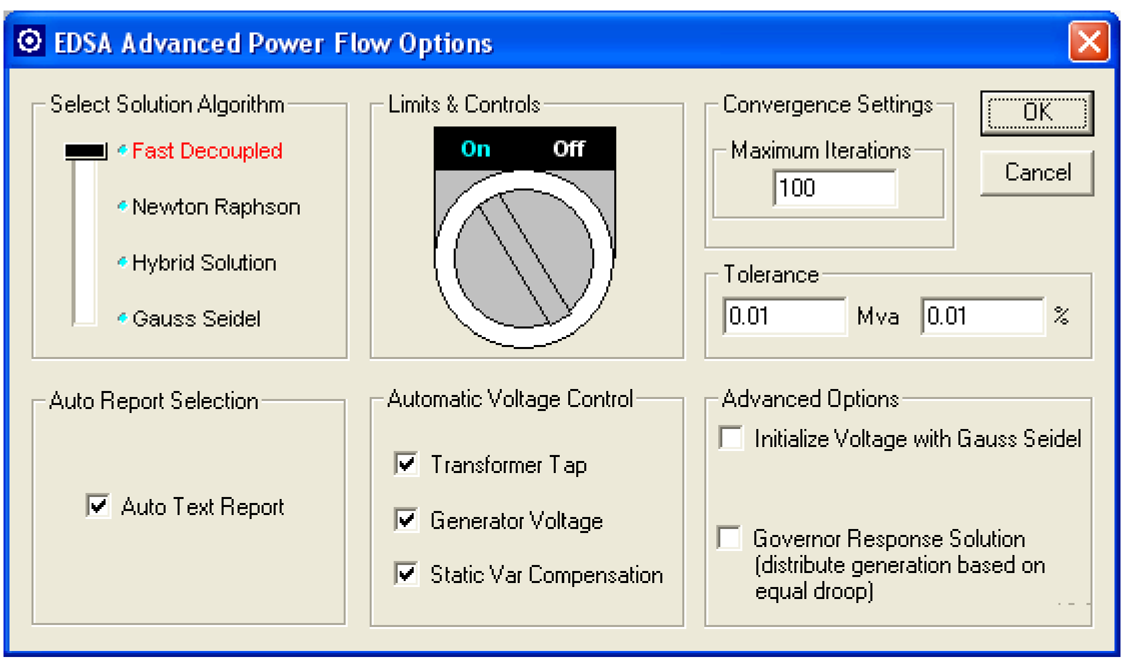
   Follow the instructions shown in the following screen capture. Repeat this procedure for as many transformers as necessary. In this example, only one transformer will be equipped with adjustable taps.

Note: There is no limit in Voltage Control Transformers.



4. Next, proceed to invoke the Advanced Power Flow Program, as indicated in the following screen capture. You will then see the Advanced Power Flow Options screen appear.





Please review and examine all the options. In this interface you can select Solution Algorithm and select/unselect the Automatic Voltage Control. You may also turn the Limits and Controls **On** or **Off**.

There are four Power Flow Methods: **Fast Decoupled**, **Newton Raphson, Hybrid Solution (**half Newton Raphson and half Gauss Seidel**)** and **Gauss Seidel**. Each of the method employed, can be used with or without applying generator reactive power limits. Turning off the generator reactive power limits (Limits& Controls switch) is particularly useful when the user wishes to determine reactive power requirements in new installation or sometimes with power system having data errors. The Gauss Seidel or Hybrid Solution methods are recommended for the networks that have branches with high R/X (cables) that both the Fast Decoupled and Newton Raphson methods do not converge**.** This situation may arise especially in a power system with predominately cable installations.

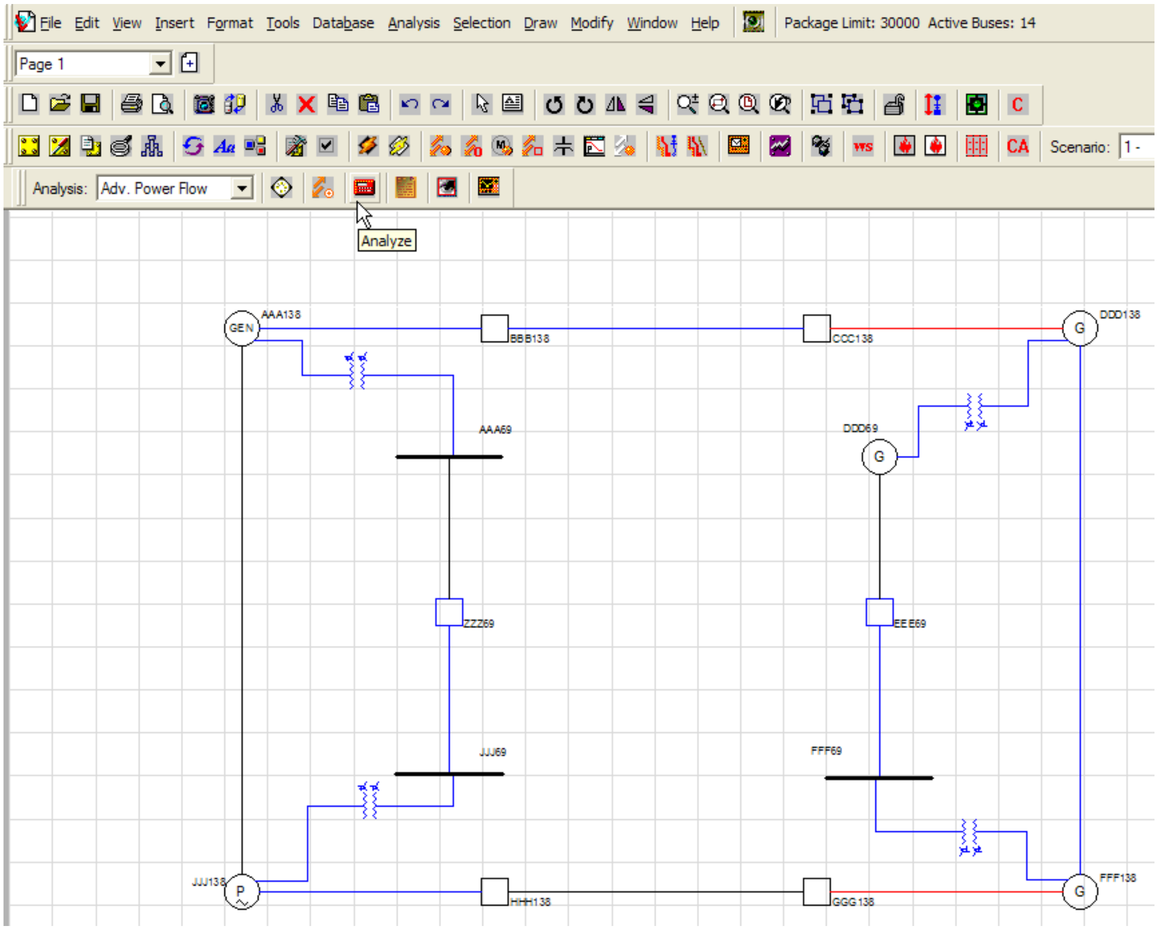
The following guidelines are offered as an aid to determine which technique may be the most appropriate for a particular system condition:

- The **Gauss Seidel** method is generally tolerant of power system operating conditions involving poor voltage distribution and difficulties with generator reactive power allocation, but does not converge well in situations where real power transfers are close to the limits of the system;
- The **Gauss Seidel** method is quite tolerant of poor starting voltages estimates but converges slowly as the voltage estimate gets close to the true solution;
- The **Gauss Seidel** method will not converge if negative reactance branches are present in the network, such as due to series capacitors or three-winding transformer models;
- The **Newton Raphson** method is generally tolerant of power system situations in which there are difficulties in transferring real power, but is prone to failure if there are difficulties in the allocation of generator reactive power output or if the solution has a particularly low voltage magnitude profile; in this situation, it is recommended to turn off "**Limits &Controls**" option;
- The **Newton Raphson** method is prone to failure if given a poor starting voltage estimate, but is usually superior to the Seidel-Gauss method once the voltage solution has been brought close to the true solution;
- The **Fast Decoupled** method will not converge when the network contains lines with resistance close to, or greater than, the reactance (cables). This is often the case in low-voltage systems.

Some experimentation is recommended to determine the best combination of methods for each particular model. The followings are recommended:

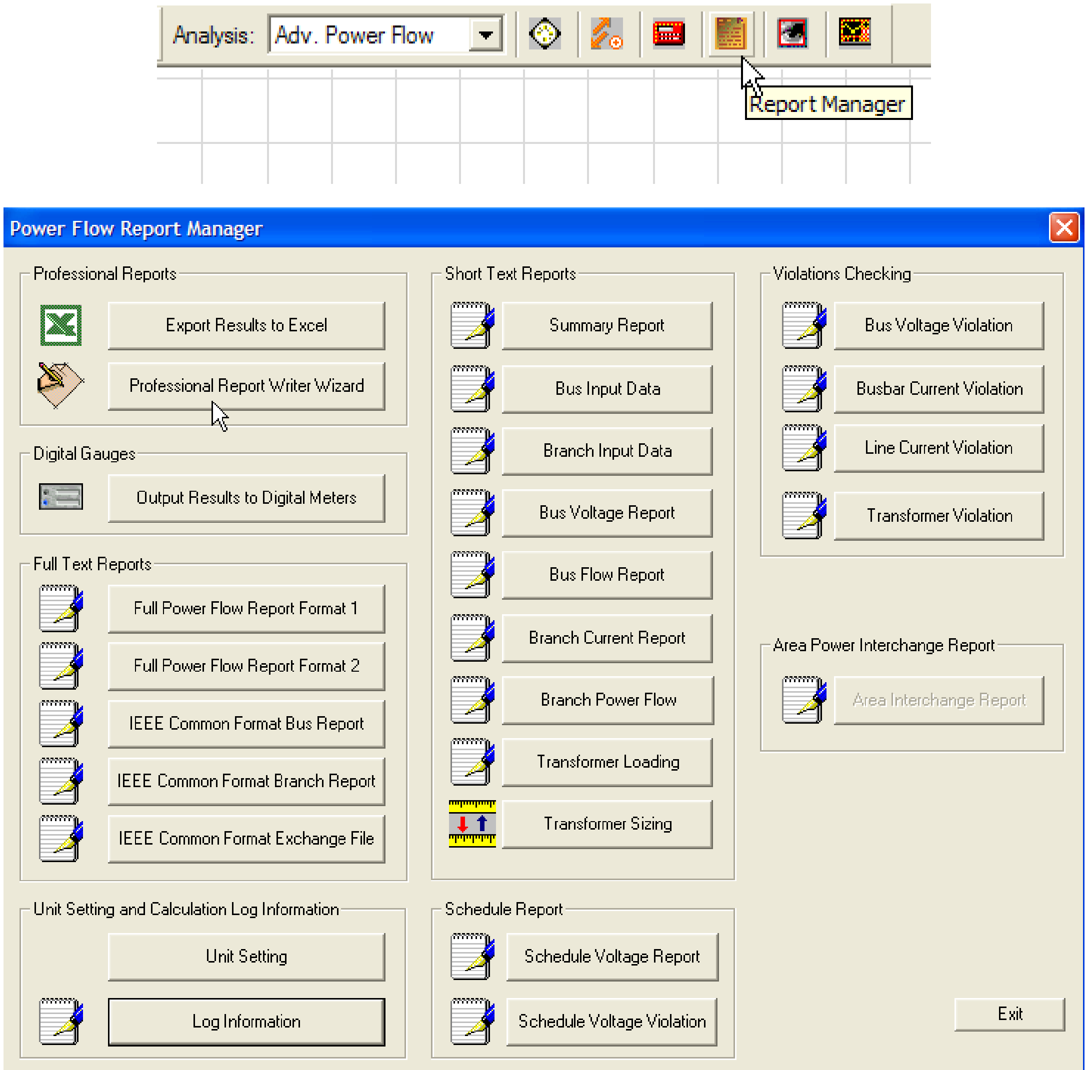
- Start with **Gauss Seidel** (20 iterations);
- Switch to **Newton Raphson** method until either the problem is converged or turning off **Limits & Controls;**
- Switch back to **Gauss Seidel** method if the **Newton Raphson** method does not settle down to a smooth convergence within 8 to 10 iterations.
- The **Hybrid Solution** technique can be used for systems that have diverse voltages, e.g., 400kV to 120v, very high or low impedance mixes and diverse loads, such as, 50HP and 5000HP. This is a very exact, fast technique for large power distribution and transmission systems.

5. Once you have selected the Power Flow options, you may click the "Analyze" icon as shown in the screen capture below.

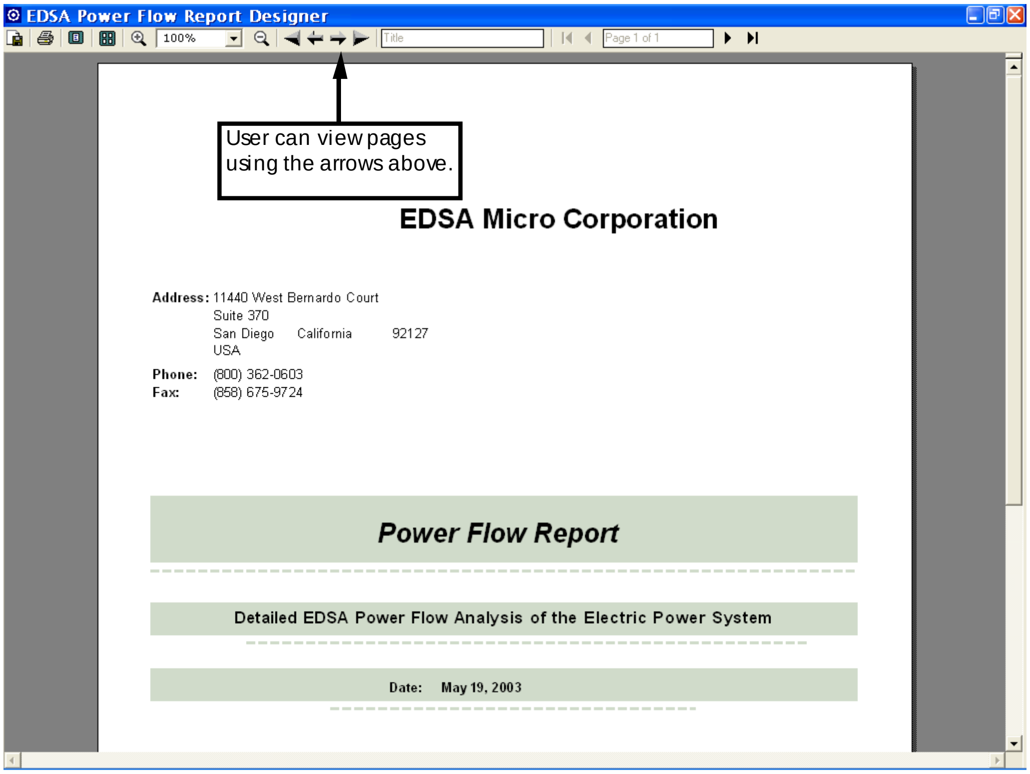


You will then see an information window that shows convergence of the calculation and the calculation iterations. The window will be automatically closed in 2 seconds. A test result report will be open if the "Auto Text Report" is checked in the options dialog box. The results will also be shown on the drawing depends on the selected data in the annotation dialog box. Close the text report now.

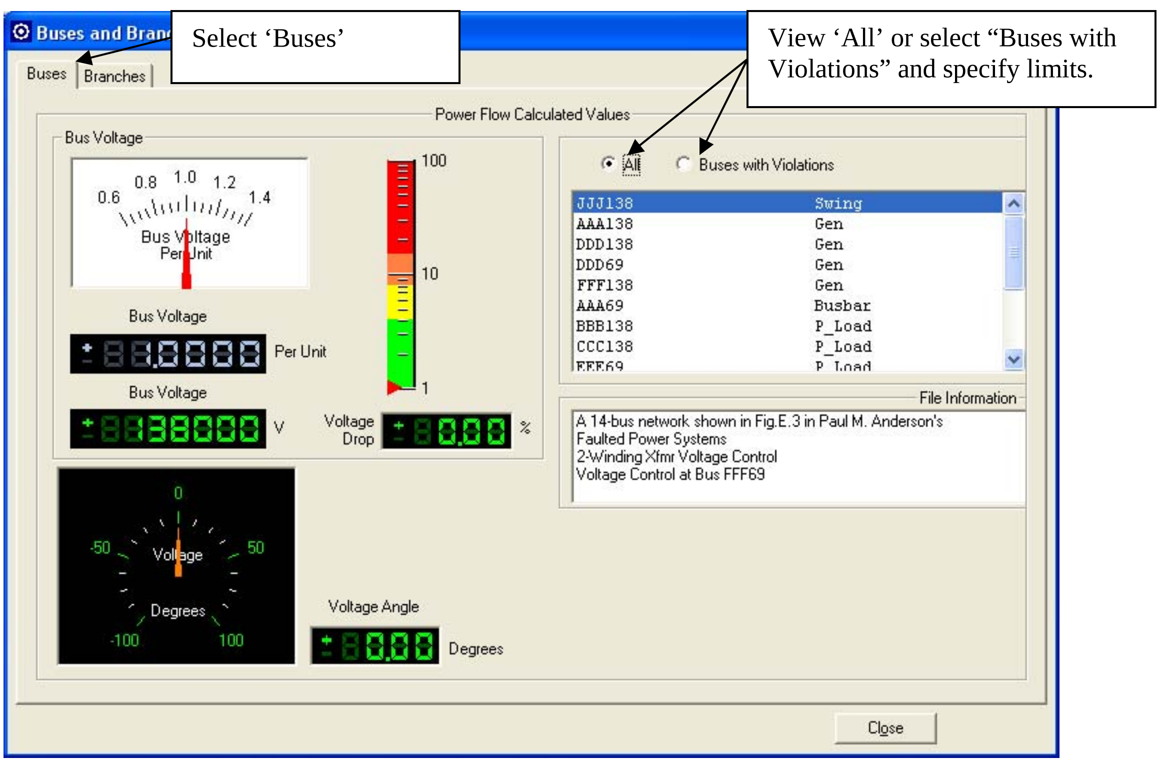
6. You may then proceed to open the Report Manager as shown in the next screen:



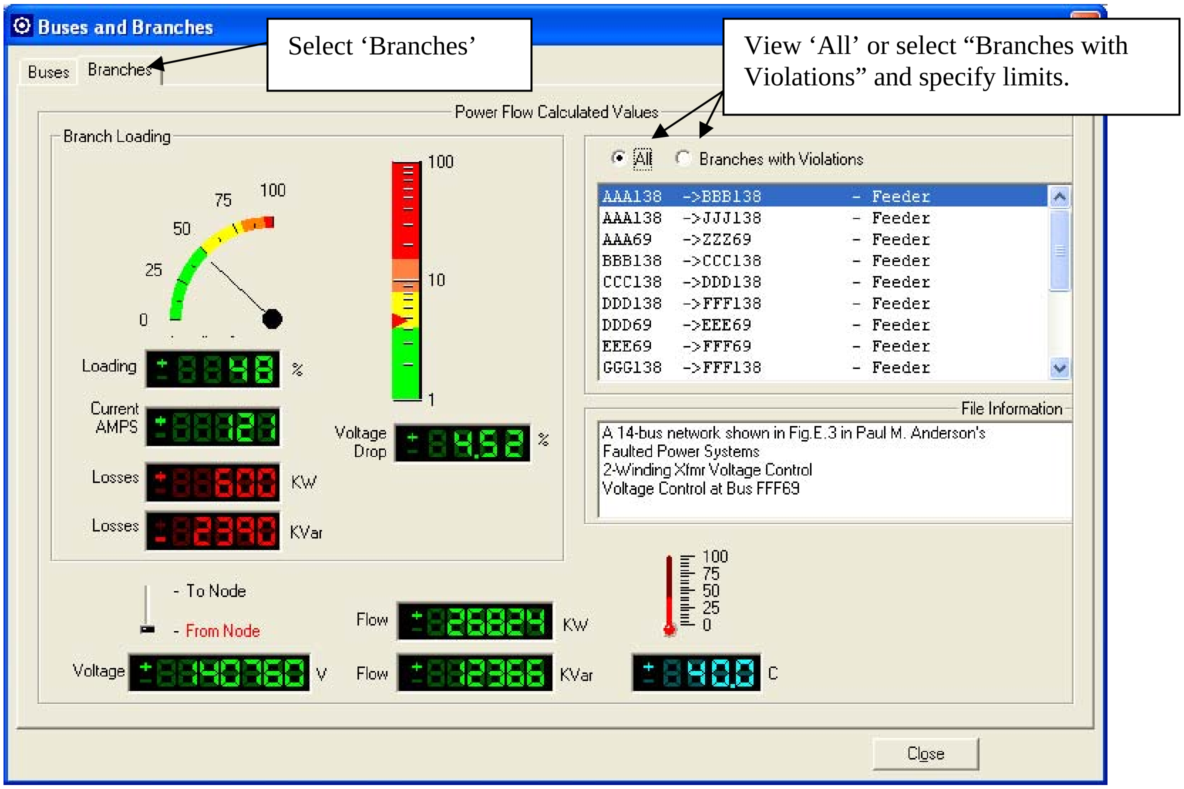
Advanced Power Flow Report Manager has all the above options. This very powerful Report Manager includes: Professional Reports generator, Digital Gauges, Full Text Report, Unit Setting, Calculation Log Information, Short Report, Schedule Report and Area Power Interchange Report. Selecting the "Professional Report Writer Wizard" will take you through the appropriate steps for building your report.



