

ECEN 667

Power System Stability

Lecture 6: Stability Overview with PowerWorld Simulator

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Announcements



- Start reading Chapter 3
- Homework 1 is due today
- Homework 2 is assigned today and due on Thursday Sept 13.

Aside: Ionized Air as a Conductor



An Interesting Video of an Uncleared Fault



- The below video shows an event from September 2, 2022 in the Netherlands (Flevoland province) in which a transmission line fault was not cleared. Note the sag and smoke (steam?) coming from the line
- <https://nos.nl/video/2443017-explosies-en-rokende-kabels-bij-verdeelstation-in-dronten>



Review of Phasors



Goal of phasor analysis is to simplify the analysis of constant frequency ac systems

$$v(t) = V_{\max} \cos(\omega t + \theta_v)$$

$$i(t) = I_{\max} \cos(\omega t + \theta_I)$$

Root Mean Square (RMS) voltage of sinusoid

$$\sqrt{\frac{1}{T} \int_0^T v(t)^2 dt} = \frac{V_{\max}}{\sqrt{2}}$$

Phasor Representation



Euler's Identity: $e^{j\theta} = \cos \theta + j \sin \theta$

Phasor notation is developed by rewriting using Euler's identity

$$v(t) = \sqrt{2}|V| \cos(\omega t + \theta_V)$$

$$v(t) = \sqrt{2}|V| \operatorname{Re} \left[e^{j(\omega t + \theta_V)} \right]$$

(Note: $|V|$ is the RMS voltage)

Phasor Representation, cont'd



The RMS, cosine-referenced voltage phasor is:

$$V = |V|e^{j\theta_V} = |V| \angle \theta_V$$

$$v(t) = \operatorname{Re} \sqrt{2} V e^{j\omega t} e^{j\theta_V}$$

$$V = |V| \cos \theta_V + j|V| \sin \theta_V$$

$$I = |I| \cos \theta_I + j|I| \sin \theta_I$$

Advantages of Phasor Analysis



Device	Time Analysis	Phasor
Resistor	$v(t) = Ri(t)$	$V = RI$
Inductor	$v(t) = L \frac{di(t)}{dt}$	$V = j\omega LI$
Capacitor	$\frac{1}{C} \int_0^t i(t) dt + v(0)$	$V = \frac{1}{j\omega C} I$

$$Z = \text{Impedance} = R + jX = |Z| \angle \phi$$

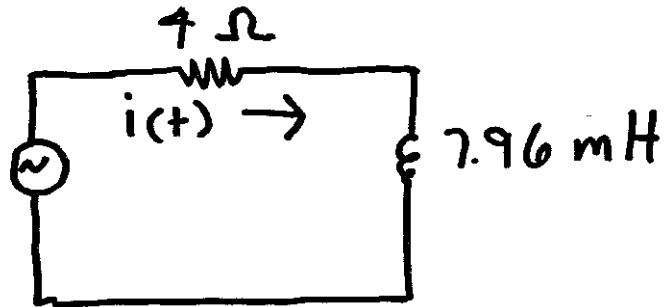
R = Resistance

X = Reactance

$$|Z| = \sqrt{R^2 + X^2} \quad \phi = \arctan\left(\frac{X}{R}\right)$$

(Note: Z is a complex number but not a phasor)

RL Circuit Example



$$V(t) = \sqrt{2} 100 \cos(\omega t + 30^\circ)$$

$$f = 60 \text{ Hz}$$

$$R = 4 \Omega \quad X = \omega L = 3$$

$$|Z| = \sqrt{4^2 + 3^2} = 5 \quad \phi = 36.9^\circ$$

$$I = \frac{V}{Z} = \frac{100 \angle 30^\circ}{5 \angle 36.9^\circ}$$
$$= 20 \angle -6.9^\circ \text{ Amps}$$

$$i(t) = 20\sqrt{2} \cos(\omega t - 6.9^\circ)$$

Complex Power



Power

$$p(t) = v(t) i(t)$$

$$v(t) = V_{\max} \cos(\omega t + \theta_V)$$

$$i(t) = I_{\max} \cos(\omega t + \theta_I)$$

$$\cos \alpha \cos \beta = \frac{1}{2} [\cos(\alpha - \beta) + \cos(\alpha + \beta)]$$

$$p(t) = \frac{1}{2} V_{\max} I_{\max} [\cos(\theta_V - \theta_I) + \cos(2\omega t + \theta_V + \theta_I)]$$

Complex Power, cont'd



Average Power

$$p(t) = \frac{1}{2} V_{\max} I_{\max} [\cos(\theta_V - \theta_I) + \cos(2\omega t + \theta_V + \theta_I)]$$

$$P_{avg} = \frac{1}{T} \int_0^T p(t) dt$$

$$= \frac{1}{2} V_{\max} I_{\max} \cos(\theta_V - \theta_I)$$

$$= |V||I| \cos(\theta_V - \theta_I)$$

Power Factor Angle = $\phi = \theta_V - \theta_I$

Complex Power



$$\begin{aligned} S &= |V||I|[\cos(\theta_V - \theta_I) + j\sin(\theta_V - \theta_I)] \\ &= P + jQ \quad (\text{Note: } S \text{ is a complex number but not a phasor}) \\ &= V I^* \end{aligned}$$

P = Real Power (W, kW, MW)

Q = Reactive Power (var, kvar, Mvar)

S = Complex power (VA, kVA, MVA)

Power Factor (pf) = $\cos \phi$

If current leads voltage then pf is leading

If current lags voltage then pf is lagging

Complex Power, cont'd



Relationships between real, reactive and complex power

$$P = |S| \cos \phi$$

$$Q = |S| \sin \phi = \pm |S| \sqrt{1 - pf^2}$$

Example: A load draws 100 kW with a leading pf of 0.85.

What are ϕ (power factor angle), Q and $|S|$?

$$\phi = -\cos^{-1} 0.85 = -31.8^\circ$$

$$|S| = \frac{100 \text{ kW}}{0.85} = 117.6 \text{ kVA}$$

$$Q = 117.6 \sin(-31.8^\circ) = -62.0 \text{ kVar}$$

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 hundreds of different dynamic models. ECEN 667 covers the major ones, with more being continually add
 - 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.

