Introduction to PowerWorld Simulator

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Contents

1 Presentation

PowerWorld Simulator (PWS) is a power system simulation software that enables easy high voltage transmission system modeling, with up to 250,000 buses. One of the strengths of the software lies in its power flow and optimal power flow (OPF) algorithms, in *ac* or in *dc*. PWS was originally created by a group of researchers of the University of Illinois, USA, who then created a company to develop and commercialize it.

An educational version of PWS, limited to 50 buses is installed on each computer in the lab room. A free demo version with 12 buses is available here.

The software online manual is also available here.

2 Features

PowerWorld Simulator has multiple features, including: power flow, optimal power flow, contingency analysis, fault analysis, time-step simulation, AGC, difference flows, transient stability, voltage stability, contoured displays, etc. In addition to that, PWS has a graphical user interface that facilitates modeling power systems (Fig. 1). You may find several tutorials and interesting examples of how PWS is used on the company's Youtube channel.

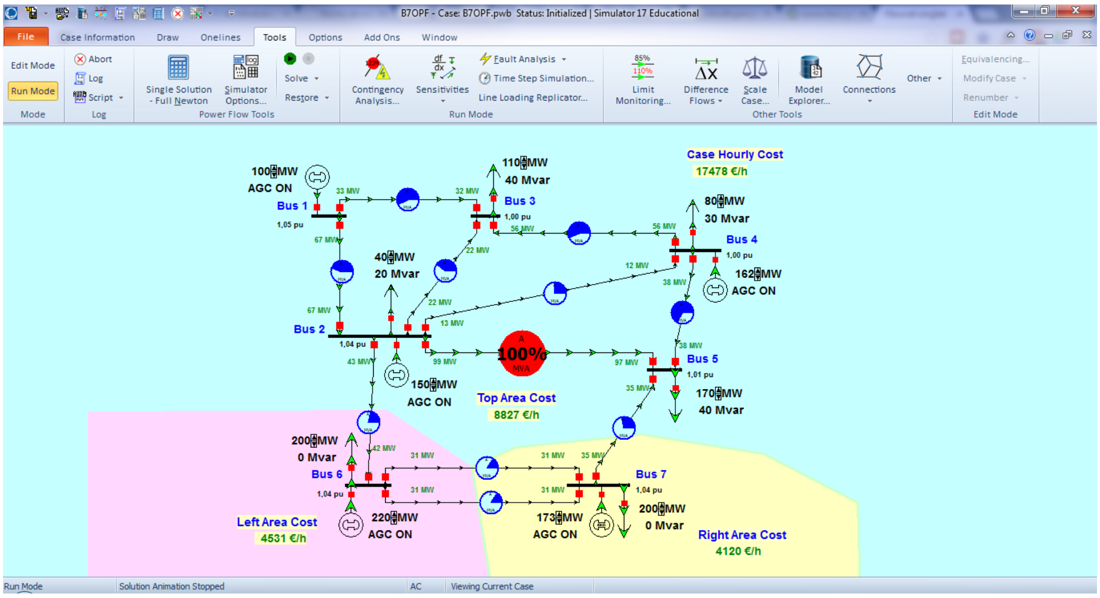


Figure 1: Interface of PowerWorld Simulator

Power flow (also known as load flow) is a numerical analysis tool to determine the voltage magnitude and angle at each bus as well as the active and reactive power flow in each power line of a given system. These values are obtained for steady state operation only, and depend on the scheduled generation and demand profiles.

OPF returns not only the resulting line flows, but also the optimal output value of generators, through the use of optimization algorithms such as linear programming, with the objective of minimizing total operation costs, losses, or any other relevant metric.

3 Files

PowerWorld Simulator uses two main types of files:

- `*.pwb` files contain the case technical data in binary form,
- `*.pwd` files contain the graphical data associated with the case.

A file with each extension is created for each new case, and *both* need to be saved or imported for use.

4 Tools and toolbars

The user can control the software through the toolbars on top of the window. In the following, the roles of the most frequently used tools are briefly detailed. Refer to their entry in PWS's user manual for more information. However, almost all tools can only be used after a system has been modeled, as described in section 5.

4.1 Case information tools

The main tools accessible from the *Case Information* toolbar (Fig. 2) are:

- The *Model Explorer*, that gives access to all information on the modeled system, such as bus, line and generator characteristics (name, voltage, currents, phase, costs, etc.). An example is shown for buses in Fig. 3. This is the main tool to use to obtain precise information on the characteristics and status of each system element.

- The *Edit Mode* and *Run Mode* buttons (also accessible from other toolbars) enable switching between both modes: the Edit mode is used to model and modify the system, while the Run mode is used for running analyses (e.g., OPF), without changing system parameters or configuration.