The user can view Digital Gauges by selecting "Output Results to Digital Meters". Please try all the options and view the outputs.

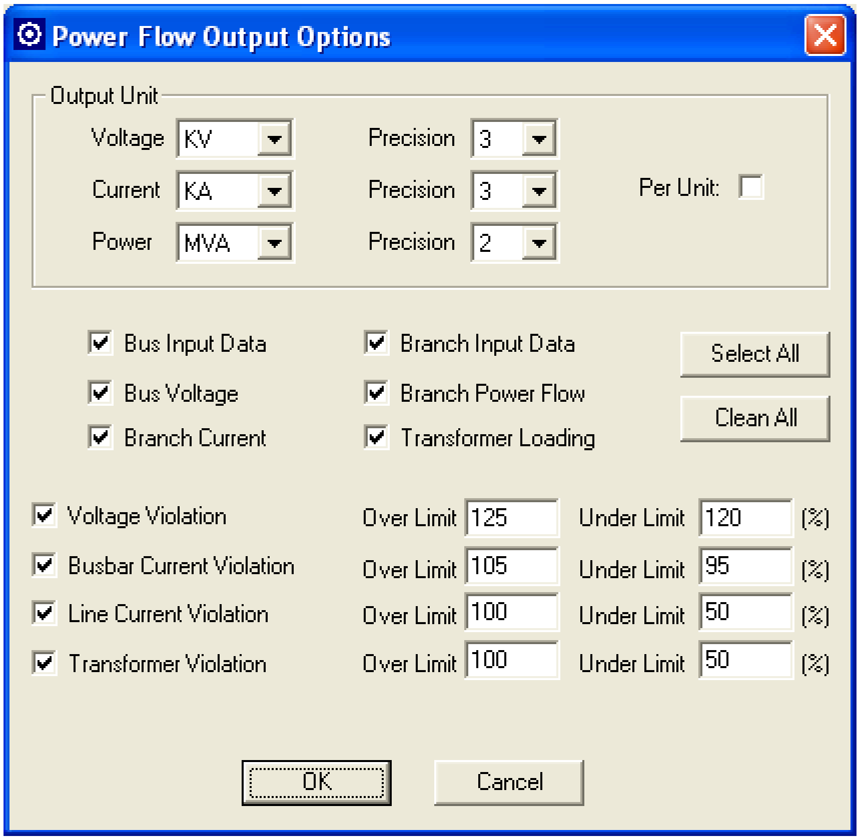


Sample Bus Digital Meters



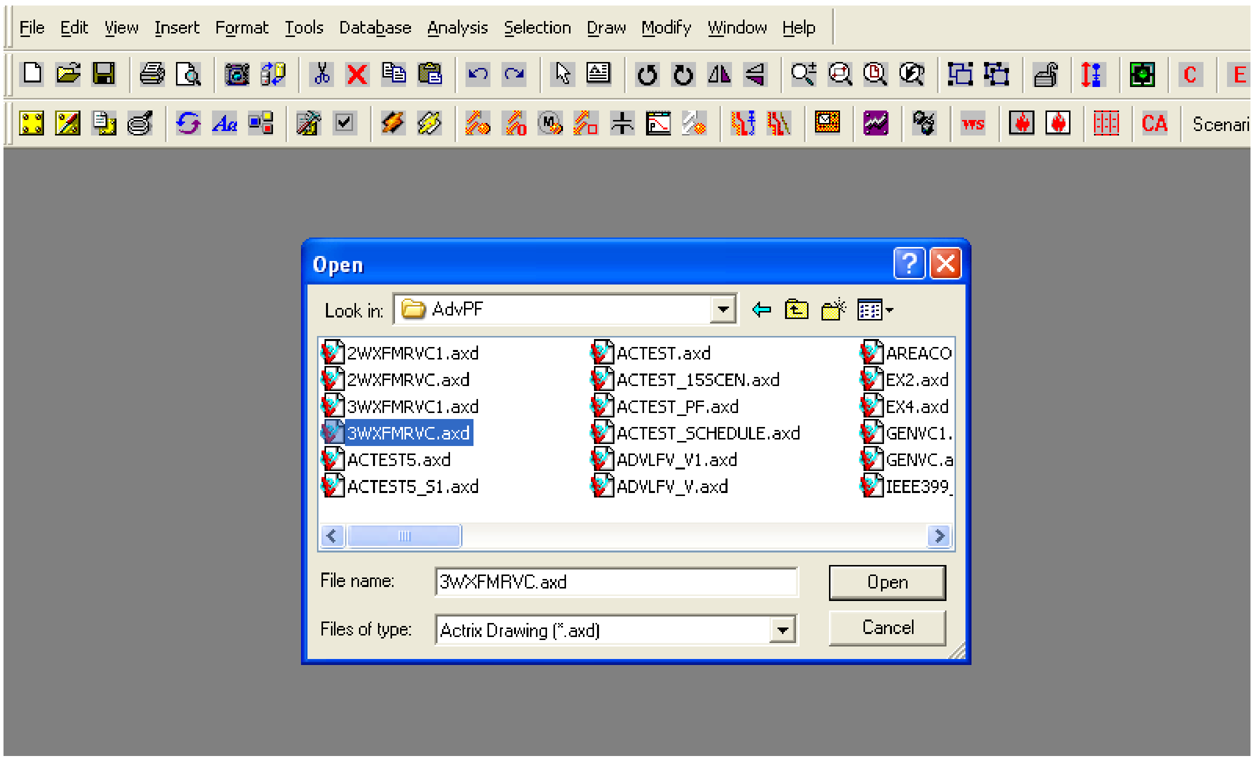
Sample Branches Digital Meters

Select the “Full Power Flow Report Format 1” button, you will see the following dialog box that you can choose the report sections desired. Try all the buttons to get familiar with the reports and settings.

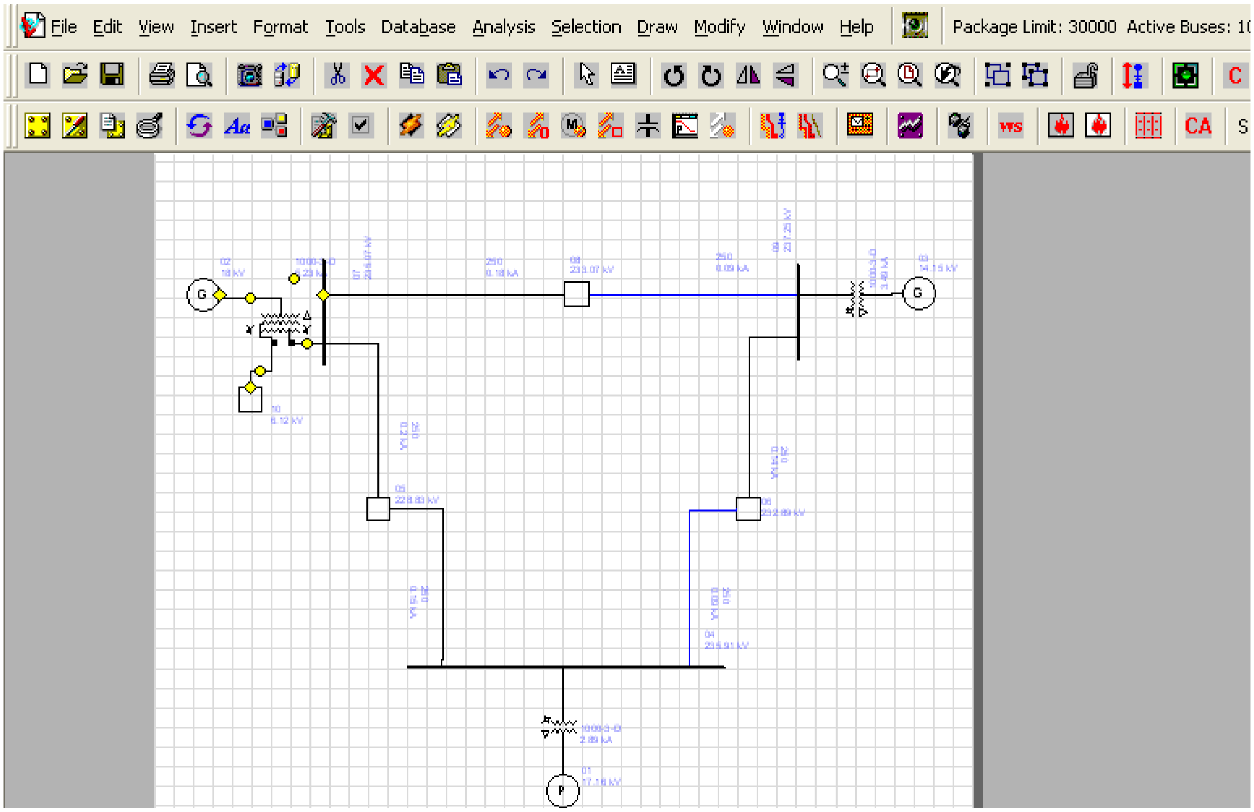


15. Tutorial: ULTC using Three-Winding Transformers

1. Invoke the EDSA interface. Proceed to open the file named “**3WXFMRVC**” as indicated in the following screen capture.



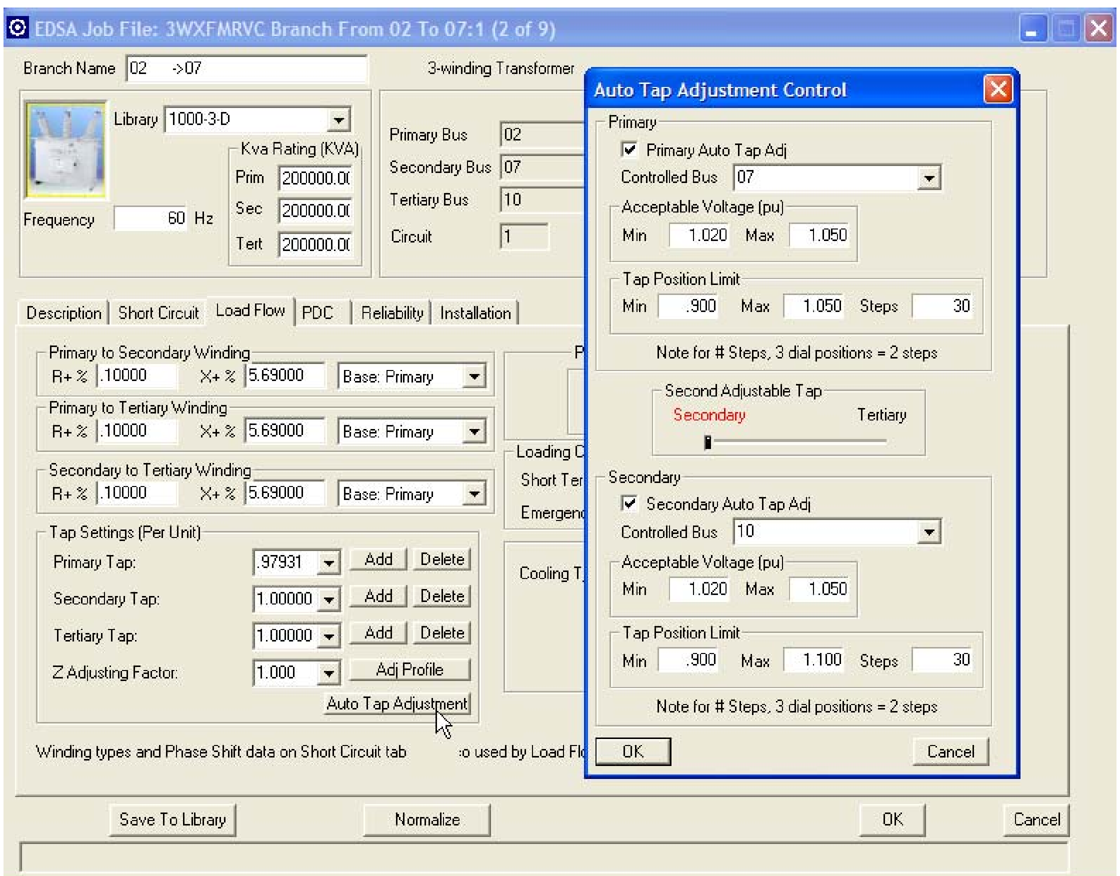
2. Next, proceed to designate the desired three-winding transformer or transformers that will be used as ULTC Control Transformers. Follow the instructions shown in the following screen capture.



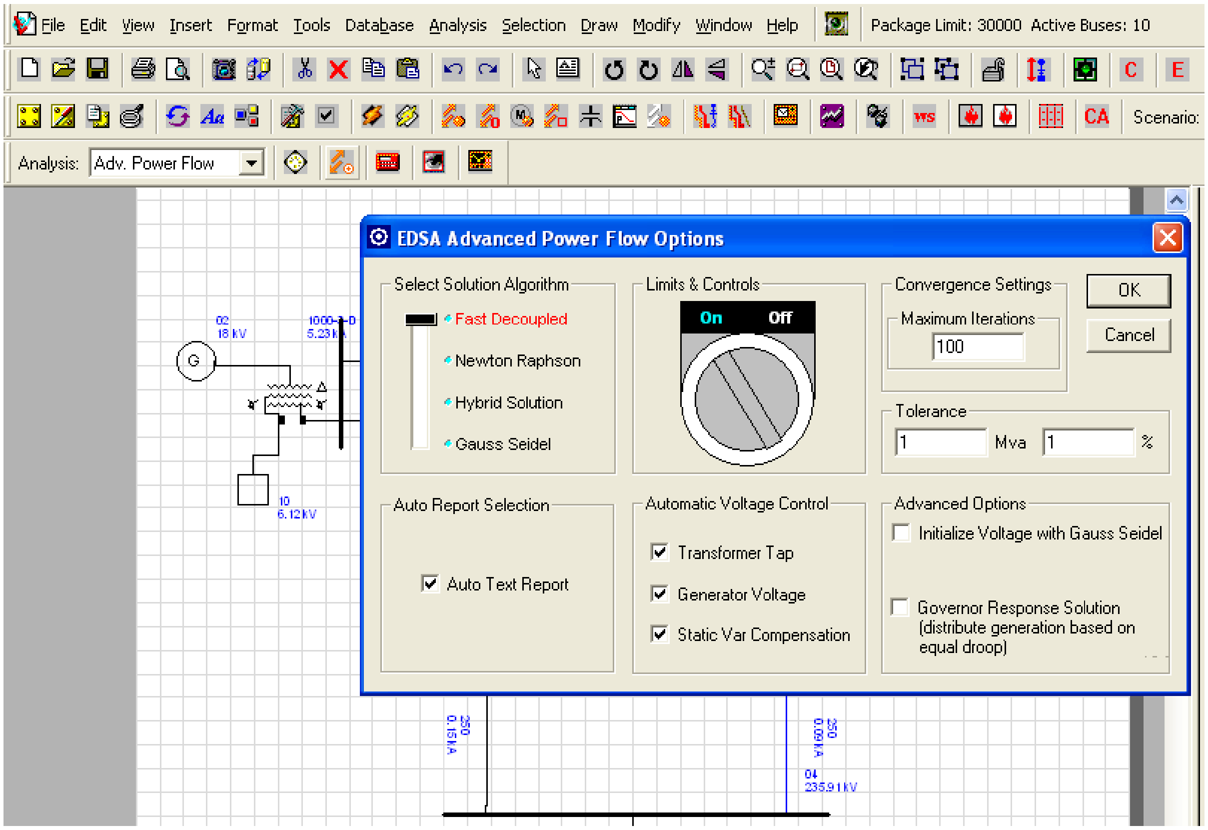
3. Proceed to enter the transformer data as well as the Auto Tap Adjustment Control options for this unit. In this example, the type of control will be defined as follows:

Control Variable:	Voltage
Winding with Taps:	Primary and Tertiary
Controlled Busses:	By Primary > Bus 07
	By Tertiary > Bus 10

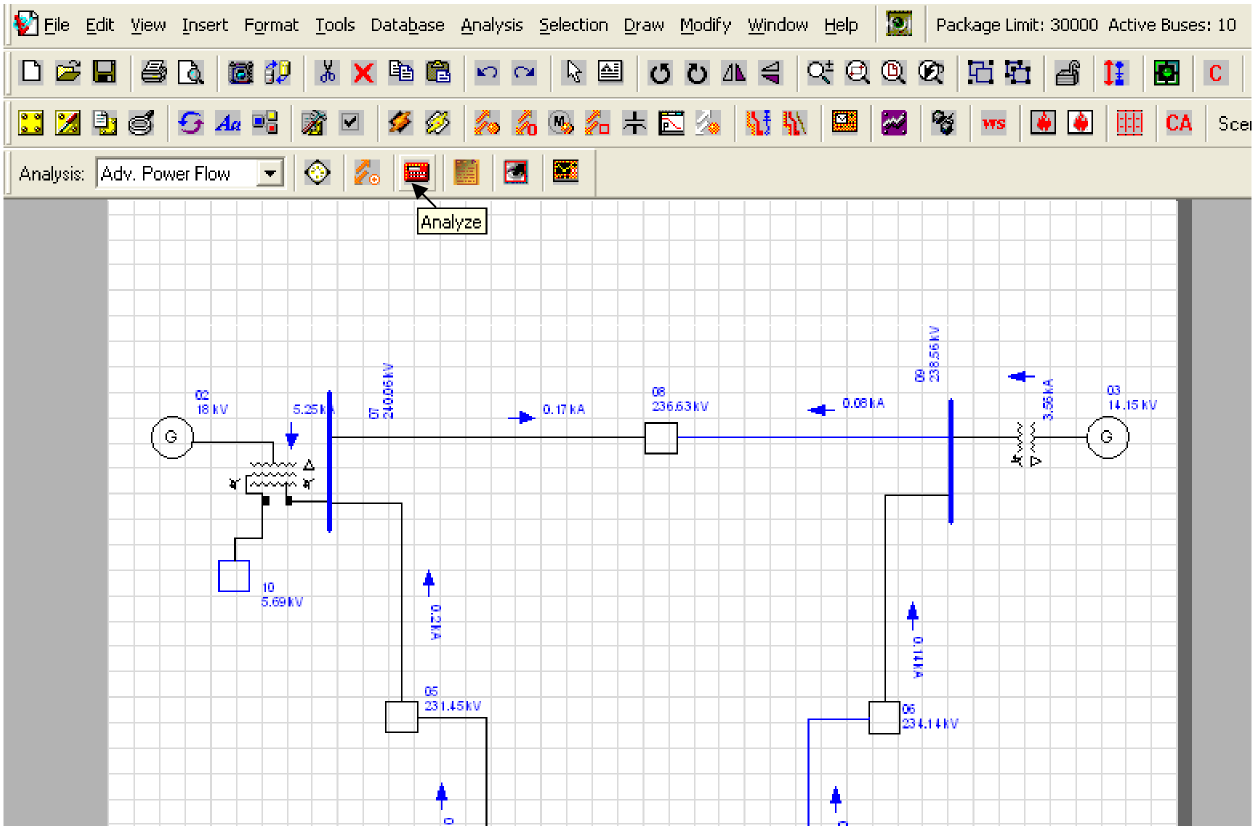
Follow the instructions shown in the following screen capture. Repeat this procedure for as many transformers as necessary. In this example, only one transformer will be equipped with adjustable taps.



