Quick Start for Using PowerWorld Simulator with Transient Stability

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Overview

- The purpose of these slides are to provide a quick introduction to the new PowerWorld Simulator transient stability capabilities.
- The slides are designed for people who already know how to use PowerWorld Simulator for power flow studies, and also have at least some familiarity with transient stability
  - To get users up to speed on PowerWorld Simulator's basic, non-transient stability functions, we have made free on-line training videos and slides available at

    http://www.powerworld.com/services/webtraining.asp

Goal

- The goal of these slides is to give you a quick introduction to the new transient stability function in PowerWorld Simulator
  - The training philosophy is “learning by doing”
- The slides do not provide a comprehensive description of all the PowerWorld Simulator transient stability capabilities, nor do they provide comprehensive coverage of the transient stability problem.
- Slides are designed for use with the version 15 beta
  - This is not the final version 15 release, so bug reports and feature enhancements are encourage (see last slide for details)

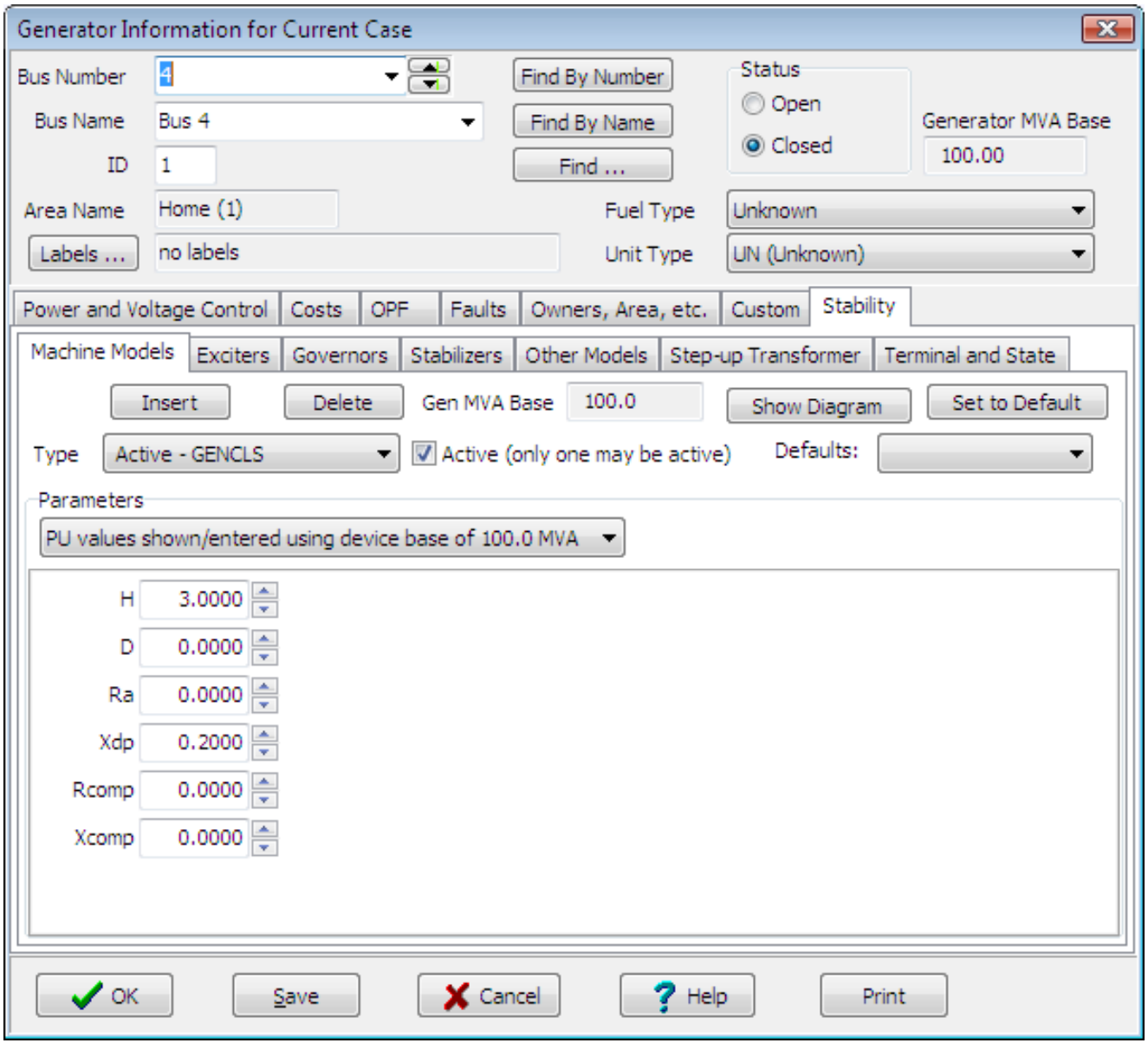
From Power Flow to Transient Stability

- With PowerWorld Simulator a power flow case can be quickly transformed into a transient stability case
  - This requires the addition of at least one dynamic model
- PowerWorld Simulator supports more than one hundred different dynamic models. These slides cover just a few of them
  - Default values are provided for most models allowing easy experimentation
  - Creating a new transient stability case from a power flow case would usually only be done for training/academic purposes; for commercial studies the dynamic models from existing datasets would be used. Use the application button and select “Load Transient Stability Data” to load in an existing dataset.

First Example Case

- Open the case Example_13_4_NoModels
- Add a dynamic generator model to an existing “no model” power flow case by:
  - In run mode, right-click on the generator symbol for bus 4, then select “Generator Information Dialog” from the local menu
  - This displays the Generator Information Dialog, select the “Stability” tab to view the transient stability models; none are initially defined.
  - Select the “Machine models” tab to enter a dynamic machine model for the generator at bus 4. Click “Insert” to enter a machine model. From the Model Type list select GENCLS, which represents a simple “Classical” machine model. Use the default values. Values are per unit using the generator MVA base.

Adding a Machine Model



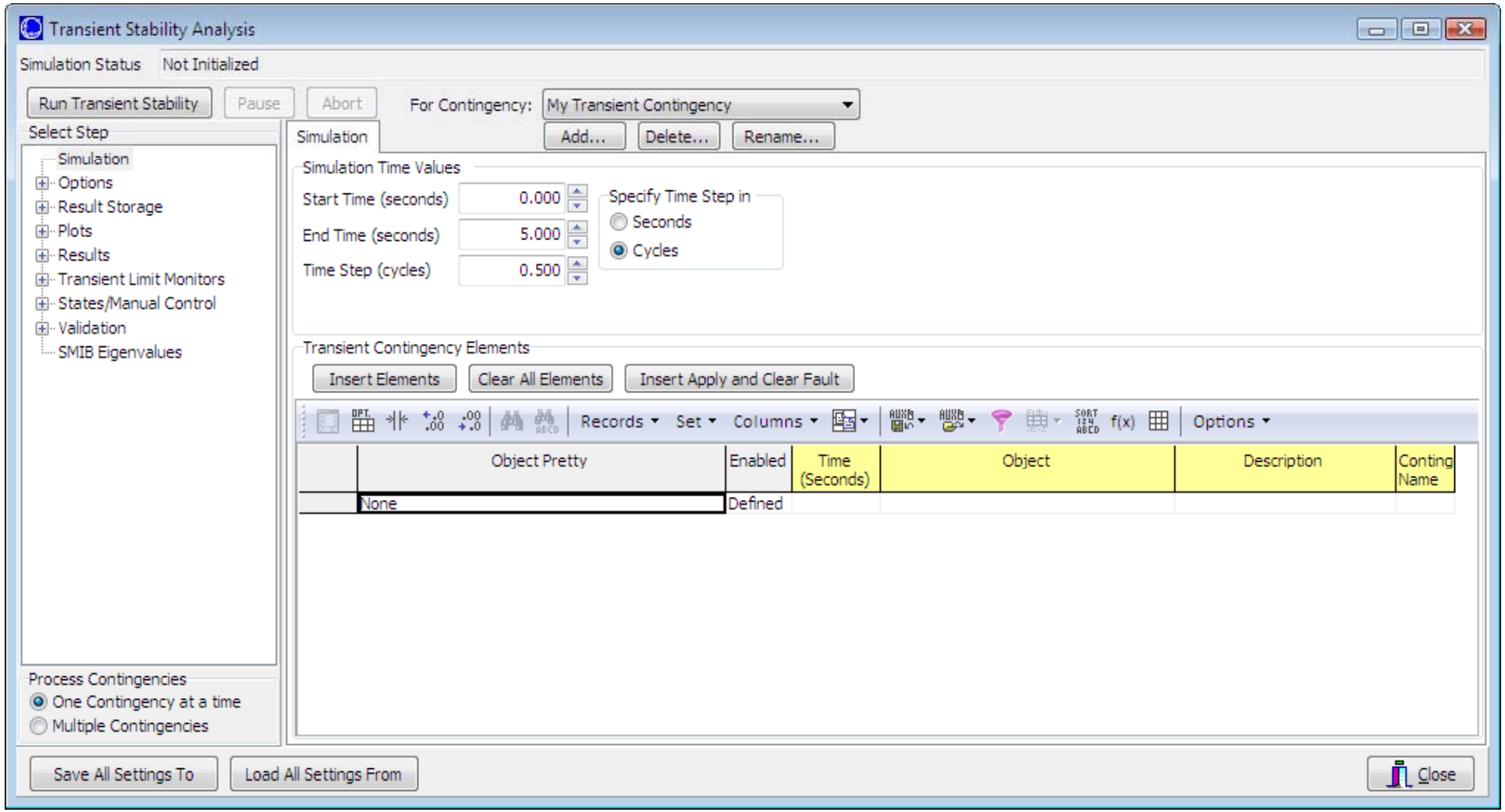
The GENCLS model represents the machine dynamics as a fixed voltage magnitude behind a transient impedance Ra + jXdp.

Hit “Ok” when done to save the data and close the dialog

Transient Stability Form Overview

- Most of the PowerWorld Simulator transient stability functionality is accessed using the Transient Stability Analysis form. To view this form, from the ribbon select "Add Ons", "Transient Stability"
- Key pages of form for quick start examples (listed under "Select Step")
  - Simulation page: Used for specifying the starting and ending time for the simulation, the time step, defining the transient stability fault (contingency) events, and running the simulation
  - Options: Various options associated with transient stability
  - Result Storage: Used to specify the fields to save and where
  - Plots: Used to plot results
  - Results: Used to view the results (actual numbers, not plots)

Transient Stability Analysis Form



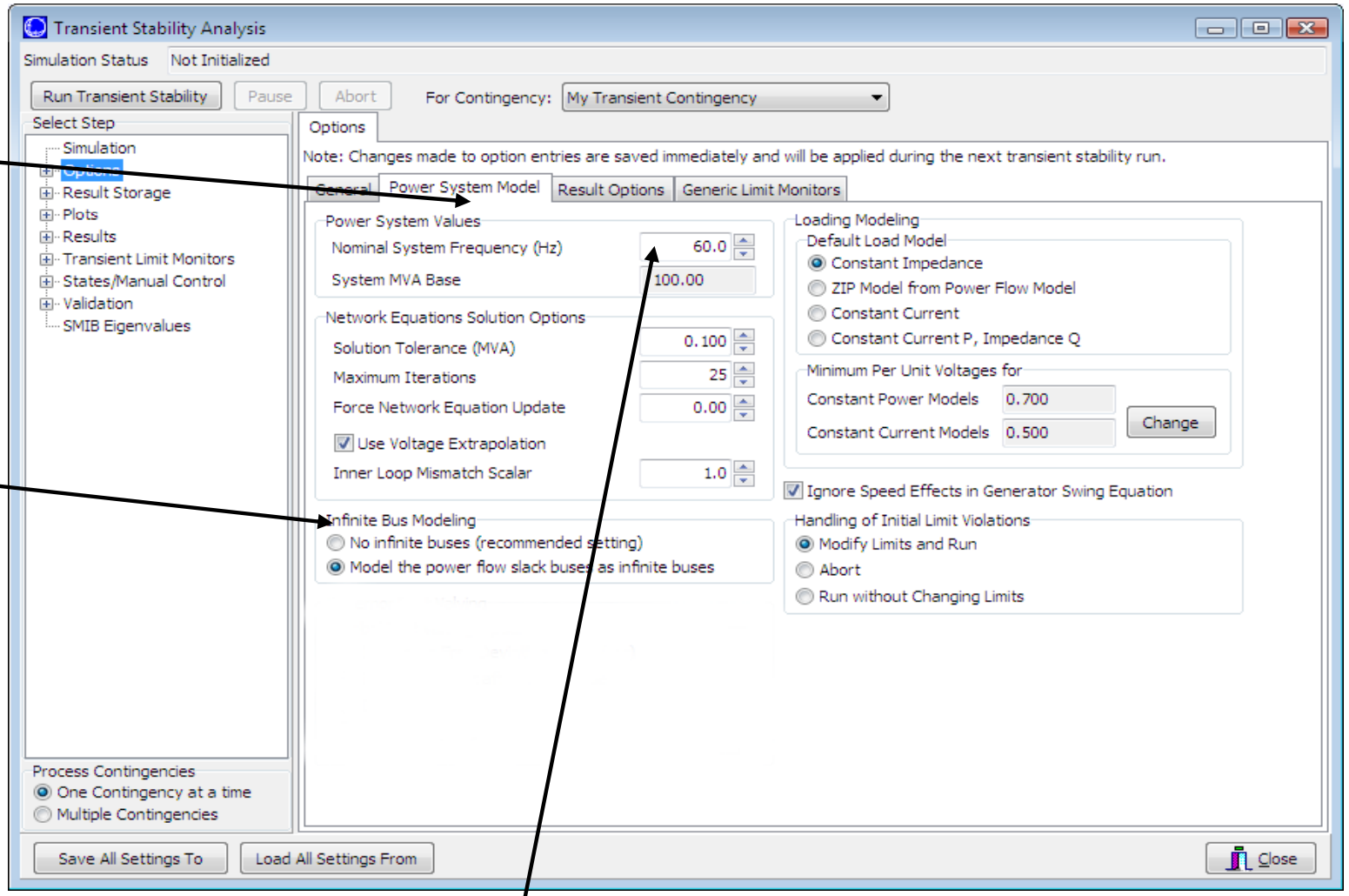
Infinite Bus Modeling

- Before doing our first transient stability run, it is useful to discuss the concept of an infinite bus. An infinite bus is assumed to have a fixed voltage magnitude and angle; hence its frequency is also fixed at the nominal value.
  - In real systems infinite buses obviously do not exist, but they can be a useful concept when learning about transient stability.
  - By default PowerWorld Simulator does NOT treat the slack bus as an infinite bus, but does provide this as an option.
  - For this first example we will use the option to treat the slack bus as an infinite bus. To do this select “Options” from the “Select Step” list. This displays the option page. Select the “Power System Model” tab, and then set Infinite Bus Modeling to “Model the power flow slack bus(es) as infinite buses” if it is not already set to do so.

Transient Stability Analysis Options Page

Power System Model Page

Infinite Bus Modeling



This page is also used to specify the nominal system frequency

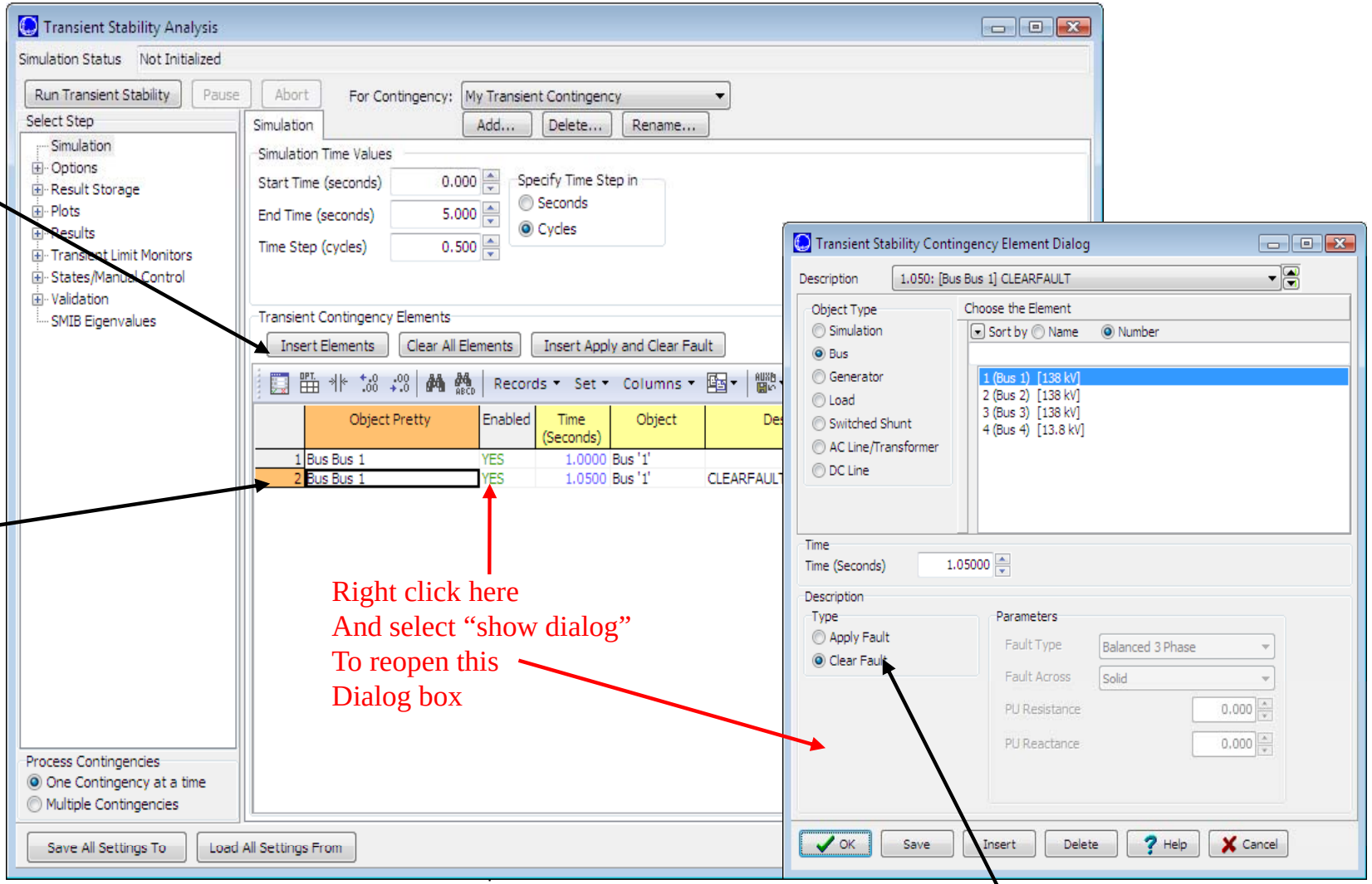
Specifying the Fault Event

- To specify the transient stability contingency go back to the "Simulation" page and click on the "Insert Elements" button. This displays the Transient Stability Contingency Element Dialog, which is used to specify the events that occur during the transient stability study.
- The event for this example will be a self-clearing, balanced 3-phase, solid (no impedance) fault at bus 1, starting at time = 1.00 seconds, and clearing at time = 1.05 seconds.
  - For the first action just choose all the defaults and select "Insert." Insert will add the action but not close the dialog.
  - For the second action simply change the Time to 1.05 seconds, and change the Type to "Clear Fault." Select "OK," which saves the action and closes the dialog.