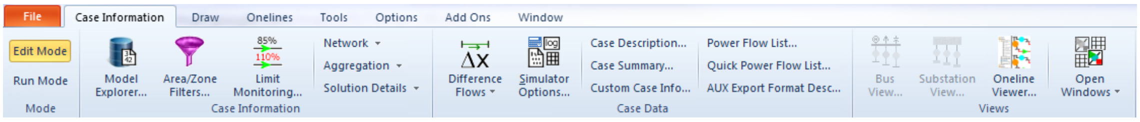
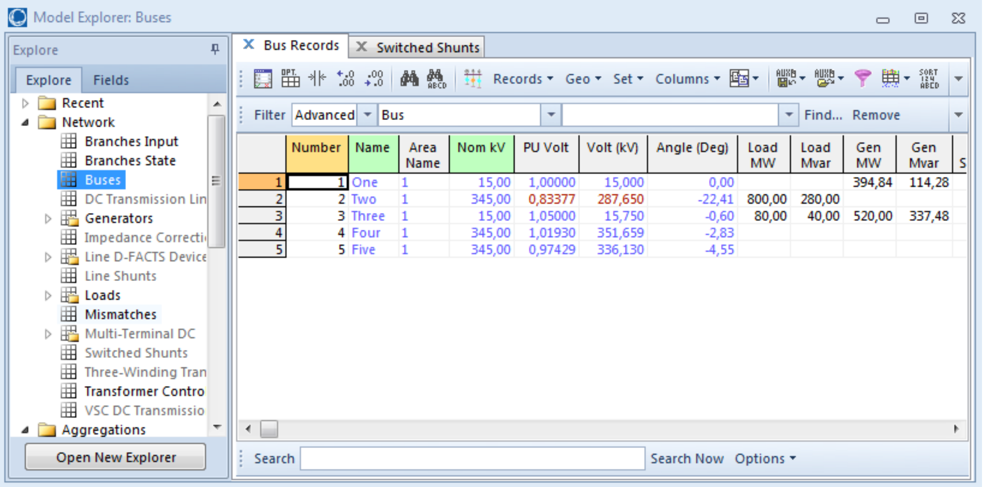


Figure 2: *Case Information* toolbar



	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	S
1	1	One	1	15,00	1,00000	15,000	0,00			394,84	114,28	
2	2	Two	1	345,00	0,83377	287,650	-22,41	800,00	280,00			
3	3	Three	1	15,00	1,05000	15,750	-0,60	80,00	40,00	520,00	337,48	
4	4	Four	1	345,00	1,01930	351,659	-2,83					
5	5	Five	1	345,00	0,97429	336,130	-4,55					

Figure 3: Model Explorer example for buses

4.2 Drawing tools

The tools accessible from the *Draw* toolbar (Fig. 4) enable modeling a power system using the graphical user interface. The *Network* drop-down list is used to add various components, such as buses, generators, loads and power lines. Section 5 describes how to model a system using these tools.

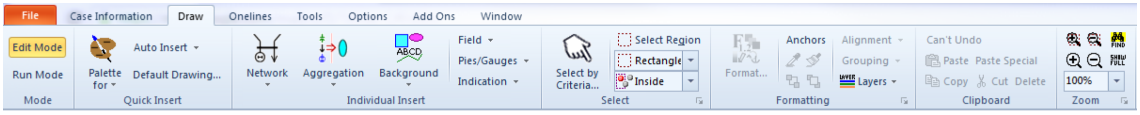


Figure 4: *Draw* toolbar

4.3 System analysis tools

The tools accessible from the *Tools* toolbar (Fig. 5) are:

- *Simulator Options* enable changing various settings, e.g., how power flow is computed, what is taken into account or not, how elements are displayed, etc.
- Clicking on the *Run* button (the green play button) runs a continuous power flow and displays flows on power lines, showing which way current is flowing and how various components are loaded.
- The *Contingency Analysis* tool can analyze the impact of a list of contingencies (e.g., when a generator or a power line trip) on the rest of the system: does it remain stable, is the $N-1$ criterion still verified, etc.
- *Fault Analysis* can then be used to determine the impact of various types of faults on the system, such as a short circuit on a line or a bus.
- *Time Step Simulation* is used to obtain power flow solutions for a set of points in time, e.g., for a given load profile.

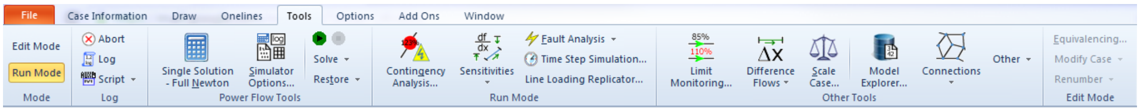


Figure 5: *Tools* toolbar

4.4 Other tools

The tools accessible from the *Add Ons* toolbar (Fig. 6) are:

- The *Primal LP* button solves the OPF using a specific algorithm. This may be used when standard power flow returns strange results.
- *OPF Case Info* gives specific information and results related to OPF, which are also accessible through the *Model Explorer*.
- Various settings related to OPF can be changed through *OPF Options and Results*.
- The *ATC* tool can determine the maximum transfer capacity between two parts of the system.
- The *Transient Stability* tool is used to analyze dynamic system response to a fault.
- The *GIC* tool can be used to study the impact of geomagnetically induced currents and other geomagnetic disturbances.

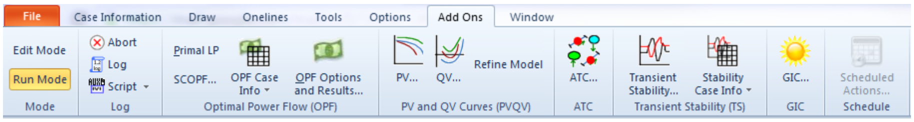


Figure 6: *Add Ons* toolbar

5 System modeling and analysis

5.1 Basics: video tutorial

A video tutorial, showing how to model a simple network, can be watched here:
`https://youtu.be/AL001xJbUmE`

You may also take a look at this document.