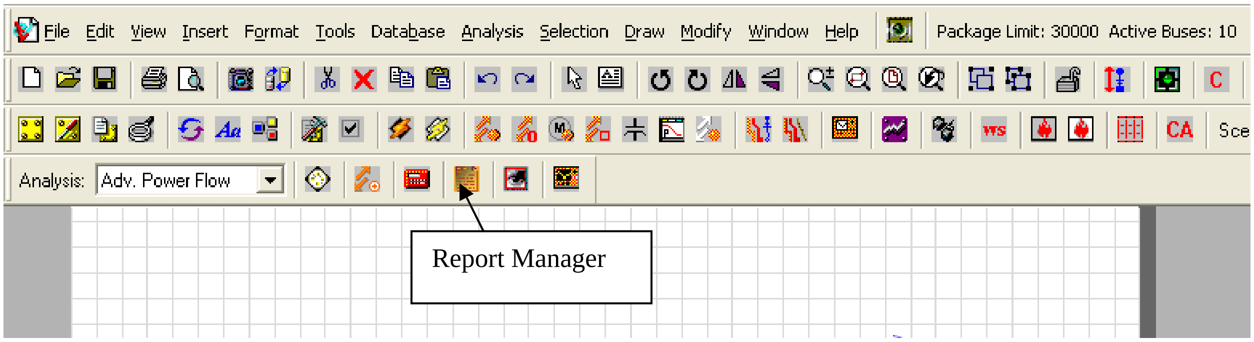
4. Next, proceed to invoke the Advanced Power Flow Options, as indicated in the following screen capture.

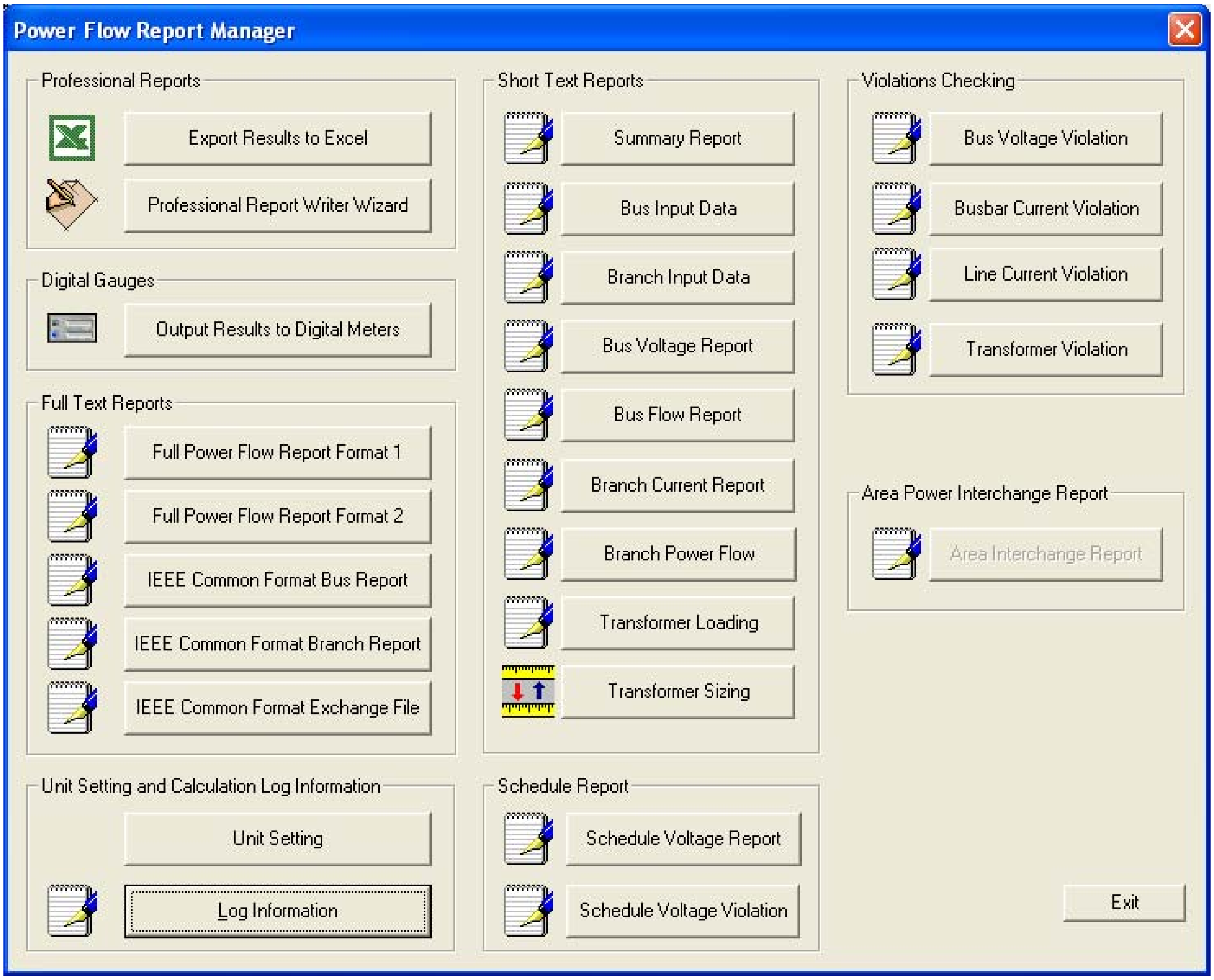


5. Run the analysis by following the instructions shown in the following screen capture.



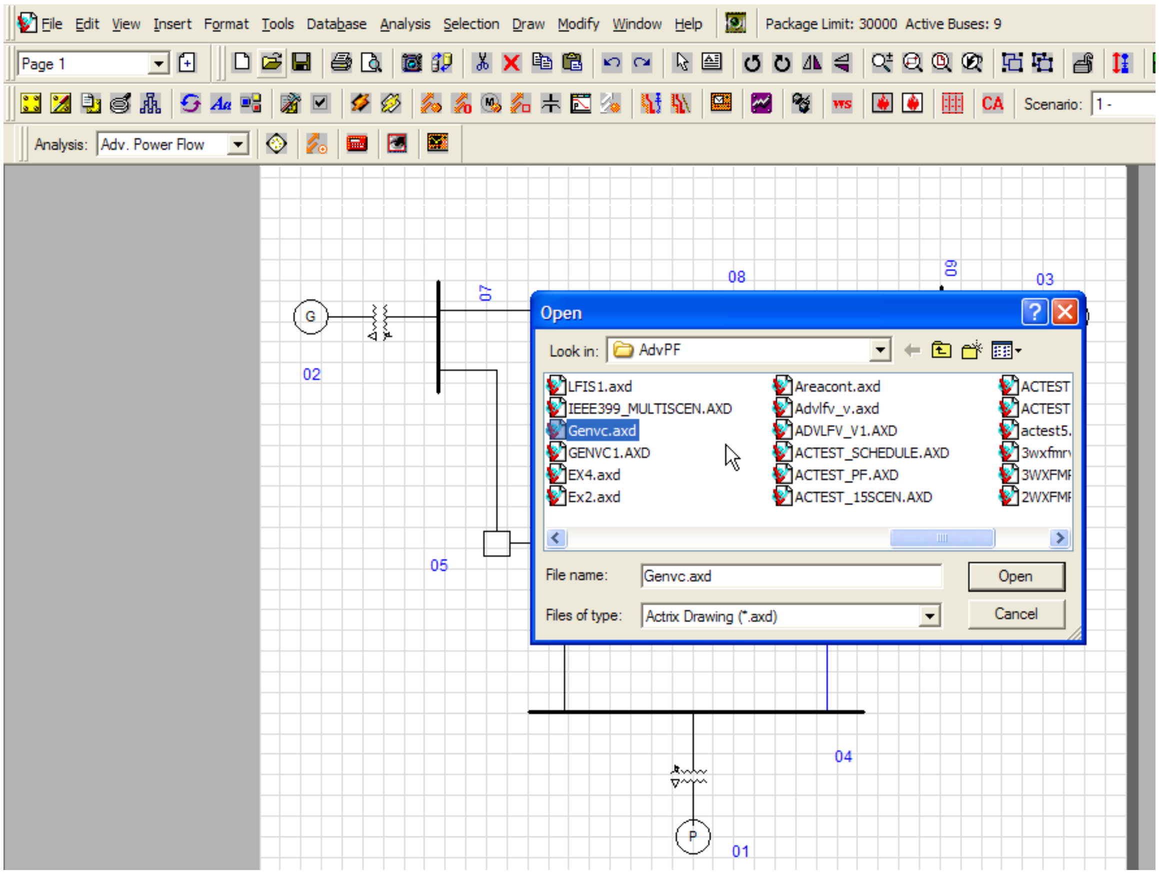
6. Next proceed to view the text output results by following the steps in the above screen capture.



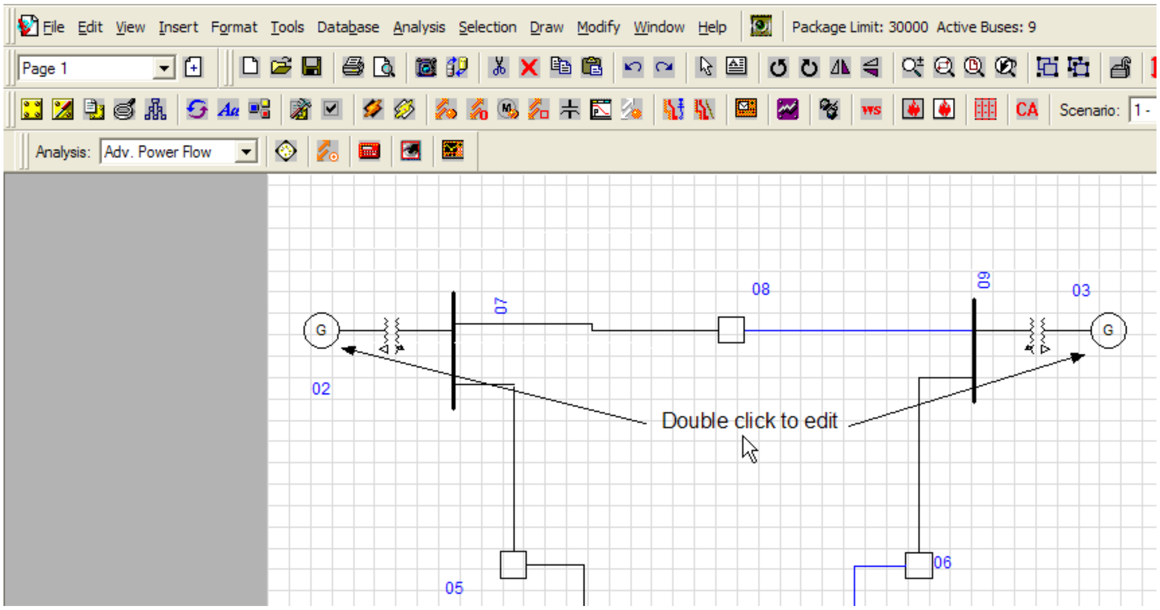


16. Tutorial: Voltage Control Using Generators

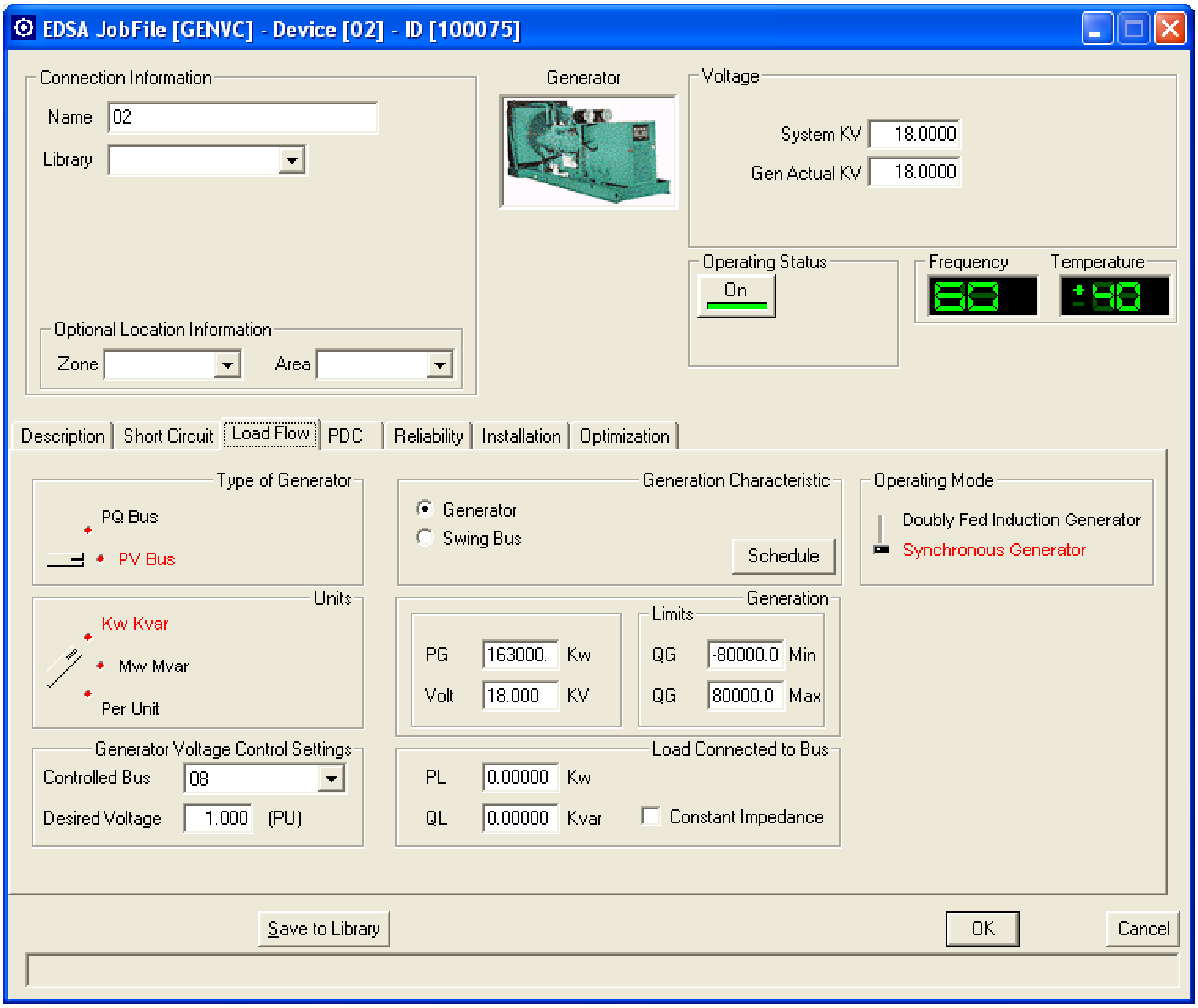
1. Invoke the EDSA interface. Proceed to open the file named "**GENVC**" as indicated in the following screen capture.



2. Next, proceed to designate Generators 2 & 3 as **Voltage Control** units. Follow the instructions shown in the following screen capture.



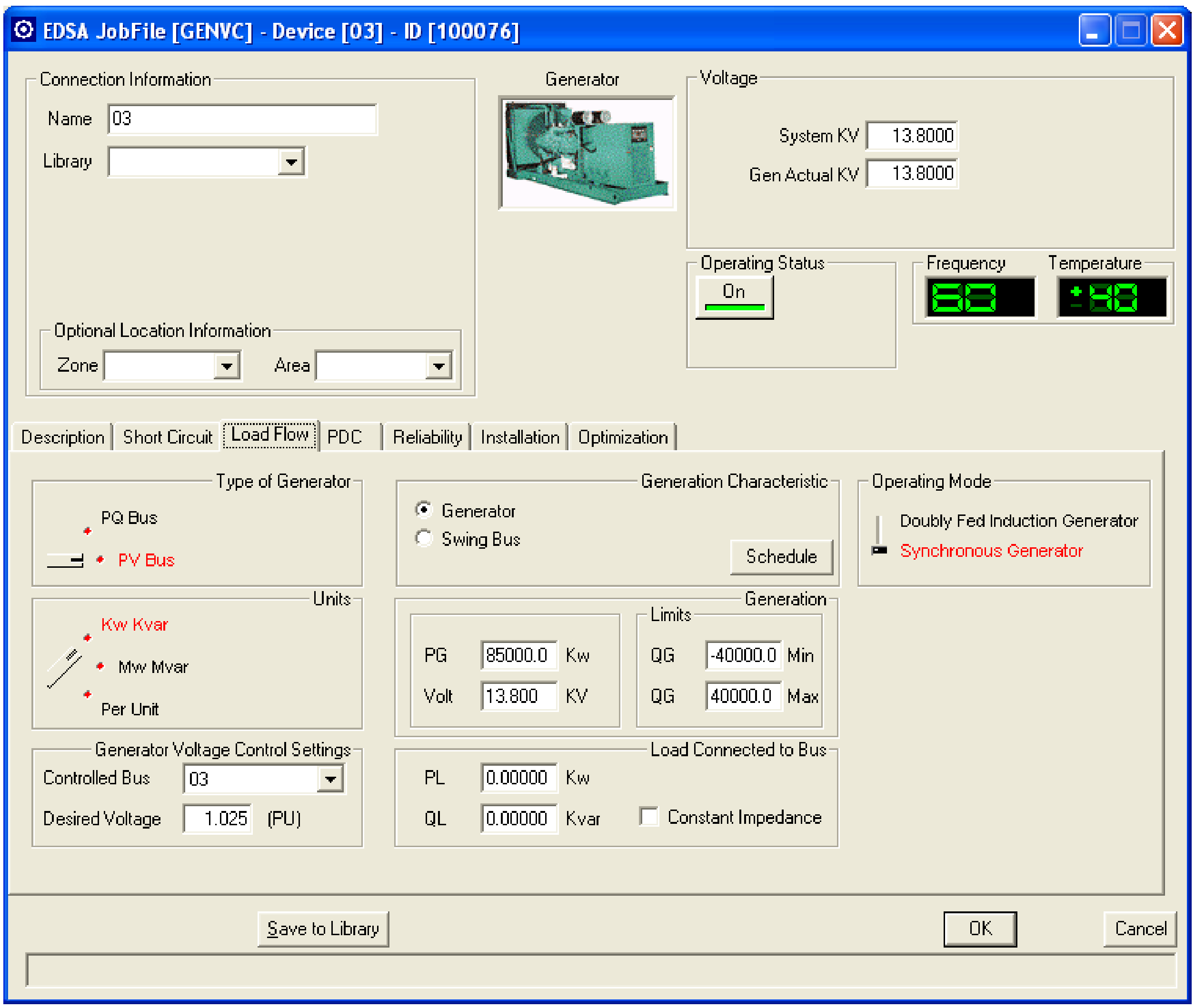
3. Proceed to enter the required data for Generator 2 as indicated in the following screen capture.