Inserting Transient Stability Contingency Elements

Click to insert new elements

Summary of all elements in contingency and time of action



Right click here
And select “show dialog”
To reopen this
Dialog box

Available element type will vary with different objects

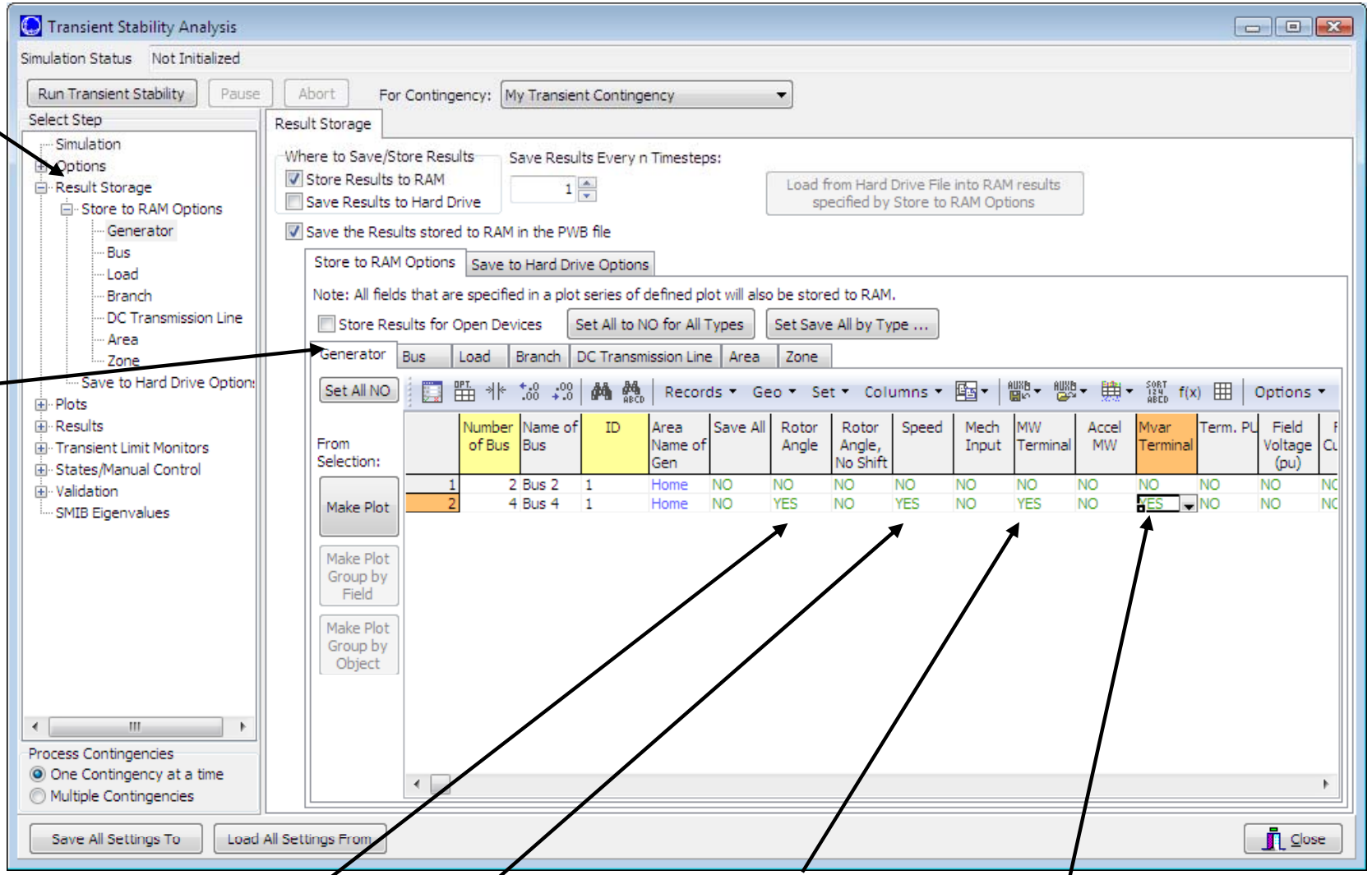
Determining the Results to View Afterward

- For large cases, transient stability solutions can generate huge amounts of data. PowerWorld Simulator provides easy ways to choose which fields to save for later viewing. These choices can be made on the "Result Storage" page.
- For this example we'll save the generator 4 rotor angle, speed, MW terminal power and Mvar terminal power.
- From the "Result Storage" page, select the generator tab and double click on the specified fields to set their values to "Yes".

Result Storage Page

Result Storage Page

Generator Tab



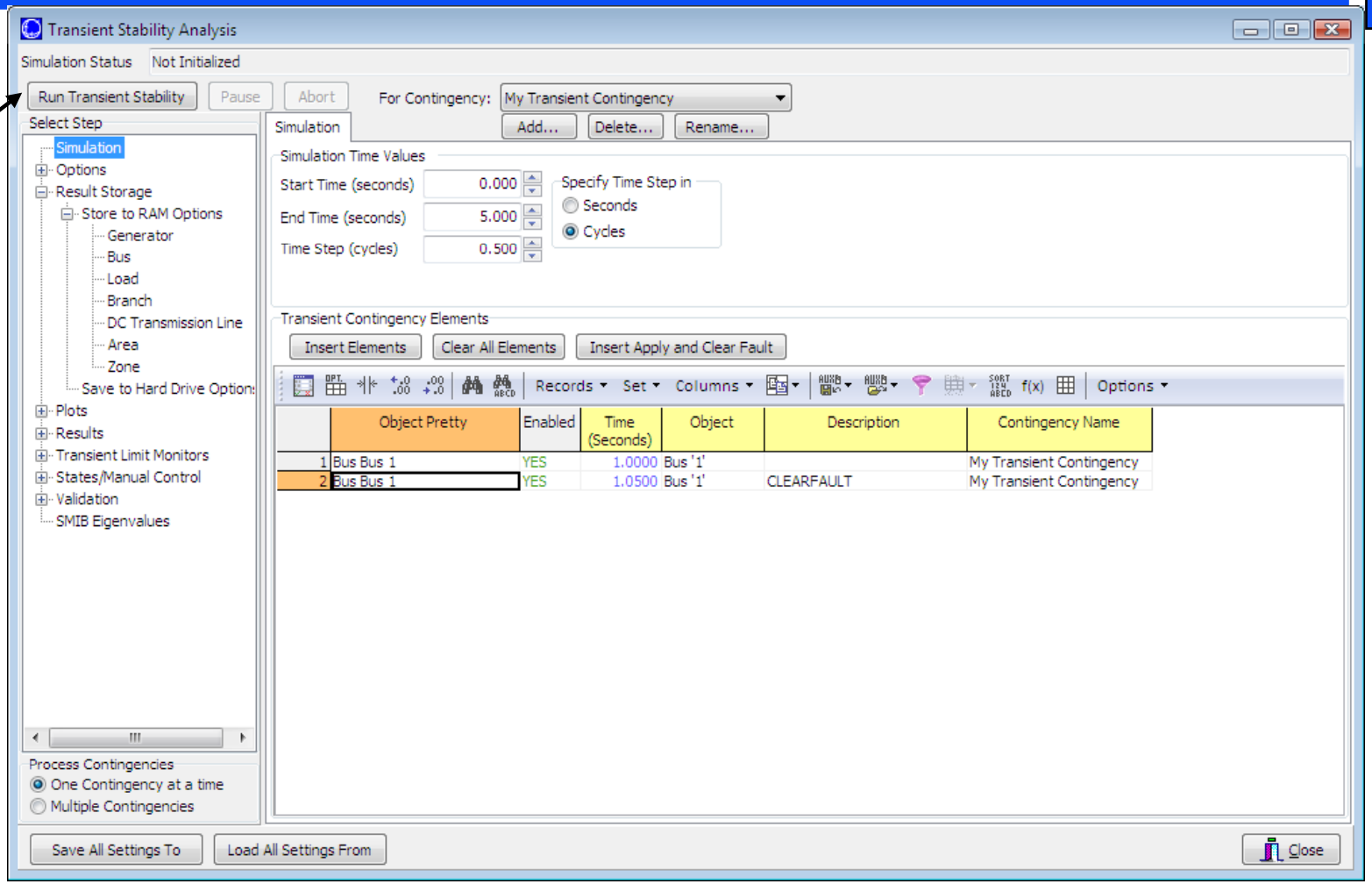
Double Click on Fields (which sets them to yes) to Store Their Values

Saving Changes and Doing First Simulation

- The last step before doing the run is to specify an ending time for the simulation, and a time step.
- Go to the “Simulation” page, verify that the end time is 5.0 seconds, and that the Time Step is 0.5 cycles
  - PowerWorld Simulator allows the time step to be specified in either seconds or cycles, with 0.5 cycles recommended.
- Before doing your first simulation, save all the changes made so far by using the main PowerWorld Simulator Ribbon, select “Save Case As” with a name of “Example_13_4_WithCLSModel_ReadyToRun”
- Click on “Run Transient Stability” to solve.

Running the Transient Stability Simulation

Click to run the specified contingency



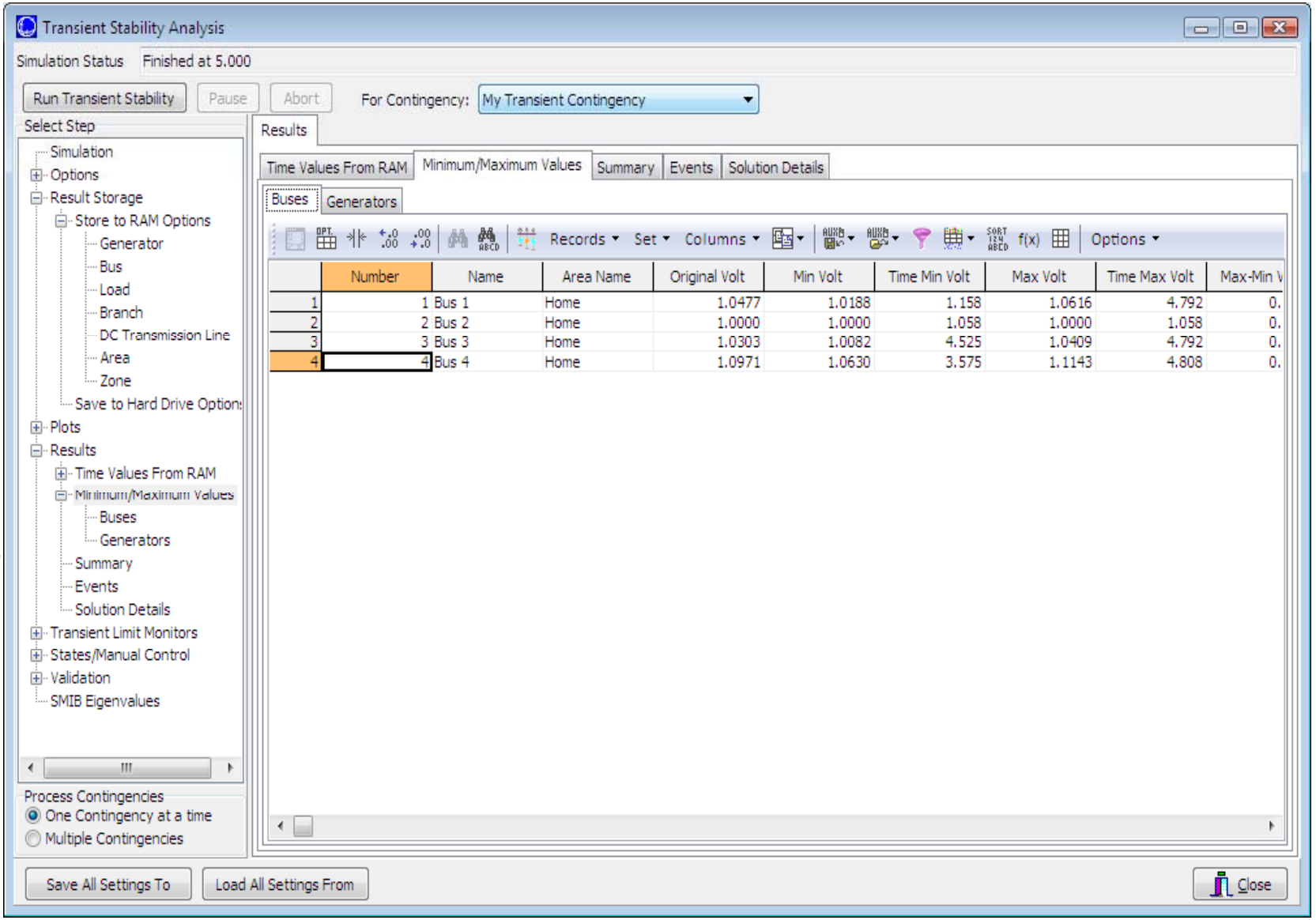
Once the contingency runs the “Results” page may be opened

Transient Stability Results

- Once the transient stability run finishes, the “Results” page provides both a minimum/maximum summary of values from the simulation, and time step values for the fields selected to view.
- The Time Values and Minimum/Maximum Values tabs display standard PowerWorld Simulator case information displays, so the results can easily be transferred to other programs (such as Excel) by right-clicking on a field and selecting “Copy/Paste/Send”

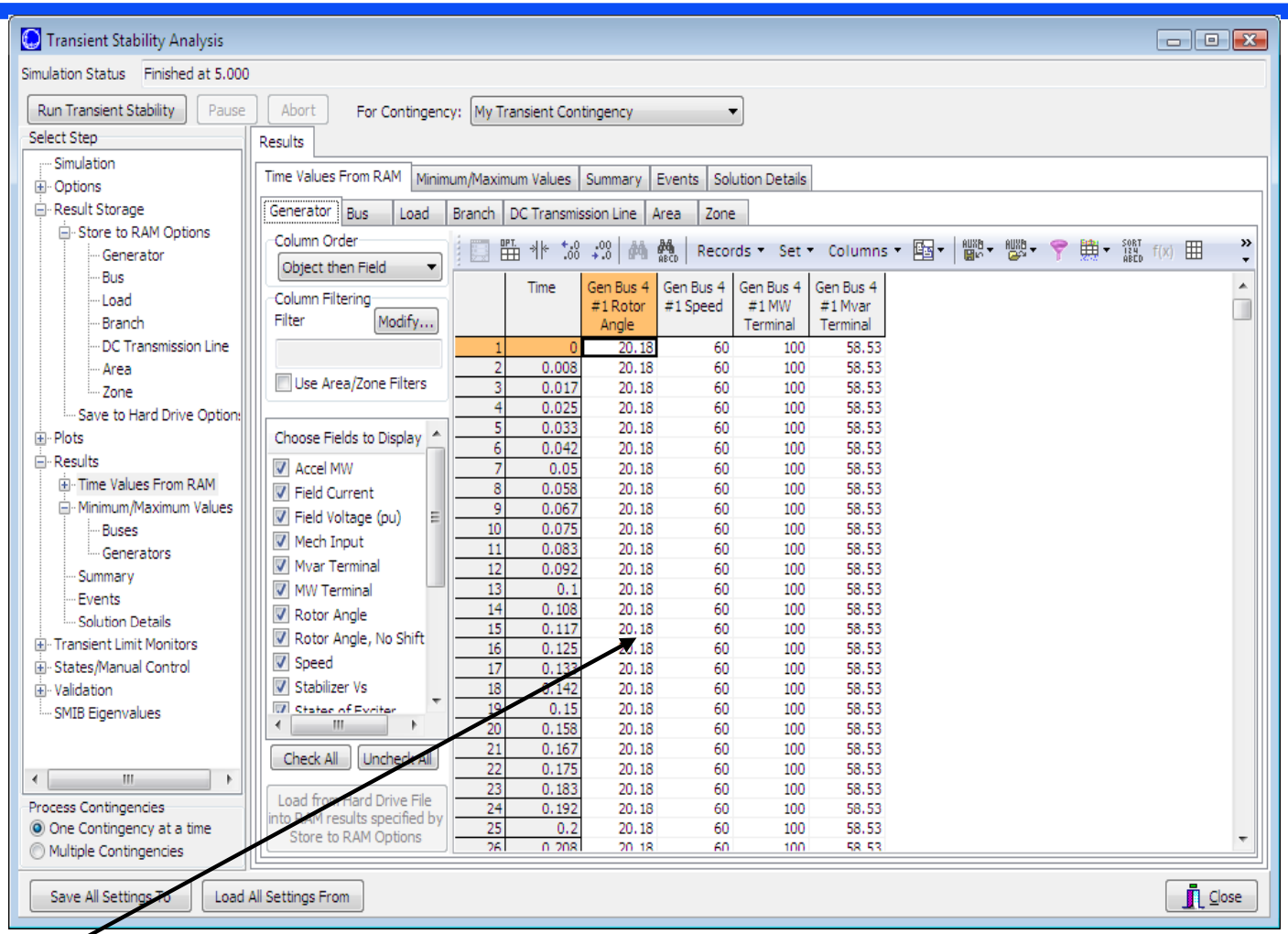
Results: Minimum/Maximum Values

Minimum and maximum values are available for all generators and buses



Time Value Results

Lots of options are available for showing and filtering the results.