First Example Case



- Open the case Example_13_4_NoModels

- Cases are on the class website

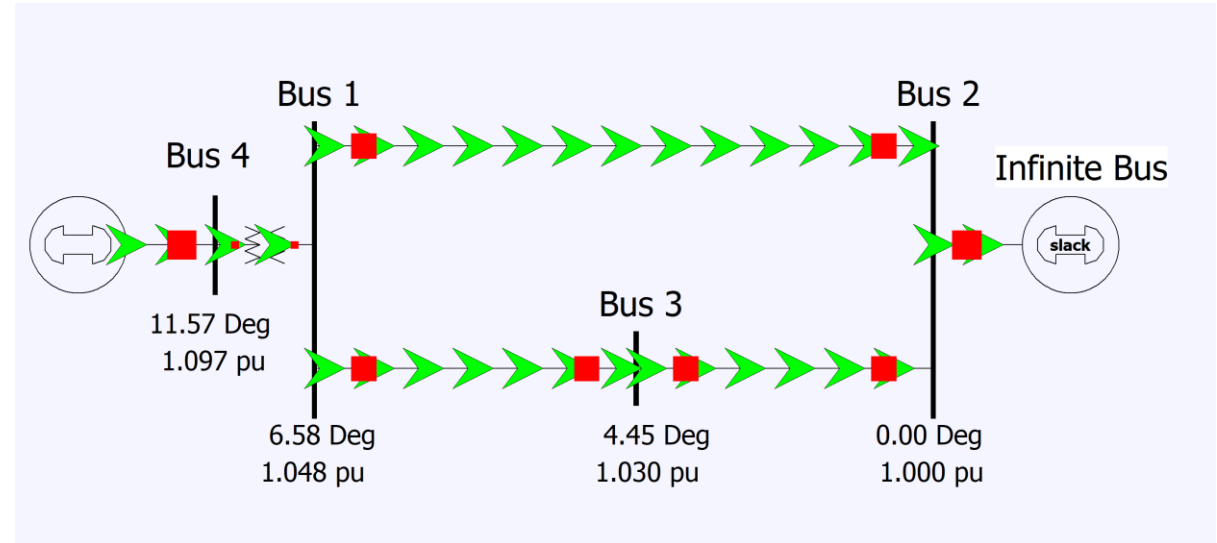
- Add a dynamic generator model to an existing “no model” power flow case by:

- 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



Generator Information for Present

Bus Number: 4
Bus Name: Bus 4
ID: 1
Area Name: Home (1)
Labels ...: no labels
Generator MVA Base: 100.00

Status:
 Open
 Closed

Energized:
 NO (Offline)
 YES (Online)

Fuel Type: Unknown
Unit Type: UN (Unknown)

Power and Voltage Control | Costs | OPF | Faults | Owners, Area, etc. | Custom | Stability

Machine Models | Exciters | Governors | Stabilizers | Other Models | Step-up Transformer | Terminal and State

Insert | Delete | Gen MVA Base: 100.0 | Show Block Diagram | Create VCurve

Type: Active - GENCLS Active (only one may be active) | Set to Defaults

Parameters
PU values shown/entered using device base of 100.0 MVA

H: 3.00000
D: 0.00000
Ra: 0.00000
Xdp: 0.20000
RComp: 0.00000
XComp: 0.00000

OK | Save | Save to Aux | Cancel | Help | Print

The GENCLS model represents the machine dynamics as a fixed voltage magnitude behind a transient impedance $R_a + jX_{dp}$.

Press **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 they should be saved
 - **Plots**: Used to plot results
 - **Results**: Used to view the results (actual numbers, not plots)

Transient Stability Overview Form



The screenshot shows the 'Transient Stability Analysis' window in a software application. The window title is 'Example_13_4_NoModels - Case: Example_13_4_NoModels.pwb Status: Initialized | Simulator 23'. The interface includes a menu bar (File, Case Information, Draw, Onelines, Tools, Options, Add Ons, Window), a toolbar with various analysis tools, and a main workspace. The workspace is divided into several sections: 'Simulation' (with 'Run Transient Stability', 'Pause', 'Abort', 'Restore Reference' buttons), 'Control' (with 'Definitions' and 'Violations' tabs), 'Transient Contingency Elements' (with a table), and 'Limit Monitor Violations' (with a table). The 'Simulation' section shows 'Start Time (seconds): 0.000', 'End Time (seconds): 5.000', and 'Time Step (cycles): 0.500'. The 'Transient Contingency Elements' table has columns for 'Object Pretty', 'Time (Cycles)', 'Time (Seconds)', 'Enabled', 'Object', and 'Description'. The 'Limit Monitor Violations' table has columns for 'Limit Monitor Name' and 'Contingency Name'. A diagram overlay on the right side of the window shows a vertical line representing a bus, with a red square and a green arrow pointing to a circle labeled 'slack'. The text 'Bus 2' is written above the bus line, and 'Infinite Bus' is written to the right of the slack circle. Below the bus line, the text 'Deg' and '00 pu' is visible.

Infinite Bus Modeling



- Before doing the first transient stability run, it is useful to discuss the concept of an infinite bus. As noted earlier, in the power flow 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 Options Page



Power System
Model Page

Infinite Bus
Modeling

Analysis
alized

Run Transient Stability Pause Abort Restore Reference For Contingency: Find My Transient Contingency

Select Step

- > Simulation
- > Options
- > Result Storage
- > Plots
- > Results from RAM
- > Transient Limit Monitors
- > States/Manual Control
- > Validation
 - SMIB Eigenvalues
 - Modal Analysis
 - Dynamic Simulator Options

Options

Changes made to option entries are saved immediately and will be applied during the next transient stability run.