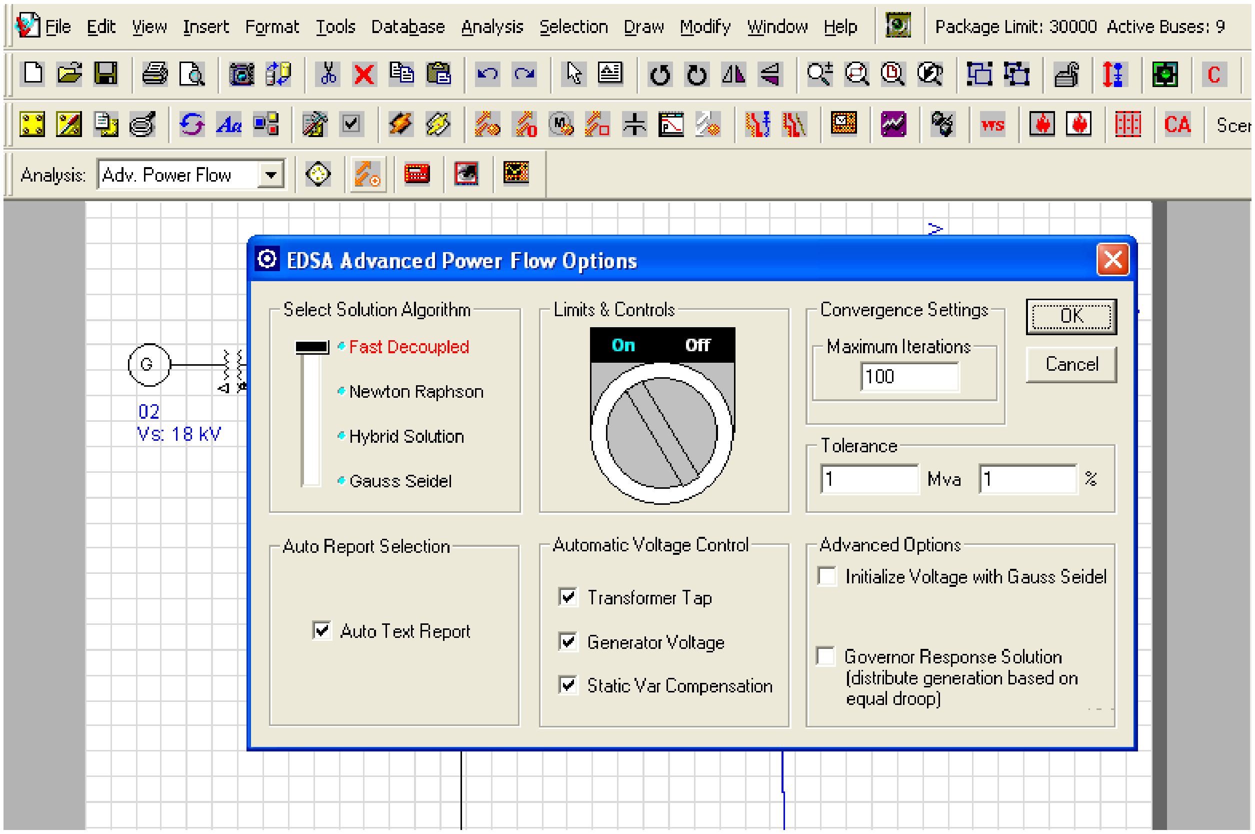
4. Proceed to enter the required data for Generator 3 as indicated in the following screen capture. In those two examples, the type of control will be defined as follows:

Generator 2:	Controlled Bus:	08
	Desired Voltage:	1.00 PU
Generator 3:	Controlled Bus:	03
	Desired Voltage:	1.025 PU

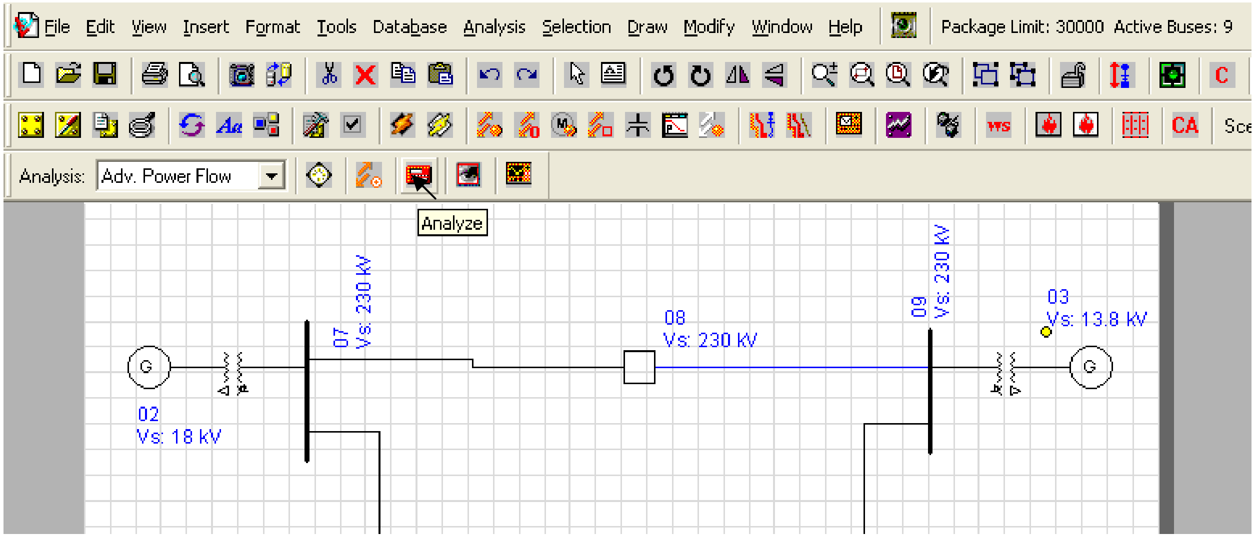
Repeat this procedure for as many generators as necessary. In this example, only two generators will be used for voltage control.



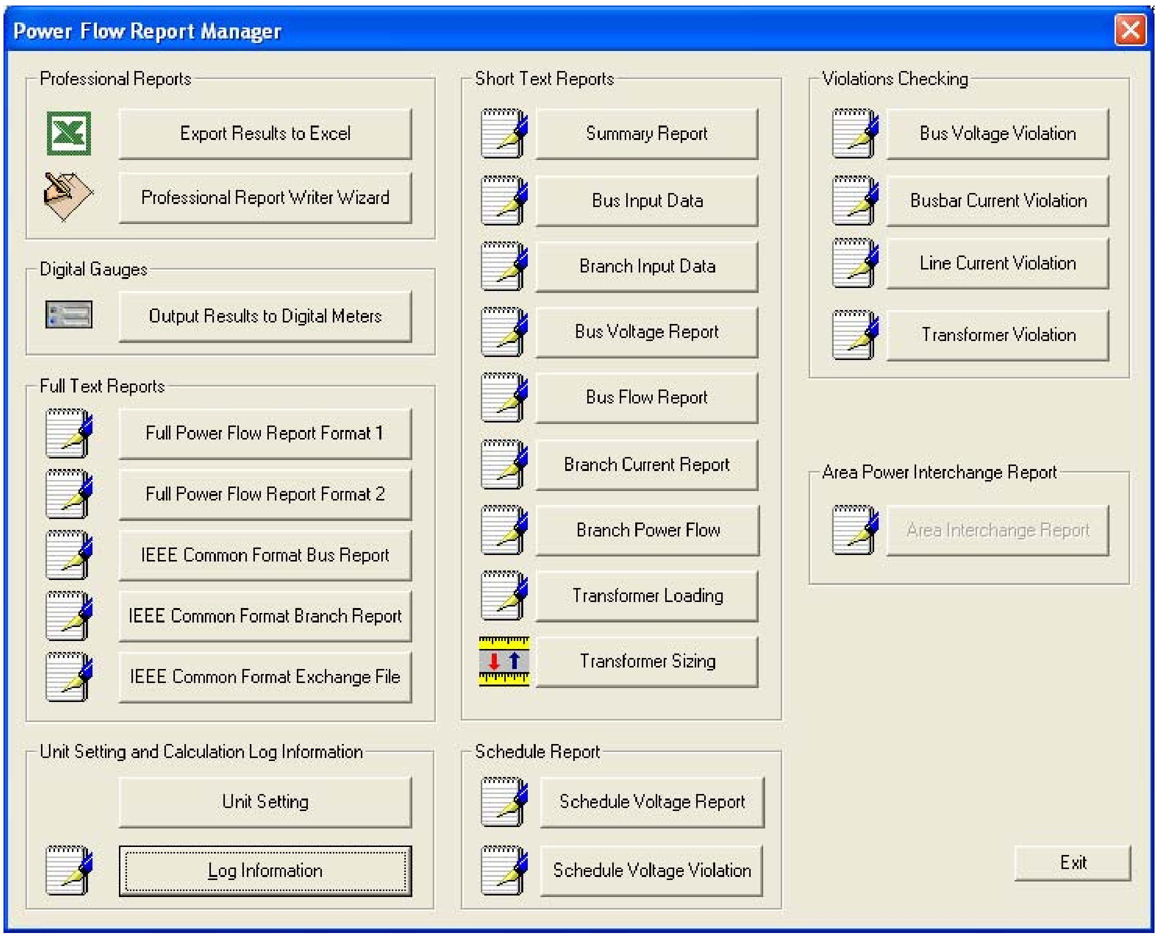
5. Next, proceed to invoke the Advanced Power Flow Options, as indicated in the following screen capture.



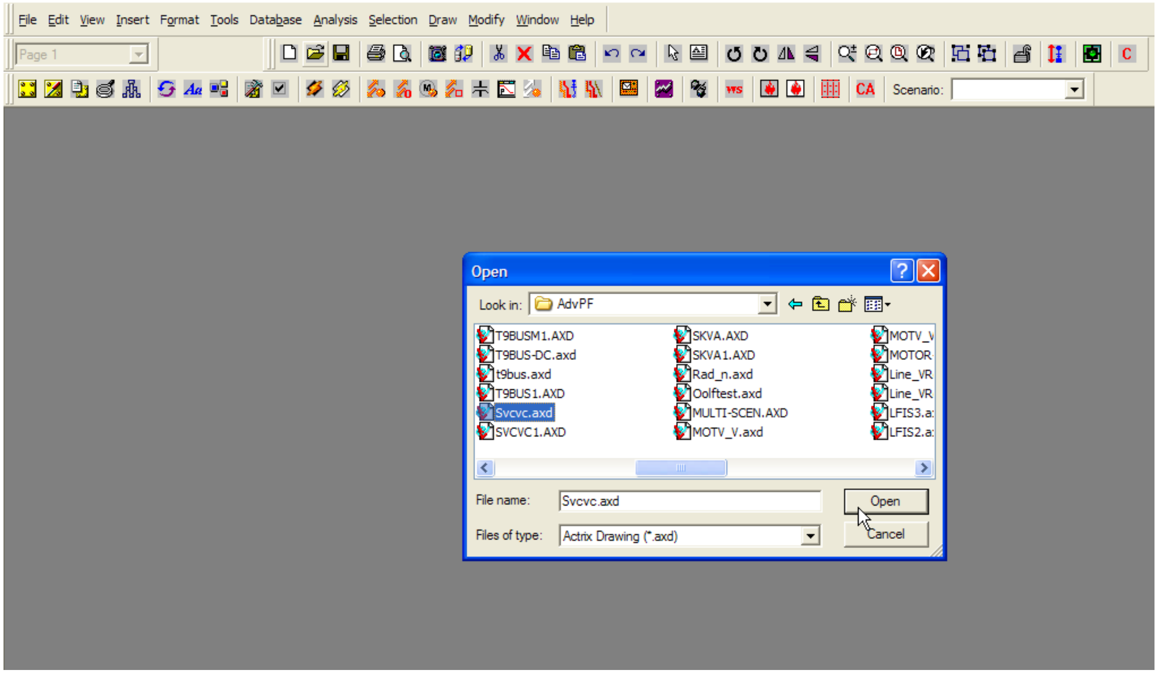
6. Run the analysis by following the instructions shown in the following screen capture, make sure power flow program converges.



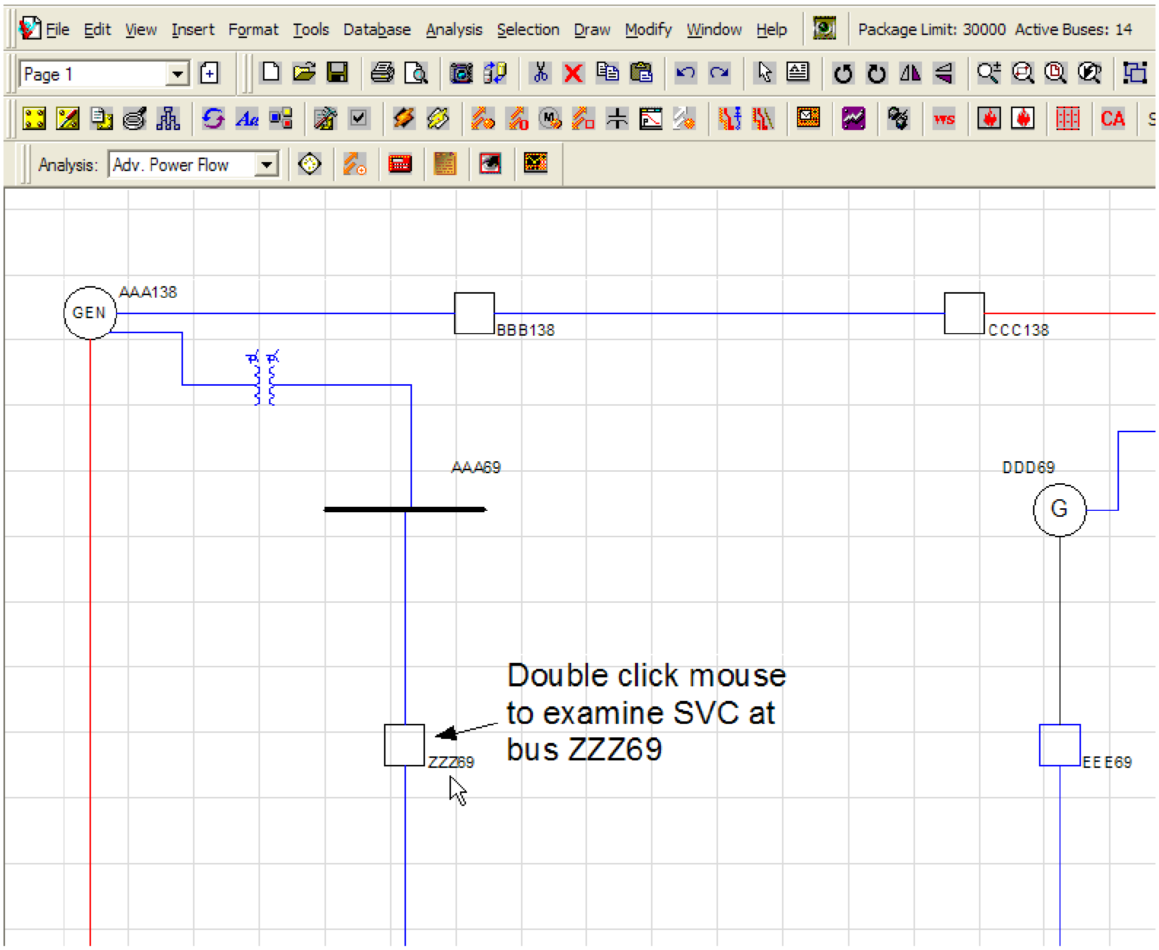
7. Once the calculations have been completed, proceed to select output reports as indicated in the following screen capture.



