

# Transient Stability Analysis with PowerWorld Simulator

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## T3: Transient Stability Basics



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## Transient Stability Basics

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- Overview of the Transient Stability Add On Functionality
  - Initialization procedure
  - State equations
  - Numerical integration procedure
  - Updating the network
- Special features of Simulator's Transient Stability Add On
- Basic Simulation Control
  - General and Power System Model Options
  - Running a simulation

# “Typical” Transient Stability Operation

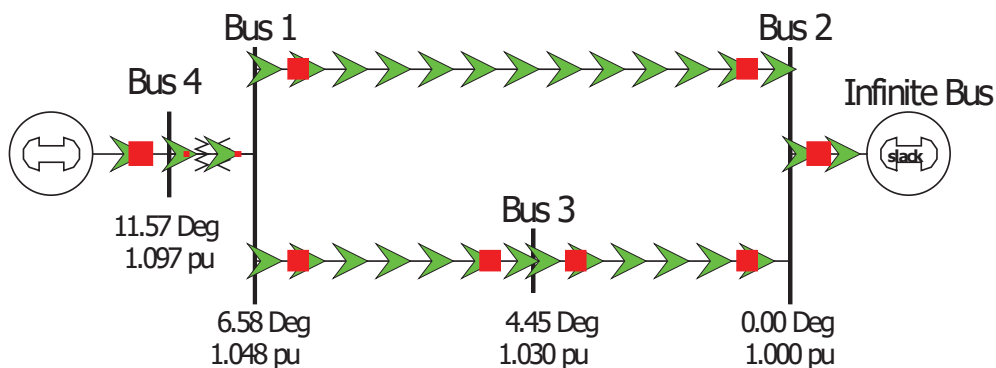


- The procedure for a “typical” transient stability study is straightforward
  - Study assumes that the transient stability models have been saved in the \*.pwb file and storage/plotting variables of interest (up to and including every is already defined)
- Open \*.pwb file, select “Add-Ons, Transient Stability” to display Transient Stability Analysis Form.
- Click “Run Transient Stability”

# Basic Simulation Control



- Open “**Example\_13\_4\_WithPlot**” – this case has already been set up
- Single-machine infinite-bus system with 4 buses
- Initial power flow solution is shown below



# Display After Selecting “Run Transient Stability”



The most important button

The Start Time, End Time, and Time Step

How the transient stability contingency is defined

Predefined plots shown automatically at end

## Going Deeper: Looking at the Generator Models



Right-click on the generator at bus 4 and select “Generator Information Dialog.” Select the “Stability” tab to view the transient stability models in the case – **GENROU** and **IEEET1**.

Generator Information for Present

Bus Number: 4, Bus Name: Bus 4, ID: 1, Area Name: Home (1), Generator MVA Base: 100.00, 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

Type: Active - GENROU (checked)

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

H: 3.00000	XI: 0.15000	XComp: 0.00000
D: 0.00000	Tdop: 7.00000	
Ra: 0.00000	Tqop: 0.75000	
Xd: 2.10000	Tdopp: 0.03000	
Xq: 0.50000	Tqopp: 0.05000	
Xdp: 0.20000	S1: 0.00000	
Xqp: 0.50000	S12: 0.00000	
Xdpp: 0.18000	RComp: 0.00000	

Generator Information for Present

Bus Number: 4, Bus Name: Bus 4, ID: 1, Area Name: Home (1), Generator MVA Base: 100.00, 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

Type: Active - IEEET1 (checked)

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

Tr: 0.00000	Tf: 1.46000
Ka: 50.00000	Switch: 0.00000
Ta: 0.02000	E1: 2.80000
Vrmax: 1.00000	SE1: 0.04000
Vrmin: -1.00000	E2: 3.73000
Ke: -0.06000	SE2: 0.33000
Te: 0.60000	Spdlim: 0.00000
Kf: 0.09000	