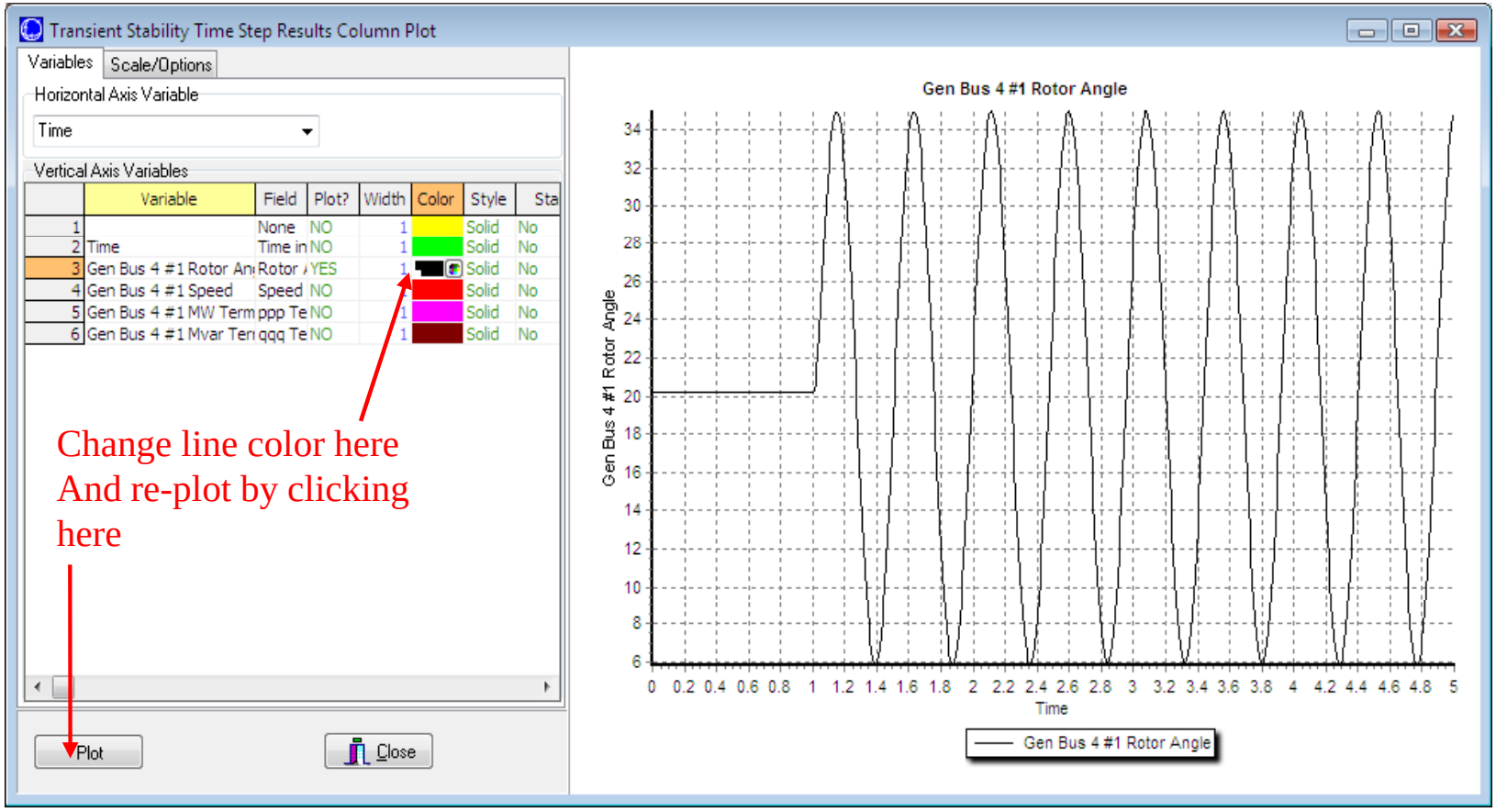


By default the results are shown for each time step. Results can be saved saved every “n” timesteps using an option on the Options, General page

Quickly Plotting Results

- Time value results can be quickly plotted by using the standard case information display plotting capability.
  - Right-click on the desired column
  - Select Plot Columns
  - Use the Column Plot Dialog to customize the results.
  - Right-click on the plot to save, copy or print it.
- More comprehensive plotting capability is provided using the Transient Stability “Plots” page; this will be discussed later.

Generator 4 Rotor Angle Column Plot

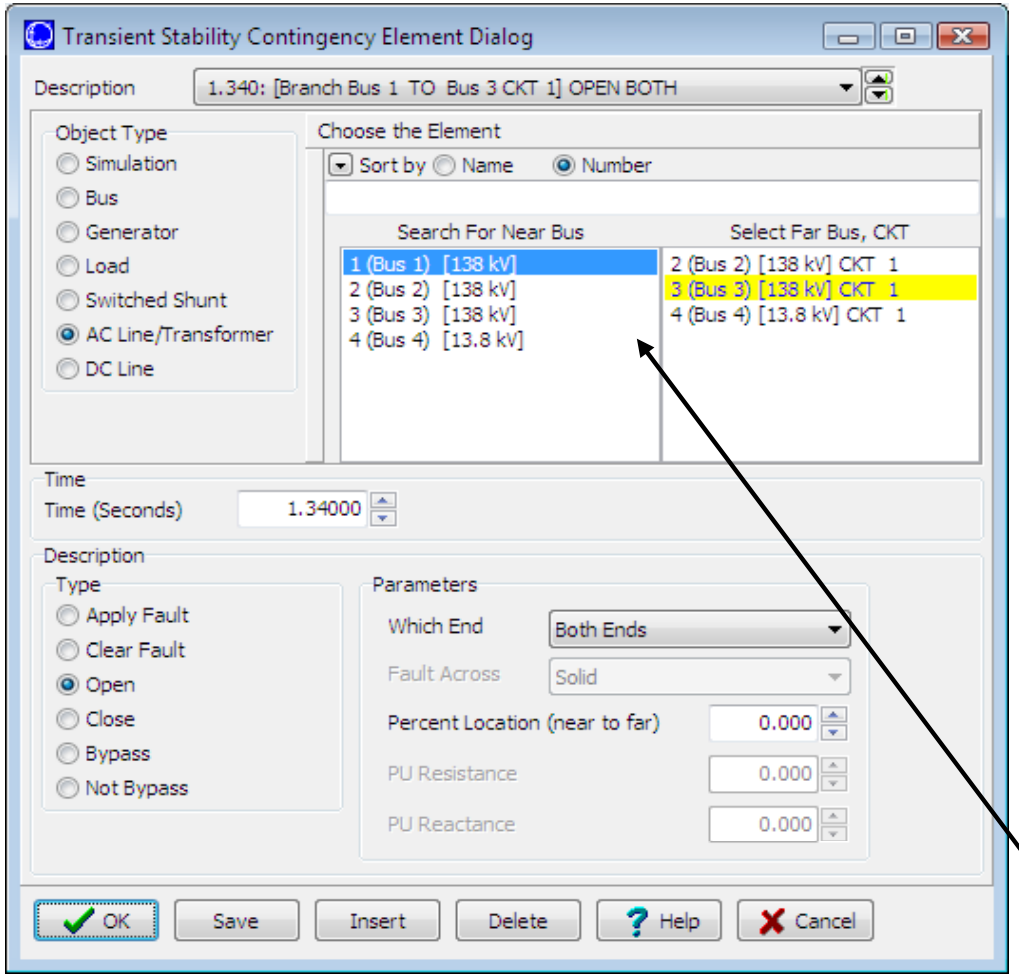


Starting the event at t = 1.0 seconds allows for verification of an initially stable operating point. The small angle oscillation indicates the system is stable, although undamped.

Changing the Case

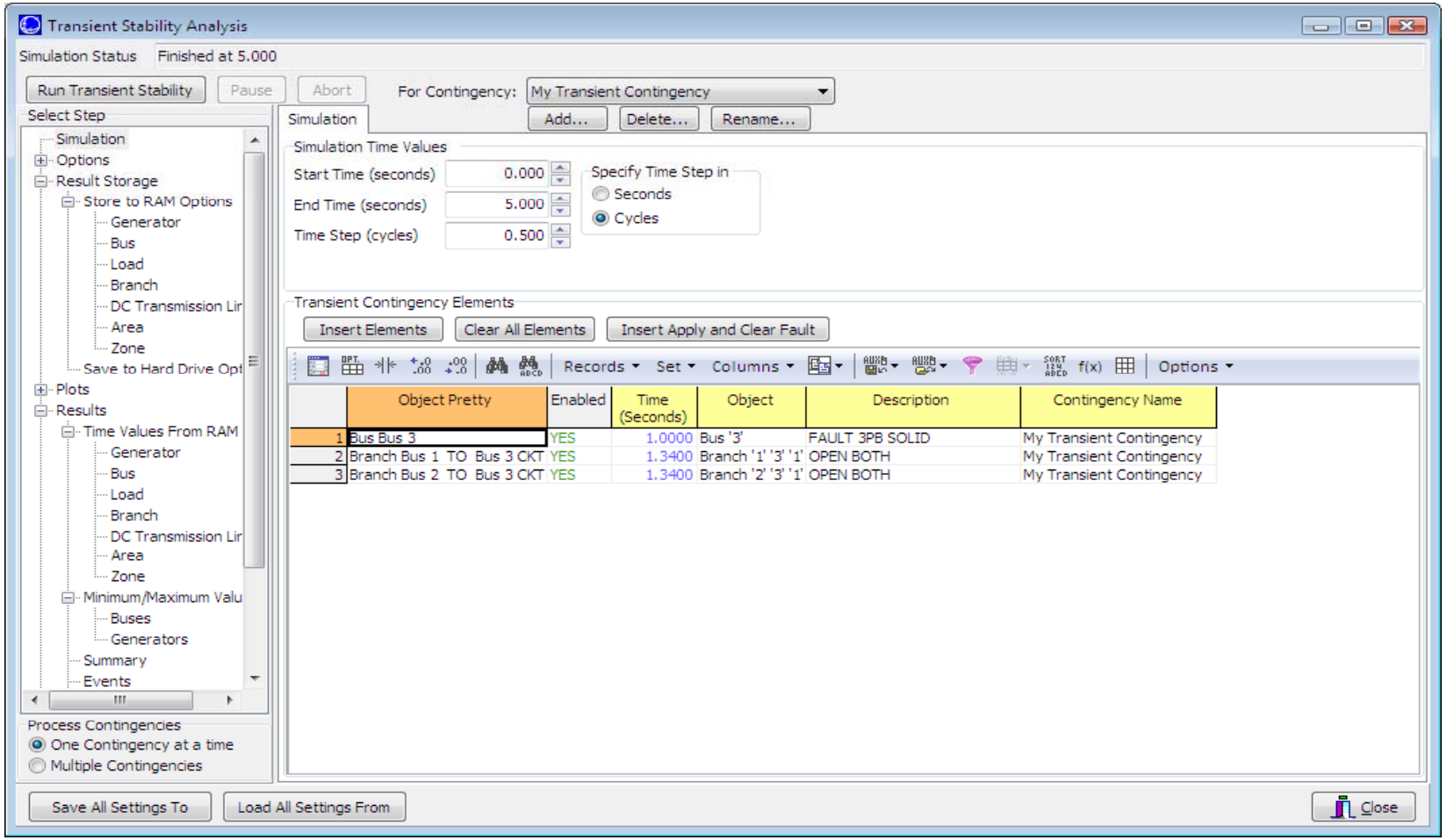
- PowerWorld Simulator allows for easy modification of the study system. As a next example we will duplicate example 13.4 from earlier editions of the Glover/Sarma Power System Analysis and Design Book.
- Back on the one-line, right-click on the generator and use the Stability/Machine models page to change the Xdp field from 0.2 to 0.3 per unit.
- On the Transient Stability Simulation page, change the contingency to be a solid three phase fault at *Bus 3*, cleared by opening *both* the line between buses 1 and 3 and the line between buses 2 and 3 at time = *1.34 seconds*.

Changing the Case: Setting up Contingency Elements



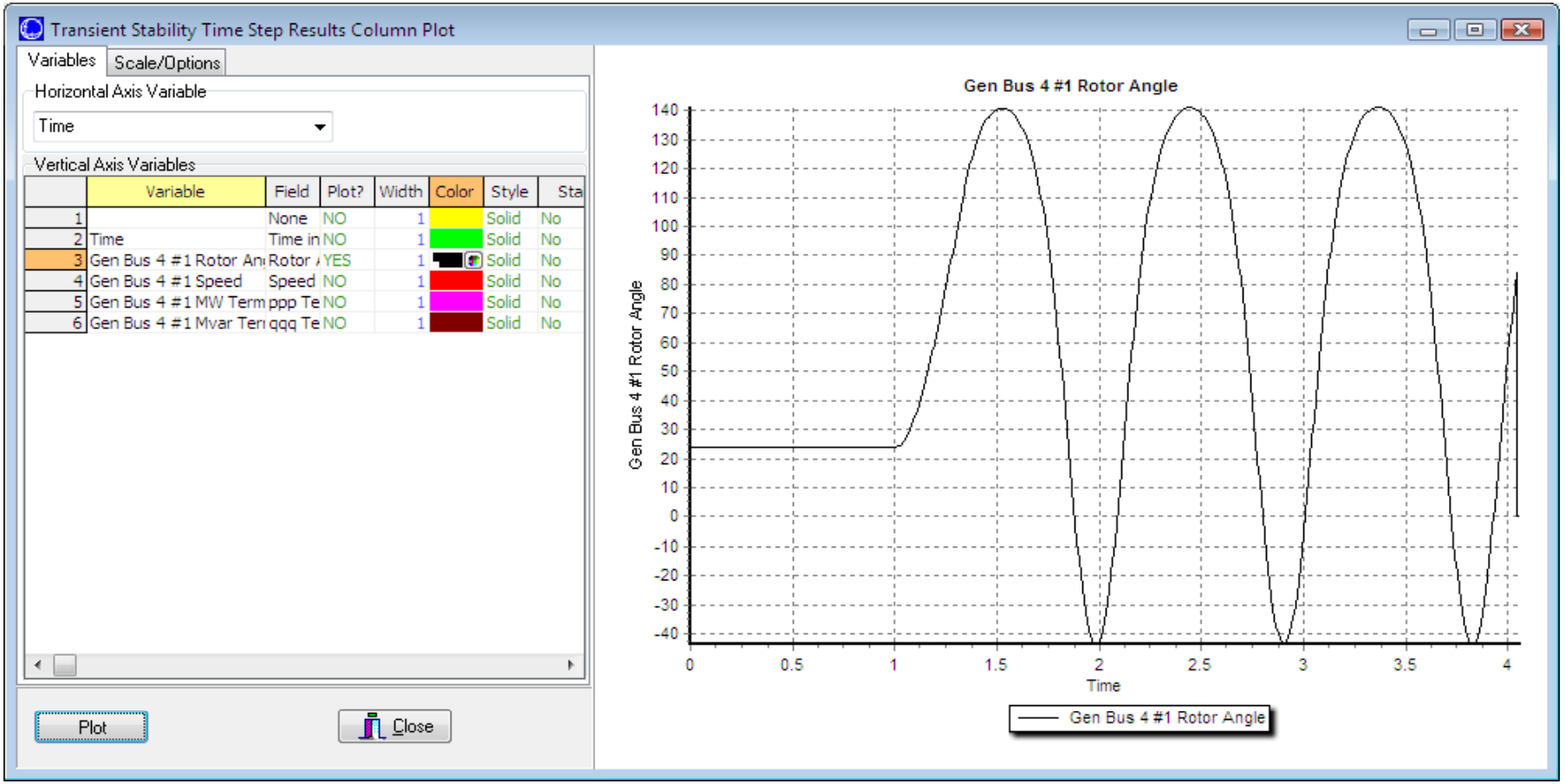
Change object type to AC Line/Transformer, select the right line, and change the element type to “Open”.

Changing the Case: Setting up Contingency Elements



Contingency Elements displays should eventually look like this. Note fault is at bus 3, not at bus 1.

Glover/Sarma Example 13.4 Case: Generator 4 Rotor Angle Plot - On the Verge of Instability

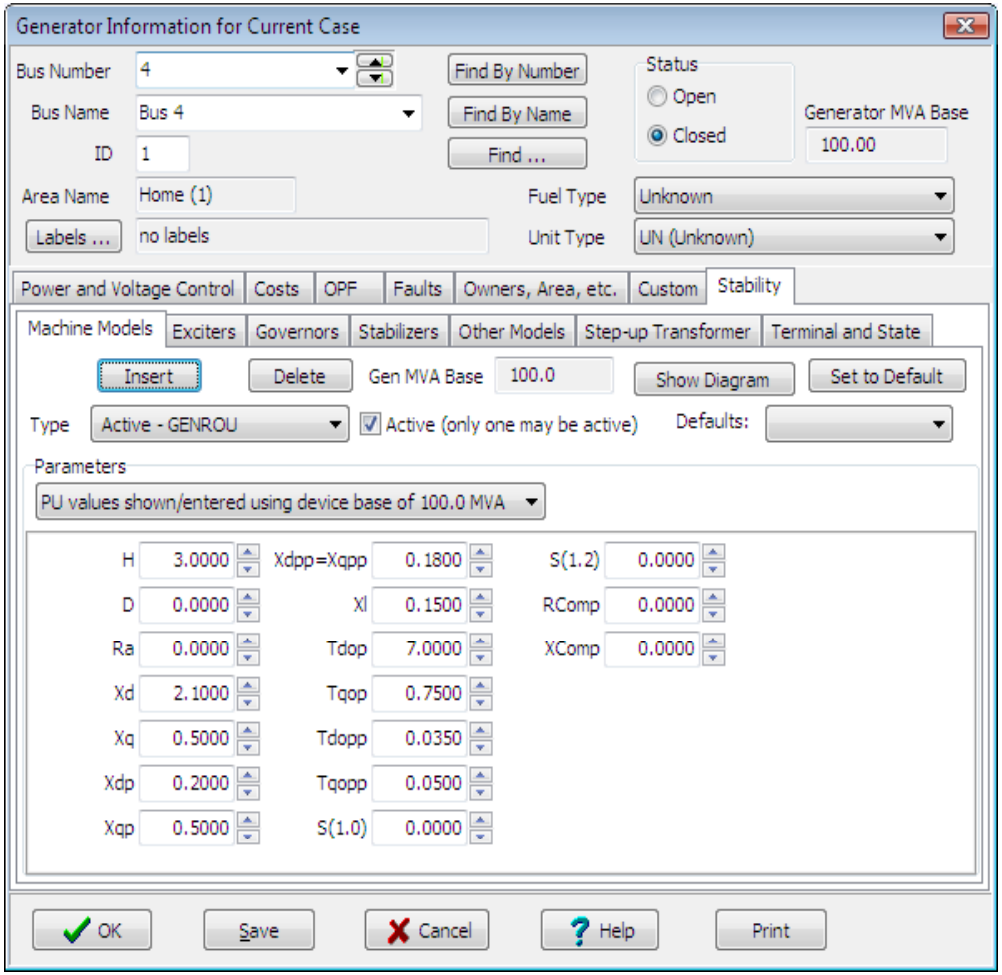


Resulting plot should look like this.

More Realistic Generator Models

- While the classical model is widely used in academic settings because of its simplicity, it is not recommended for actual power system studies.
- PowerWorld Simulator includes a number of much more realistic models that can be easily used
  - A detailed explanation of these models is beyond the scope of these slides with many books discussing the details
- To replace the classical model with a detailed solid rotor, subtransient level model, go to the generator dialog Machine Models page, click “Delete” to delete the existing model, select “Insert” to display the Model Type dialog and select the GENROU model; accept the defaults.