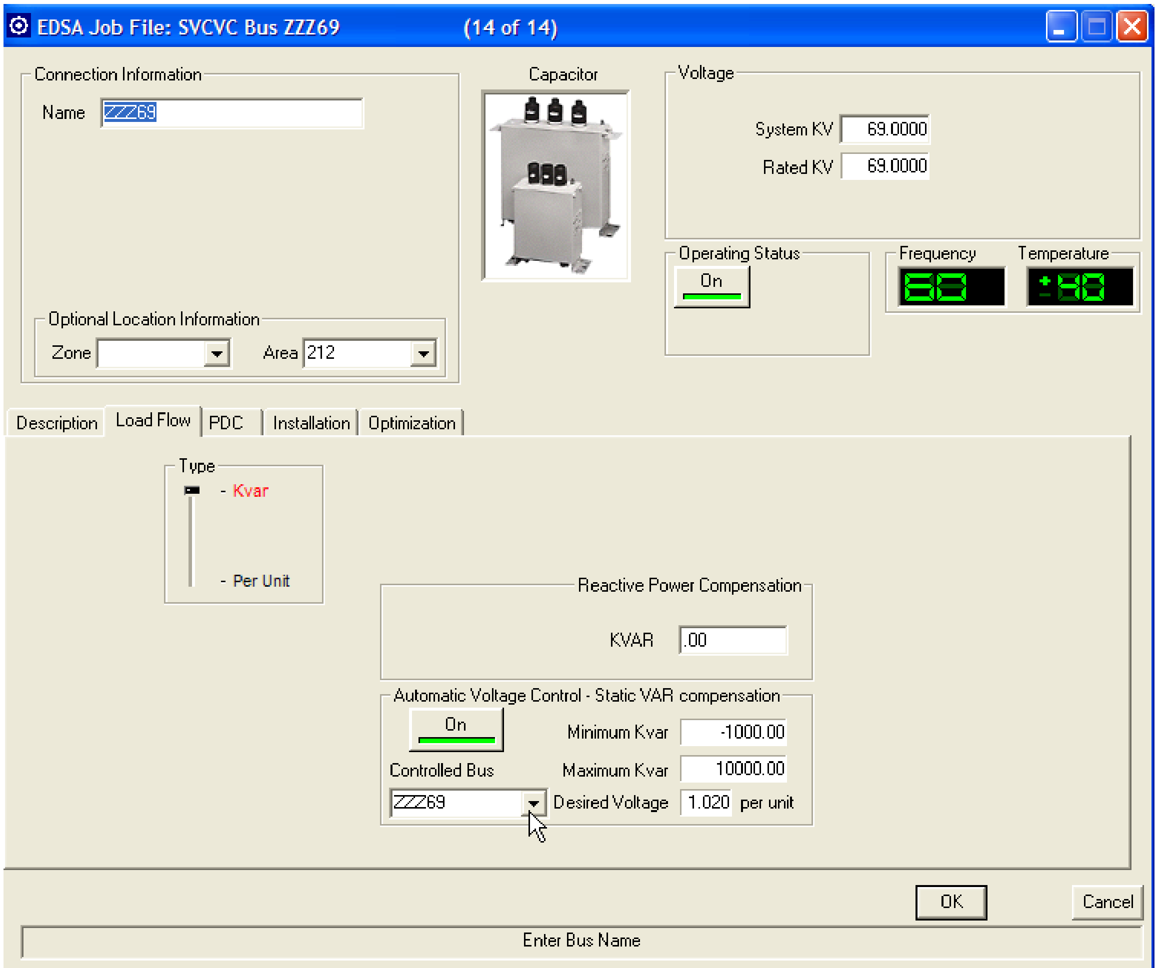
17. Tutorial: Voltage Control Using Static VAR Compensators



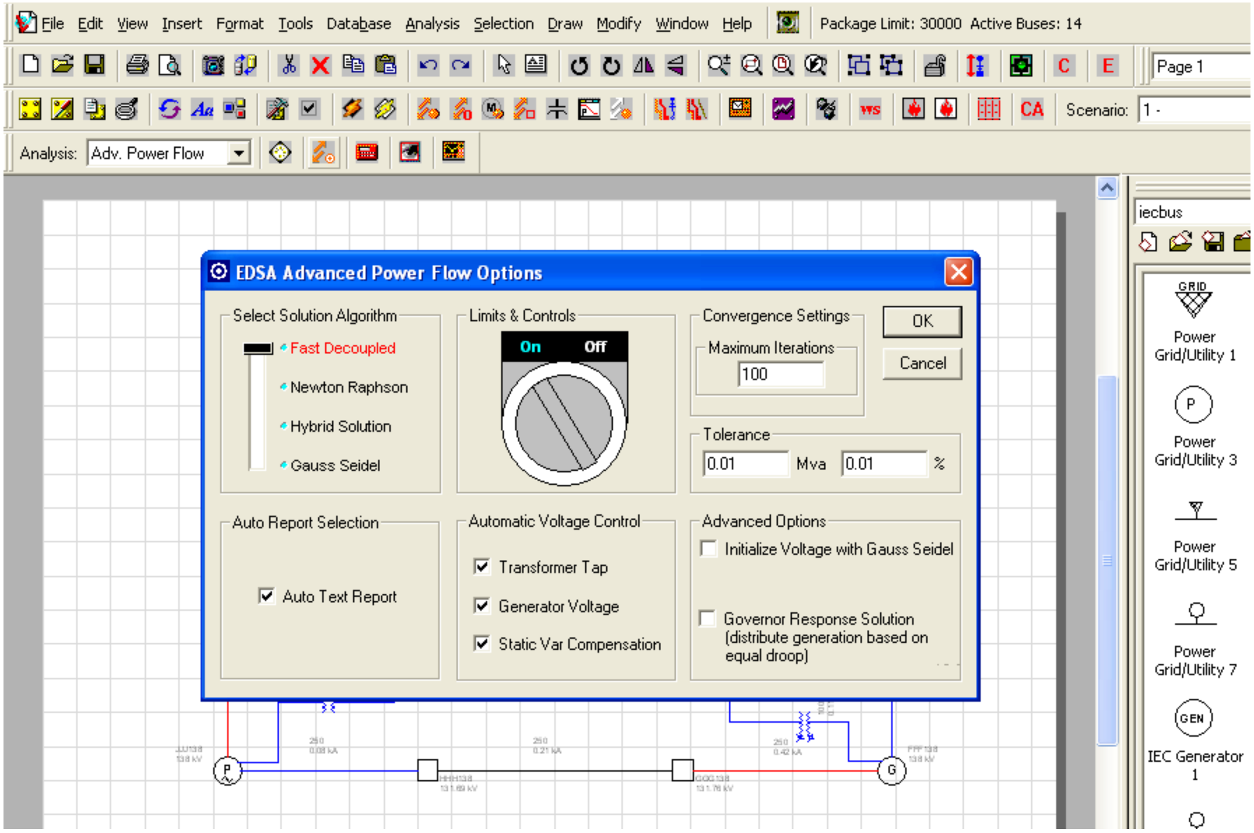
1. Invoke the EDSA interface. Proceed to open the file named "**SVCVC**" as indicated in the above screen capture.



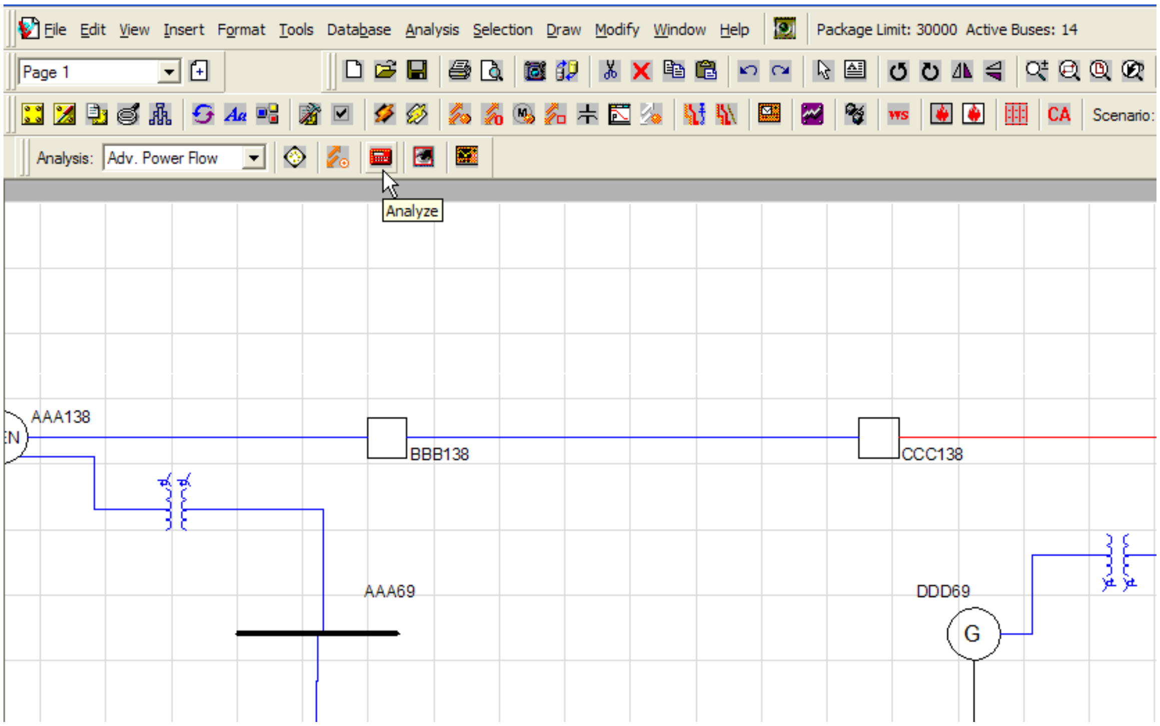
2. Next, proceed to designate Bus ZZZ69 as a Static VAR Compensation Bus. Follow the instructions shown in the above screen capture.



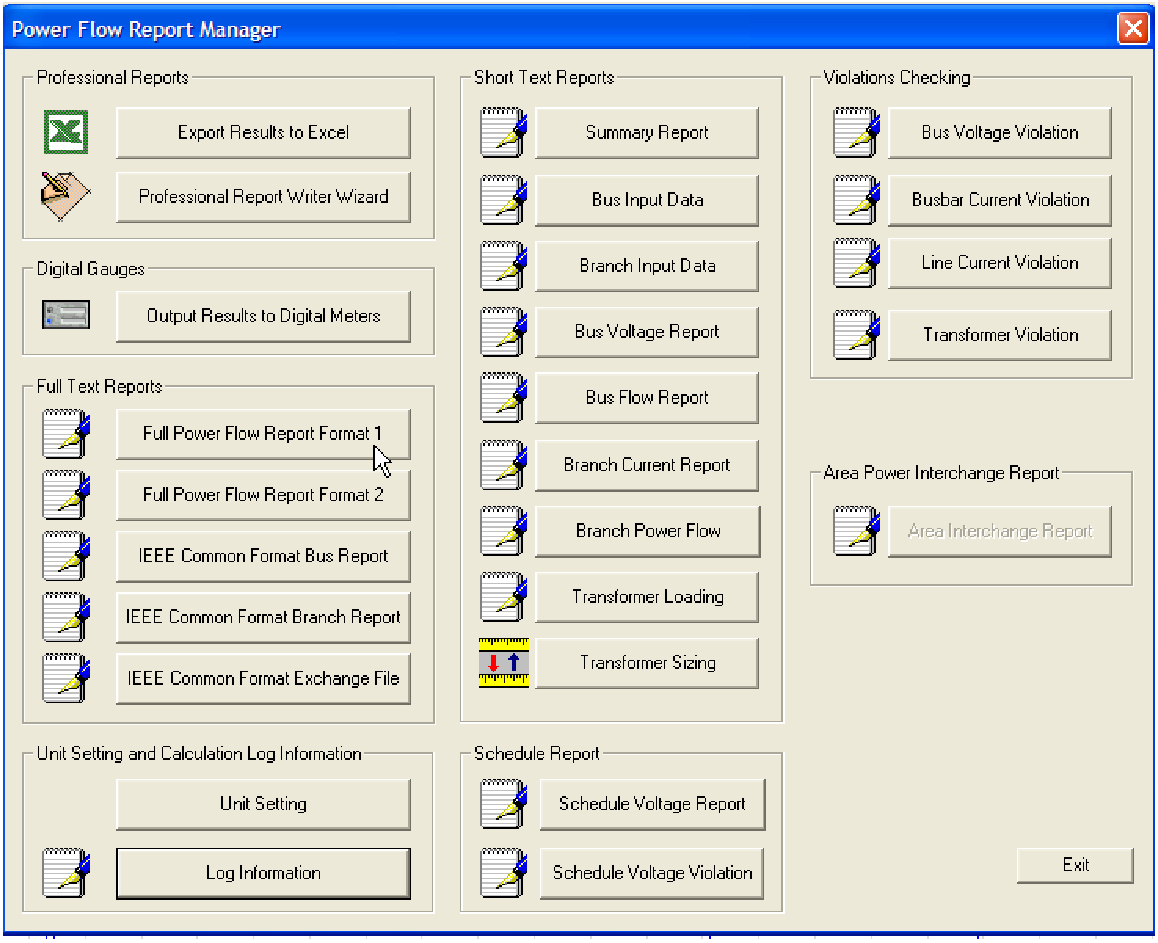
3. Proceed to enter the required data for the SVC Bus, as indicated in the above screen capture. Repeat this procedure for as many SVC's as necessary. In this example, only one SVC will be used for voltage control.



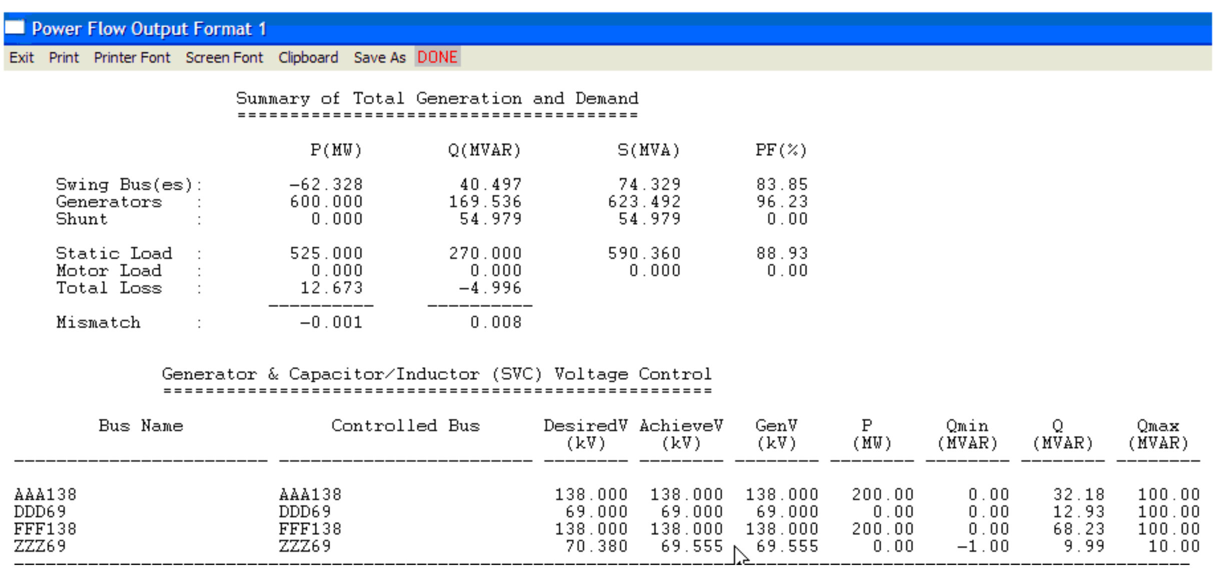
4. Next, proceed to invoke the Advanced Power Flow Program and then the program option, as indicated in the above screen capture.



5. Run the analysis by following the instructions shown in the above screen capture. Make sure the powerflow program converges.



6. Once the calculations have been completed, proceed to view the output report as indicated in the above screen capture.



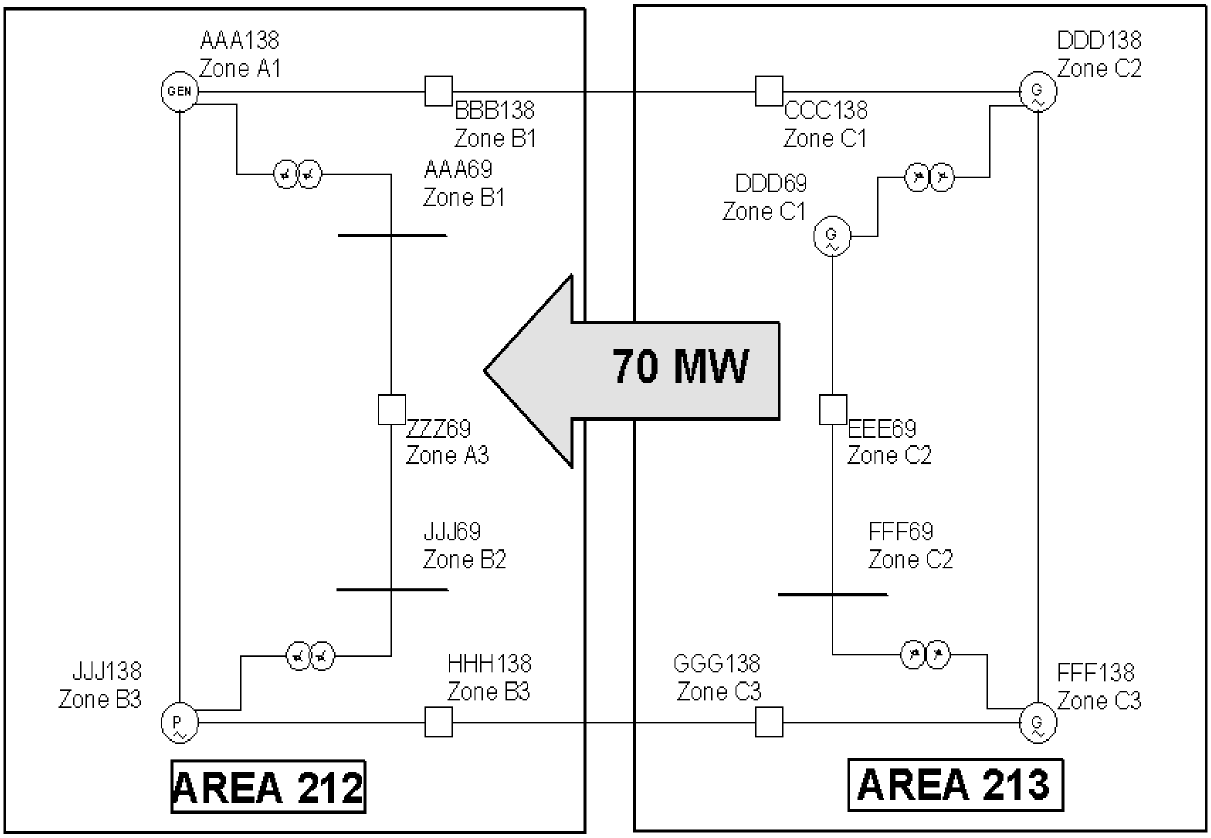
Summary of Total Generation and Demand

	P(MW)	Q(MVAR)	S(MVA)	PF(%)
Swing Bus(es):	-62.328	40.497	74.329	83.85
Generators :	600.000	169.536	623.492	96.23
Shunt :	0.000	54.979	54.979	0.00
Static Load :	525.000	270.000	590.360	88.93
Motor Load :	0.000	0.000	0.000	0.00
Total Loss :	12.673	-4.996		
Mismatch :	-0.001	0.008		

Generator & Capacitor/Inductor (SVC) Voltage Control

Bus Name	Controlled Bus	DesiredV (kV)	AchieveV (kV)	GenV (kV)	P (MW)	Qmin (MVAR)	Q (MVAR)	Qmax (MVAR)
AAA138	AAA138	138.000	138.000	138.000	200.00	0.00	32.18	100.00
DDD69	DDD69	69.000	69.000	69.000	0.00	0.00	12.93	100.00
FFF138	FFF138	138.000	138.000	138.000	200.00	0.00	68.23	100.00
ZZZ69	ZZZ69	70.380	69.555	69.555	0.00	-1.00	9.99	10.00