# Basic Simulation Control



- How do you design and control the simulation?
- Transient Stability Dialog
  - Customize the options to fit your needs
  - Setup automatic plotting and storing of results
  - Specify events to occur
  - Setup and run the simulation
  - Step through the simulation using States/Manual Control
- More details will be covered in later sections
- Here we'll look at the Transient Stability Dialog and cover the basics of running a simulation

# Transient Stability Dialog



Go to the **Add Ons** ribbon tab and select **Transient Stability**

**This is the main place to design and control the simulation**

**Simulation page of the Transient Stability Analysis Dialog**

**The dialog contains several pages**

**“Transient Contingency Monitor Violations” can be shown here**

**The simulated events consist of “Transient Contingency Elements” which are defined here**  
**These are covered in a later section**

Object	Time (Cycles)	Time (Seconds)	Object	Description
1 Bus Bus 3	60.0	1.000000	Bus '3'	FAULT 3PB SOLID
2 Line Bus 1 TO Bus 3 CKT 1	80.4	1.340000	Branch '1' '3' '1'	OPEN BOTH
3 Line Bus 2 TO Bus 3 CKT 1	80.4	1.340000	Branch '2' '3' '1'	OPEN BOTH

# Simulation Dialog

The simulation is designed and typically run from here

Clicking this will start the simulation

Specify start time, end time, and time step

Multiple Transient Contingencies may be defined

Here, a 3-phase fault at 1.0 seconds is cleared by opening the two adjacent lines

Object Pretty	Time (Cycles)	Time (Seconds)	Object	Description
1 Bus Bus 3	60.0	1.000000	Bus '3'	FAULT 3PB SOLID
2 Line Bus 1 TO Bus 3 CKT 1	80.4	1.340000	Branch '1' '3' '1'	OPEN BOTH
3 Line Bus 2 TO Bus 3 CKT 1	80.4	1.340000	Branch '2' '3' '1'	OPEN BOTH

## Transient Stability Dialog Pages Allow for Customization

### Simulation

Define events, start time, end time, and time step

### Options

General, Power System Model, Results, Generic Limit Monitors

### Results Storage

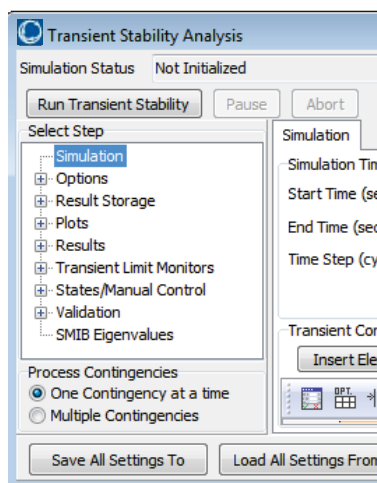
Specify what to store during the simulation for viewing, plotting, and contouring

### Plots

Create plot descriptions that can be automatically generated upon completion of a transient stability run

### Results

View numeric results of a simulation and a summary of events that occurred



### SMIB Eigenvalues

Perform Single Machine Infinite Bus analysis on each generator

### Validation

Options to validate the data for possible errors and warnings

### States/Manual Control

Manually step through the simulation and view initialized states and initial limit violations