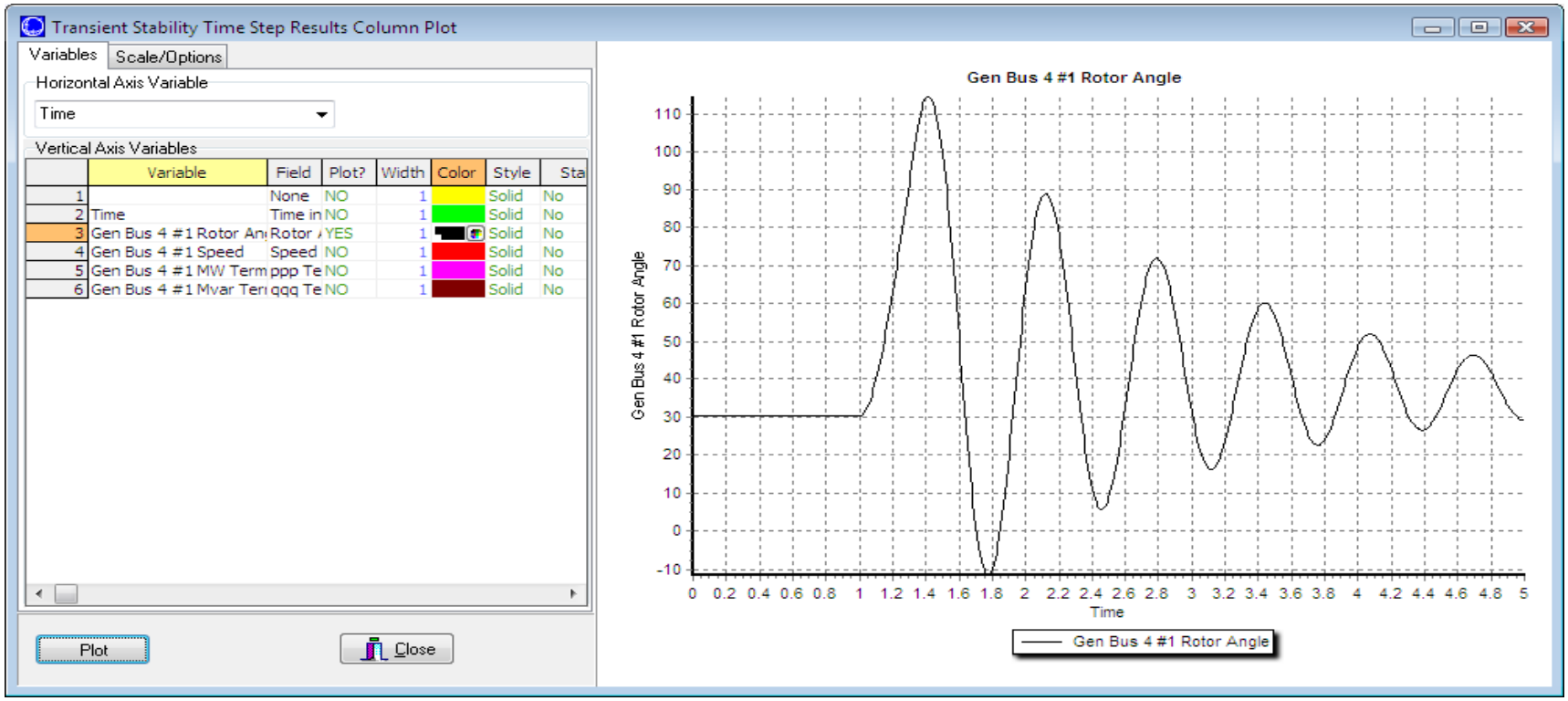
GENROU Model



The GENROU model provides a very good approximation for the behavior of a synchronous generator over the dynamics of interest during a transient stability study (up to about 10 Hz).
It is used to represent a solid rotor machine with three damper windings.

More than 2/3 of the machines in the 2006 North American Eastern Interconnect case (MMWG) are represented by GENROU models.

Repeat of Glover/Sarma Example 13.4



This plot repeats the previous example with the bus 3 fault. The generator response is now damped due to the damper windings included in the GENROU model. Case is saved in examples as

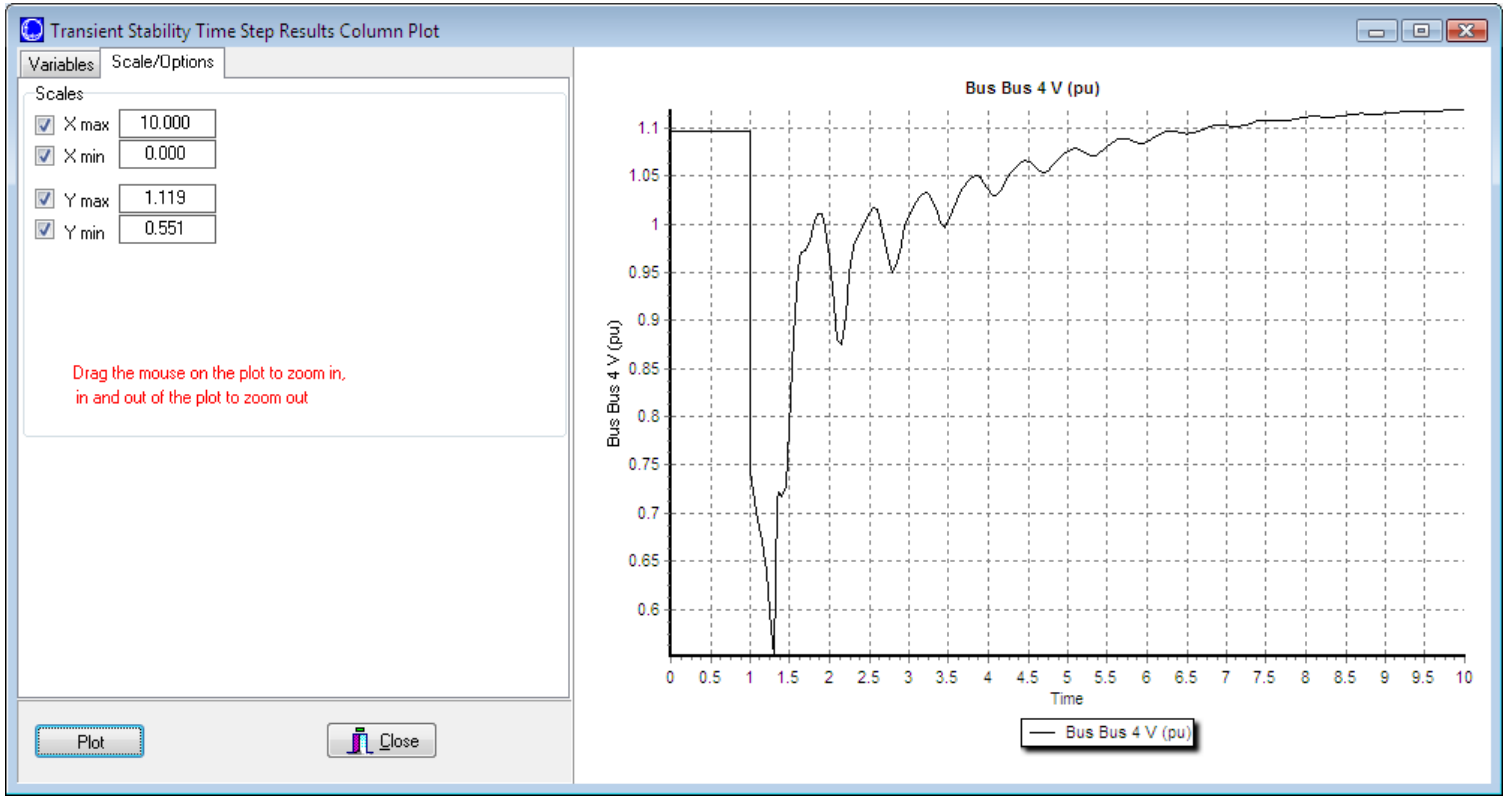
Example_13_4_GENROU.

Viewing Additional Fields, Saving Results Every n Timesteps

- Before moving on it will be useful to save some additional fields. On the Transient Stability Analysis form select the “Result Storage” page. Then on the Generator tab toggle the generator 4 “Field Voltage” field to Yes. On the Bus tab toggle the bus 4 “V (pu)” field to Yes.
- At the top of the “Result Storage” page, change the “Save Results Every n Timesteps” to 6.
  - PowerWorld Simulator allows you to store as many fields as desired. On large cases one way to save on memory is to save the field values only every n timesteps with 6 a typical value (i.e., with a ½ cycle time step 6 saves 20 values per second)

Plotting Bus Voltage: The Need for an Generator Exciter

- Change the end time to 10 seconds on the “Simulation” page, and rerun the previous. Then on “Results” page, “Time Values from RAM”, “Bus”, plot the bus 4 pu voltage. The results are shown below. Note: do not plot generator field voltage. Plot is the bus voltage.



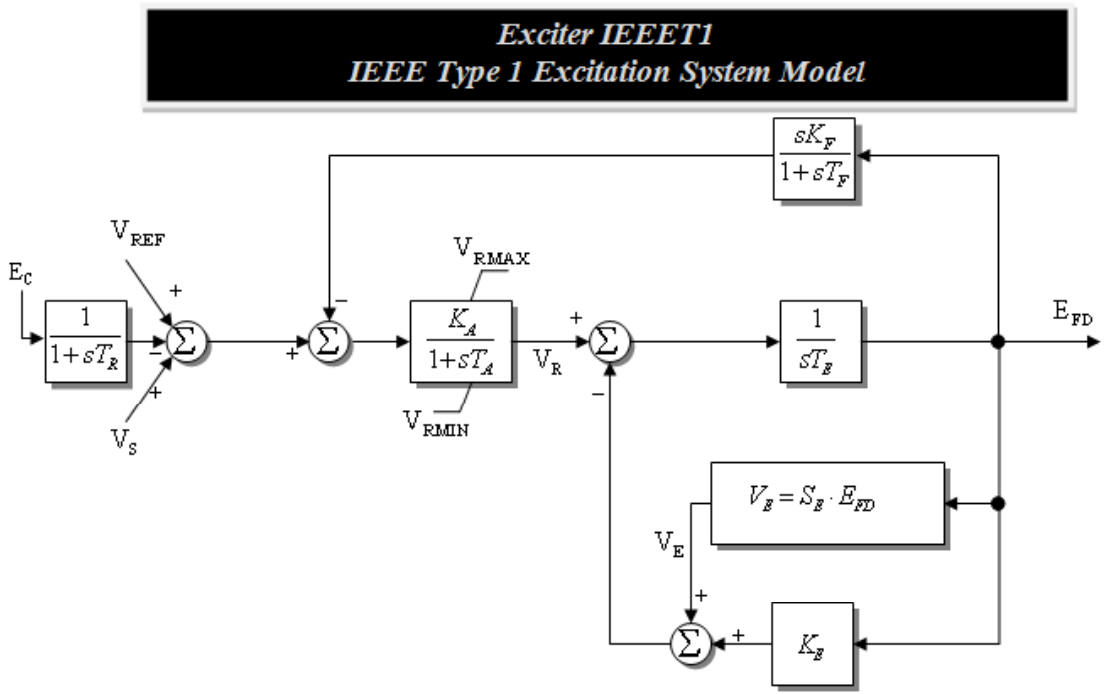
Notice following the fault the voltage does not recover to its pre-fault value. This is because we have not yet modeled an exciter.

Adding a Generator Exciter

- The purpose of the generator excitation system (exciter) is to adjust the generator field current to maintain a constant terminal voltage.
- PowerWorld Simulator includes many different types of exciter models. One simple exciter is the IEEET1. To add this exciter to the generator at bus 4 go to the generator dialog, “Stability” tab, “Exciters” page. Click Insert and then select IEEET1 from the list. Use the default values.
  - The IEEET1 is by far the most common exciter used in the 2006 MMWG case; the next most common is its close relative, the IEEEX1.

IEEET1 Exciter

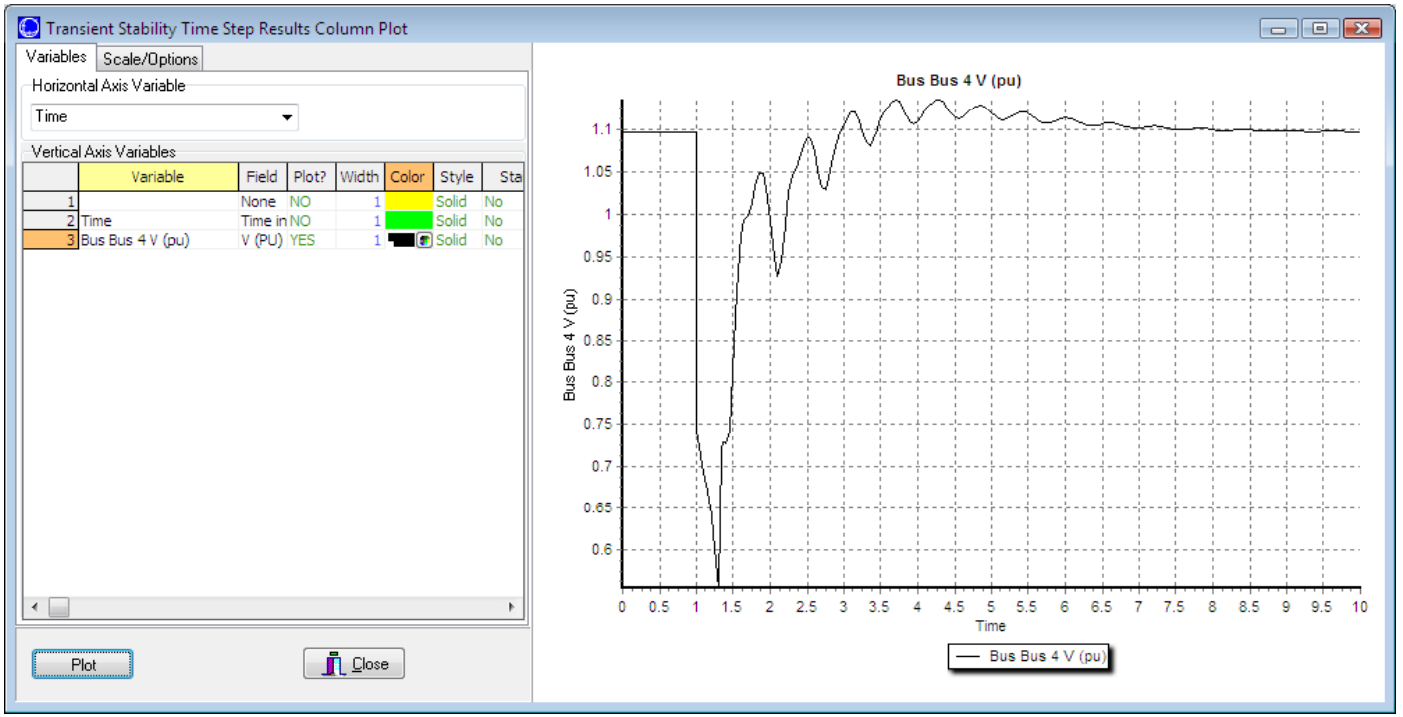
- Once you have inserted the IEEET1 exciter you can view its block diagram by clicking on the “Show Diagram” button. This opens a PDF file in Adobe Reader to the page with that block diagram. The block diagram for this exciter is also shown below.



The input to the exciter, E_c, is usually the terminal voltage. The output, E_{FD}, is the machine field voltage.

Voltage Response with Exciter

- Re-do the run. The terminal time response of the terminal voltage is shown below. Notice that now with the exciter it returns to its pre-fault voltage.

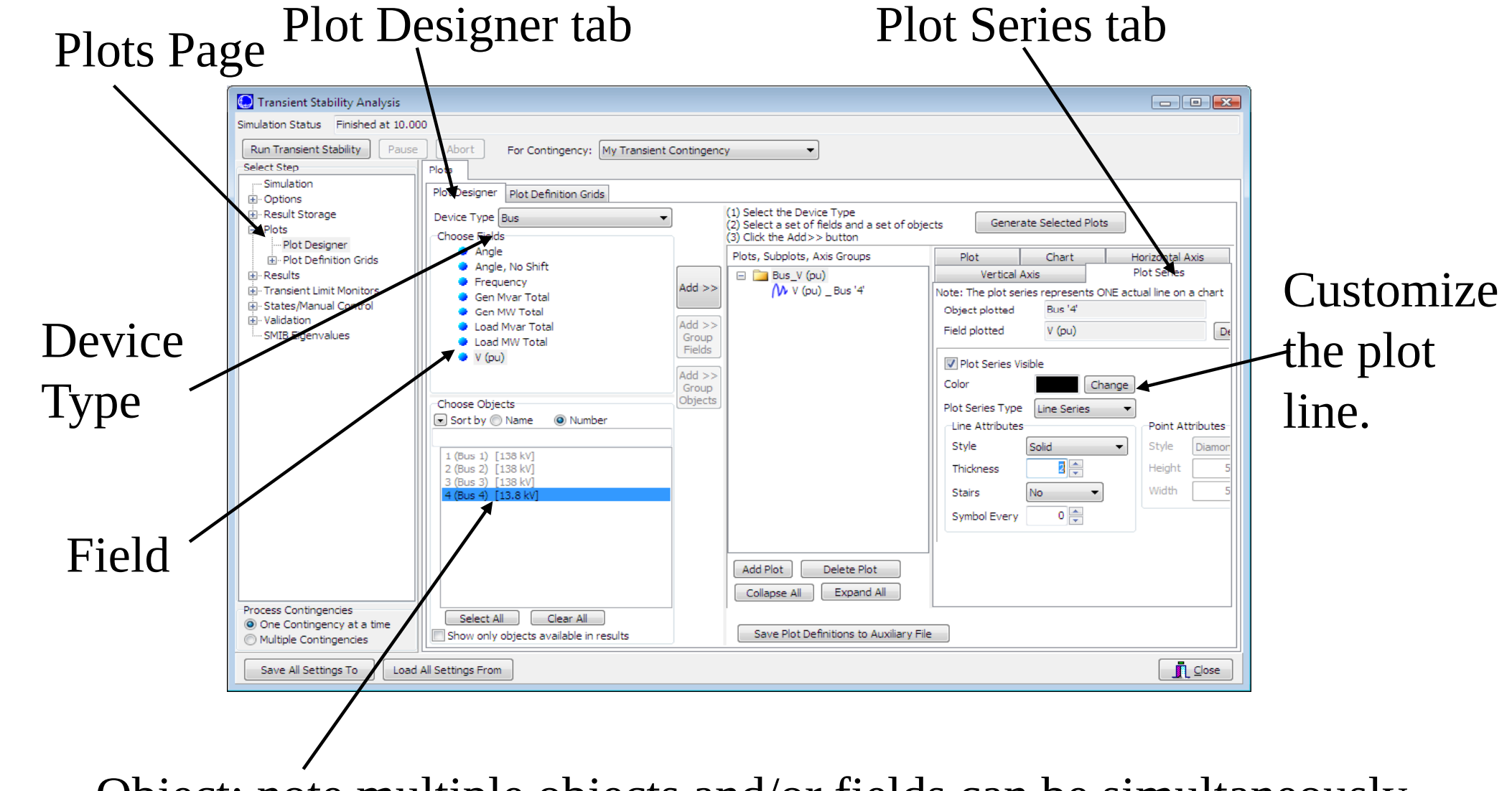


This example is saved in the example case Example_13_4_GenROU_IEEET1

Defining Plots

- Because time plots are commonly used to show transient stability results, PowerWorld Simulator makes it easy to define commonly used plots.
  - Plot definitions are saved with the case, and can be set to automatically display at the end of a transient stability run.
- To define some plots on the Transient Stability Analysis form select the “Plots” page. Initially we’ll setup a plot to show the bus voltage.
  - Use the Plot Designer to choose a Device Type (Bus), Field, (Vpu), and an Object (Bus 4). Then click the “Add” button. Next click on the Plot Series tab (far right) to customize the plot’s appearance; set Color to black and Thickness to 2.