18. Tutorial: Area Control



Area Controlled Network Under Study

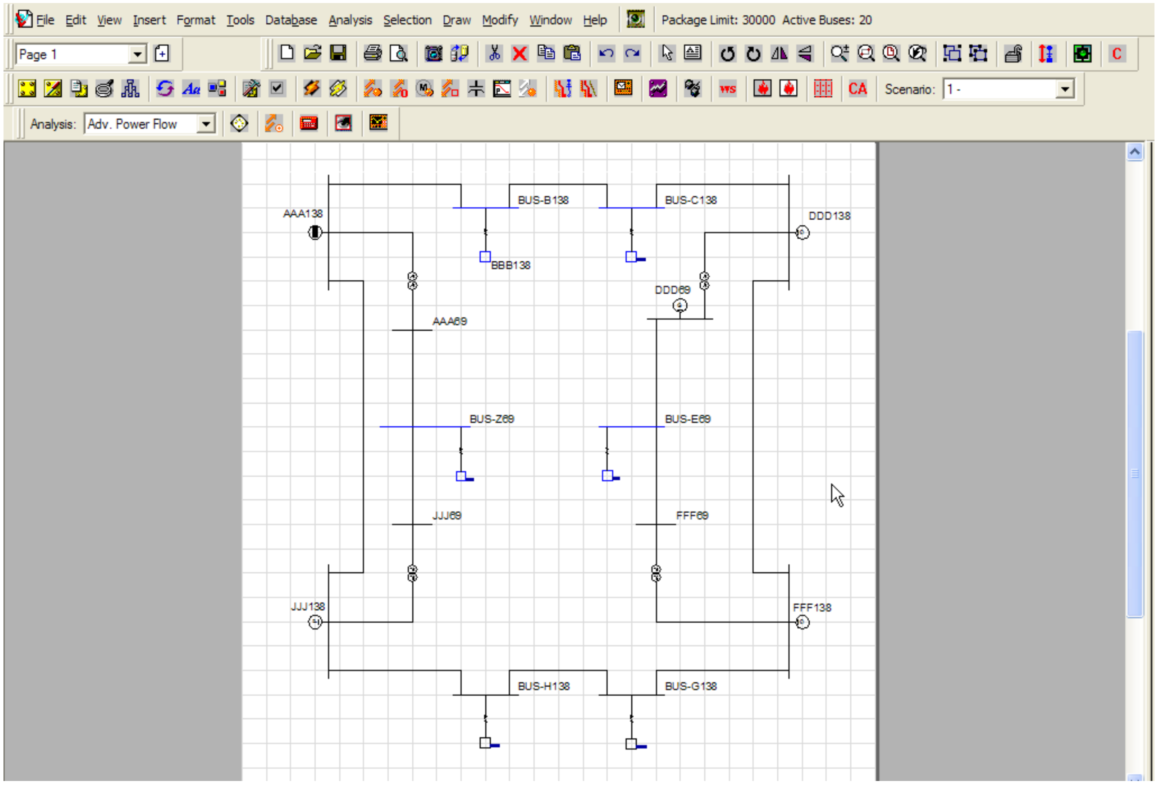
This tutorial will be based on the network shown above. This power system has been subdivided into two Areas (212 & 213) as indicated above. In turn, each node within these areas belongs to its own Zone, also as indicated in the figure. The intent here is to export 70 MW from Area 213 into Area 212. Each area has the following operational characteristics:

a. AREA 212

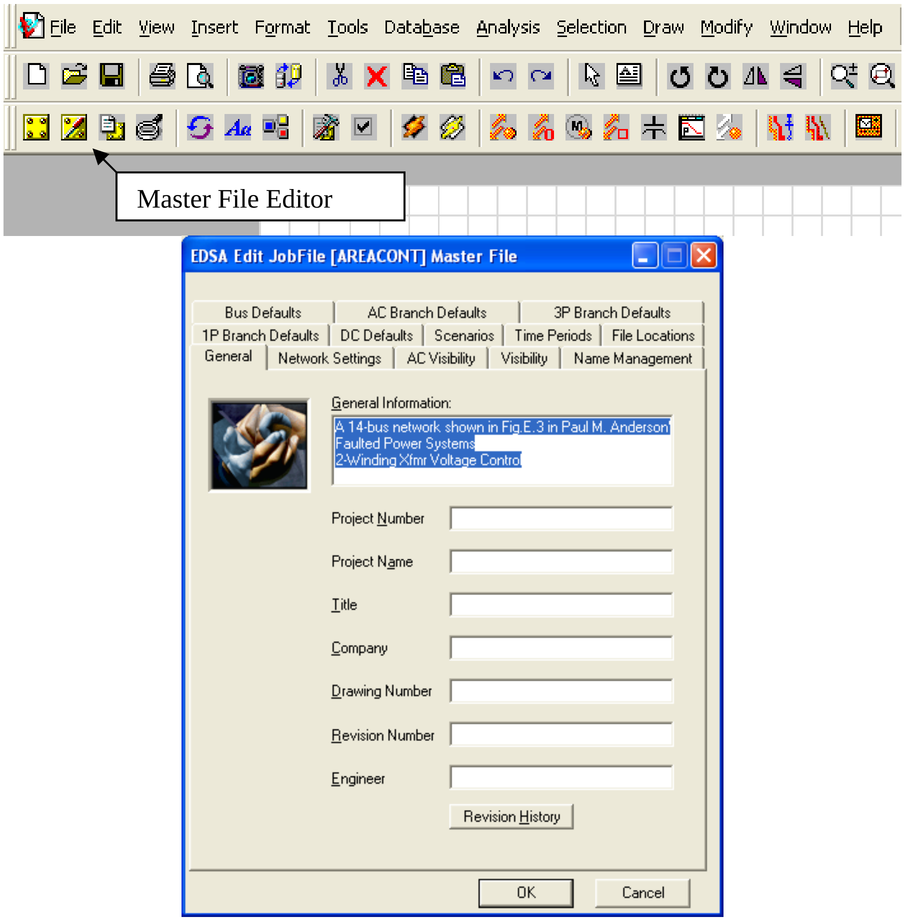
Zones:	B3, A1, B1, B2, A3
Area Control Generator ID:	AAA138
Maximum Active Generation =	200.000 MW
Minimum Active Generation =	10.000 MW
Desired Net **Import** Active Power =	70.000 MW
Power Exchange Tolerance=	5.000 MW

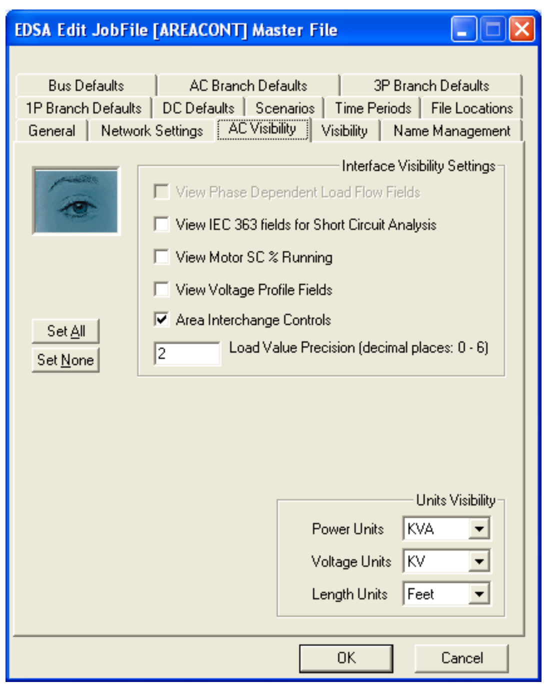
b. AREA 213

Zones:	C2, C1, C3
Area Control Generator ID:	DDD138
Maximum Active Generation =	200.000 MW
Minimum Active Generation =	6.000 MW
Desired Net **Export** Active Power =	70.000 MW
Power Exchange Tolerance =	5.000 MW

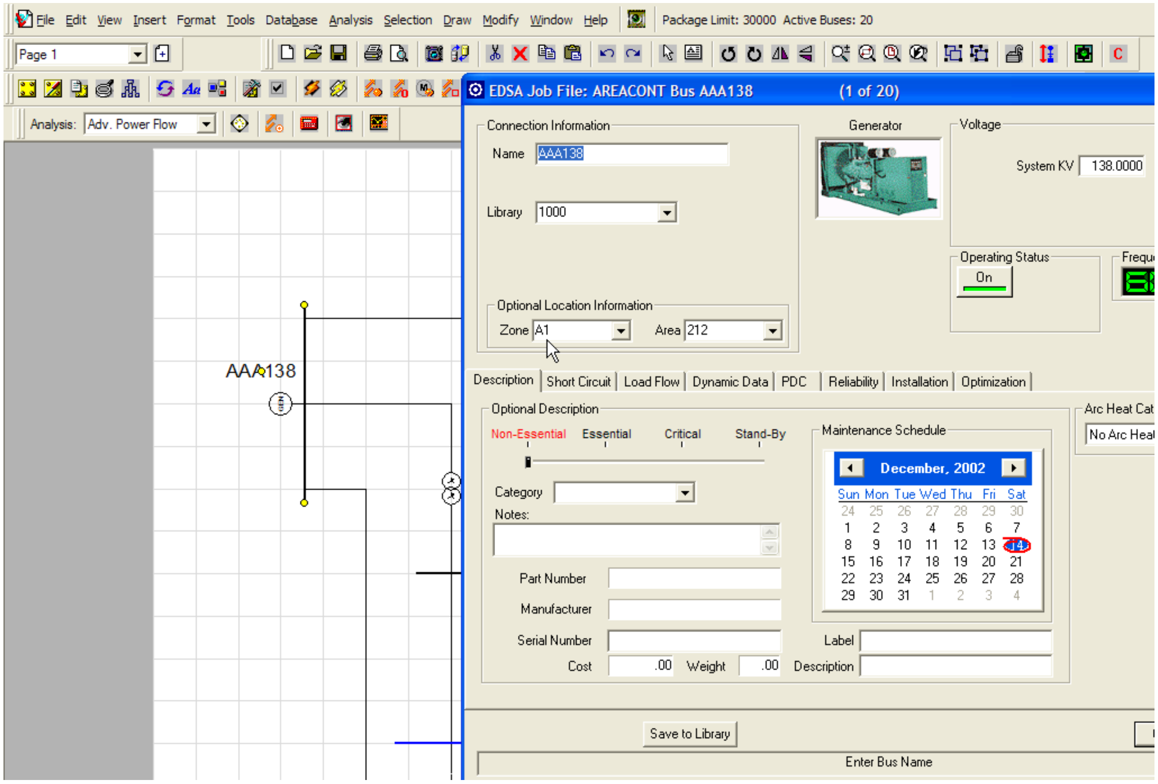


1. Invoke the EDSA, and proceed to load the pre-arranged file called "**Areacont.axd**". The network should look as indicated in the above screen capture.

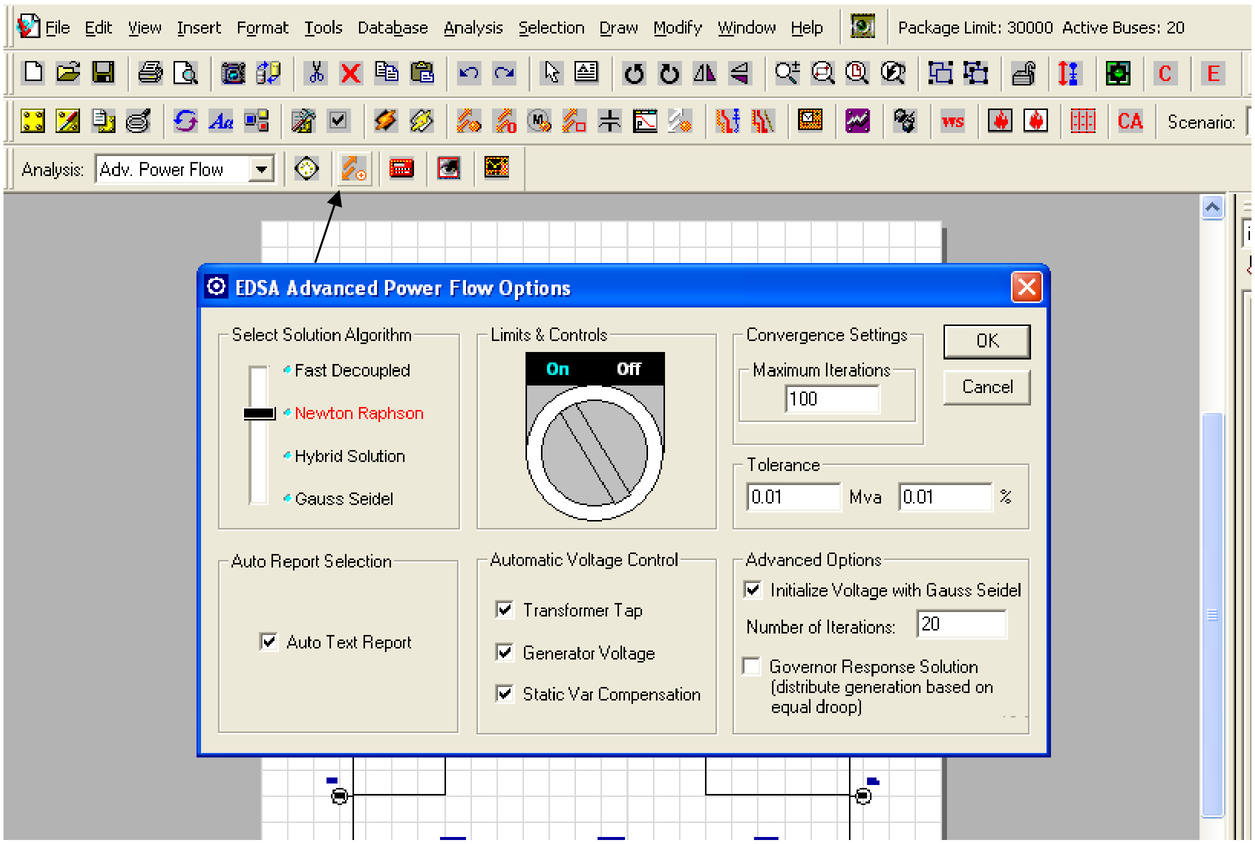




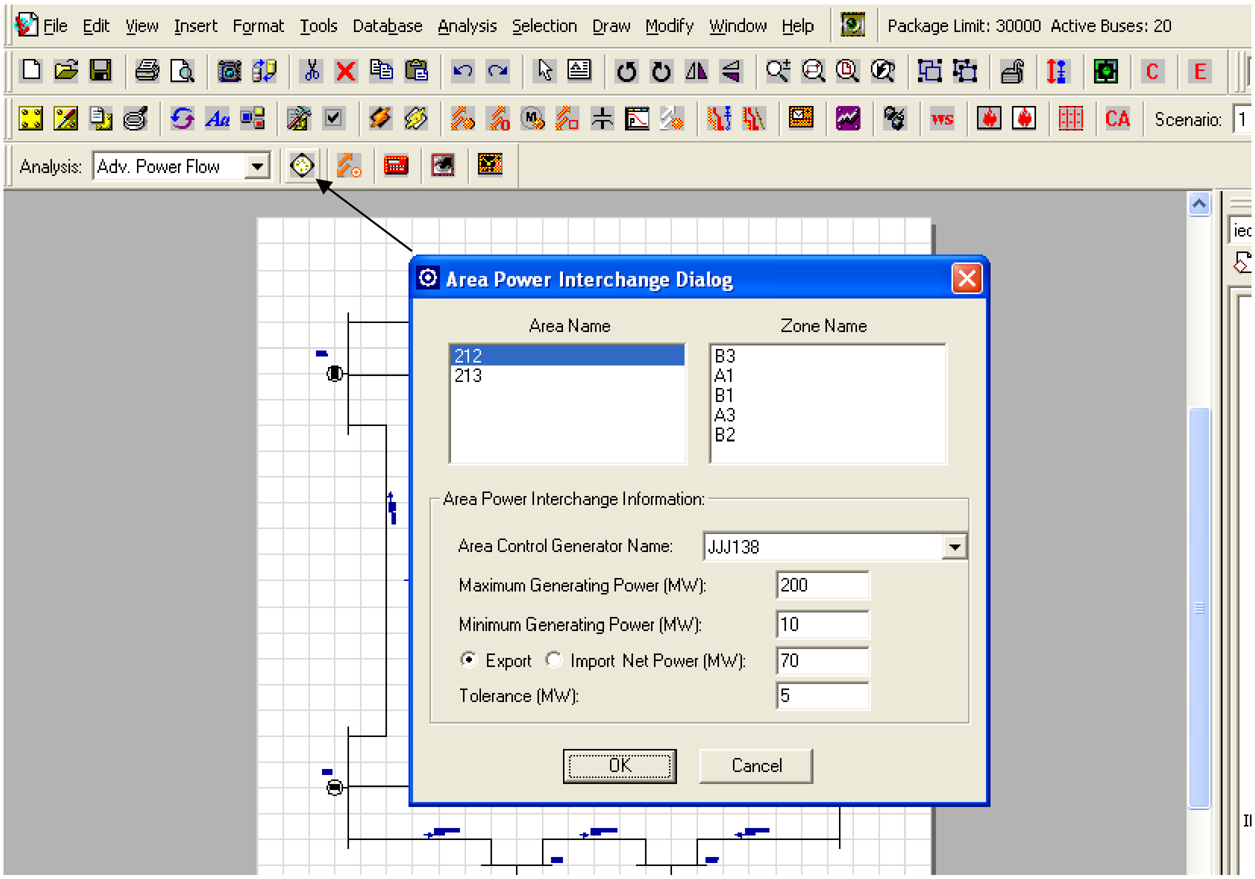
2. Enable the Area Interchange Control command, as indicated in the above screen capture.



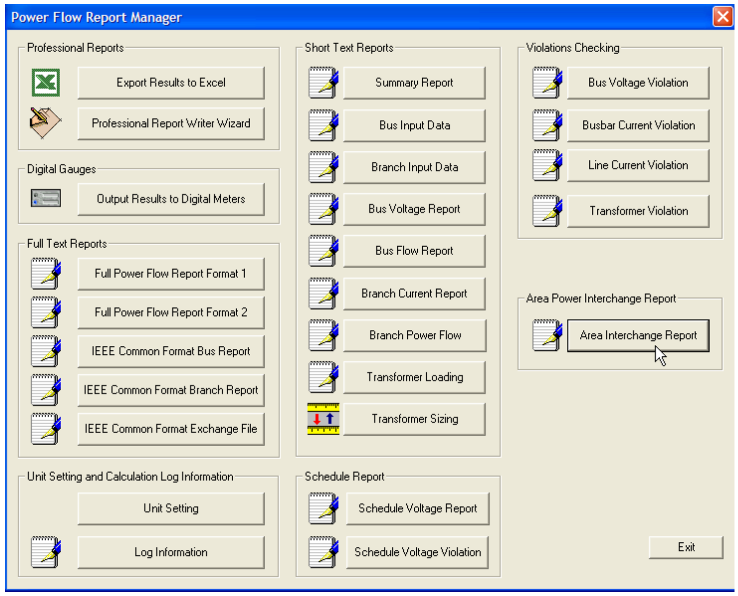
3. Proceed to assign the Area and Zone information to every bus in the network, according to the information provided previously. Follow the instructions shown in the above screen capture, and repeat these instructions for every single bus in the network.



4. Proceed to invoke the Advanced Power Flow program, as indicated in the above screen capture.



5. Specify the Area Control parameters and run the Load Flow analysis, as indicated in the above screen capture.




```
                  Area ID : 212
                  =============
Zone:
B3, A1, B1, A3, B2
Area Control Generator Name             : AAA138
Maximum Active Generation               = 200.000 MW
Minimum Active Generation               = 10.000 MW
Desired Net Export Active Power         = 70.000 MW
Power Exchange Tolerance                = 5.000 MW

Actual Net Export Active Power          = 70.100 MW
Total Area Active Generation            = 310.880 MW
Total Area Reactive Generation          = 73.740 MVAR
Total Area Shunt Capacitor              = 44.410 MVAR
Total Area Shunt Inductor               = 0.000 MVAR
Total Area Active Load                  = 225.000 MW
Total Area Reactive Load                = 120.000 MVAR
Total Area Active Loss                  = 15.780 MW
Total Area Reactive Loss                = 30.150 MVAR

                  Area ID : 213
                  =============
Zone:
C2, C1, C3
Area Control Generator Name             : DDD138
Maximum Active Generation               = 200.000 MW
Minimum Active Generation               = 6.000 MW
Desired Net Export Active Power         = -70.000 MW
Power Exchange Tolerance                = 5.000 MW

Actual Net Export Active Power          = -70.100 MW
Total Area Active Generation            = 261.840 MW
Total Area Reactive Generation          = 130.500 MVAR
Total Area Shunt Capacitor              = 8.620 MVAR
Total Area Shunt Inductor               = 0.000 MVAR
Total Area Active Load                  = 325.000 MW
Total Area Reactive Load                = 170.000 MVAR
Total Area Active Loss                  = 6.930 MW
Total Area Reactive Loss                = -6.690 MVAR
```

6. Once the calculations are completed, the results are shown in the ***Advanced Power Flow Output*** screen for “Area Power Interchange”.