### Transient Limit Monitors

Set monitors to check for stability criteria violations during the simulation

# Transient Stability Options: General



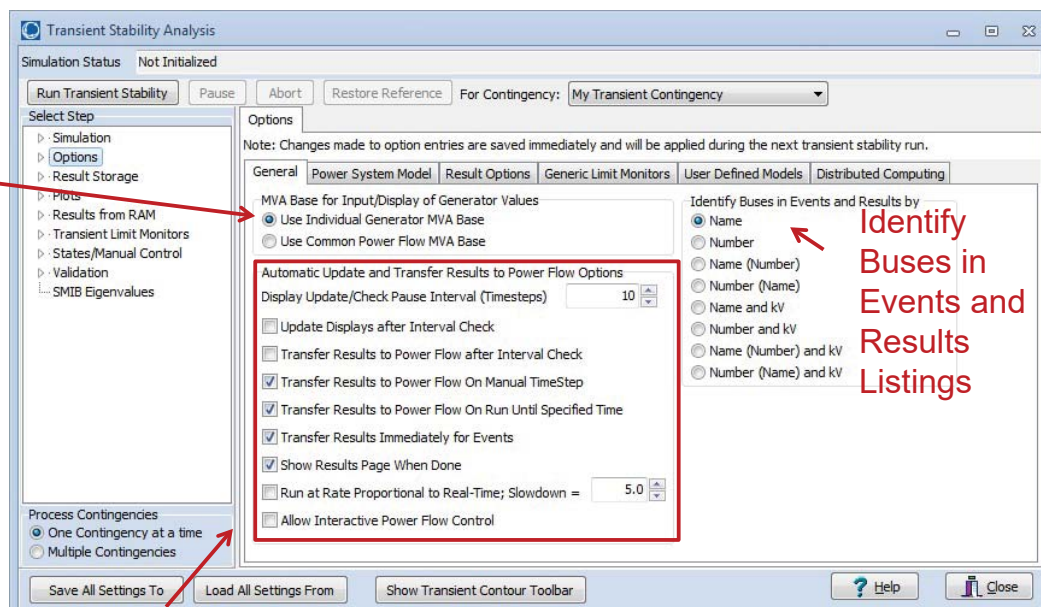
- Options to Transfer Results
  - Interval check
  - After manual time step
  - After manual control “Run Until Time”
  - Immediately after events
- Run at a Rate Proportional to Real-Time
  - Runs the simulation at a slower rate for educational/demonstrational purposes
  - i.e., to view a contour of transient stability data changing with time
  - Does not actually change the time step
  - Slowdown = 5 runs at 1/5 of real-time rate

# Transient Stability Options: General



- Open the Options page to the General tab

Option affects Generator Dialog inputs (Case Info Displays always show values on generator MVA base)



Identify Buses in Events and Results Listings

Options for transferring results to power flow are discussed during Manual Control examples

# States/Manual Control



- In addition to running the simulation, you can also step through it
- Go to the States/Manual Control page - options related to States/Manual Control are on the General tab of the Options page

Simulation is initialized

Click to do a timestep

Initial states and derivatives

Model Class	Model Type	Object Name	At Limit	State Ignored	State Name	Value	Derivative	Delta X K1
1 Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Angle	0.5244	0.000000	0.000000
2 Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Speed w	0.0000	0.000000	0.000000
3 Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Eqp	1.1995	0.000000	0.000000
4 Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	PsiDp	1.1597	0.000000	0.000000
5 Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	PsiOpp	0.2434	0.000000	0.000000
6 Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Edp	0.0000	0.000000	0.000000
7 Gen Exciter	IEEET1	4 (Bus 4) #1		NO	EField	2.7098	0.000000	0.000000
8 Gen Exciter	IEEET1	4 (Bus 4) #1		YES	Sensed Vt	1.0971	0.000000	0.000000
9 Gen Exciter	IEEET1	4 (Bus 4) #1		NO	VR	-0.0743	0.000000	0.000000
10 Gen Exciter	IEEET1	4 (Bus 4) #1		NO	VF	0.0000	0.000000	0.000000
11 Bus Frequency	Bus Frequency	1 (Bus 1)		NO	Frequency	0.0000	0.000000	0.000000
12 Bus Frequency	Bus Frequency	2 (Bus 2)		NO	Frequency	0.0000	0.000000	0.000000
13 Bus Frequency	Bus Frequency	3 (Bus 3)		NO	Frequency	0.0000	0.000000	0.000000
14 Bus Frequency	Bus Frequency	4 (Bus 4)		NO	Frequency	0.0000	0.000000	0.000000

# States/Manual Control



- Click “Do Specified Number of Timesteps” – the simulation will take one step and then pause
- Dialog now shows the values after 1 time step