Defining Plots

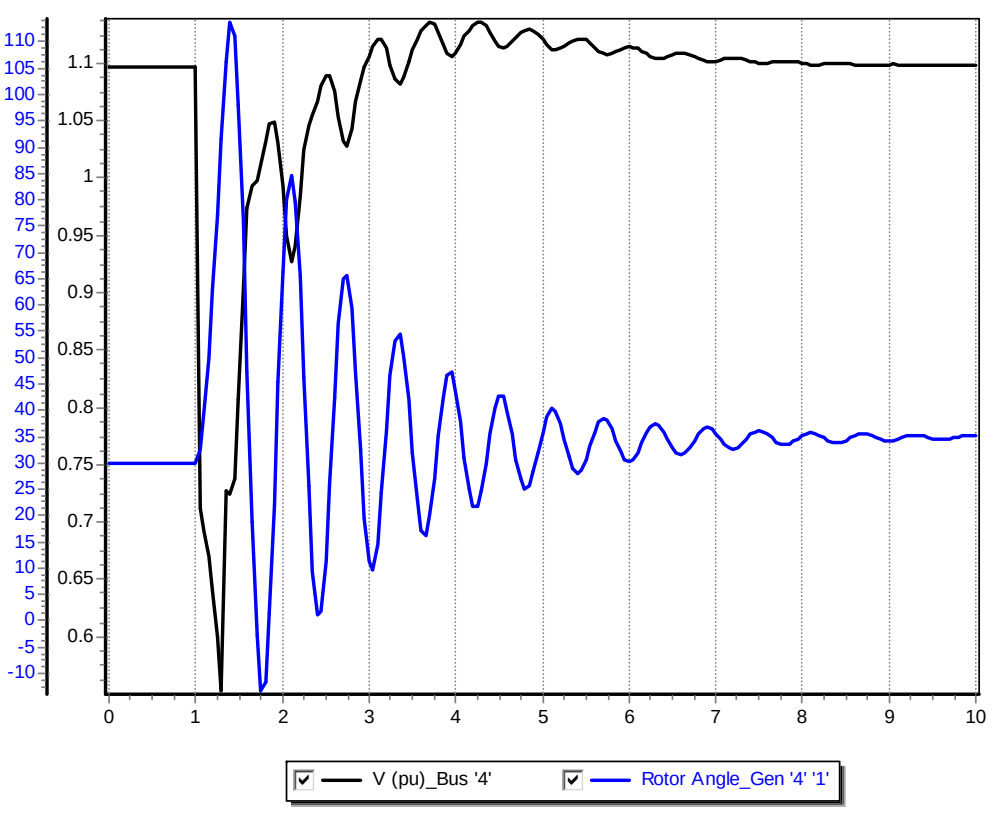


Adding Multiple Axes

- Once the plot is designed, save the case and rerun the simulation. The plot should now automatically appear.
- In order to compare the time behavior of various fields an important feature is the ability to show different values using different y-axes on the same plot.
- To add a new Vertical Axis to the plot, close the plot, go back to the “Plots” page, select the Vertical Axis tab (immediately to the left of the Plot Series tab). Then click “Add Axis Group”. Next, change the Device Type to Generator, the Field to Rotor Angle, and choose the Bus 4 generator as the Object. Click the “Add” button. Customize as desired. There are now two axis groups.

Two Axes Plot

- The resultant plot is shown below. To copy the plot to the windows clipboard, or to save the plot, right click towards the bottom of the plot to display the local menu, or click on the small arrow in the lower right-hand corner. You can re-do the plot without re-running the simulation by clicking on “Generate Selected Plots” button.



Lots of options are available for customizing the appearance of the plots (like adding a title) both at design time and once the plot has been created. Play around with them.

This case is saved as Example_13_4_WithPlot

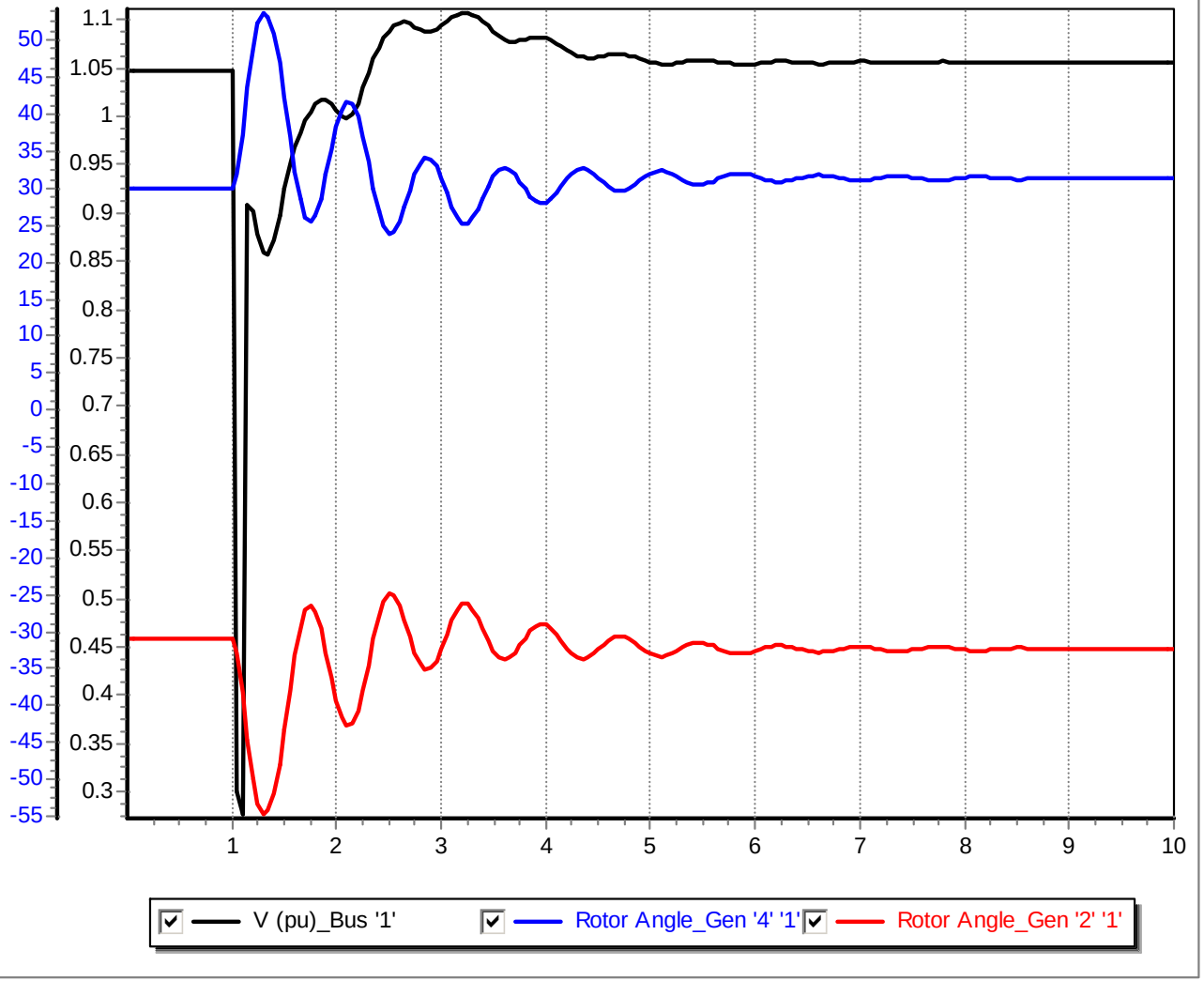
Setting the Angle Reference

- Infinite buses do not exist, and should not usually be used except for small, academic cases.
  - An infinite bus has a fixed frequency (e.g. 60 Hz), providing a convenient reference frame for the display of bus angles.
- Without an infinite bus the overall system frequency is allowed to deviate from the base frequency
  - With a varying frequency we need to define a reference frame
  - PowerWorld Simulator provides several reference frames with the default being average of bus frequency.
  - Go to the “Options”, “Power System Model” page. Change Infinite Bus Model to “No Infinite Buses”; Under “Options, Result Options”, set the Angle Reference to “Average of Generator Angles.”

Setting Models for Bus 2

- Without an infinite bus we need to set up models for the generator at bus 2. Use the same procedure as before, adding a GENROU machine and an IEEET1 exciter.
  - Accept all the defaults, except *set the H field for the GENROU model to 30* to simulate a large machine.
  - Go to the Plot Designer, click on PlotVertAxisGroup2 and use the "Add" button to show the rotor angle for Generator 2. Note that the object may be grayed out but you can still add it to the plot.
  - Without an infinite bus the case is no longer stable with a 0.34 second fault; on the main Simulation page change the event time for the *opening on the lines to be 1.10 seconds* (you can directly overwrite the seconds field on the display).
  - Case is saved as Example_13_4_NoInfiniteBus

No Infinite Bus Case Results



Plot shows the rotor angles for the generators at buses 2 and 4, along with the voltage at bus 1. Notice the two generators are swinging against each other.

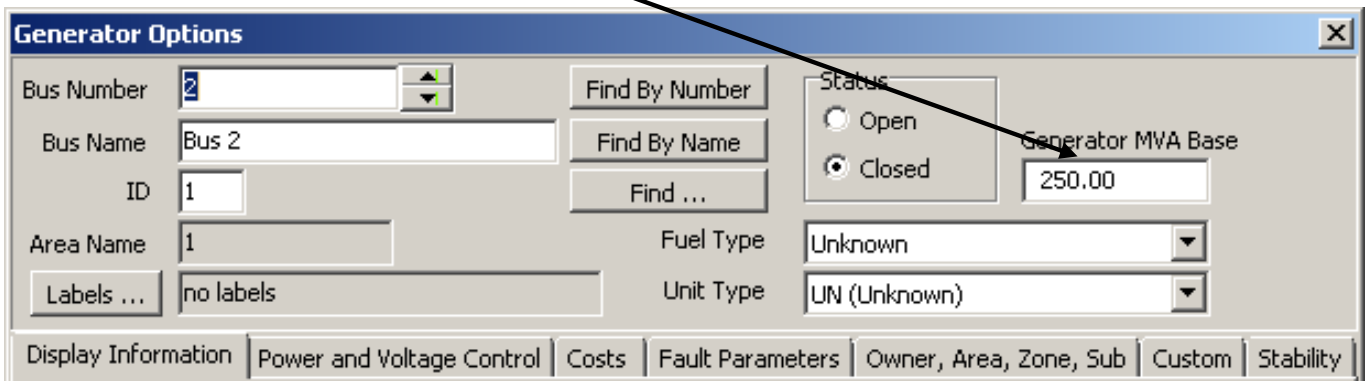
Note: All fields specified to plot will automatically be stored in RAM. So if you select what to plot first, and that is all you want to do, you do not have to pre-specify what to store in RAM.

WSCC Nine Bus, Three Machine Case

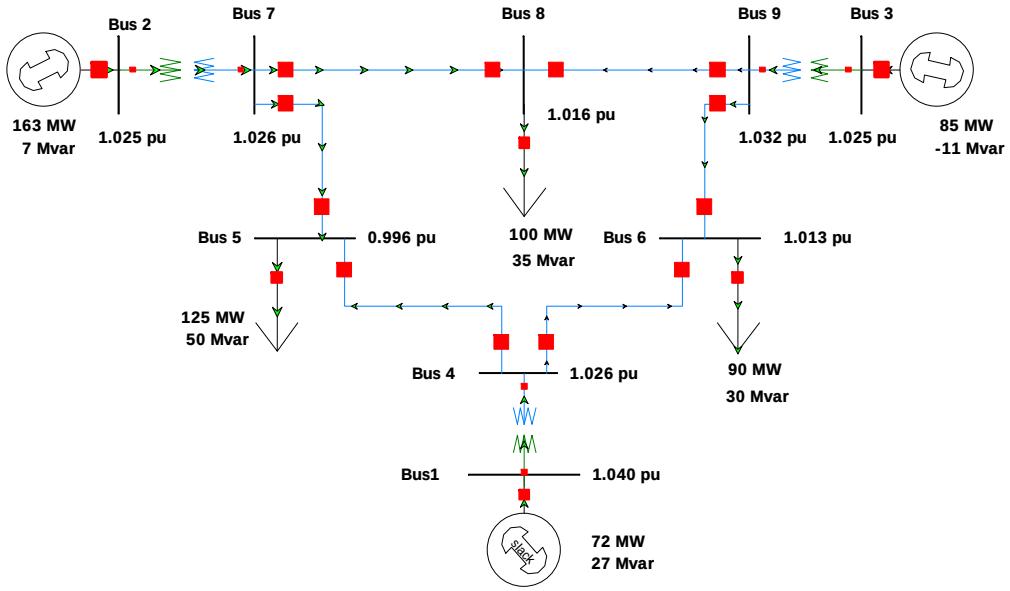
- As a next step in complexity we consider the WSCC (now WECC) nine bus case, three machine case.
  - This case is described in several locations including EPRI Report EL-484 (1977), the Anderson/Fouad book (1977). Here we use the case as presented in the Sauer/Pai "Power System Dynamics and Stability" book (1997) except the generators are modeled using the subtransient GENROU model, and data is in per unit on generator MVA base (see next slide).
  - The Sauer/Pai book contains a derivation of the system models, and a fully worked initial solution for this case.
  - Case is named *WSCC_9Bus. Load this case.*

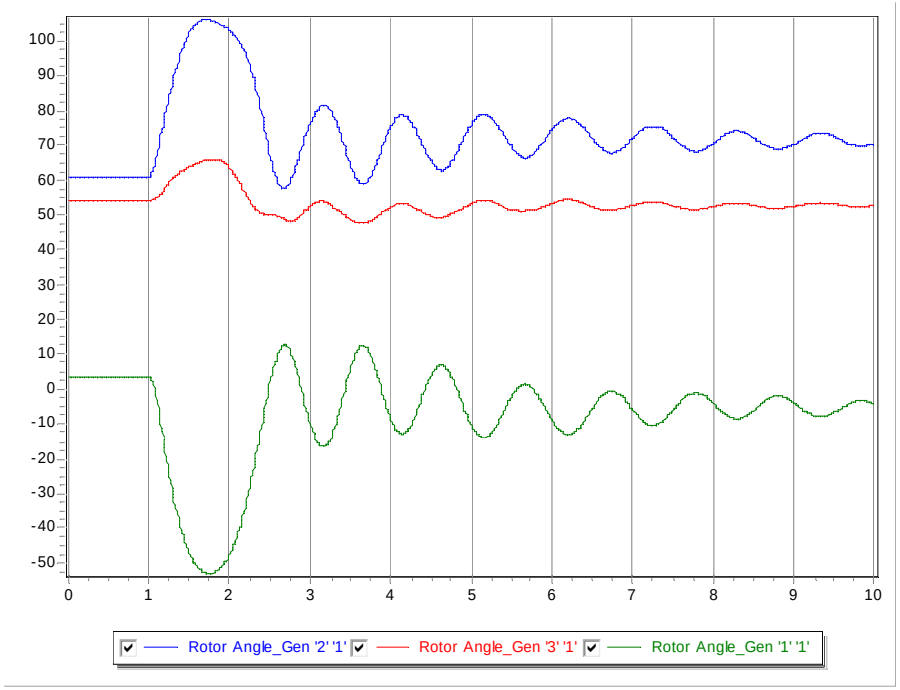
Generator MVA Base

- Like most commercial transient stability programs, generator transient stability data in PowerWorld Simulator is entered in per unit using the generator MVA base.
- The generator MVA base can be modified in the “Edit Mode” (upper left portion of the ribbon), using the Generator Information Dialog. You will see the MVA Base in “Run Mode” but not be able to modify it.



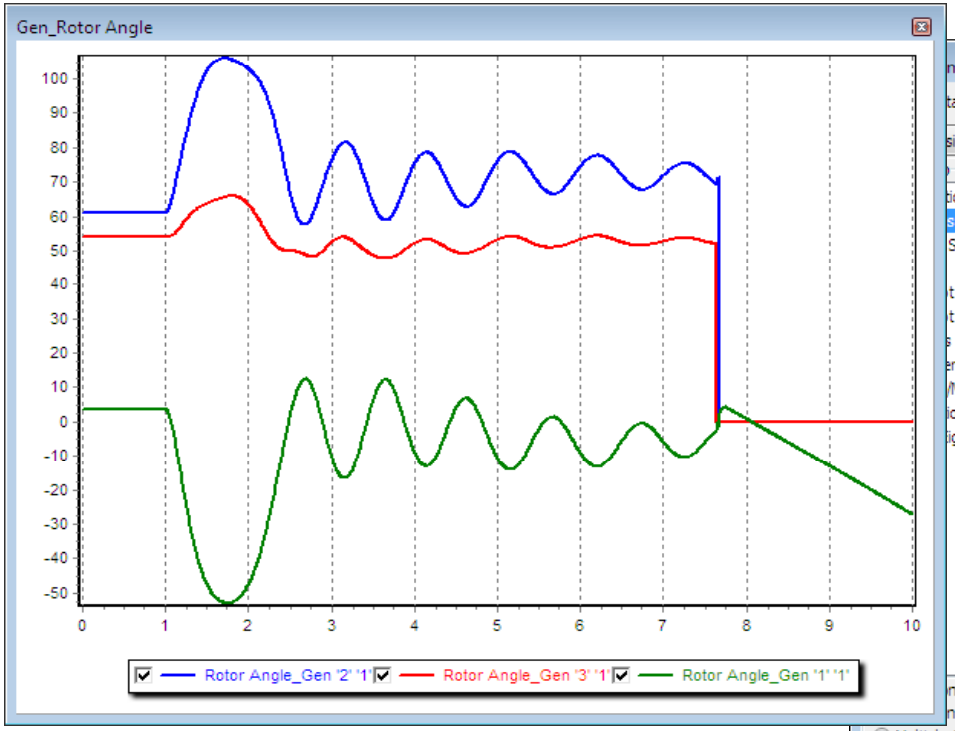
WSCC_9Bus Case

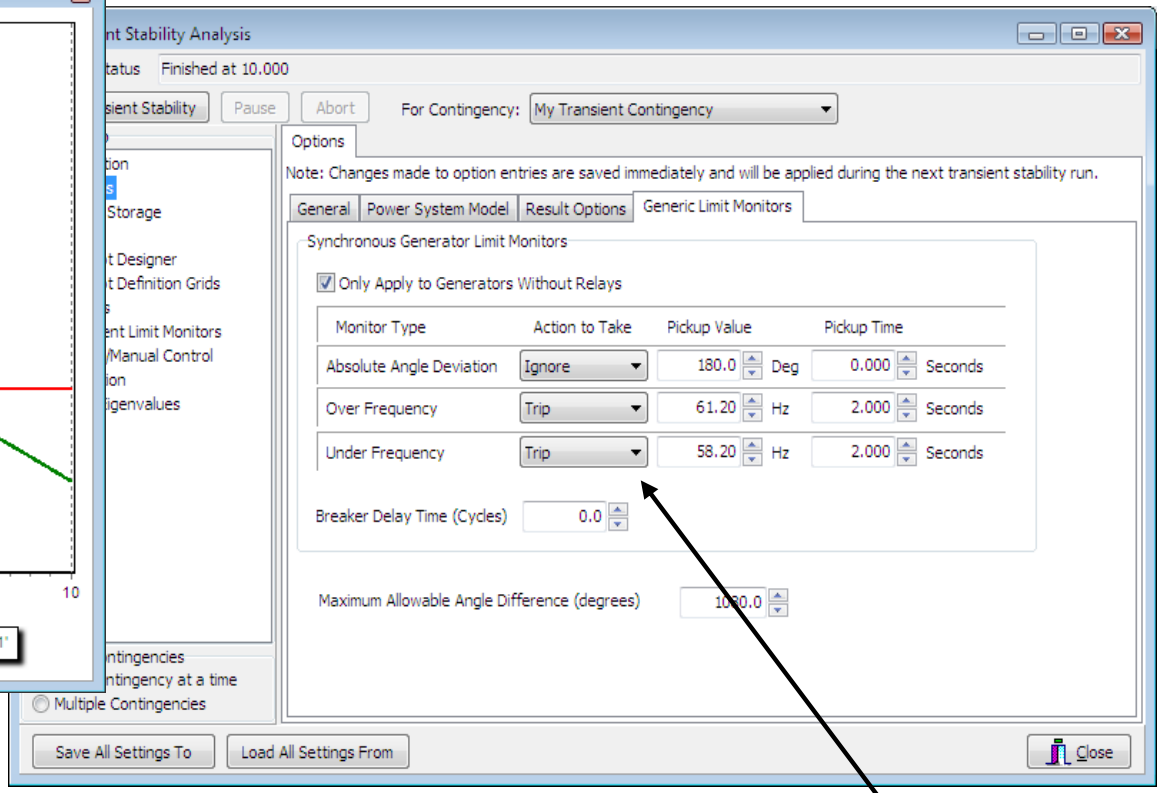




The left figure shows the initial power flow solution for the WSCC 9 bus case. The right figure shows the generator angles for a fault on the line between buses 5 and 7 near the bus 7 terminal, which is cleared after 0.77 seconds by opening the bus 5 to 7 line. Change the fault clearing time to verify that system loses stability for a clearing time between 0.078 and 0.079 seconds. This fault and the associated plots are already set up in the case, starting with a clearing at 0.077 seconds.