General Power System Model Remedial Actions Result Options Generic Limit Monitors User Defined Model Distributed Computing Transfer to Power Flow

Common Load Modeling Compatibility Options

Power System Values

Nominal System Frequency (Hz) 60.000

Initial System Frequency (Hz) 60.000

When Using Playin Models Set Initial Hz to First Value

System MVA Base 100.0

Network Equations Solution Options

Solution Tolerance (MVA) 0.10000

Maximum Iterations 5

Abort after number of failed solutions 3

Force Network Equation Update 0.0

Use Voltage Extrapolation

Inner Loop Mismatch Scalar 1.0

Integration Method

Second Order Runge-Kutta

Euler

Infinite Bus Modeling

No infinite buses (recommended setting)

Model power flow slack buses as infinite buses

Frequency Measurement Options

Bus Frequency Measurement Time Constant (Sec.) 0.020

Minimum PU voltage for relay frequency measurement 0.300

Calculate Bus ROCOF (Rate of Change of Freq)

Use Parallel Code

Island Synchronization

Angle Options

Set to Degree Value

Set if > Degree Value

No Change

Frequency Options

Set to Hz Value

Set if > Hz Value

No Change

Degree Value 0.000 Hz Value 0.000

Geomagnetic Induced Current Options

Ignore GIC Effects (Option Set on GIC Form)

Just Calculate GIC with No Network Solution

GIC XF Time Constant (Sec) 0.0

Process Contingencies

One Contingency at a time

Multiple Contingencies

Save All Settings To Load All Settings From Show Transient Contour Toolbar Auto Insert... Critical Clearing Time Calculator... Help Close

This page is also used to specify the nominal system frequency

Specifying the Contingency Event



- The grid is pushed away from its equilibrium by a disturbance, known as a contingency; an example would be lightning hitting a transmission line
- 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 study.
- Usually start at time > 0 to showcase runs flat
- 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 sec, and clearing at 1.05 sec
 - For the first action just choose all the defaults and select “Insert.” Insert will add the action but not close the dialog.
 - For second action change the Time to 1.05 seconds 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 the contingency, and the time of each action

Simulation Status: Not Initialized

Run Transient Stability | Pause | Abort | Restore Reference | For Contingency: Find | My Transient Contingency | Add... | Delete... | Rename... | Clone Contingency...

Select Step

- Simulation
 - Control
 - Definitions
 - Violations
- Options
- Result Storage
- Plots
- Result Analyzer - Damping
- Results from RAM
- Transient Limit Monitors
- States/Manual Control
- Validation
- SMIB Eigenvalues
- Modal Analysis
- Dynamic Simulator Options

Simulation

Control | Definitions | Violations

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: Change...

Summary Results

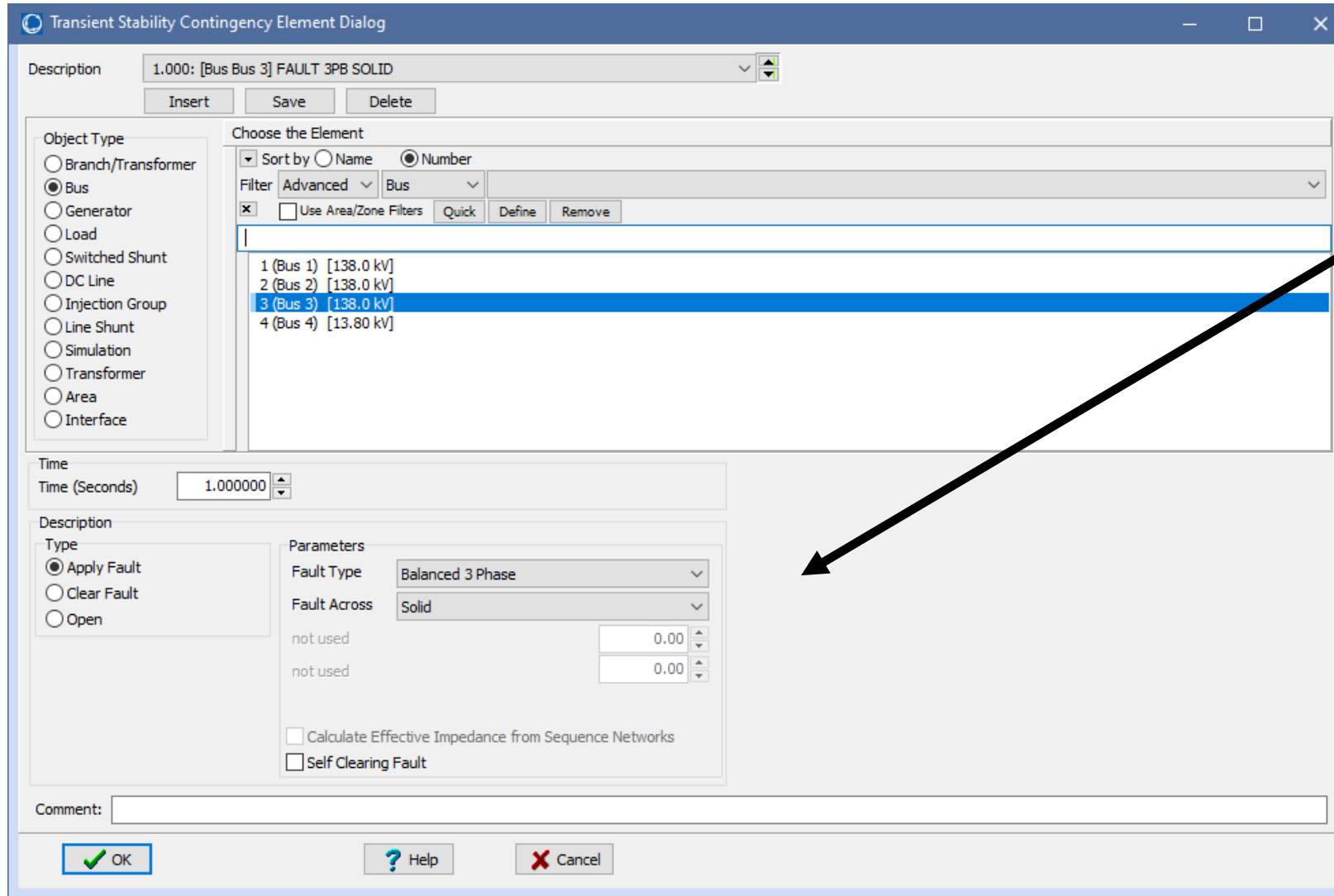
	Generation	Load
Tripped	0.00	0.00
Relay Tripped		0.00
Model Tripped		0.00
Islanded	0.00	0.00

Transient Contingency Elements

Insert | Clear All | Insert Apply/Clear/Open | Time Shift (seconds): 0.000

	Object Pretty	Time (Cycles)	Time (Seconds)	Enabled	Object
1	Bus Bus 3	60.0	1.000000	CHECK	Bus '3'
2	Line Bus 1 TO Bus 3 CKT 1	63.0	1.050000	CHECK	Branch '1' '3' '1'
3	Line Bus 2 TO Bus 3 CKT 1	63.0	1.050000	CHECK	Branch '2' '3' '1'

Event Contingency Dialog



Available element type will vary with different objects

Determining the Results to View



- 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

The screenshot shows the 'Transient Stability Analysis' software window. The 'Result Storage' tab is active, and the 'Generator' sub-tab is selected. The main area displays a table with columns for various parameters. The 'Mvar Terminal' column is highlighted in orange, and its value is set to 'YES' for the selected row. Arrows indicate that double-clicking on these fields sets their values to 'yes'.