19. Tutorial: Using DC Lines and Verification and Validation

In this section we will show how to use DC lines in a power system. The sample power system is defined in the jobfile named “T9bus-dc”. The single line diagram of this system is shown below:

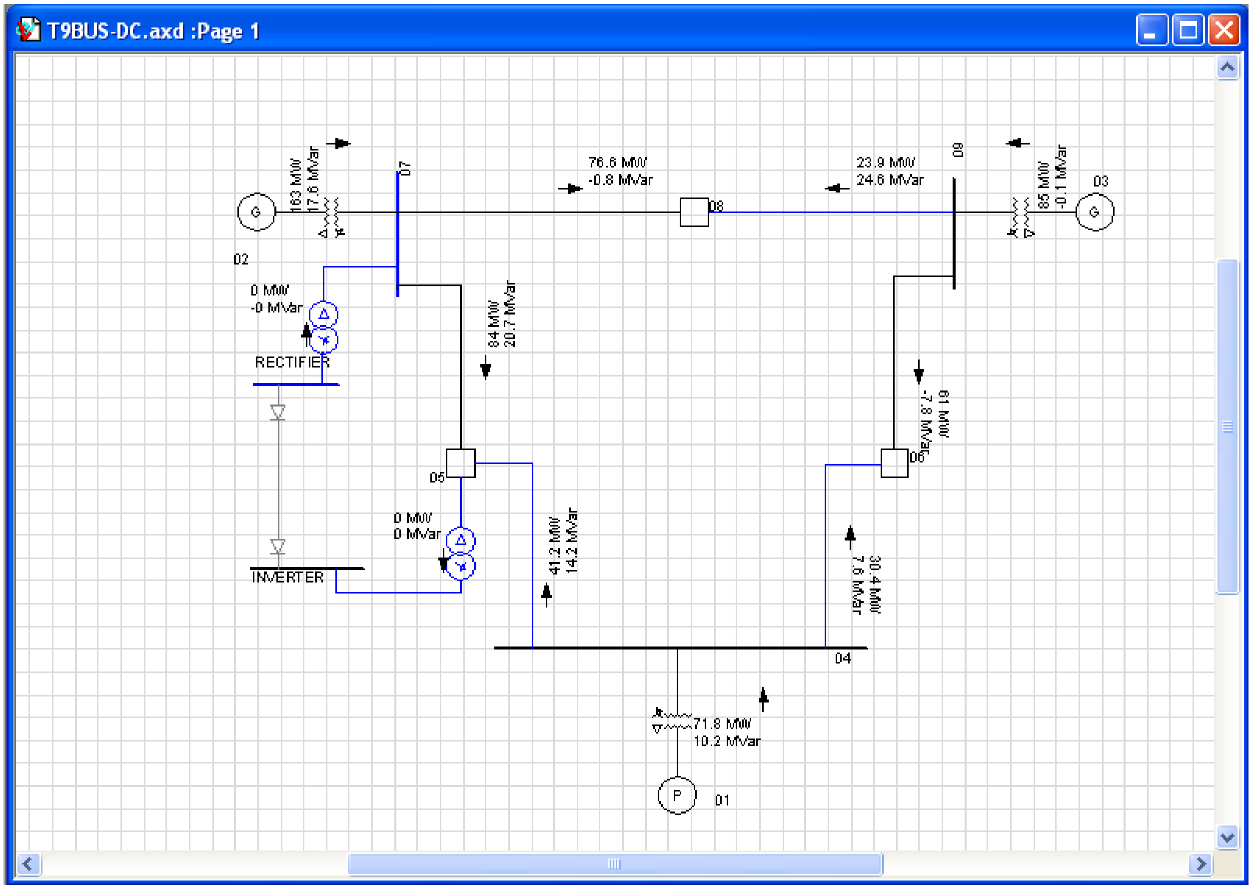


Figure 9: Sample Power System used for DC Line Tutorial

A DC line has several components that are required for its proper operation. These are:

1. Rectifier Transformer
2. Rectifier
3. DC Line
4. Inverter
5. Invert Transformer

To be able to use a DC line in a power system, the user should make sure that the above components are modeled. Items 1 and 5 should be modeled similar to a normal “voltage regulating/control” transformer. In the sample network we have modeled two voltage regulation transformers one for the rectifier (between buses “7” and “RECTIFIER”) and the other for the inverter (between buses “INVERTER” and “05”) as shown in Figure 9. Items 2 through 4 above are addressed in the DC line dialog. To insert a DC line, select its symbol from the branch catalog as shown in Figure 10:

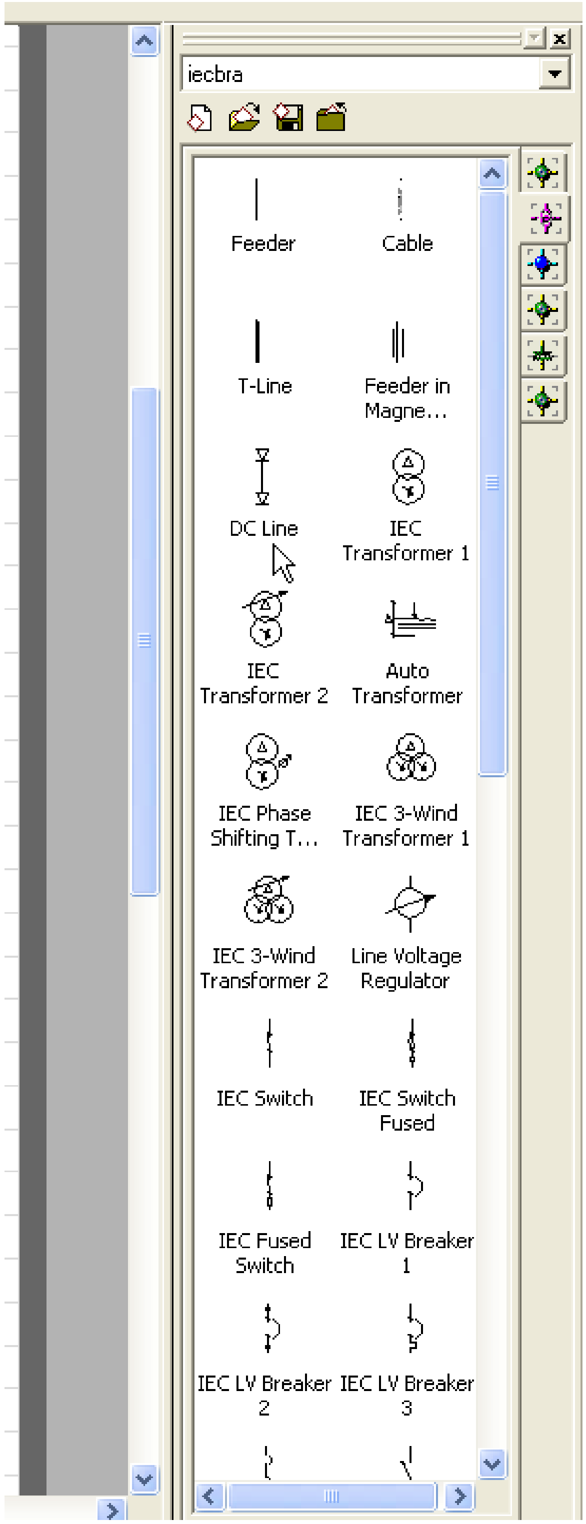


Figure 10: Selecting DC line Symbol

After selecting the DC line symbol drag it into single line diagram area and connect it to the buses “RECTIFIER” and “INVERTER” as seen in Figure 9.

To enter the DC line data, double left mouse click on its symbol. The data dialog is shown below:

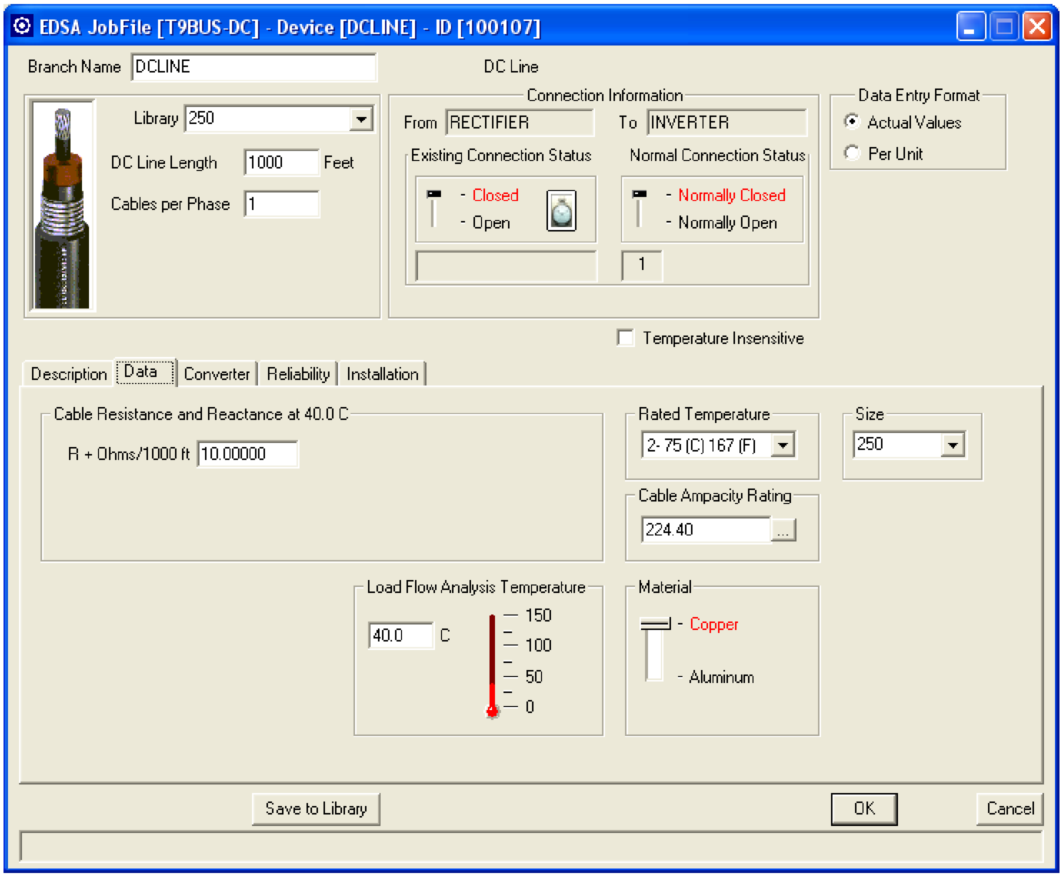


Figure 11: DC Line Data Dialog

DC line identification (branch name), resistance, and ampacity are specified in this section of data dialog. Next select “Converter” tab to enter data for the rectifier and inverter:

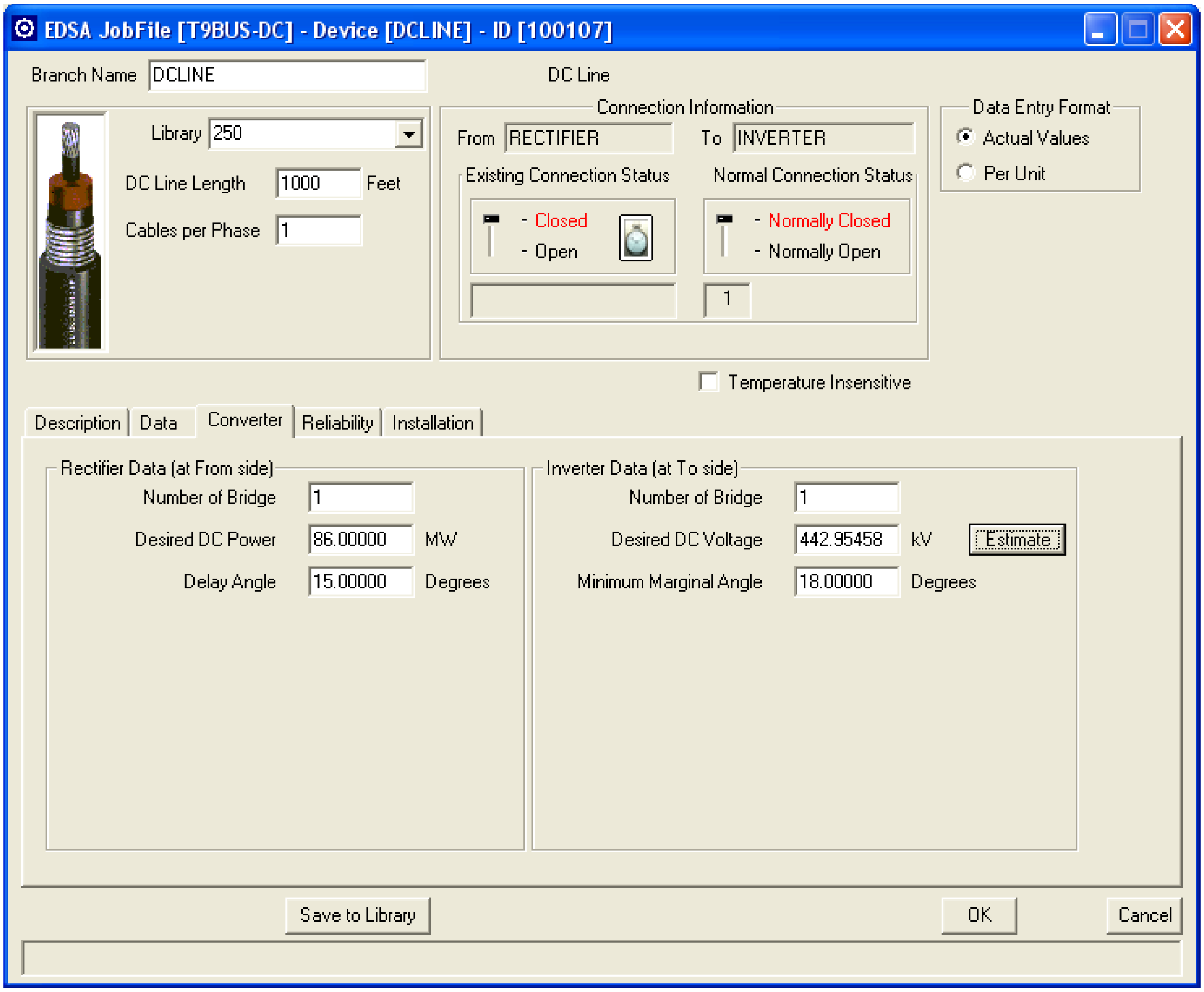


Figure 12: DC Line Data Dialog - Rectifier and Inverter

It is important to notice that the rectifier is always on the “From” side and inverter is on the “To” side as shown in the upper right part of the Figure 12. For both rectifier and inverter the user should specify number of bridges. For rectifier, the desired delay (also known as firing) angle as well as desired active power flow through DC line should be entered. For inverter, the minimum marginal angle (also known as extinction) angle as well as desired DC line voltage needs to be specified. The proper selection of the DC line voltage is crucial to DC line operation and solution convergence. To assist the user, the program can suggest an approximate value of the DC line voltage. Press “Estimate” button shown next to the field for “Desired DC Voltage”. For case at hand the program has calculated a value of 442.95 kV as shown in the above figure. For this example, let’s enter 450 kV as shown in Figure 13.

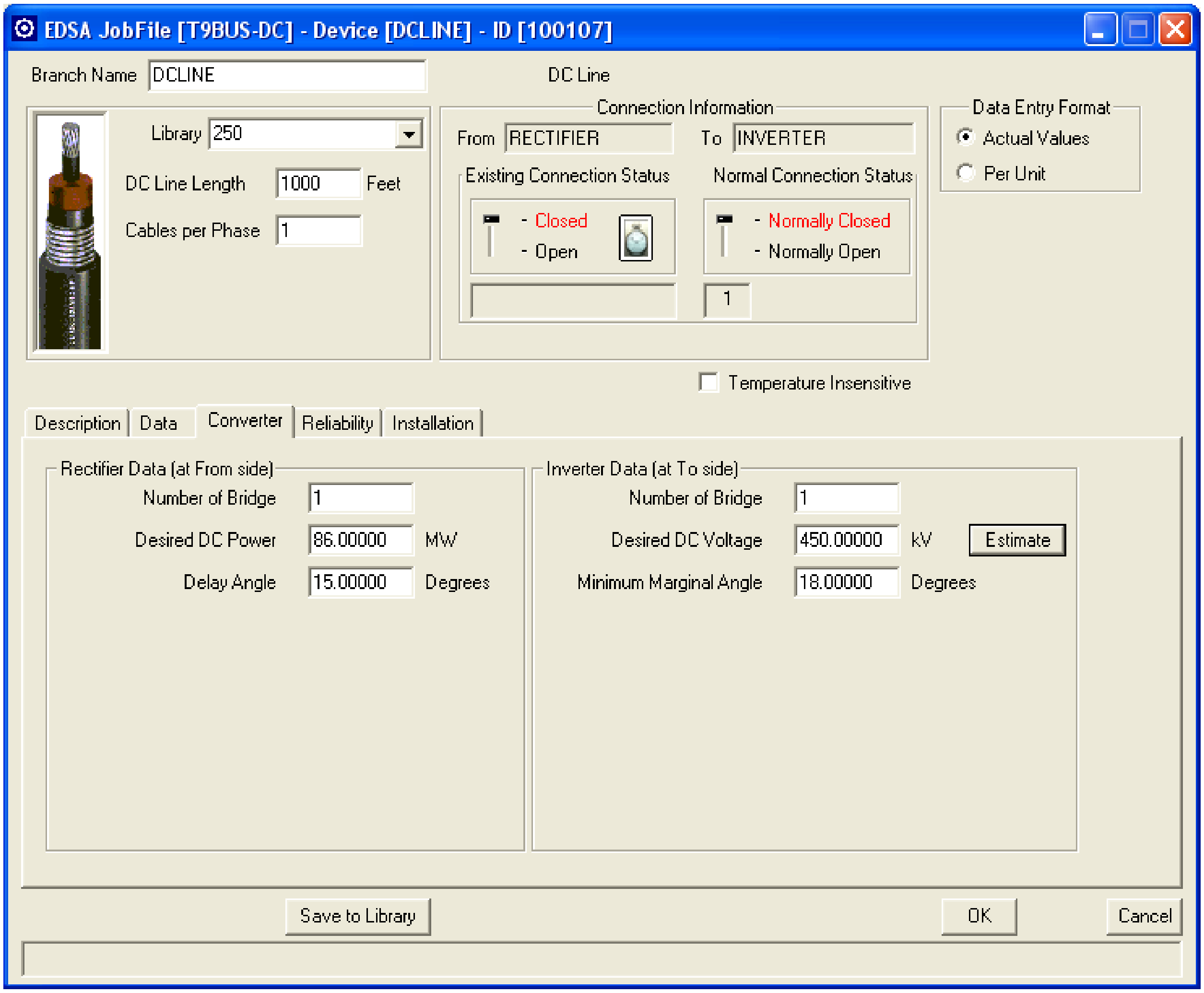


Figure 13: Rectifier and Inverter Data

After completing DC line data we solve the power flow. The iteration report for the above sample network is shown below:

```
                  Mismatch Report
Iteration No.          kW   Bus                           kVAR    Bus
       1          95169.2  INVERTER                    77804.8  09
       2           9410.5  05                          12424.8  RECTIFIER
       3           1129.3  05                           2102.7  05
       4            128.5  05                            305.5  05
       5           5117.3  07                          29846.8  07
Ctrl Adjustments made for:  V Ctrl
       6            309.7  05                           2204.5  RECTIFIER
       7             66.7  05                            199.5  RECTIFIER
       8           5358.3  07                          31696.4  07
Ctrl Adjustments made for:  V Ctrl
       9            199.8  INVERTER                     2241.7  RECTIFIER
      10             45.7  INVERTER                      246.8  RECTIFIER
      11           1830.3  07                          30589.4  05
Ctrl Adjustments made for:  V Ctrl
      12            137.2  INVERTER                     1398.5  INVERTER
      13             29.1  INVERTER                      311.0  INVERTER
      14           1785.6  05                          32605.3  05
Ctrl Adjustments made for:  V Ctrl
      15             70.7  INVERTER                     1674.5  05
      16             50.3  05                            442.6  INVERTER
      17           1309.2  05                          22855.0  05
Ctrl Adjustments made for:  V Ctrl
      18             97.5  05                           1527.7  05
      19             51.0  05                            385.9  INVERTER
      20             12.9  05                             76.8  INVERTER
      21              3.0  05                             17.8  INVERTER
Ctrl Adjustments made for:    DC
      22              0.7  05                              4.0  INVERTER
Ctrl Adjustments made for:    DC
      23              0.2  05                              0.9  INVERTER
Ctrl Adjustments made for:    DC

*** Solution converged in    23 iterations
```

The above iteration report shows that the solution was achieved in 23 iterations. Also note that control adjustments were made for both voltage control transformers as well as DC line. The results of power flow for the sample system is shown Figure 14.