Simulation is paused

Model Class	Model Type	Object Name	At Limit	State Ignored	State Name	Value	Derivative	Delta X K1
1 Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Angle	0.5244	0.000000	0.000000
2 Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Speed w	0.0090	0.000000	0.000000
3 Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Eqp	1.1995	0.000000	0.000000
4 Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	PsiDp	1.1597	0.000000	0.000000
5 Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	PsiOpp	0.2434	0.000000	0.000000
6 Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Edp	0.0000	0.000000	0.000000
7 Gen Exciter	IEEET1	4 (Bus 4) #1		NO	EField	2.7098	0.000002	0.000000
8 Gen Exciter	IEEET1	4 (Bus 4) #1		YES	Sensed Vt	1.0971	0.000000	0.000000
9 Gen Exciter	IEEET1	4 (Bus 4) #1		NO	VR	-0.0743	0.0000106	0.0000001
10 Gen Exciter	IEEET1	4 (Bus 4) #1		NO	VF	0.0000	0.000000	0.000000
11 Bus Frequency	Bus Frequency	1 (Bus 1)		NO	Frequency	0.0000	0.000000	0.000000
12 Bus Frequency	Bus Frequency	2 (Bus 2)		NO	Frequency	0.0000	0.000000	0.000000
13 Bus Frequency	Bus Frequency	3 (Bus 3)		NO	Frequency	0.0000	0.000000	0.000000
14 Bus Frequency	Bus Frequency	4 (Bus 4)		NO	Frequency	0.0000	0.000000	0.000000

This page can be used as a debugging tool for your simulations

Can also help to identify incorrect parameters

# States/Manual Control



Now, enter 1.35 seconds for “Run Until Time” and click “Run Until Specified Time”

Simulation is paused after the fault is cleared

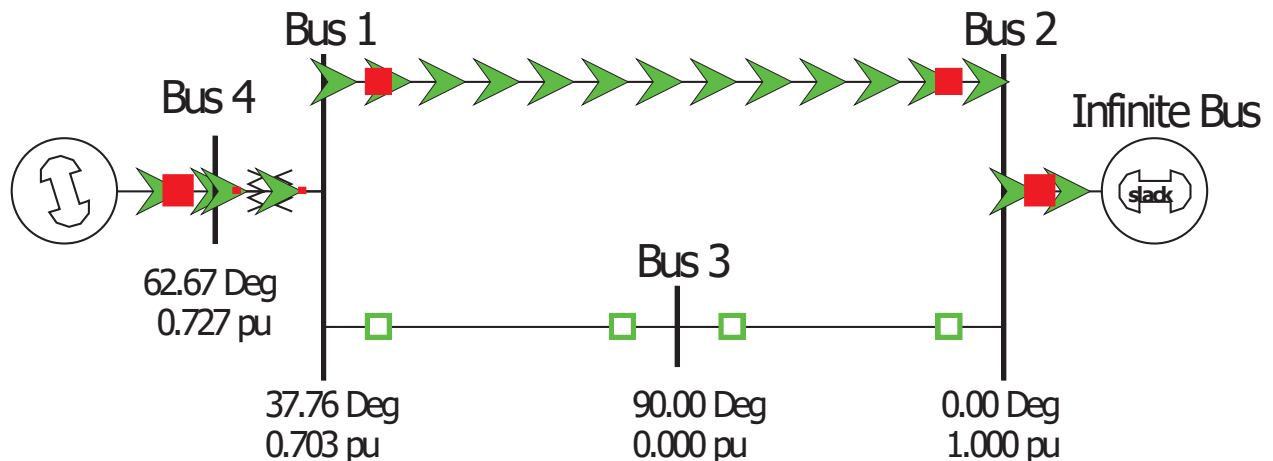
Model Class	Model Type	Object Name	At Limit	State Ignored	State Name	Value	Derivative	Delta X K1
1	Gen Synch. Ma	GENROU 4 (Bus 4) #1		NO	Angle	1.8515	4.4627830	0.0420774
2	Gen Synch. Ma	GENROU 4 (Bus 4) #1		NO	Speed w	0.0118	-0.1877873	-0.0015395
3	Gen Synch. Ma	GENROU 4 (Bus 4) #1		NO	Eqp	1.0519	-0.4121754	-0.0034233
4	Gen Synch. Ma	GENROU 4 (Bus 4) #1		NO	PsiDp	0.9190	-0.0388139	0.0017779
5	Gen Synch. Ma	GENROU 4 (Bus 4) #1		NO	PsiQpp	0.2415	5.9240555	0.0663222
6	Gen Synch. Ma	GENROU 4 (Bus 4) #1		NO	Edp	0.0000	0.0000000	0.0000000
7	Gen Exciter	IEEET1 4 (Bus 4) #1		NO	EField	3.2458	1.2121919	0.0102521
8	Gen Exciter	IEEET1 4 (Bus 4) #1	High Limit	YES	Sensed Vt	0.7269	0.0000000	0.0000000
9	Gen Exciter	IEEET1 4 (Bus 4) #1		NO	VR	1.0000	0.0000000	0.0000000
10	Gen Exciter	IEEET1 4 (Bus 4) #1		NO	VF	0.0292	-0.0199898	-0.0001639