5.2 Modeling process

As a general rule, it is recommended to model a system as follows:

1. Add all buses, with their rated voltage values. Change the slack bus if necessary.
2. Add all loads on buses, with their set real and reactive power values.
3. Add all generators on buses, including the slack bus.
   Do not bother setting the generators outputs for now. Set the cost function if necessary.
4. Set the bus voltage magnitude for generator buses.
5. Add the transmission lines connecting the buses, and set their properties.
6. Change the AGC mode if necessary.
7. Set the generators active power output.
8. Run the system simulation, by switching to *Run mode*, and clicking on *Play*.

For more details on how to make some changes, see the next subsection below. Also remember to make model changes in *Edit mode*, not *Run mode*, otherwise your changes may not be saved.

If you observe strange results, use the *Model explorer* (see Fig. 3) to check that your model parameters are correct for all buses, loads, generators and lines.

5.3 Modeling tips

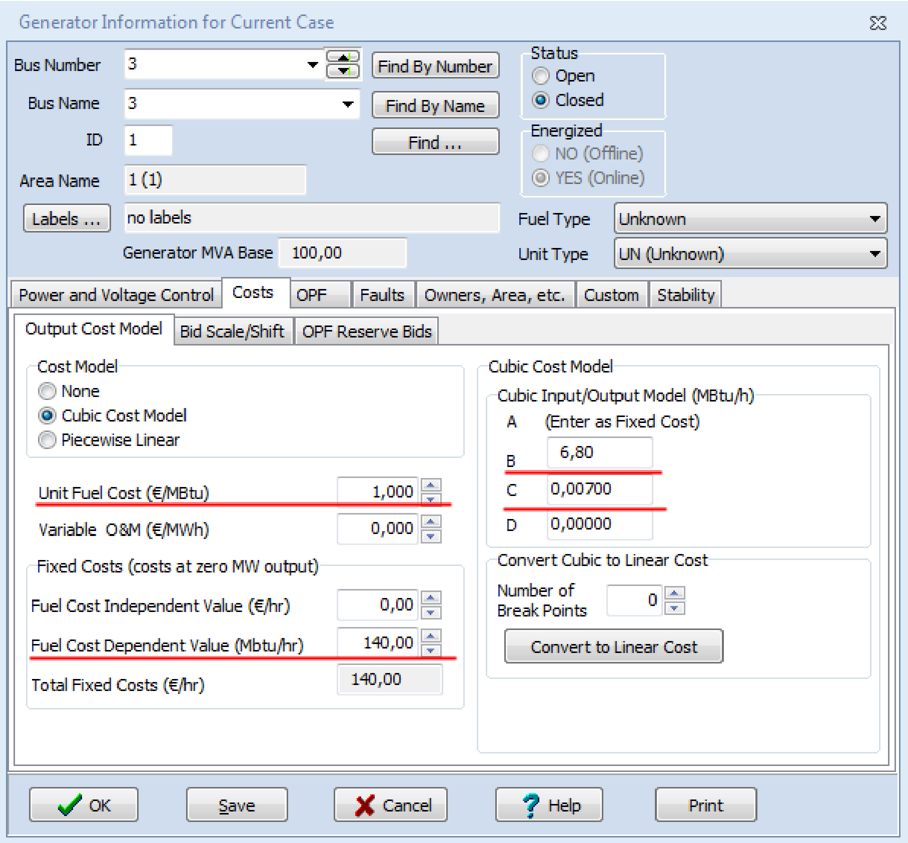
Slack bus selection

By default, the slack bus is the first bus you add. If you need to change this, open the *Bus Options* of the first bus, and uncheck *System slack bus*. Open the *Bus Options* of the bus you want to become the slack bus, and check *System slack bus*.

Generator cost function

The cost C of a generator can be set in its options window, in the *Costs* tab, and is set as in (1). F is the fuel cost, and a, b and c are the cost coefficients, in MBtu/h, MBtu/(h·MW), and MBtu/(h·MW^2), respectively. Fig. 7 shows how to input these costs using the cubic cost model.

$$C(P) = F \cdot (a + b\,P + c\,P^2) \tag{1}$$


Generator Information for Current Case

Bus Number: 3

Bus Name: 3

ID: 1

Area Name: 1 (1)

Labels ...: no labels

Generator MVA Base: 100,00

Status: ○ Open ● Closed

Energized: ○ NO (Offline) ● YES (Online)

Fuel Type: Unknown

Unit Type: UN (Unknown)

Costs → Output Cost Model

Cost Model: ○ None ● Cubic Cost Model ○ Piecewise Linear

Unit Fuel Cost (€/MBtu): 1,000

Variable O&M (€/MWh): 0,000

Fixed Costs (costs at zero MW output)

Fuel Cost Independent Value (€/hr): 0,00

Fuel Cost Dependent Value (Mbtu/hr): 140,00

Total Fixed Costs (€/hr): 140,00

Cubic Cost Model

Cubic Input/Output Model (MBtu/h)

A (Enter as Fixed Cost)

B 6,80

C 0,00700

D 0,00000

Convert Cubic to Linear Cost

Number of Break Points: 0

Figure 7: The *Costs* tab in the generation options

Generator bus voltage magnitude

To set the voltage magnitude of a generator bus, open the *Bus Options*, and click on *Bus Voltage Regulator Devices* in tab *Bus Information*. Set the *Device Voltage Target* for the generator to the desired value (e.g., 1.05 p.u.).