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 Terminal	Accel MW	Mvar Terminal	Term. PL	Field Voltage (pu)	F
1	2	Bus 2	1	Home	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NC
2	4	Bus 4	1	Home	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NC

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

Saving Changes and Doing 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 0.25 or 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_WithCLSMModel_ReadyToRun”
- Click on **Run Transient Stability** to solve.

Doing the Run



Click to run the specified contingency

Simulation Status: Not Initialized

Run Transient Stability | Pause | Abort | Restore Reference | For Contingency: Find | 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

Summary Results

	Generation	Load
Tripped	0.00	0.00
Relay Tripped		0.00
Model Tripped		0.00
Islanded	0.00	0.00

Transient Contingency Elements

Object Pretty	Time (Cycles)	Time (Seconds)	Enabled	Object	Description
1 Bus Bus 1	60.0	1.000000	CHECK	Bus '1'	FAULT 3PB SOLID
2 Bus Bus 1	63.0	1.050000	CHECK	Bus '1'	CLEARFAULT

Once the contingency runs the **Results from RAM** page may be opened

Transient Stability Results



- Once the transient stability run finishes, the **Results from RAM** 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: Time Values



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

The screenshot displays the 'Transient Stability Analysis' software interface. The simulation status is 'Finished at 5.000'. The 'Results from RAM' section is active, showing a table of 'Time Values'. The table has columns for 'Time', 'Gen Bus 4 #1 Rotor Angle', 'Gen Bus 4 #1 Speed', 'Gen Bus 4 #1 MW Terminal', and 'Gen Bus 4 #1 Mvar Terminal'. The 'Time' column ranges from 0 to 0.117. The 'Rotor Angle' column shows values starting at 20.18 and increasing slightly. The 'Speed', 'MW Terminal', and 'Mvar Terminal' columns show constant values of 60, 100, and 58.5305 respectively. The interface also includes a 'Select Step' tree on the left, a 'Column Order' dropdown set to 'Object then Field', and a 'Choose Fields to Display' section with several checked options like 'Rotor Angle' and 'MW Terminal'.

	Time	Gen Bus 4 #1 Rotor Angle	Gen Bus 4 #1 Speed	Gen Bus 4 #1 MW Terminal	Gen Bus 4 #1 Mvar Terminal
1	0	20.18	60	100	58.5305
2	0.008	20.18	60	100	58.5305
3	0.017	20.18	60	100	58.5305
4	0.025	20.18	60	100	58.5305
5	0.033	20.18	60	100	58.5305
6	0.042	20.18	60	100	58.5305
7	0.05	20.18	60	100	58.5305
8	0.058	20.18	60	100	58.5305
9	0.067	20.18	60	100	58.5305
10	0.075	20.18	60	100	58.5305
11	0.083	20.18	60	100	58.5305
12	0.092	20.18	60	100	58.5305
13	0.1	20.18	60	100	58.5305
14	0.108	20.18	60	100	58.5305
15	0.117	20.18	60	100	58.5305

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

Results: Minimum and Maximum Values



Minimum and maximum values are available for all generators and buses

The screenshot shows the 'Transient Stability Analysis' software interface. The simulation status is 'Finished at 5.000'. The 'Results' tab is active, displaying a table of minimum and maximum values for buses and generators. The table has columns for Number, Name, Area Name, Original Volt, Min Volt, Time Min Volt, Max Volt, Time Max Volt, and Max-Min V. The data is as follows:

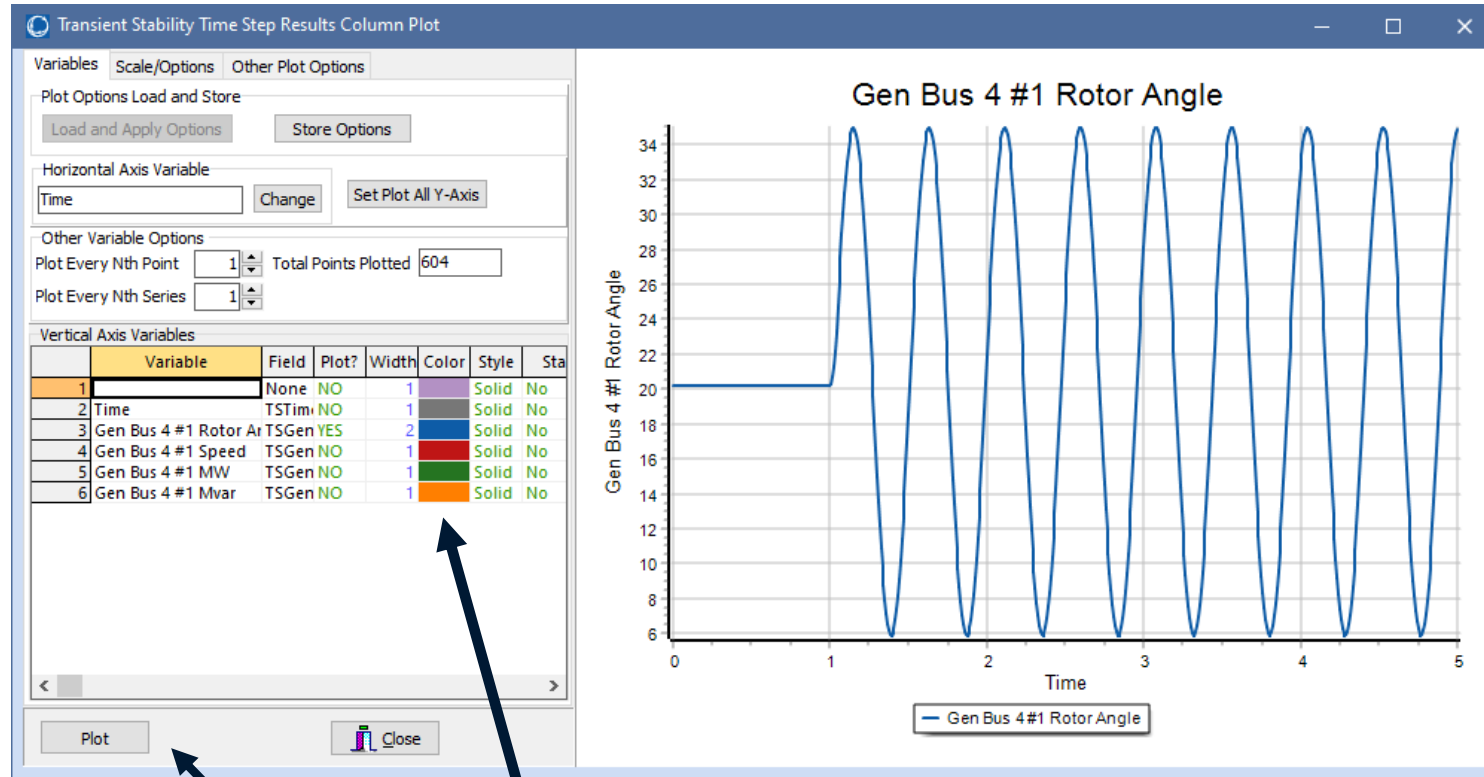
Number	Name	Area Name	Original Volt	Min Volt	Time Min Volt	Max Volt	Time Max Volt	Max-Min V
1	1 Bus 1	Home	1.0477	1.0188	1.158	1.0616	4.792	0.
2	2 Bus 2	Home	1.0000	1.0000	1.058	1.0000	1.058	0.
3	3 Bus 3	Home	1.0303	1.0082	4.525	1.0409	4.792	0.
4	4 Bus 4	Home	1.0971	1.0630	3.575	1.1143	4.808	0.