Exciter state is at a limit

# States/Manual Control



The “Transfer Results to Power Flow on Manual TimeStep” option was checked, so the power flow and the oneline were updated

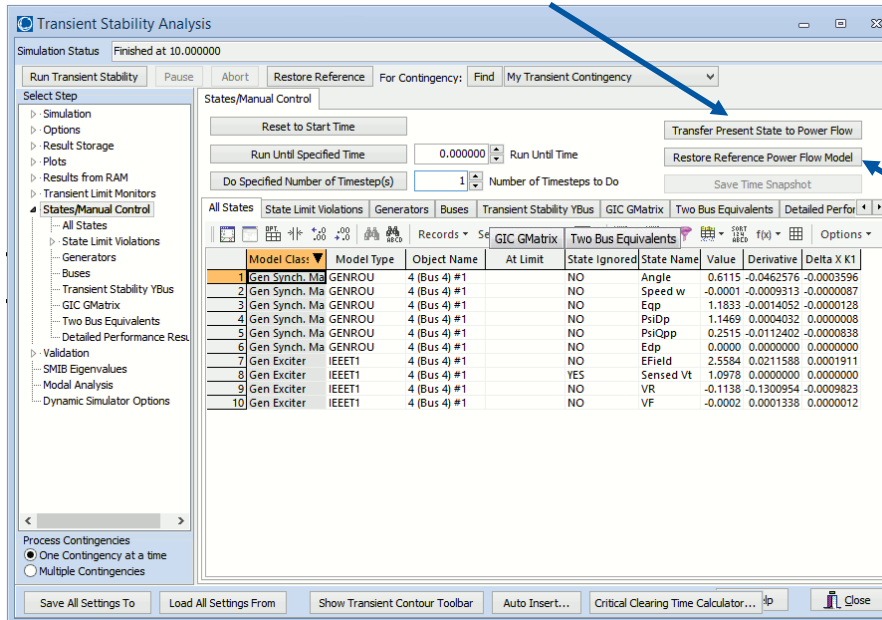




# States/Manual Control



Can click “Transfer Present State to Power Flow” to transfer the state and update the display with the transient stability results