AGC mode

You may change the AGC settings on two levels: for each generator, or for an entire area (i.e., several generators). For individual generators, open the generator options window, and uncheck *Available for AGC*. Checking this box enables the AGC system (a type of controller) to automatically compute a new value for the generator output.

To change the AGC mode for the entire area, open the *Model Explorer* window, and browse to the *Areas* in the left-side list. The *AGC Status* of any area may then be changed to:

- Off AGC: no area control scheme, i.e., generator output is not changed automatically;
- Part. AGC: runs a control scheme called AGC that considers participation factors;
- ED: runs an economic dispatch algorithm;
- OPF: runs an optimal power flow algorithm.

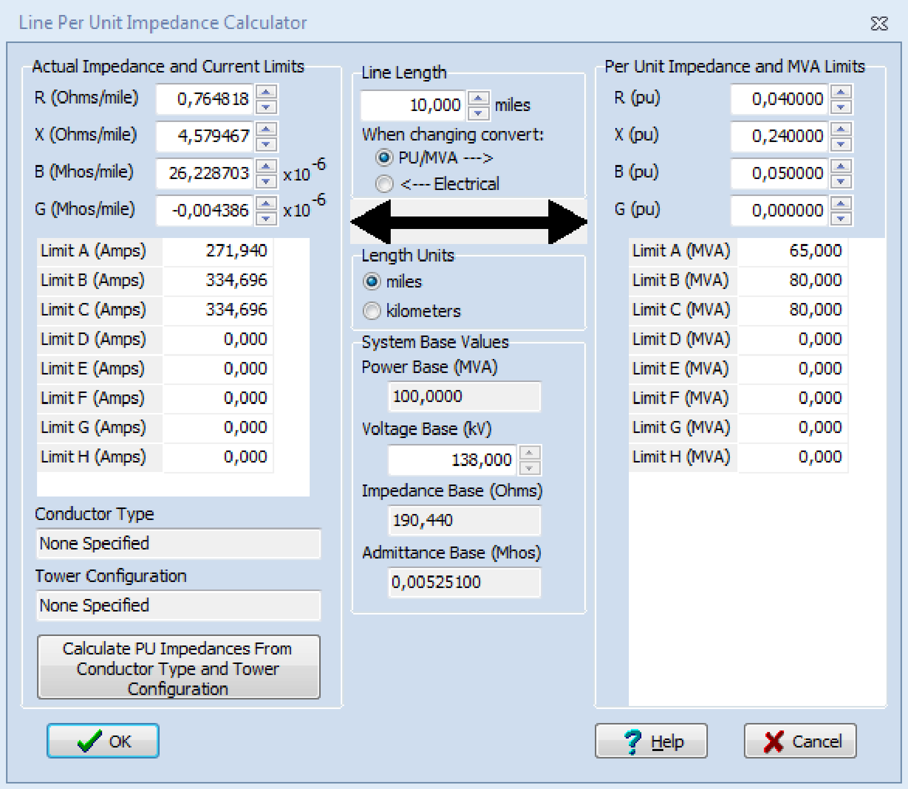
It is also possible to disable AGC for specific generators. To do that, in the *Generator Information Dialog*, uncheck *Available for AGC* next to the generator *MW Output*.

Adding information fields

You may add various information fields around buses, loads, generators, lines or areas: voltage, real and reactive power, costs, etc. To do so, right-click on the element and select *Add new fields* *around [element]*. Select the position (click on one of the *PosX* labels) and then the content of the field.

Line per unit impedance calculator

PWS provides a tool to compute the per unit impedance and MVA limit of a line. To open the tool, double click on the selected transmission line and on *Calculate Impedances* in the *Parameters* tab, and then click on *From Per Distance Impedances*. The tool (Fig. 8) should then show up, and enable you to compute the per unit impedance and MVA limits from the actual impedance and current limits.



Actual Impedance and Current Limits

R (Ohms/mile) 0,764818
X (Ohms/mile) 4,579467
B (Mhos/mile) 26,228703 $\times 10^{-6}$
G (Mhos/mile) -0,004386 $\times 10^{-6}$

Limit A (Amps)	271,940
Limit B (Amps)	334,696
Limit C (Amps)	334,696
Limit D (Amps)	0,000
Limit E (Amps)	0,000
Limit F (Amps)	0,000
Limit G (Amps)	0,000
Limit H (Amps)	0,000

Conductor Type: None Specified
Tower Configuration: None Specified

Line Length: 10,000 miles
When changing convert: ● PU/MVA ---> ○ <--- Electrical

Length Units: ● miles ○ kilometers

System Base Values
Power Base (MVA): 100,0000
Voltage Base (kV): 138,000
Impedance Base (Ohms): 190,440
Admittance Base (Mhos): 0,00525100