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



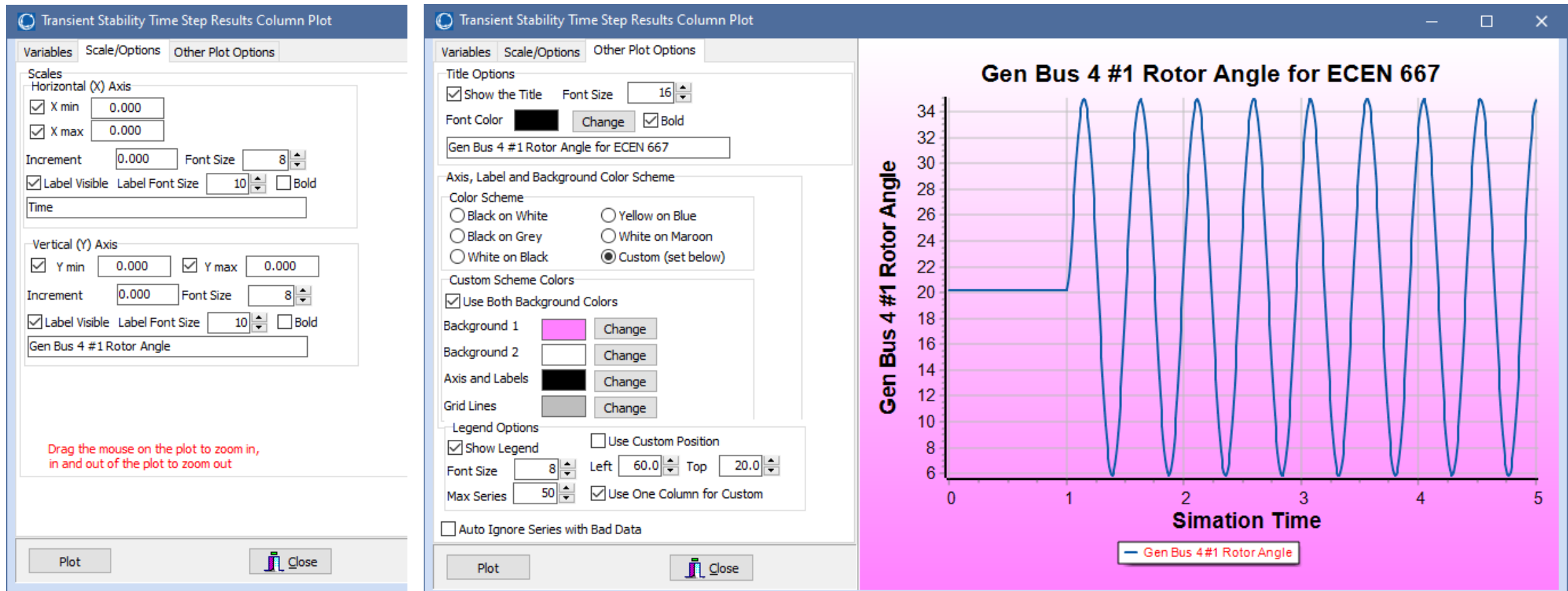
Notice that the result is undamped; damping is provided by damper windings

Change line color here And re-plot by clicking here

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.

Column Plots Option Page

- The Column Plot page has recently been enhanced to provide more options, so good plots can be quickly made for papers and presentations