Automatic Generator Tripping



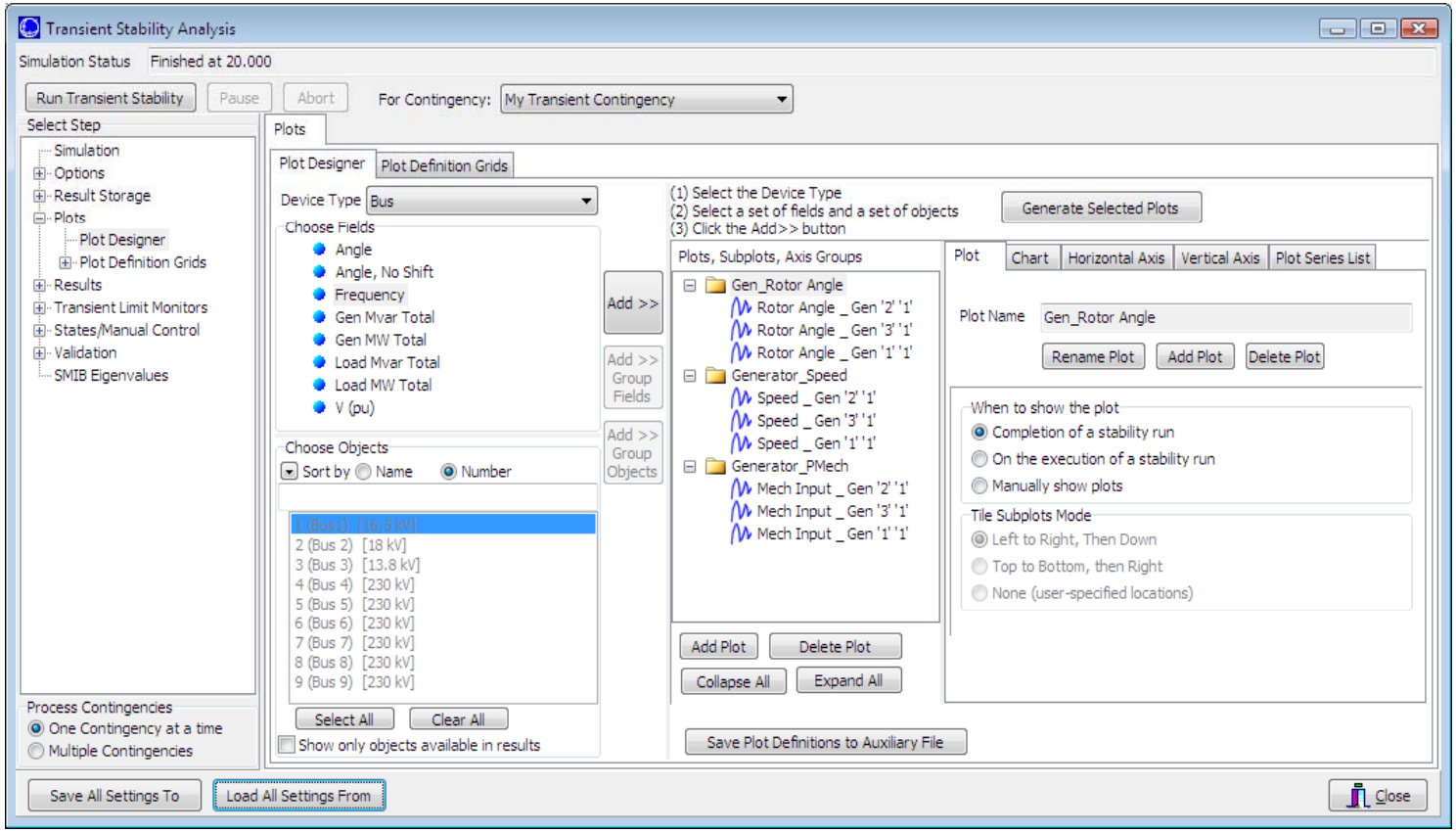


Because this case has no governors and no infinite bus, the bus frequency keeps rising throughout the simulation, even though the rotor angles are stable. Users may set the generators to automatically trip in “Options”, “Generic Limit Monitors”. All generators that do not have relays may be set to have under- and over-frequency tripping if they exceed those amounts for greater than the pickup time. In this example, setting automatic tripping as above causes Generator 2 and 3 to trip out between 7 and 8 seconds (with a 0.077 seconds clearing). If all generators trip out (which would happen eventually in this simulation), the simulation aborts as there are no longer any viable islands.

Generator Governors

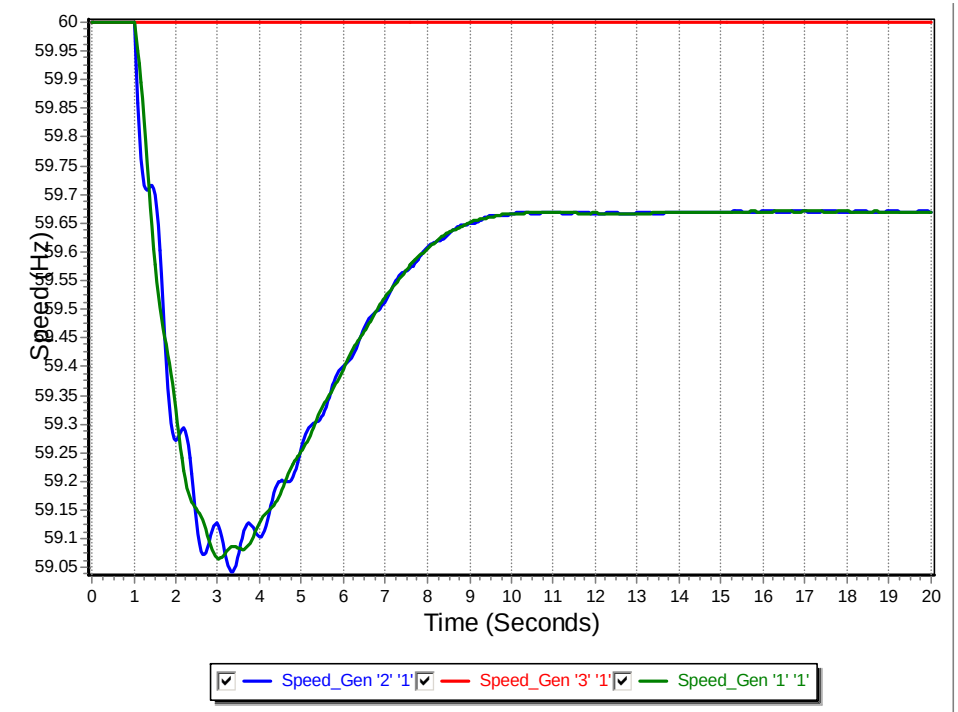
- As was the case with machine models and exciters, governors can be entered using the Generator Dialog.
- Add TGOV1 models for all three generators using the default values.
- Use the “Add Plot” button on the plot designer to insert new plots to show 1) the generator speeds, and 2) the generator mechanical input power.
- Change contingency to be the opening of the bus 3 generator at time t=1 second. *There is no “fault” to be cleared in this example, the only event is opening the generator.* Run case for 20 seconds.
- Case with governors included and plots designed is named WSCC_9Bus_WithGovernors.

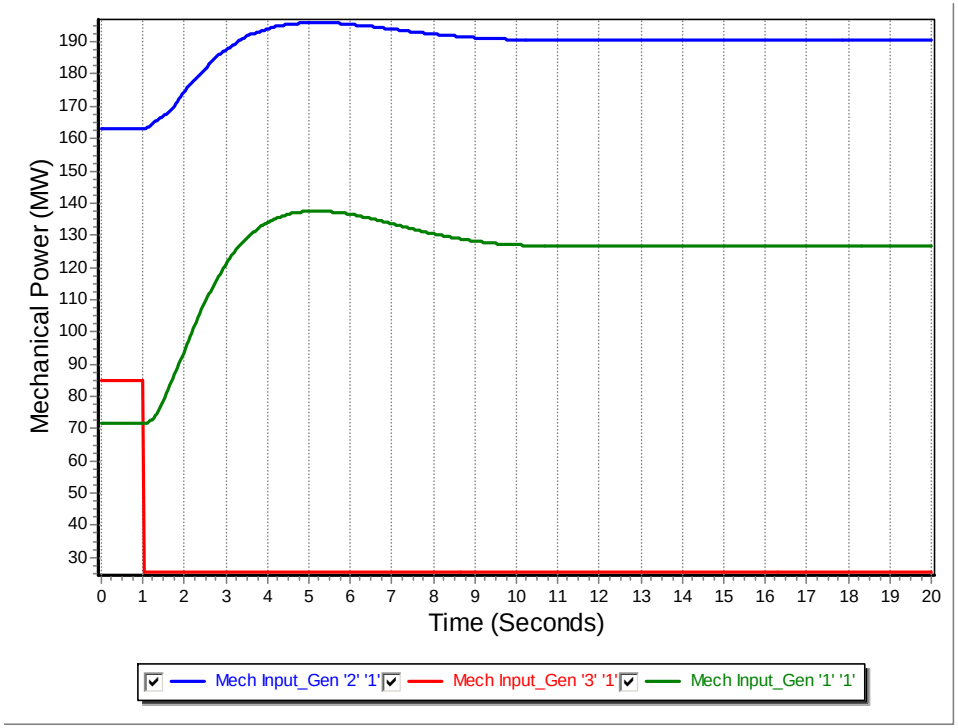
Plot Designer with New Plots Added



Note that when new plots are added using “Add Plot”, new Folders appear in the plot list. This will result in separate plots for each group (unlike putting different values on the same plot as with AxisGroups).

Gen 3 Open Contingency Results

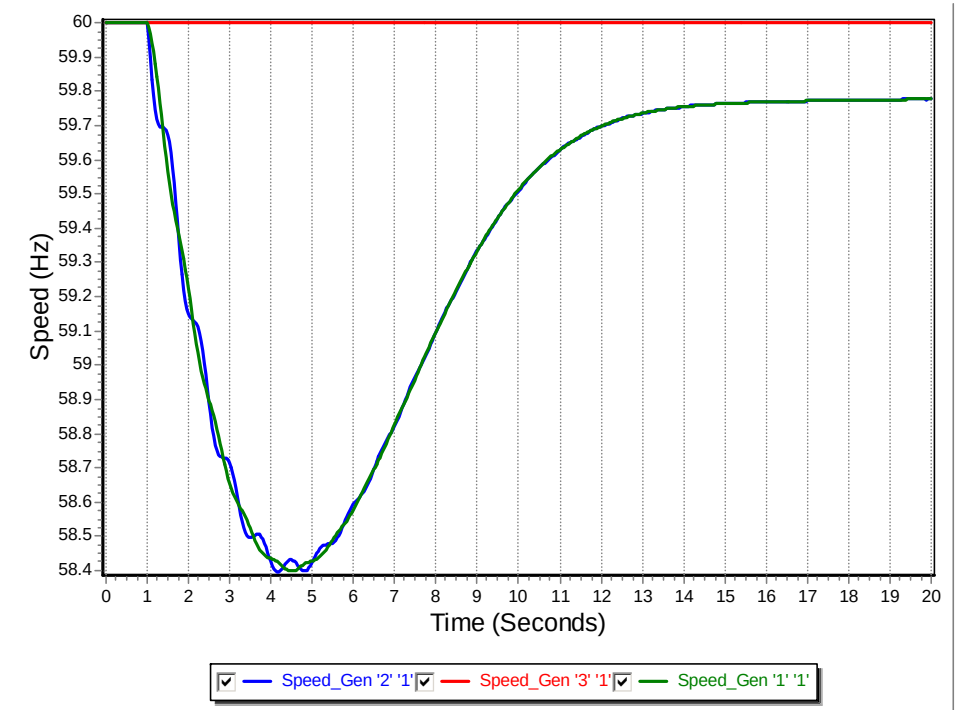


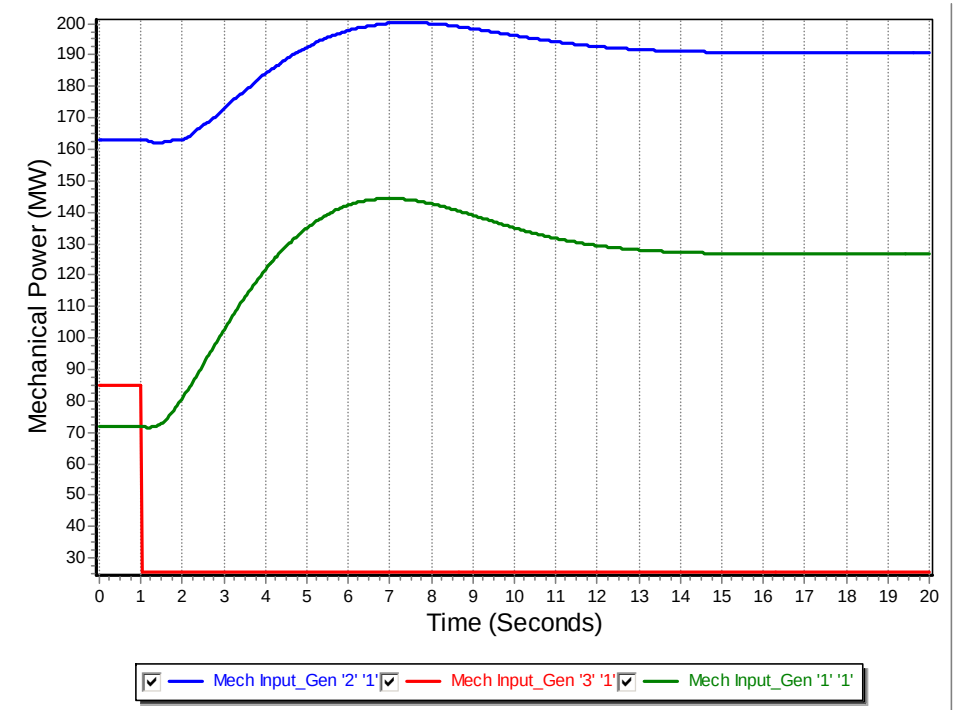


Note: You can switch between the plots by clicking on the plot name at the top of the window

The left figure shows the generator speed, while the right figure shows the generator mechanical power inputs for the loss of generator 3. This is a severe contingency since more than 25% of the system generation is lost, resulting in a frequency dip of almost one Hz. Notice frequency does not return to 60 Hz.

Gen 3 Open Contingency with Hydro Models

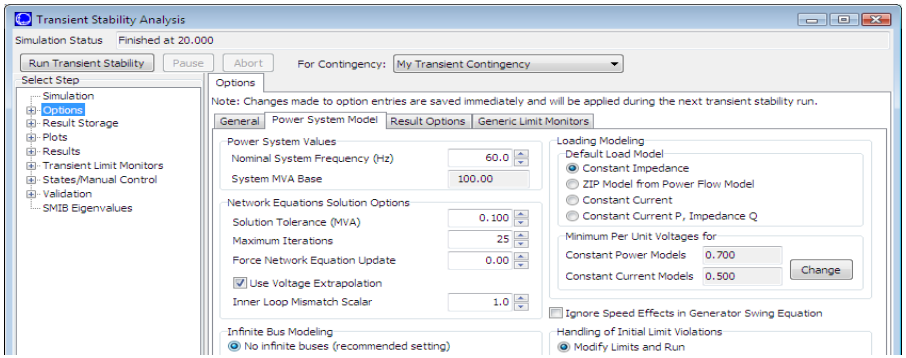




The slower hydro governors now result in a much more severe frequency dip of more than 1.5 Hz. Of course in actual operation this frequency decline may have been interrupted by the action of under-frequency relays (which can be modeled in Simulator but this example does not meet the specified criteria of 58.2 Hz).

Load Modeling

- The load model used in transient stability can have a significant impact on the result, particularly for voltage studies. A useful discussion is found in [1].
- By default PowerWorld uses constant impedance models but makes it very easy to add more complex loads.
- The default (global) models are specified on the Options, Power System Model page.

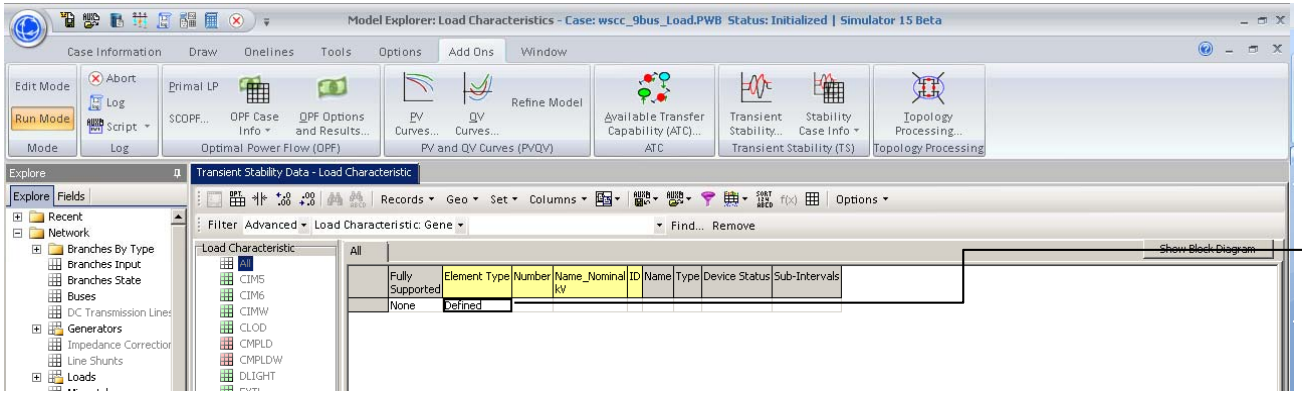


These models are used only when no other models are specified.