Per Unit Impedance and MVA Limits

R (pu) 0,040000
X (pu) 0,240000
B (pu) 0,050000
G (pu) 0,000000

Limit A (MVA)	65,000
Limit B (MVA)	80,000
Limit C (MVA)	80,000
Limit D (MVA)	0,000
Limit E (MVA)	0,000
Limit F (MVA)	0,000
Limit G (MVA)	0,000
Limit H (MVA)	0,000

Figure 8: Line per unit impedance calculate interface

5.4 Using analysis tools

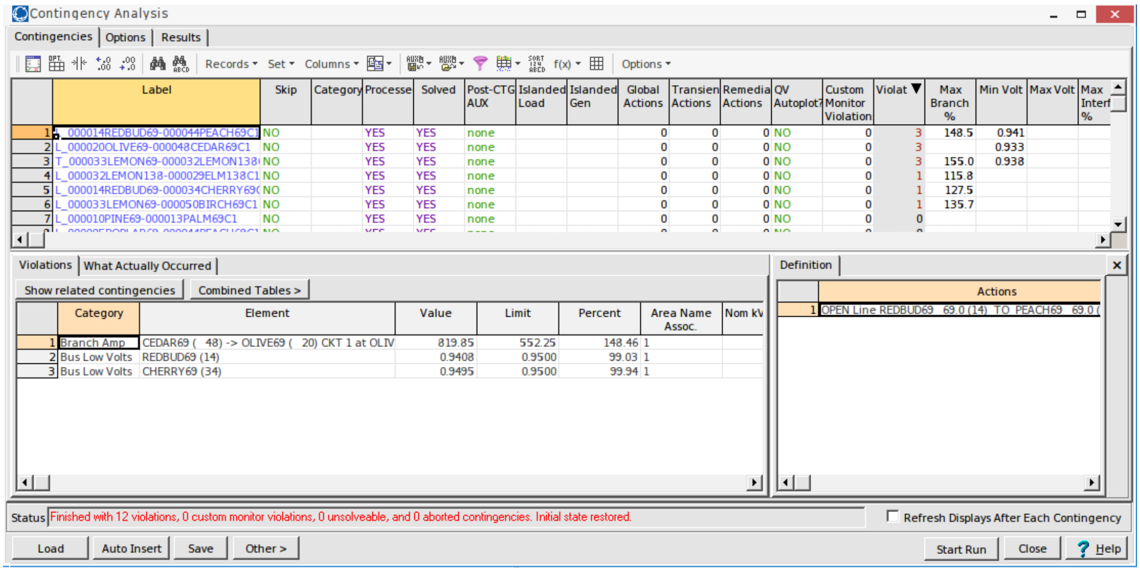
Y_{bus} matrix

To observe the Y_{bus} matrix computed by PWS, open the *Model Explorer* and browse to *YBus* in *Solutions Details*.

Contingency analysis

To run a contingency analysis, e.g., for an $(n-1)$ system security check, click on the *Contingency Analysis* icon in the *Tools* tab, in *Run Mode*. Add the desired contingencies (right click and *Insert . . .*), and click on *Start Run*. The analysis results should then show up (Fig. 9). You can also automatically insert all contingencies of a given type (e.g., opening of each line one after another) by clicking on Auto Insert and selecting the type of contingency.

In Fig. 9, the top part of the window summarizes the results, and lists each tests contingency together with the corresponding results. The bottom left part of the windows lists the violations resulting from the tested contingency, and right part shows the detailed definition of the tested contingency (e.g., line opened between bus A and B).



	Label	Skip	Category	Processe	Solved	Post-CTG AUX	Islanded Load	Islanded Gen	Global Actions	Transien Actions	Remedia Actions	QV Autoplot?	Custom Monitor Violation	Violat	Max Branch %	Min Volt	Max Volt	Max Interf %
1	L_000014REDBUD69-000044PEACH69C1	NO		YES	YES	none			0	0	0	NO	0	3	148.5	0.941		
2	L_000020OLIVE69-000048CEDAR69C1	NO		YES	YES	none			0	0	0	NO	0	3		0.933		
3	T_000033LEMON69-000032LEMON138	NO		YES	YES	none			0	0	0	NO	0	3	155.0	0.938		
4	L_000032LEMON138-000029ELM138C1	NO		YES	YES	none			0	0	0	NO	0	1	115.8			
5	L_000014REDBUD69-000034CHERRY69	NO		YES	YES	none			0	0	0	NO	0	1	127.5			
6	L_000033LEMON69-000050BIRCH69C1	NO		YES	YES	none			0	0	0	NO	0	1	135.7			
7	L_000010PINE69-000013PALM69C1	NO		YES	YES	none			0	0	0	NO	0	0				

	Category	Element	Value	Limit	Percent	Area Name Assoc.	Nom kV
1	Branch Amp	CEDAR69 (48) -> OLIVE69 (20) CKT 1 at OLIV	819.85	552.25	148.46	1	
2	Bus Low Volts	REDBUD69 (14)	0.9408	0.9500	99.03	1	
3	Bus Low Volts	CHERRY69 (34)	0.9495	0.9500	99.94	1	

	Actions
1	OPEN Line REDBUD69 69.0 (14) TO PEACH69 69.0 (

Status: Finished with 12 violations, 0 custom monitor violations, 0 unsolveable, and 0 aborted contingencies. Initial state restored.