Changing the Case

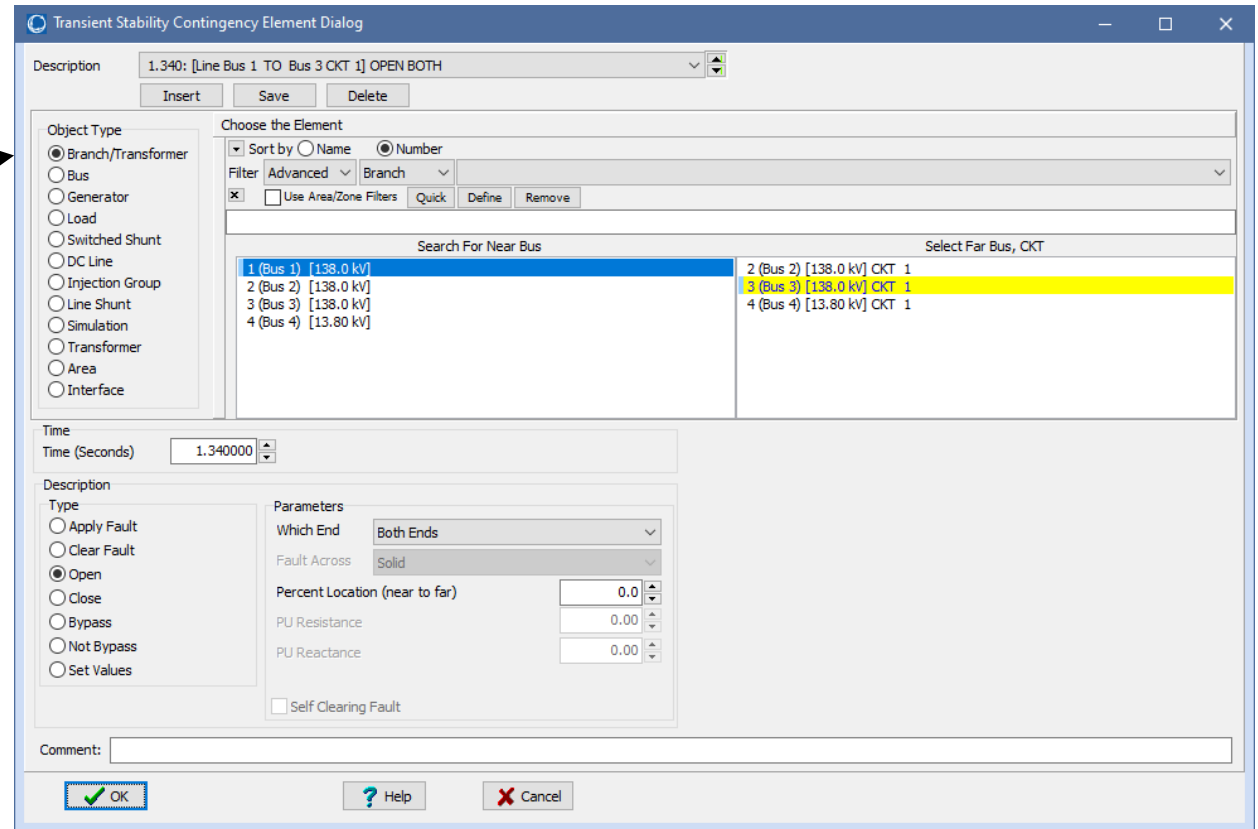


- PowerWorld Simulator allows for easy modification of the study system. As a next example we will duplicate example 13.4 from earlier editions of the Glover/Overbye/Birchfield/Sarma *Power System Analysis and Design* book.
- Back on the one-line, right-click on the generator and use the **Stability/Machine 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 Contingency Elements



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



Changing the Contingency Elements



Simulation Status: Finished at 5.000

Run Transient Stability | Pause | Abort | Restore Reference | 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: [] Change...

Transient Contingency Elements

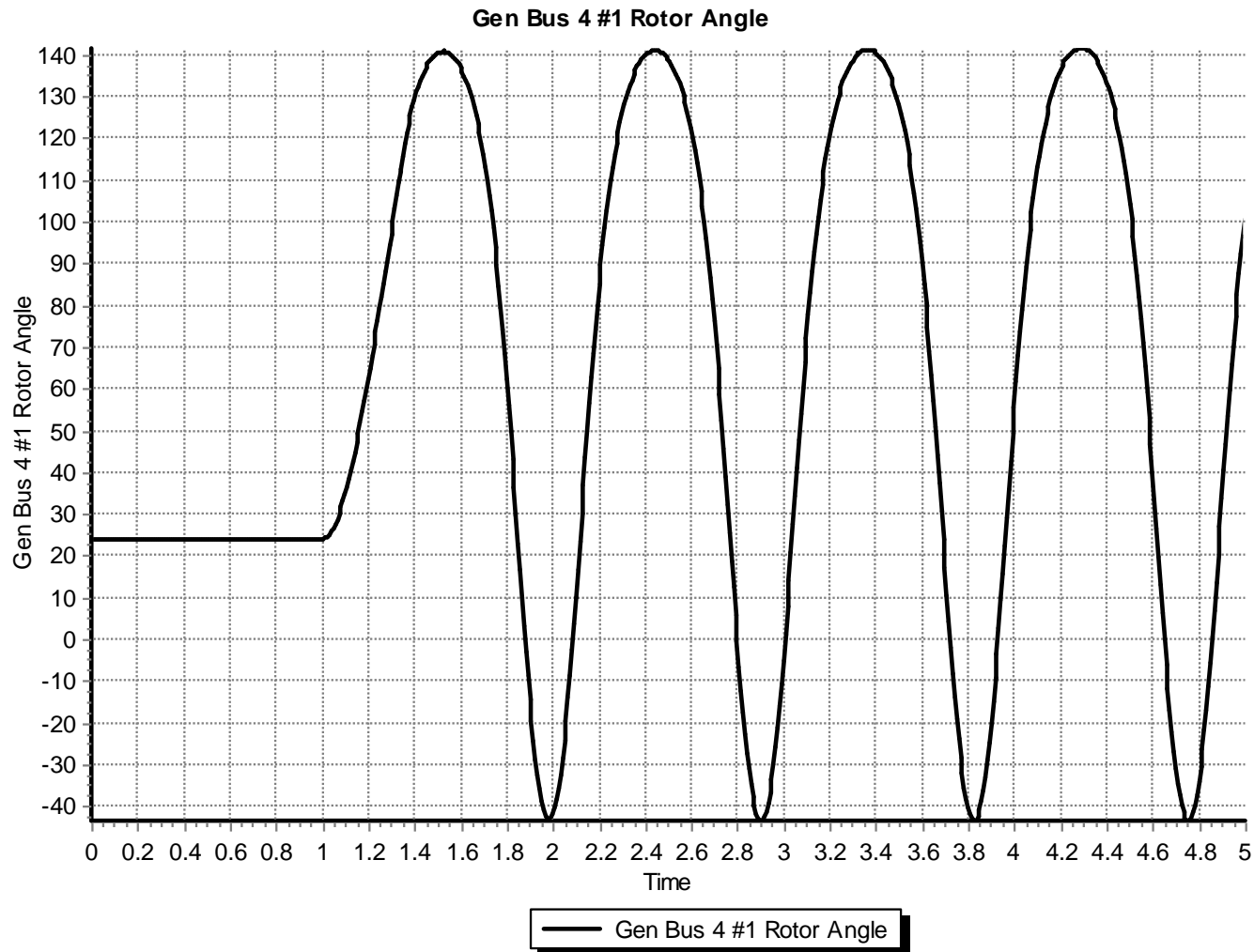
Insert | Clear All | Insert Apply and Clear Fault | Time Shift (seconds): 0.000