[1] J.A. Diaz de Leon II, B. Kehrli, "The Modeling Requirements for Short-Term Voltage Stability Studies," Power Systems Conference and Exposition (PSCE), Atlanta, GA, October, 2006, pp. 582-588.

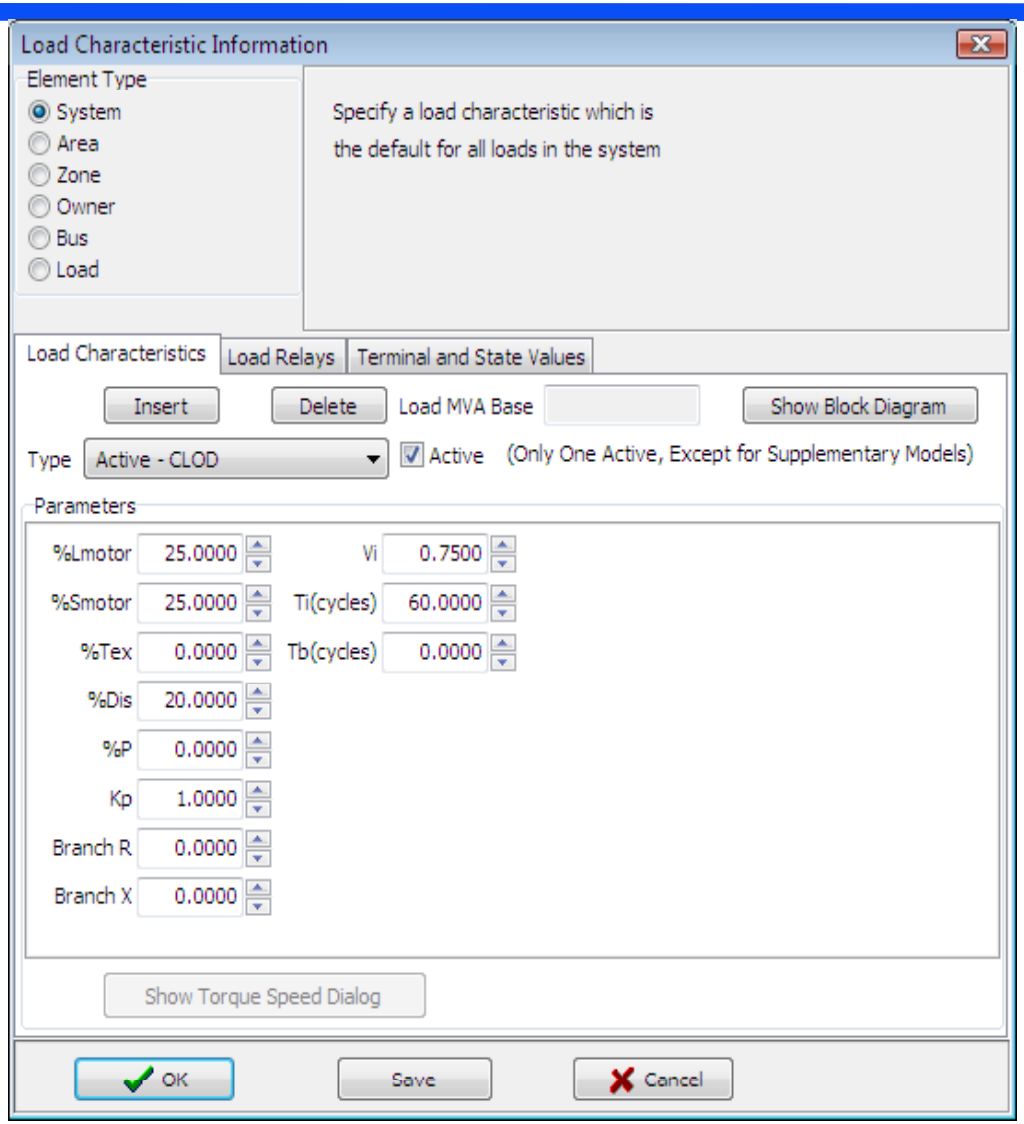
Load Modeling

- More detailed models are added by selecting “Stability Case Info” from the ribbon, then Case Information, Load Characteristics Models.
- Models can be specified for the entire case (system), or individual areas, zones, owners, buses or loads.
- To insert a load model click right click and select insert to display the Load Characteristic Information dialog.



Right click here to get local menu and select insert.

Load Characteristic Information Dialog



Case and plots are saved as *WSCC_9Bus_Load*

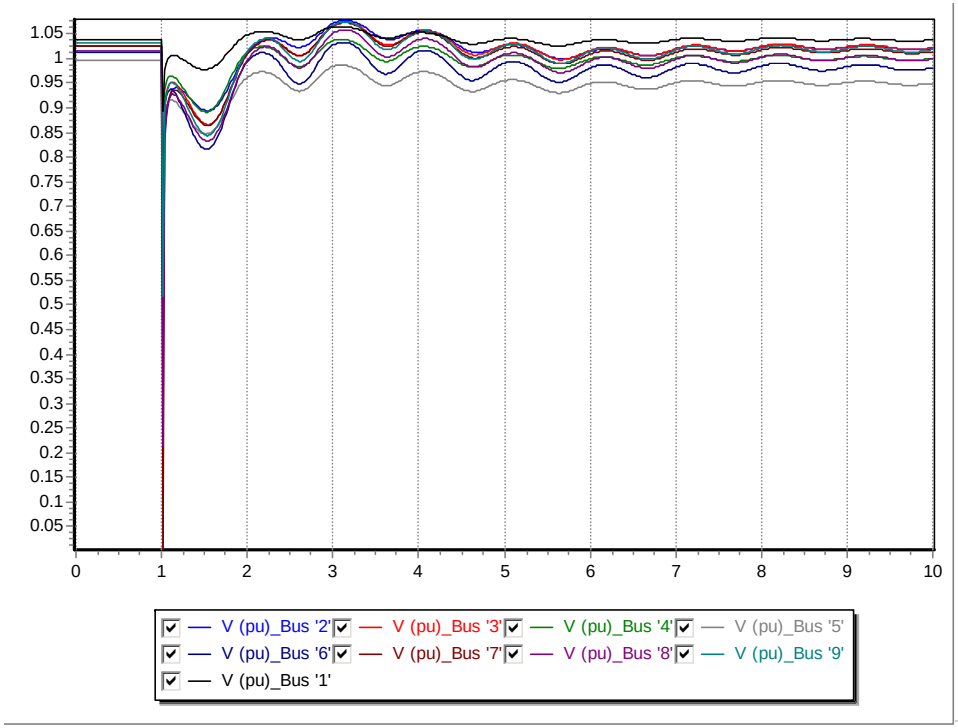
1. *Start with the original WSCC_9Bus case*
2. Add a TGOV1 to "Generator 3"

3. In the Load Characteristic Dialog, click "System" in the Element Type box to apply the load model to all buses in the system.

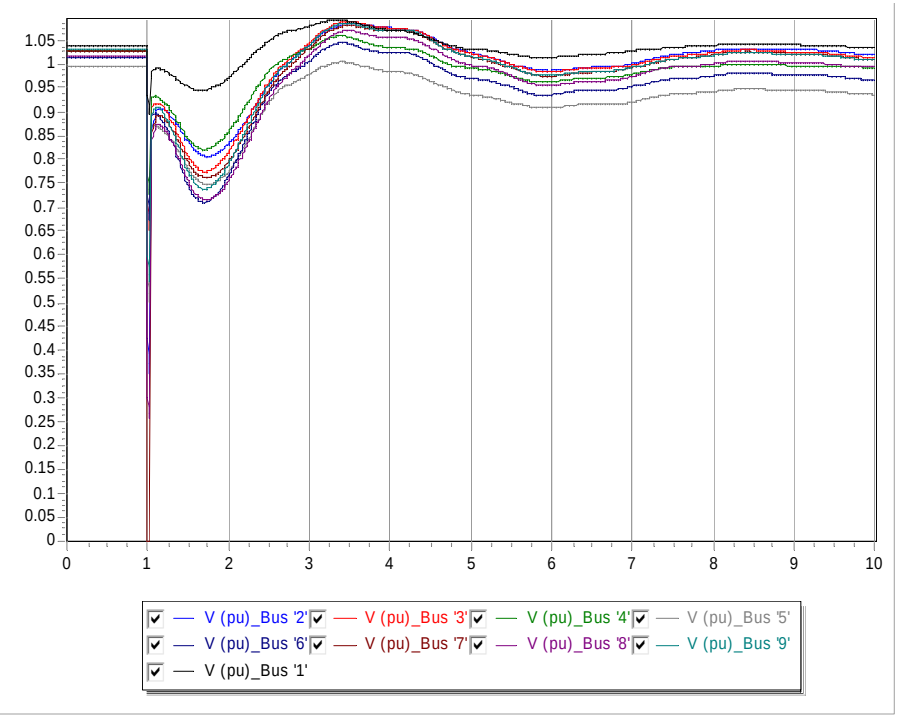
4. Click Insert to select the model type. For this example we'll use the CLOD, which is the complex load model described in [1] that models the load as a combination of large and small induction motors, constant power and discharge lighting loads.

4. Then click "Close"

WSCC Case Without/With Complex Loads



Bus Voltages: Impedance Load



Bus Voltages: Complex Load

The impact of the complex load on the solution is demonstrated above in which the figures show the bus voltages for the line 7 to 5 contingency case with a clearing time of just 0.033 seconds. The left figure uses a constant impedance load while the right is with the CLOD model. The reason for the voltage decrease is during the fault the smaller induction motors start to slow down, getting close to stalling. The critical clearing time for the case has decreased from 0.078 to about 0.040.

Under-Voltage Motor Tripping

- In the PowerWorld CLOD model, under-voltage motor tripping may be set by the following parameters
  - Vi = voltage at which trip will occur (default = 0.75 pu)
  - Ti (cycles) = length of time voltage needs to be below Vi before trip will occur (default = 60 cycles, or 1 second)
- In this example as you move the clearing time from 0.033 up to 0.040, you will see the motors tripping out on buses 5, 6, and 8 (the load buses) – this is especially visible on the bus voltages plot. These trips allow the clearing time to be a bit longer than would otherwise be the case.
- Set Vi = 0 in this model to turn off under-voltage motor tripping.

Modeling Wind Turbines in PowerWorld

- PowerWorld Simulator provides support of each of the four major types of wind turbine models used in transient stability studies
  - Type 1: Induction generators with fixed rotor resistance
  - Type 2: Wound rotor induction generators with variable rotor resistance
  - Type 3: Doubly-fed induction generators (DFIGs)
  - Type 4: Full converter generators
- More detailed GE models are also provided based on the data provided in

http://www.gepower.com/prod_serv/products/utility_software/en/downloads/09100_Modeling_of_GE_Wind_Turbine-Generators_for_Grid_Studies.pdf

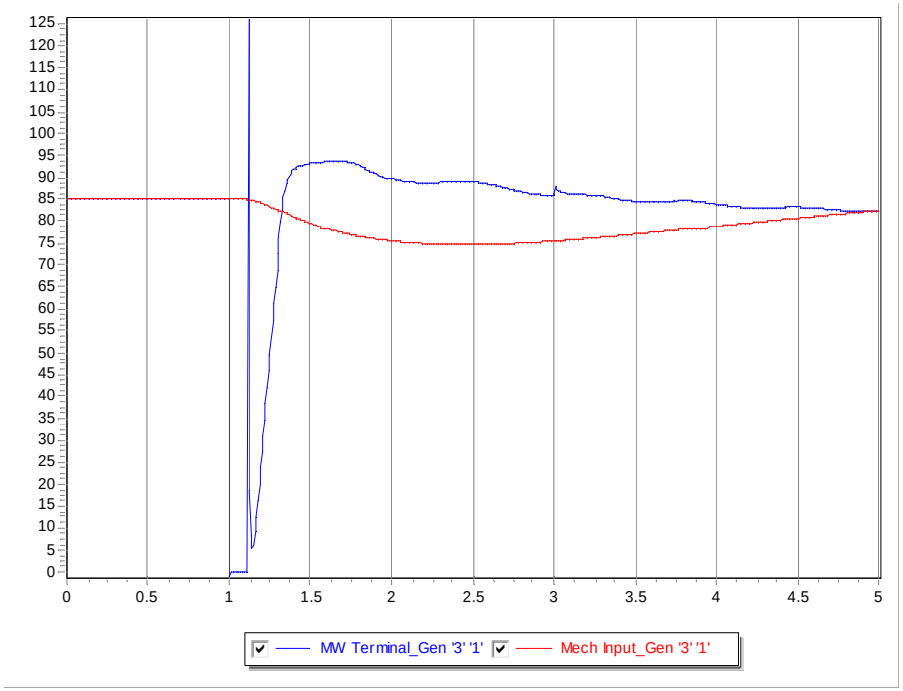
Quick Start Wind Models: WSCC 9 Bus

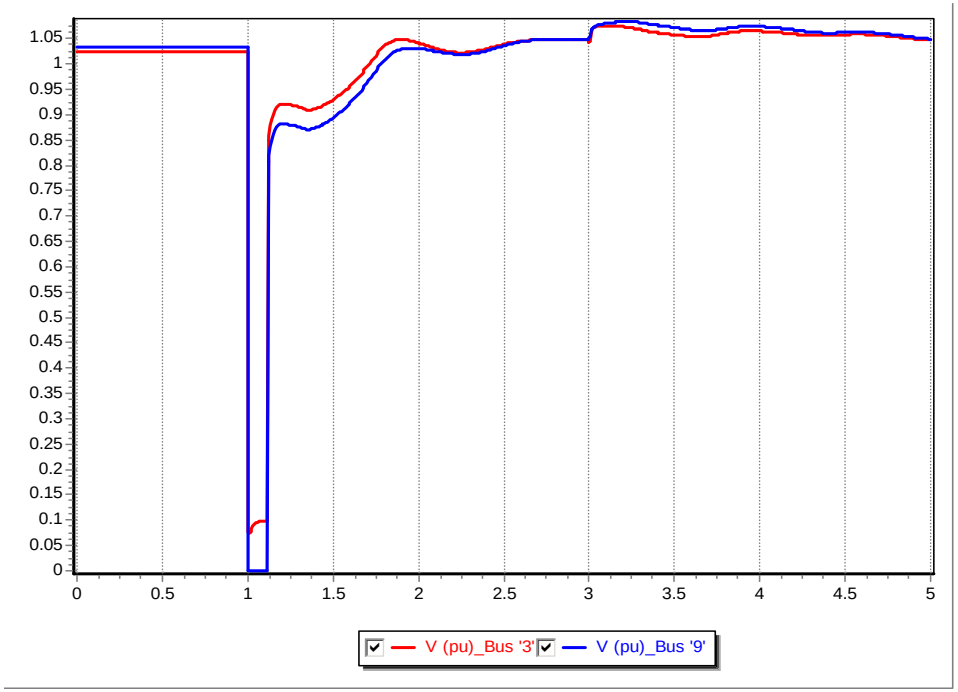
- As a quick introduction to wind turbine models, we'll replace the WSCC 9 bus case "generator 3" models with wind turbine models. Start with case: *wscc_9bus_WithGovernors.pwb*.
  - Add a CLOD load model to the system, as on slide 53
  - Do the following steps for Generator 3 only:
  - Replace the machine model with a GEWTG machine, which models a 85 MW aggregation of GE 1.5 MW doubly-fed induction generators (DFIGs); accept all the default values.
  - Replace the exciter model with a EXWTGE, which models the reactive power control of the wind turbines; accept the defaults.
  - Replace the governor model with a WNTDGE, which models the inertia of the wind turbine and its pitch control; accept the defaults.
  - Case is saved as WSCC_9Bus_Wind

Quick Start Wind Models: WSCC 9 Bus

- In this example we'll look at the low voltage ride through capability of the turbine.
  - *A new contingency event has been used for this case.* Example contingency is a fault at t = 1 second on the line between buses 6 and 9, near bus 9, cleared by opening the line at 1.12 seconds. The line is then closed back in at t = 3 seconds.
  - Wind turbine DFIG is modeled as a voltage-source converter. During the fault the wind turbine terminal bus voltage will be quite low. This will cause the turbine's Low Voltage Power Logic (LVPL) to reduce the real power current to zero. This will cause the wind turbine pitch control system to begin to pitch the blades to reduce the mechanical power into the rotor to present an over speed condition.

WSCC 9 Bus Wind Results



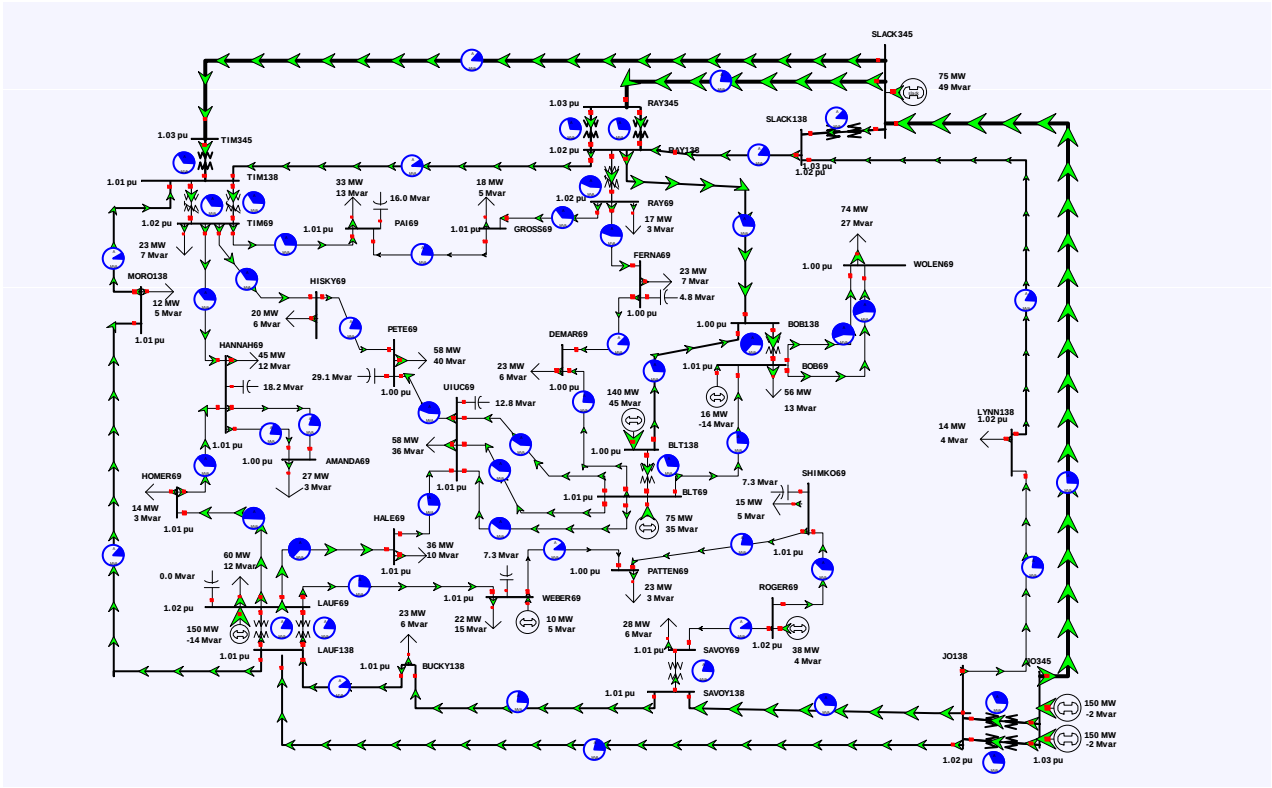


The left shows the real power output (MW) and the mechanical power input at Generator 3. During the fault the LVPL sets the real power current at zero. Once the fault is cleared this current is ramped back up, subject to a rate limit. The mechanical power output is slowly decreased by the pitch control, which cannot respond quickly.