Figure 9: The contingency analysis tool window

Fault analysis

To run a fault analysis, switch to *Run mode*, and right-click on the element (bus or line) that sustains a fault, and select *Fault...*. The Fault Analysis window should then open (Fig. 10):

- Define the type (3-phase balance 3PB, single line-to-ground SLG, line-to-line LL, or double line-to-ground DLG) and location of the fault(s). In the case of an in-line fault, set the fault location.
- Click on *Run Faults* to run the analysis.
- In the left panel, in *Single fault*, click on *Bus Records*, and on *Calculate* to obtain detailed results.

Transient stability analysis

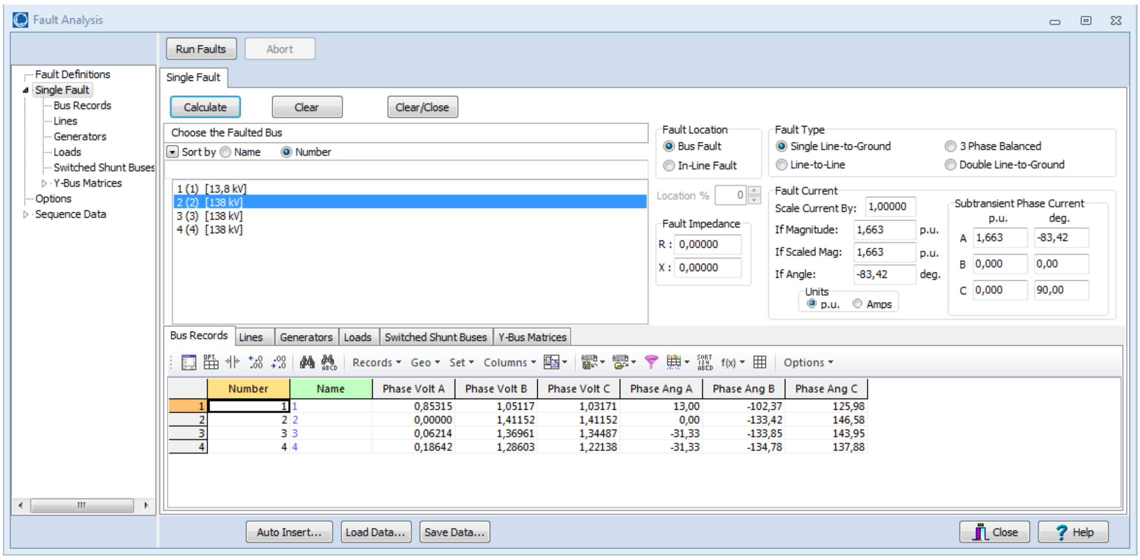
Before running such an analysis, selected grid components (e.g., generators) must be configured for stability analyses. For example, for generators:

- Add the generator to study. Set the generator bus voltage magnitude, its MW power output, and disable AGC if suitable.
- After it has been added, open its properties and click on the *Stability* tab (Fig. 11).
- Select the *Machine Models* subtab, and insert a model such as *GENCLS*.
- Input the parameters of the model, such as H and X'_d (X_{dp}).

If an infinite bus is used, model it as a generator connected to a slack bus. A transient model is not required for this generator. Then, to run the stability analysis, switch to *Run mode*, and click on the *Transient Stability* analysis tool in *Add-Ons*.

In the stability analysis window (Fig. 12):

- In *Simulation*: set the start and end times (usually 3 to 10 seconds), as well as the time step (0.5 cycle is enough).



Choose the Faulted Bus

Sort by ○ Name ● Number

1 (1) [13,8 kV]
2 (2) [138 kV]
3 (3) [138 kV]
4 (4) [138 kV]

Fault Location: ● Bus Fault ○ In-Line Fault

Location % 0

Fault Impedance
R : 0,00000
X : 0,00000

Fault Type: ● Single Line-to-Ground ○ Line-to-Line ○ 3 Phase Balanced ○ Double Line-to-Ground

Fault Current
Scale Current By: 1,00000
If Magnitude: 1,663 p.u.
If Scaled Mag: 1,663 p.u.
If Angle: -83,42 deg.
Units: ● p.u. ○ Amps