	Object Pretty	Time (Cycles)	Time (Seconds)	Object	Description	Enabled
1	Bus Bus 3	60.0	1.0000	Bus '3'	FAULT 3PB SOLID	CHECK
2	Line Bus 1 TO Bus 3 CKT 1	80.4	1.3400	Branch '1' '3' '1'	OPEN BOTH	CHECK
3	Line Bus 2 TO Bus 3 CKT 1	80.4	1.3400	Branch '2' '3' '1'	OPEN BOTH	CHECK

Case Name:
Example_13_4_Bus3Fault

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

Results: On Verge of Instability



Also note that the oscillation frequency has decreased

A More Realistic Generator Model



- The classical model is considered in section 5.6 of the book, as the simplest but also the hardest to justify
 - Had been widely used, but is not rapidly falling from use
- PowerWorld Simulator includes a number of much more realistic models that can be easily used
 - Coverage of these models is beyond the scope of this intro
- To replace the classical model with a detailed solid rotor, subtransient model, go to the generator dialog **Machine Models**, 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



Generator Information for Current Case

Bus Number: 4
Bus Name: Bus 4
ID: 1
Area Name: Home (1)
Labels: no labels

Status: Open Closed
Generator MVA Base: 100.00

Fuel Type: Unknown
Unit Type: UN (Unknown)

Machine Models: Exciters, Governors, Stabilizers, Other Models, Step-up Transformer, Terminal and State

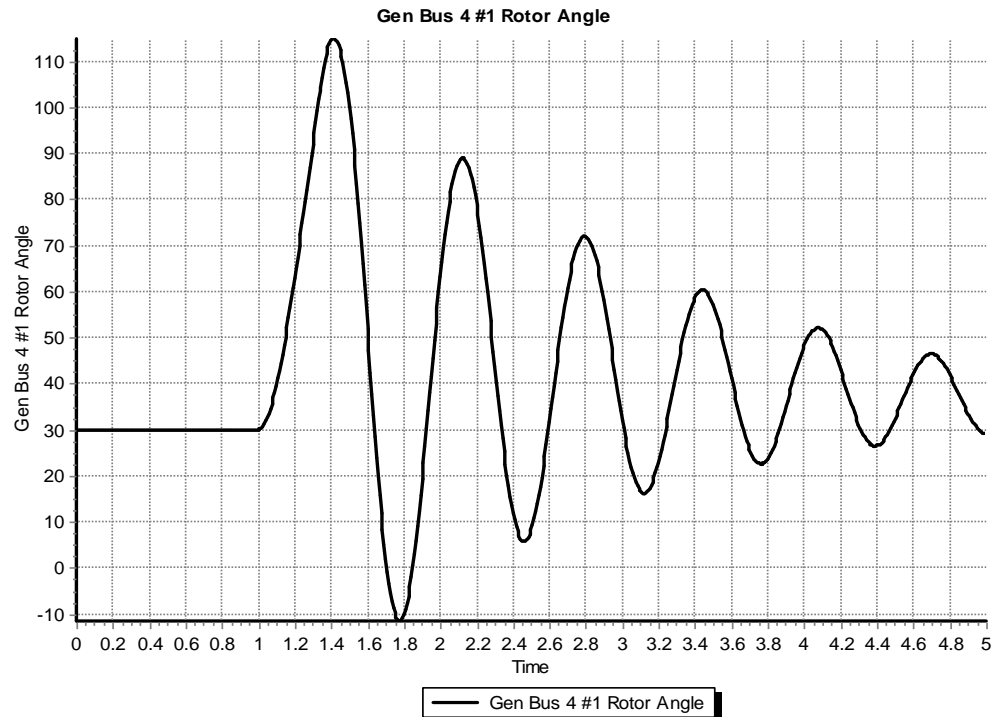
Type: Active - GENROU Active (only one may be active)

Parameters (PU values shown/entered using device base of 100.0 MVA):

H	3.0000	Xdpp=Xqpp	0.1800	S(1,2)	0.0000
D	0.0000	Xl	0.1500	RComp	0.0000
Ra	0.0000	Tdop	7.0000	XComp	0.0000
Xd	2.1000	Tqop	0.7500		
Xq	0.5000	Tdopp	0.0350		
Xdp	0.2000	Tqopp	0.0500		
Xqp	0.5000	S(1,0)	0.0000		

The GENROU model provides a 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.

Repeat of Example 13.1 with GENROU



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**.