The right figure shows the voltage magnitudes at the terminal and high buses.

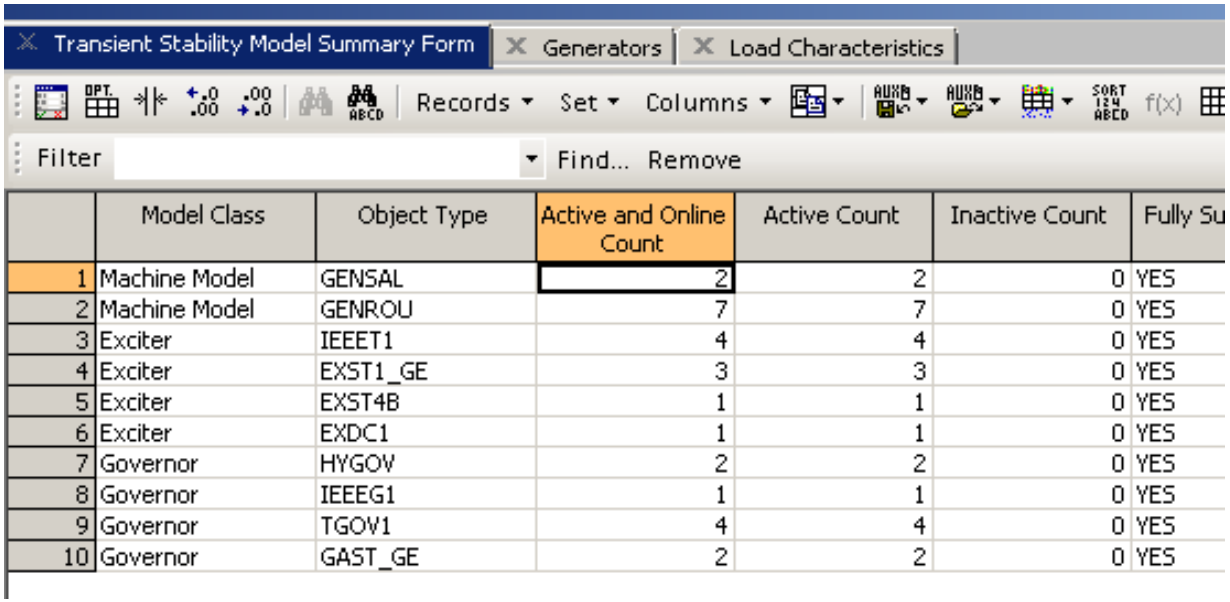
37 Bus Case

- Next we consider a slightly larger, 9 generator, 37 bus system. To view this system *open case GSO_37Bus*. The system one-line is shown below.

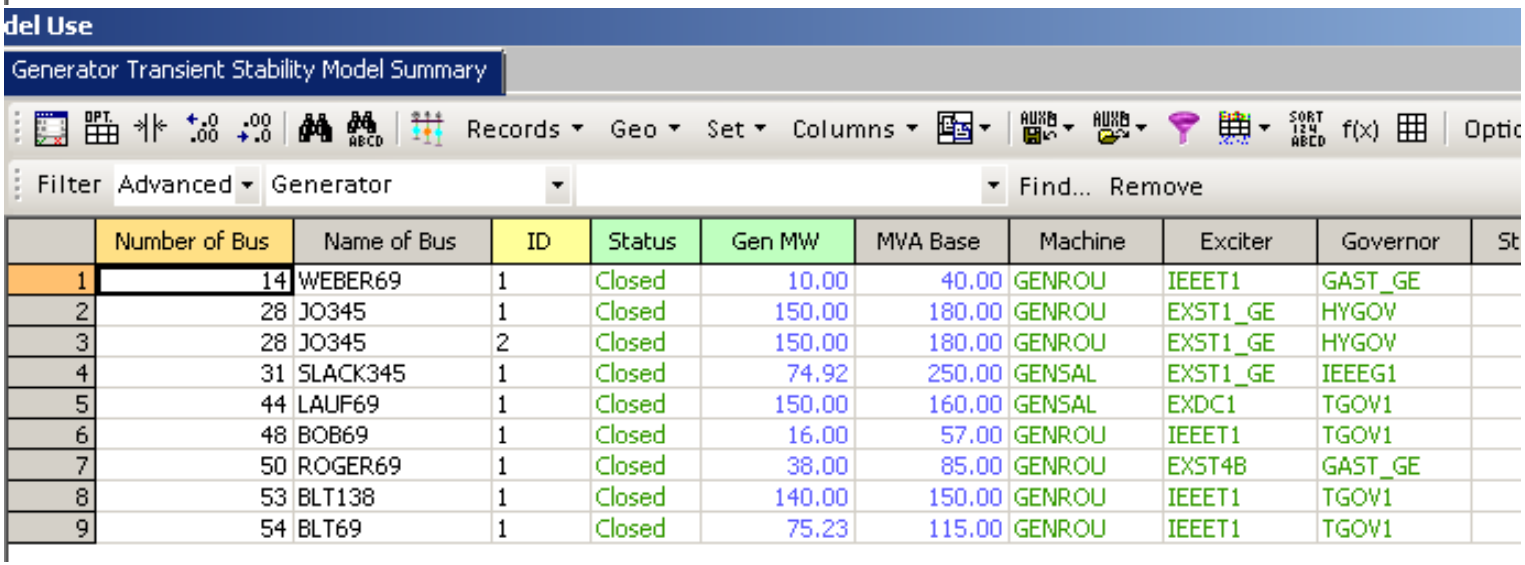


To see summary listings of the transient stability models in this case select “Stability Case Info” from the ribbon, and then either “TS Generator Summary” or “TS Case Summary”

Transient Stability Case and Model Summary Displays



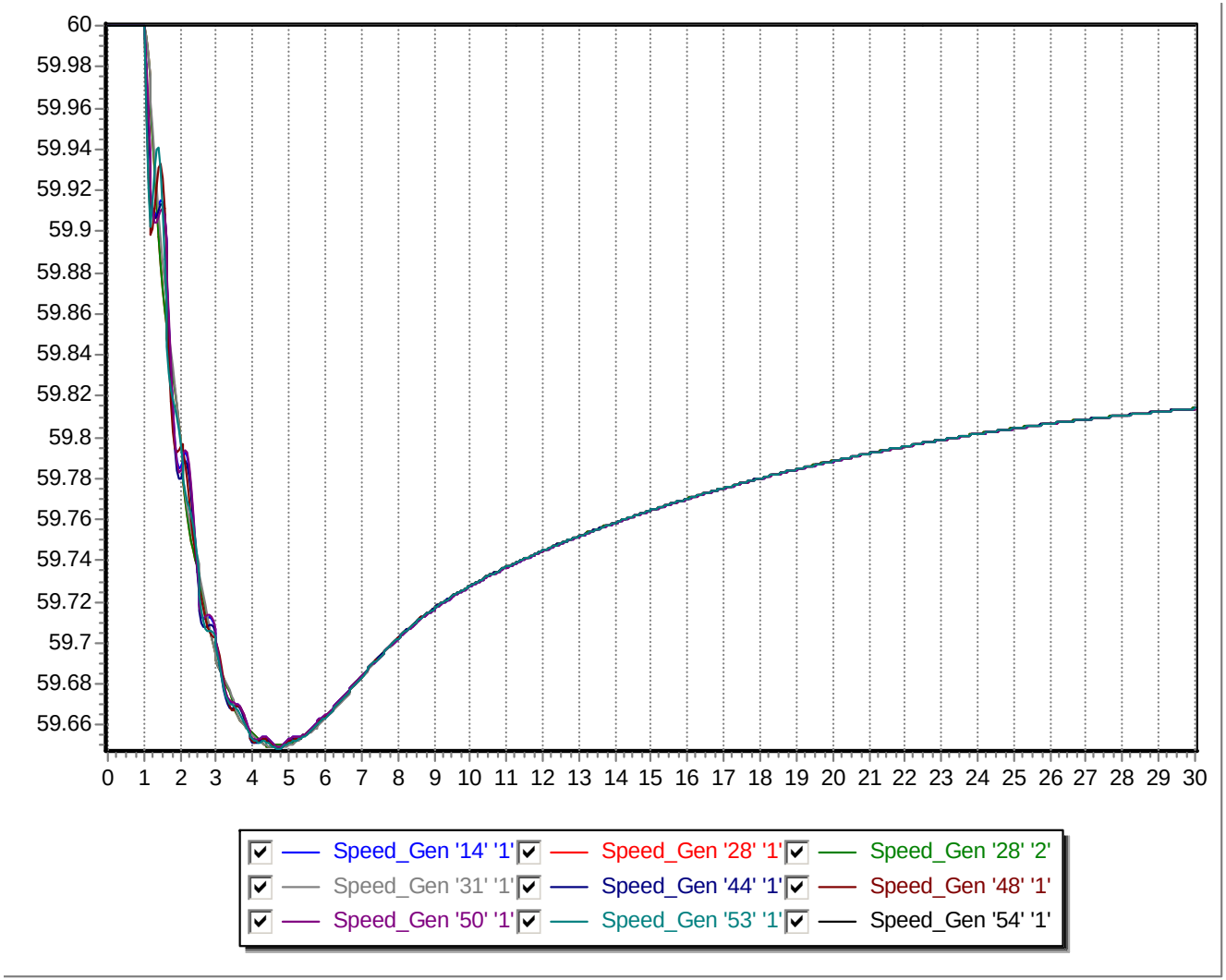
	Model Class	Object Type	Active and Online Count	Active Count	Inactive Count	Fully Su
1	Machine Model	GENSAL	2	2	0	YES
2	Machine Model	GENROU	7	7	0	YES
3	Exciter	IEEET1	4	4	0	YES
4	Exciter	EXST1_GE	3	3	0	YES
5	Exciter	EXST4B	1	1	0	YES
6	Exciter	EXDC1	1	1	0	YES
7	Governor	HYGOV	2	2	0	YES
8	Governor	IEEEG1	1	1	0	YES
9	Governor	TGOV1	4	4	0	YES
10	Governor	GAST_GE	2	2	0	YES



	Number of Bus	Name of Bus	ID	Status	Gen MW	MVA Base	Machine	Exciter	Governor	St
1	14	WEBER69	1	Closed	10.00	40.00	GENROU	IEEET1	GAST_GE	
2	28	JO345	1	Closed	150.00	180.00	GENROU	EXST1_GE	HYGOV	
3	28	JO345	2	Closed	150.00	180.00	GENROU	EXST1_GE	HYGOV	
4	31	SLACK345	1	Closed	74.92	250.00	GENSAL	EXST1_GE	IEEEG1	
5	44	LAUF69	1	Closed	150.00	160.00	GENSAL	EXDC1	TGOV1	
6	48	BOB69	1	Closed	16.00	57.00	GENROU	IEEET1	TGOV1	
7	50	ROGER69	1	Closed	38.00	85.00	GENROU	EXST4B	GAST_GE	
8	53	BLT138	1	Closed	140.00	150.00	GENROU	IEEET1	TGOV1	
9	54	BLT69	1	Closed	75.23	115.00	GENROU	IEEET1	TGOV1	

Right click on a line and select “Show Dialog” for more information.

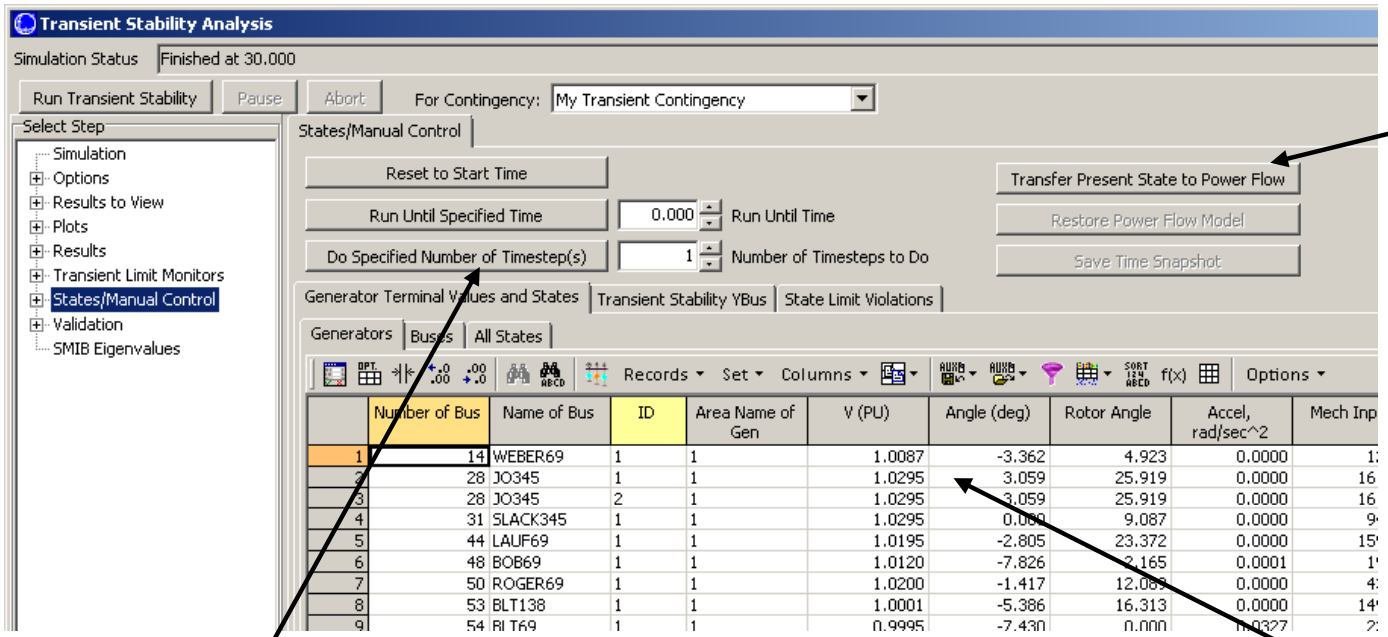
BLT 69 Generator Outage Contingency Results



This graph shows the variation in the frequency for all the generators in the case for a contingency in which the BLT69 generator is opened 1.0 sec. Note the frequency does not recover to because of the governor droop characteristics.

Stepping Through the Solution

- Simulator provides functionality to make it easy to see what is occurring during a solution. This functionality is accessed on the States/Manual Control Page



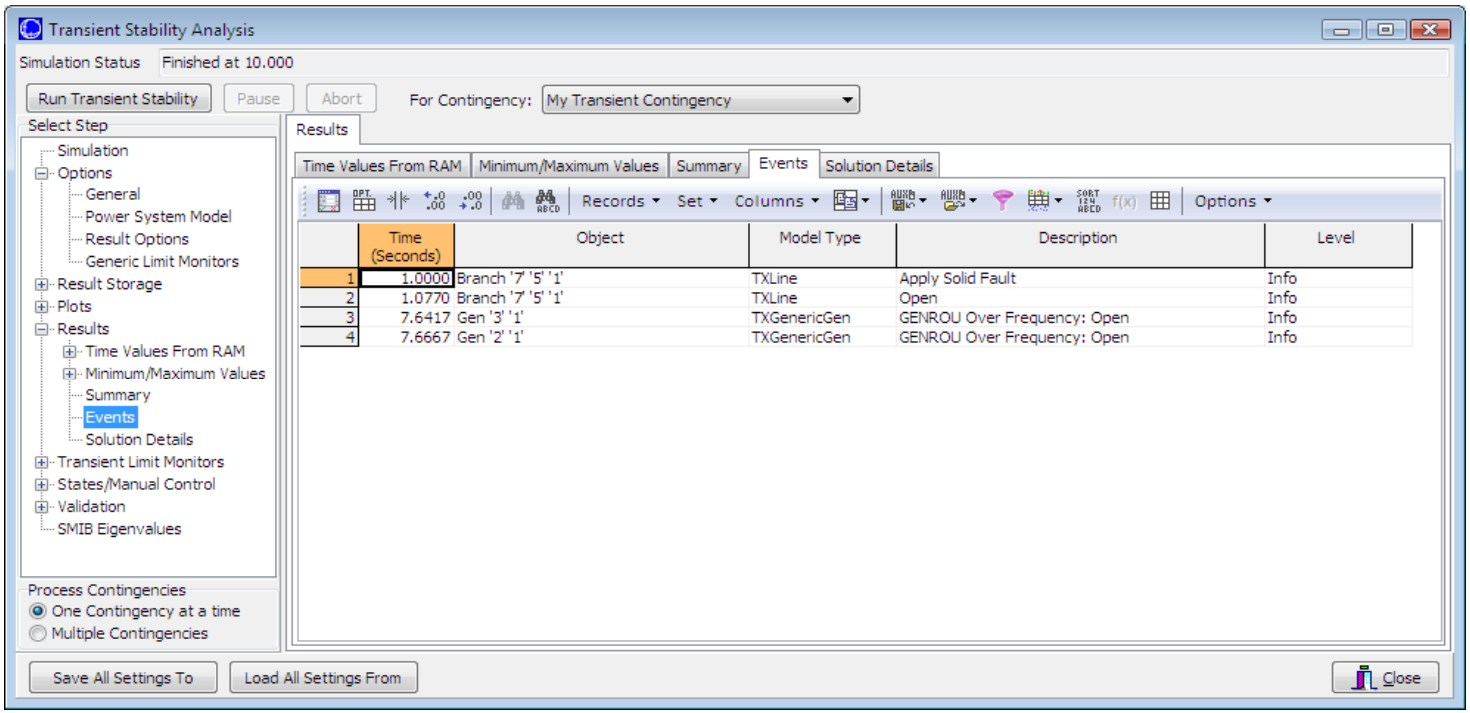
Transfer results to Power Flow to view using standard PowerWorld displays and one-lines

Run a Specified Number of Timesteps or Run Until a Specified Time, then Pause.

See detailed results at the Paused Time

Events

- After a simulation, the user can view any events that happened by going to “Results”, “Events”



The first two listed events are the fault and its clearing. The second two events show automatic generator trippings.

Looking at the events after a simulation is a good way to find an explanation for anything unusual that might have affected the run.

Solving Large Cases

- The commercial version of PowerWorld Simulator with Transient Stability is designed to solve systems of just about any size.
- Speed for large cases is comparable to other commercial packages. Benchmarks between TS packages must be taken with a grain of salt (e.g, some packages require large amounts of setup time not required by Simulator)
  - Solves a 20 second simulation of a 2000 bus, 4000 state system using a ¼ cycle time step in 26 seconds
  - Solves a 5 second simulation of the 16386 bus, 96000 state WECC system using a ½ cycle time step in 95 seconds.