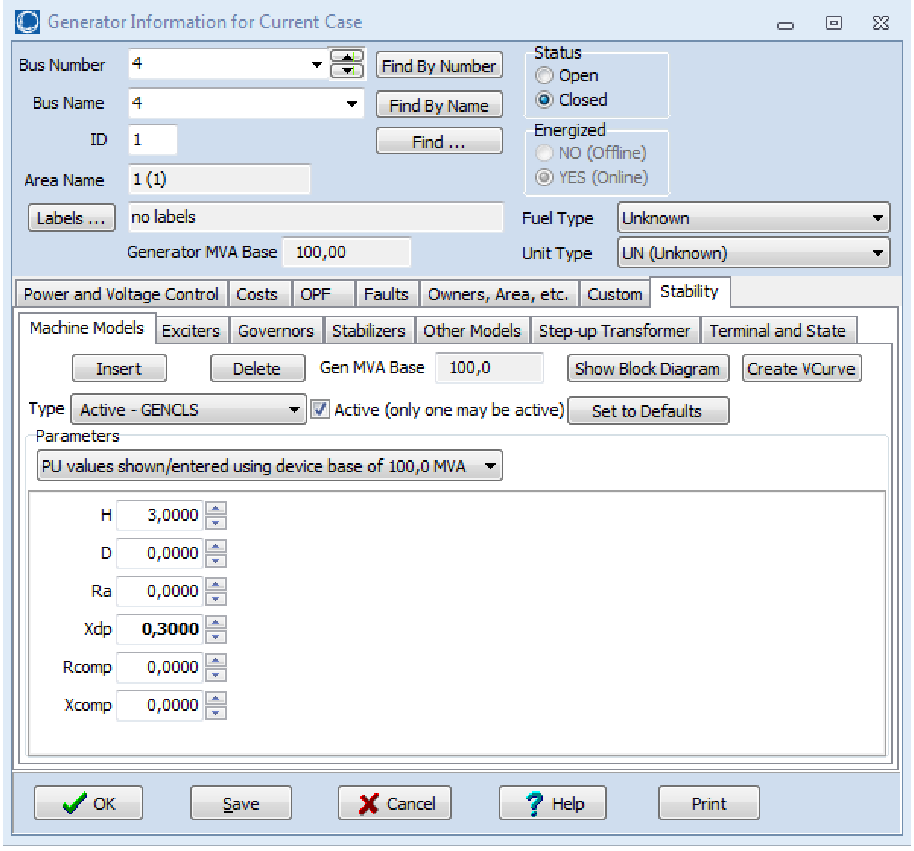
Subtransient Phase Current

	p.u.	deg.
A	1,663	-83,42
B	0,000	0,00
C	0,000	90,00

Bus Records | Lines | Generators | Loads | Switched Shunt Buses | Y-Bus Matrices

	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	1	0,85315	1,05117	1,03171	13,00	-102,37	125,98
2	2	2	0,00000	1,41152	1,41152	0,00	-133,42	146,58
3	3	3	0,06214	1,36961	1,34487	-31,33	-133,85	143,95
4	4	4	0,18642	1,28603	1,22138	-31,33	-134,78	137,88

Figure 10: The fault analysis tool window



Bus Number 4
Bus Name 4
ID 1
Area Name 1 (1)
no labels
Generator MVA Base 100,00

Status: ○ Open ● Closed
Energized: ○ NO (Offline) ● YES (Online)
Fuel Type: Unknown
Unit Type: UN (Unknown)

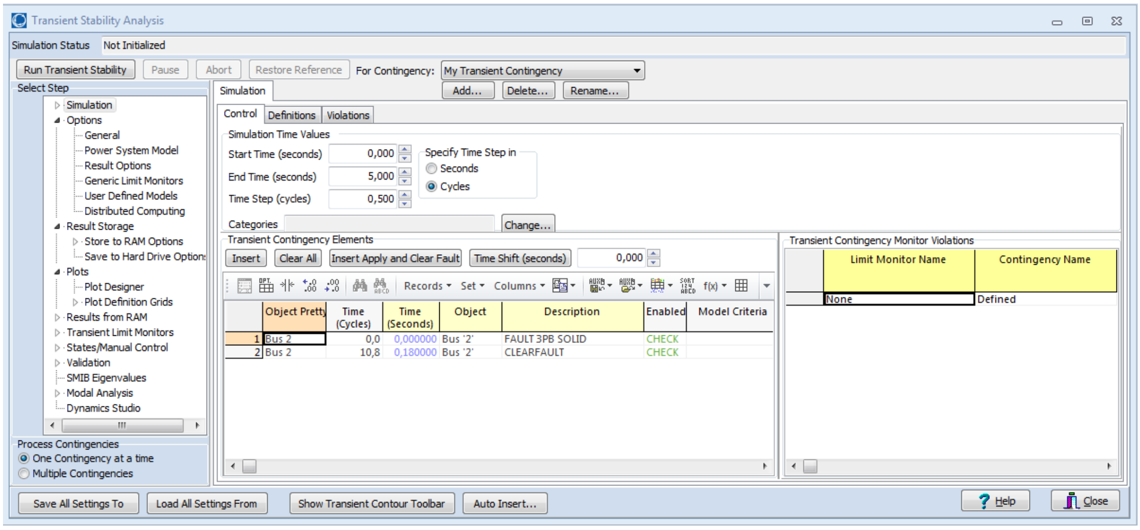
Gen MVA Base 100,0
Type: Active - GENCLS
☑ Active (only one may be active)

Parameters
PU values shown/entered using device base of 100,0 MVA

H 3,0000
D 0,0000
Ra 0,0000
Xdp **0,3000**
Rcomp 0,0000
Xcomp 0,0000

Figure 11: Generator properties window with stability model

- Insert a transient contingency element (i.e., a disturbance), such as a three-phase fault. If relevant, add another contingency element in which the fault is cleared or a line is opened after a given duration.
- In *Options > Power System Model > Common*, select *Model the power flow slack buses as infinite buses*. In *Compatibility Options*, check *Ignore Speed Effects in Generator Swing Equation*.
- In *Result Storage*: check *Store results to RAM* to save simulation data. In *Store to RAM Options*, in the *Generator* tab, set the *Rotor Angle* cell of the studies generator to *YES* (Fig. 13).
- Select the cell you just set to *YES*, and click on *Make Plot*.
- Click on *Run Transient Stability* to run the simulation. The plot of the rotor angle should display at the end of the simulation.