Saving Results Every n Timesteps

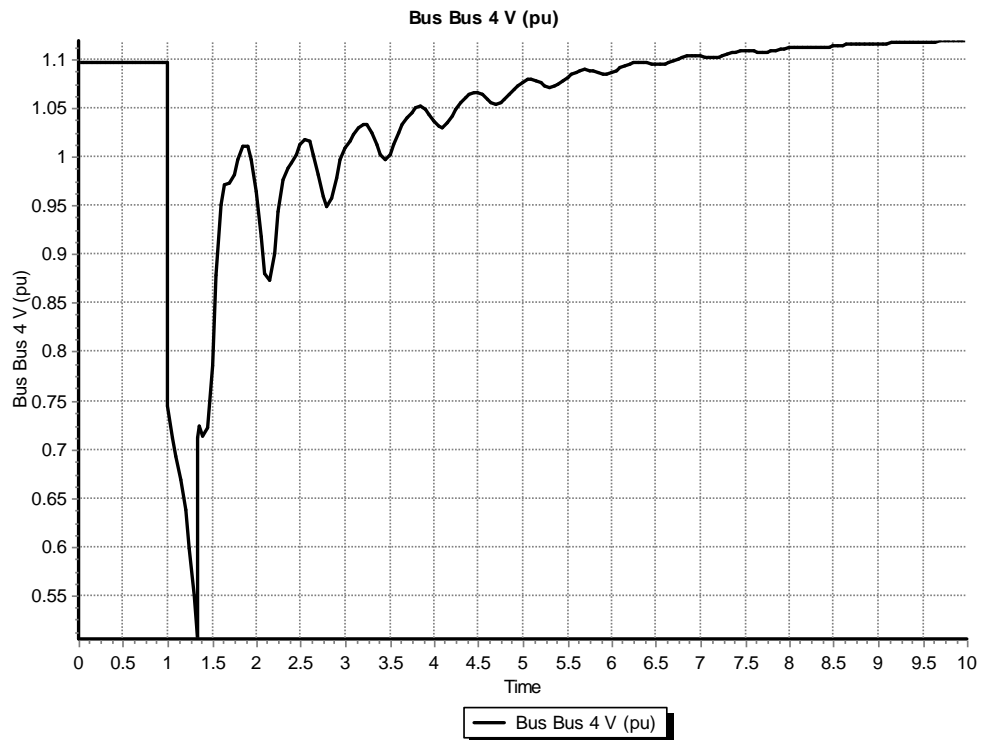


- Before moving on it will be useful to save some additional fields. On the Transient Stability Analysis form select the “Result Storage” page. Then on the Generator tab toggle the generator 4 “Field Voltage” field to Yes. On the Bus tab toggle the bus 4 “V (pu)” field to Yes.
- At the top of the “Result 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 $\frac{1}{2}$ cycle time step 6 saves 20 values per second)

Plotting Bus Voltage



- 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 per unit voltage. The results are shown below.



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

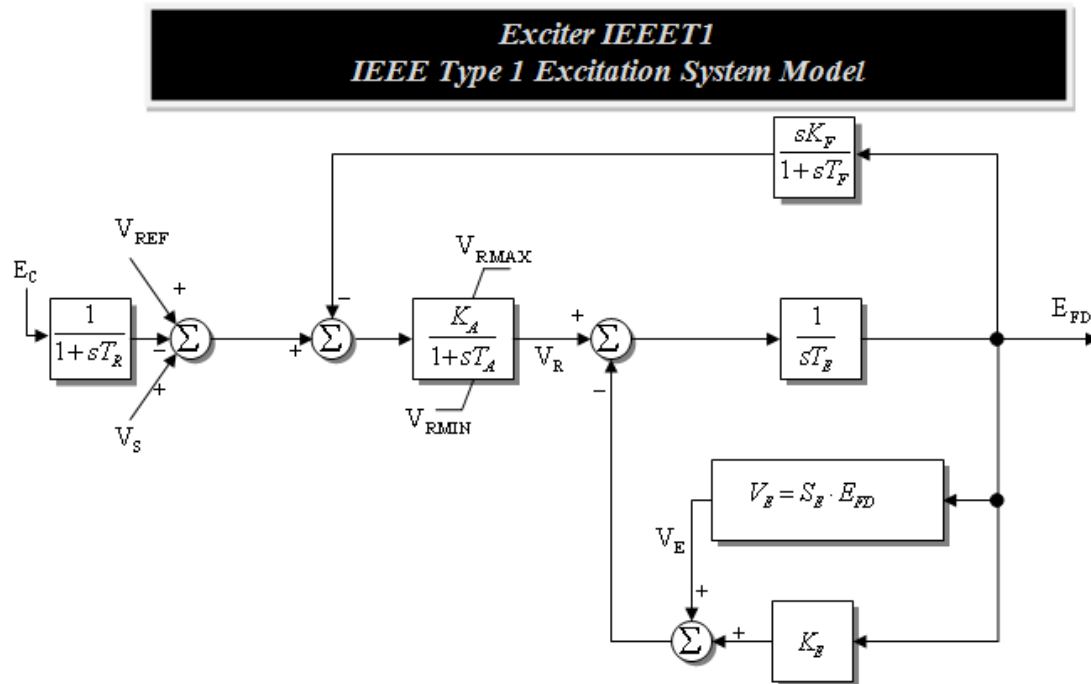
Adding a Generator Exciter



- 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 IEEE1. To add this exciter to the generator at bus 4 go to the generator dialog, “Stability” tab, “Exciters” page. Click Insert and then select IEEE1 from the list. Use the default values.
- Exciters will be covered in the first part of Chapter 4

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.

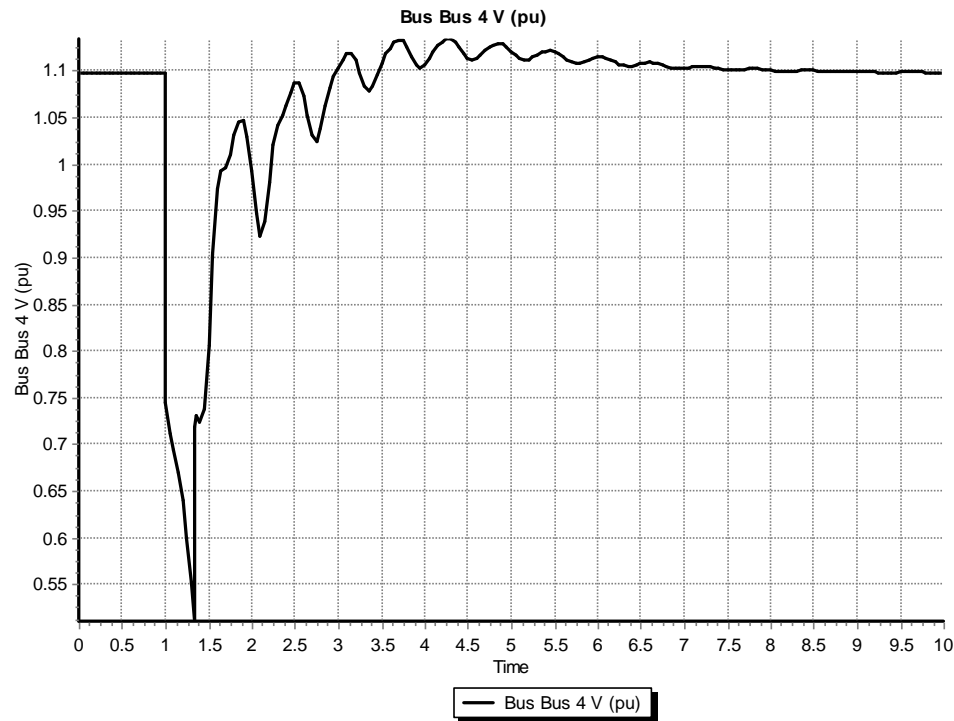


The input to the exciter, E_C , is usually the terminal voltage. The output, E_{FD} , is the machine field voltage.

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.



Case Name: **Example_13_4_GenROU_IEEET1**