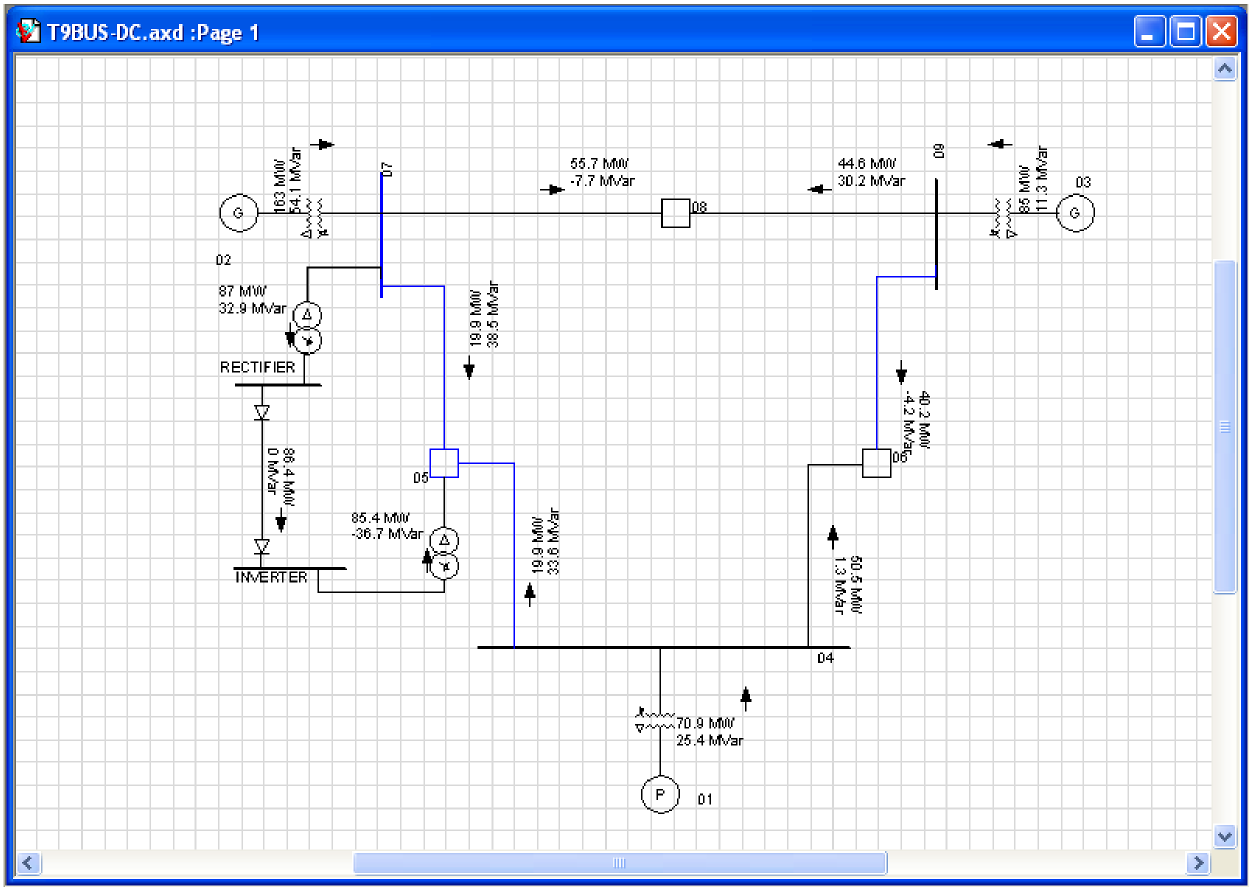


Figure 14: Power Flows Shown on the Single Line Diagram of the Sample Network with DC Line

The summary as well as branch reports are also shown below. **It is important to note that in the branch report for DC line, the MVAR flow is not the reactive power flow on the DC line but it is the reactive power consumed in the rectifier and inverter.**

System Information

Base MVA	=	100.000 (MVA)
Frequency	=	60 (HZ)
Unit System	=	U.S. Standard
MaxIterations	=	1000
Error Tolerance	=	0.00100 (MVA), 0.000010 (PU), 0.0010 (%)
# of total Buses	=	11
# of Active Buses	=	11
# of Swing Buses	=	1
# of Generators	=	2
# of Loads	=	3
# of Shunts	=	0
# of Branches	=	12
# of Transformers	=	5
# of Reactors/capacitors	=	0
# of Circuit Breakers	=	0

Abbreviations

2-W xfmr	= 2-winding transformer	3-W xfmr	= 3-winding transformer
Autoxfmr	= Autotransformer	DReactor	= Duplex Reactor
F_Load	= Functional load	FeederM	= Feeder in Magnetic Conduit
Gen	= Generator	I_Load	= Constant current load
None	= None contributing	P_Load	= Constant power load
PhS xfmr	= Phase-Shift Transformer	SeriesC	= Series Capacitor
ShuntC	= Shunt Capacitor	ShuntR	= Shunt Reactor
Z_Load	= Constant impedance load	UPS_L	= UPS load
Ref °C	= Reference Temperature		

Power Flow By Fast Decoupled CONVERGED
Iteration: 23

Summary of Total Generation and Demand

	P(MW)	Q(MVAR)	S(MVA)	PF(%)
Swing Bus(es):	70.904	25.330	75.292	94.17
Generators :	248.000	65.375	256.472	96.70
Shunt :	0.000	0.000	0.000	0.00
Static Load :	315.000	115.000	335.336	93.94
Motor Load :	0.000	0.000	0.000	0.00
Total Loss :	3.904	-24.296		
Mismatch :	-0.000	0.002		

Generator & Capacitor/Inductor (SVC) Voltage Control

Bus Name	Controlled Bus	DesiredV (kV)	AchieveV (kV)	GenV (kV)	P (MW)	Qmin (MVAR)	Q (MVAR)	Qmax (MVAR)
02	02	18.450	18.450	18.450	163.00	-80.00	54.05	80.00
03	03	14.145	14.145	14.145	85.00	-40.00	11.33	40.00

Transformer Voltage Control & Line Voltage Regulator

Branch Name	Type	Controlled Bus Name	MinV (kV)	CalcuV (kV)	MaxV (kV)	MinTap (PU)	Tap (PU)	MaxTap (PU)
INV-TRSFO	2-W xfmr	INVERTER	327.750	355.124	362.250	0.900	0.907	1.100
REC-TRSFO	2-W xfmr	RECTIFIER	327.750	351.442	362.250	0.900	0.953	1.100

DC Line Result

Branch Name	Type	Library CodeName	From kV	To kV	Current (kA)	Firing Ang (Deg.)	Extinction Ang (Deg.)
DCLINE	DC Line	250	451.911	450.000	0.191	15.30	18.44

DC Line Sample Network 2

A second example for the DC line is provided below. This example (jobfile named “T14bus-dc”) is similar to the sample power system used in the jobfile named “T14bus”. We have added rectifier and inverter transformer as shown below:

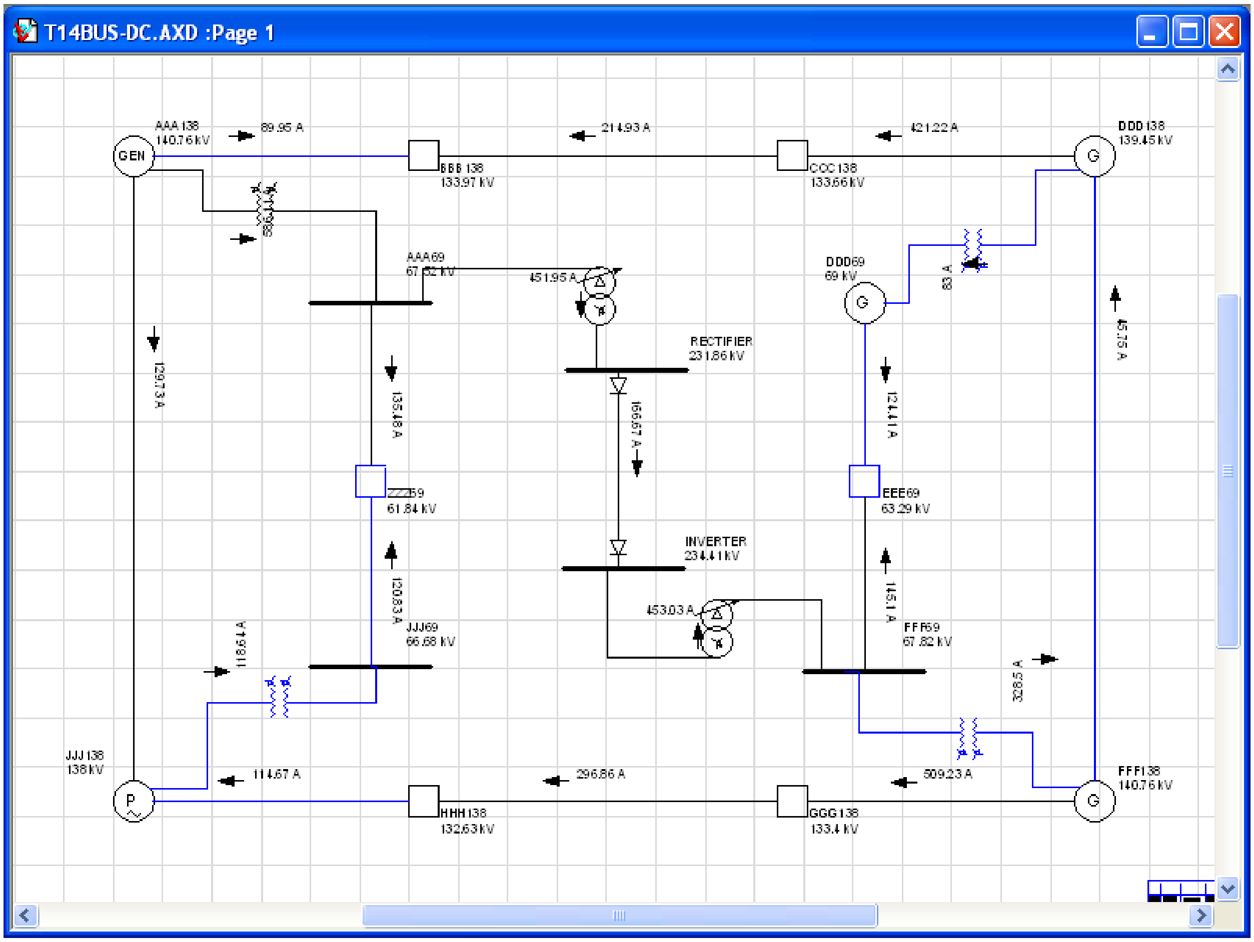


Figure 15: Example of a Power System using DC Line, “T14bus-dc”

The data for the rectifier and inverter for this system is shown below:

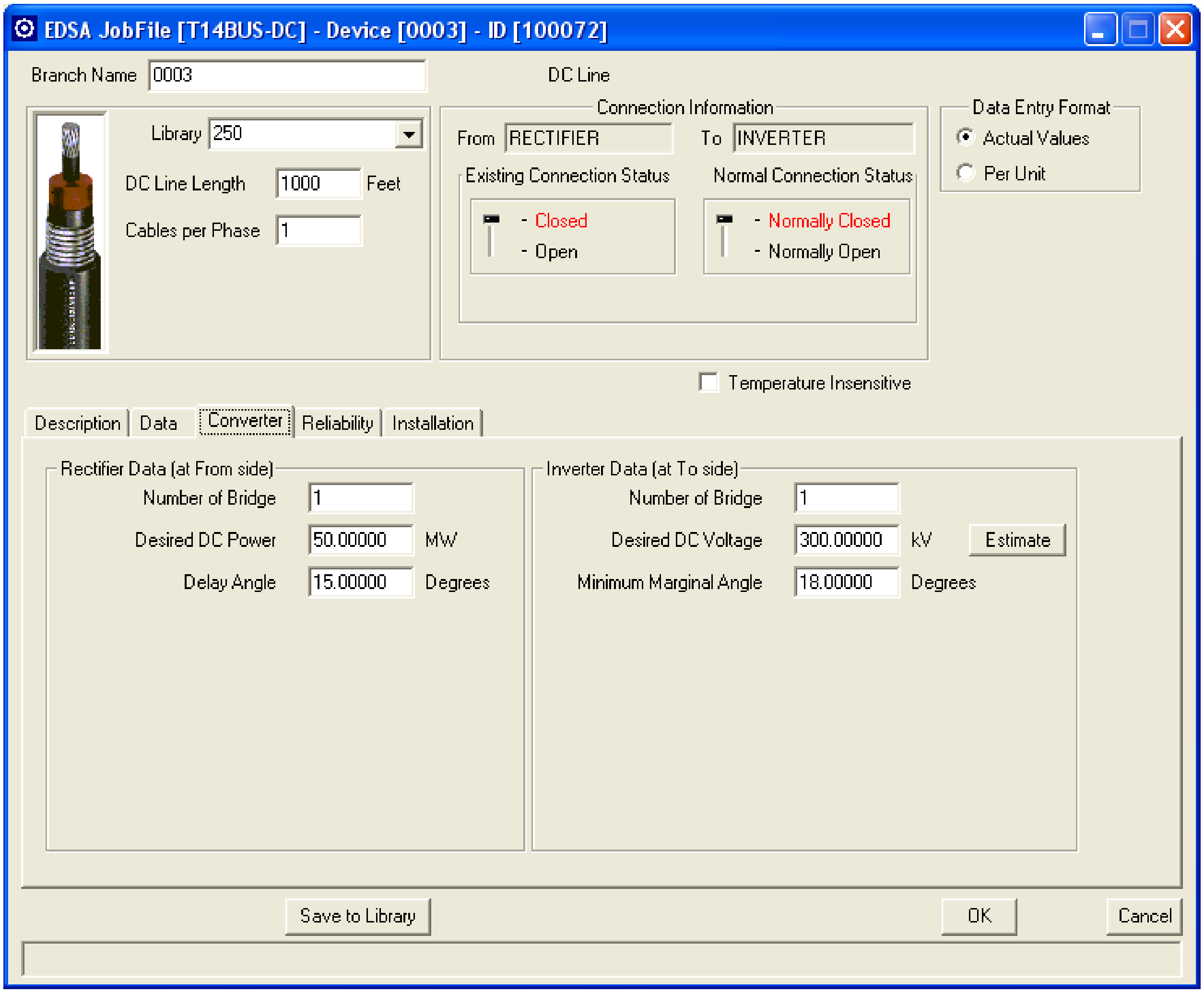


Figure 16: DC Line Data for the Sample Network using DC Line

The solution is shown in Figure 15 and the text result report is shown below:

```
                                    System Information
                                    ==================

Base MVA                  =    100.000 (MVA)
Frequency                 =         60 (HZ)
Unit System               =         U.S. Standard
MaxIterations             =        100
Error Tolerance           =    0.01000 (MVA),   0.000100 (PU),   0.0100 (%)

# of total Buses          =         16
# of Active Buses         =         16
# of Swing Buses          =          1
# of Generators           =          4
# of Loads                =          9
# of Shunts               =          4

# of Branches             =         19
# of Transformers         =          6
# of Reactors/capacitors  =          0
# of Circuit Breakers     =          0
```

Abbreviations

2-W xfmr	= 2-winding transformer	3-W xfmr	= 3-winding transformer
Autoxfmr	= Autotransformer	DReactor	= Duplex Reactor
F_Load	= Functional load	FeederM	= Feeder in Magnetic Conduit
Gen	= Generator	I_Load	= Constant current load
None	= None contributing	P_Load	= Constant power load
PhS xfmr	= Phase-Shift Transformer	SeriesC	= Series Capacitor
ShuntC	= Shunt Capacitor	ShuntR	= Shunt Reactor
Z_Load	= Constant impedance load	UPS_L	= UPS load
Ref °C	= Reference Temperature		

Power Flow By Newton Raphson CONVERGED
Iteration: 11

Summary of Total Generation and Demand

	P(MW)	Q(MVAR)	S(MVA)	PF(%)
Swing Bus(es):	-33.449	29.115	44.345	75.43
Generators :	600.000	251.850	650.714	92.21
Shunt :	0.000	54.155	54.155	0.00
Static Load :	550.000	290.000	621.772	88.46
Motor Load :	0.000	0.000	0.000	0.00
Total Loss :	16.552	45.124		
Mismatch :	-0.001	-0.004		

Generator & Capacitor/Inductor (SVC) Voltage Control

Bus Name	Controlled Bus	DesiredV (kV)	AchieveV (kV)	GenV (kV)	P (MW)	Qmin (MVAR)	Q (MVAR)	Qmax (MVAR)
AAA138	AAA138	140.760	140.760	140.760	200.00	0.00	98.98	100.00
DDD69	DDD69	69.000	69.000	69.000	0.00	0.00	5.81	100.00
FFF138	FFF138	140.760	140.760	140.760	200.00	0.00	90.87	100.00

Transformer Voltage Control & Line Voltage Regulator

Branch Name	Type	Controlled Bus Name	MinV (kV)	CalcuV (kV)	MaxV (kV)	MinTap (PU)	Tap (PU)	MaxTap (PU)
INVERTER-TRSFO	2-W xfmr	INVERTER	218.500	235.050	241.500	0.900	0.967	1.100
RECTFIER-TRSFO	2-W xfmr	RECTIFIER	218.500	231.085	241.500	0.900	0.973	1.100

DC Line Result

Branch Name	Type	Library CodeName	From kV	To kV	Current (kA)	Firing Ang (Deg.)	Extinction Ang (Deg.)
0003	DC Line	250	300.167	300.000	0.167	14.30	18.03