Simulation Status: Not Initialized

For Contingency: My Transient Contingency

Simulation Time Values

Start Time (seconds) 0,000

End Time (seconds) 5,000

Time Step (cycles) 0,500

Specify Time Step in
○ Seconds
● Cycles

Categories

Transient Contingency Elements

Time Shift (seconds) 0,000

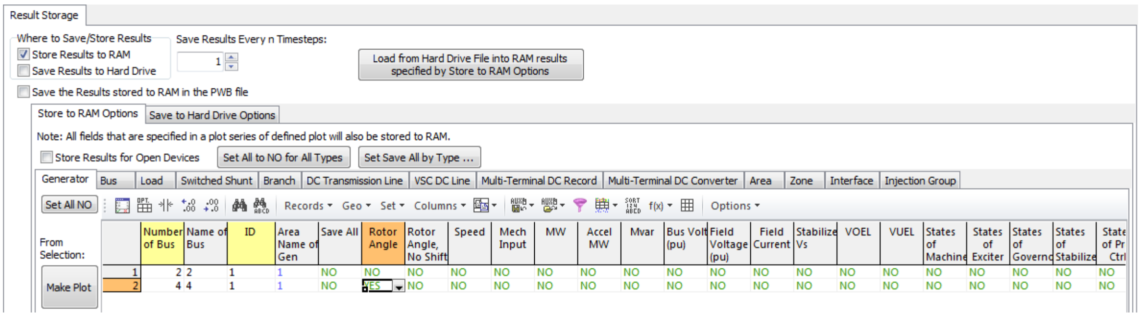
	Object Pretty	Time (Cycles)	Time (Seconds)	Object	Description	Enabled	Model Criteria
1	Bus 2	0,0	0,000000	Bus '2'	FAULT 3PB SOLID	CHECK	
2	Bus 2	10,8	0,180000	Bus '2'	CLEARFAULT	CHECK	

Transient Contingency Monitor Violations

Limit Monitor Name	Contingency Name
None	Defined

Process Contingencies
● One Contingency at a time
○ Multiple Contingencies

Figure 12: The transient stability analysis tool window



Where to Save/Store Results
☑ Store Results to RAM
☐ Save Results to Hard Drive

Save Results Every n Timesteps: 1

☐ Save the Results stored to RAM in the PWB file

Note: All fields that are specified in a plot series of defined plot will also be stored to RAM.

☐ Store Results for Open Devices

From Selection:

	Number of Bus	Name of Bus	ID	Area Name of Gen	Save All	Rotor Angle	Rotor Angle, No Shift	Speed	Mech Input	MW	Accel MW	Mvar	Bus Volt (pu)	Field Voltage (pu)	Field Current	Stabilize Vs	VOEL	VUEL	States of Machine	States of Exciter	States of Governo	States of Stabilize	State of Pr Ctrl
1	2	2	1	1	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2	4	4	1	1	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Figure 13: The transient stability analysis tool window – Saving results to RAM

Difference flows

The difference flows tool enables comparing two different system states. First, for the base case, click on the *Difference flows* icon and on *Set Present As Base Case*. Modify the system and click on *Difference Case*. The values shown in the system should then change to show the differences between both states. Click on *Clear Base Case* to return to the modified state.

Contours

Contours provide a simple visualization tool, to analyze large amounts of information at once. They may represent bus voltage values, net injection, etc. To add a contour, click on *Contouring* in the *Onelines* tab, and select *Contouring...*. Select the quantity to visualize in the *Value* dropdown list, and on the *OK* button. Note that the contour (example in Fig. 14) does not automatically refresh unless you select the *Continuously Update* option.

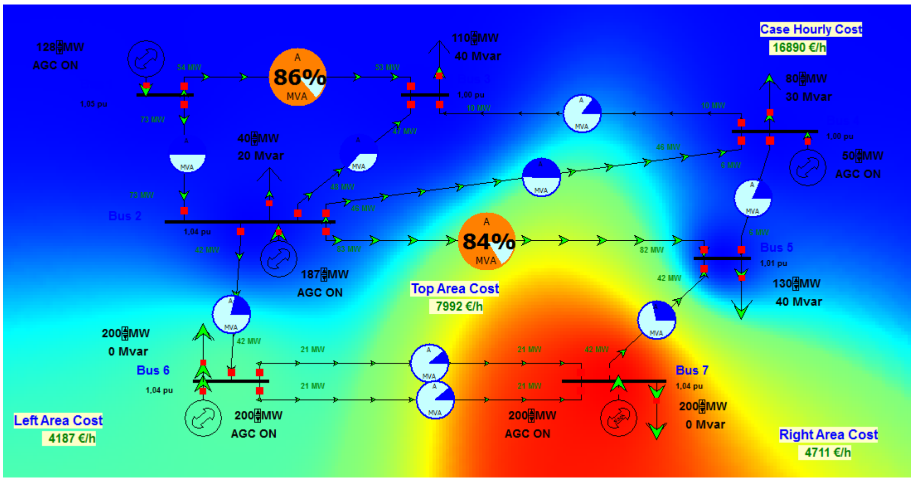


Figure 14: Example showing the marginal MW cost contour