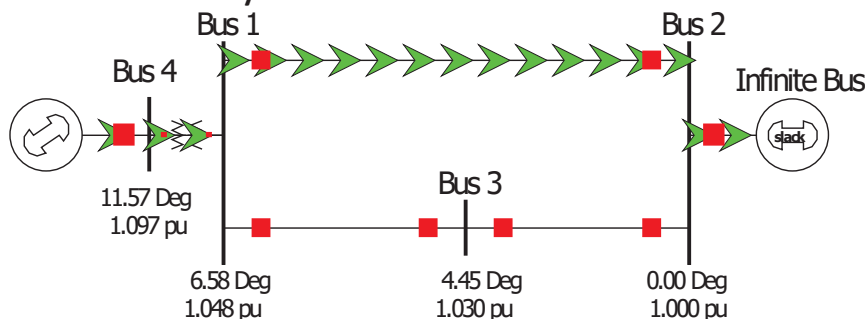
Option to restore state prior to transient stability run

# States/Manual Control

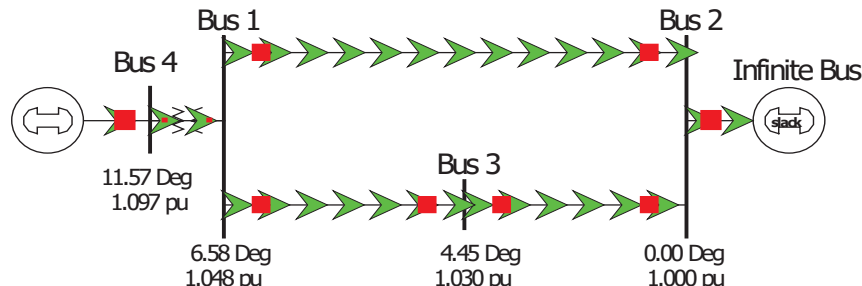


- Click “Restore Power Flow Model” to restore the power flow state of the system before the transient stability run

Restored model, unsolved

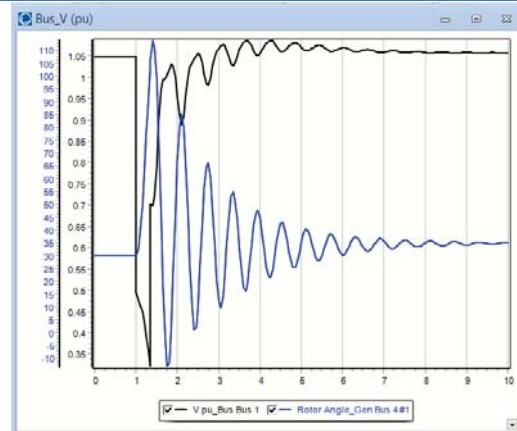


Restored model after a power flow solution



# Run a Simulation

- On the States/Manual Control page, click “Reset to Start Time”
- This reinitializes the simulation
- Then, go back to the Simulation page
- Click on “Run Transient Stability” to solve- the simulation will run for 10 seconds
- After the run, the plot to the right will be automatically generated



Resultant plot of Bus 1 voltage and Generator 4 rotor angle

Lots of options are available for customizing the appearance of the plots and for exporting plot information. These will be talked about later in the Plot Definition Section.

# Transient Stability Options: Power System Model

- Open the Power System Model page to the General tab
- Options related to the solution of the algebraic network equations

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

General Power System Model Result Options Generic Limit Monitors User Defined Models Distributed Computing

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 100.00

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

Network Equations Solution Options

Solution Tolerance (MVA) 0.10000

Maximum Iterations 25

Abort after number of failed solutions 10

Force Network Equation Update 0.00

Use Voltage Extrapolation

Inner Loop Mismatch Scalar 1.0

Handling of Initial Limit Violations

Modify Limits and Run

Abort

Run without Changing Limits

Nominal Frequency (Typically 60 Hz or 50 Hz)

# Transient Stability Options: Power System Model - Common



## Network Equation Solution Options

- Solution tolerance and maximum iterations
  - For transient stability power flow algorithm only
- Force network equation update
  - Specify a time for a full network equation update, can be helpful to avoid small oscillations caused by small mismatches
- Use voltage extrapolation
  - Estimate the voltages based on the voltage at the last three time steps, aids in the initial guess of the network equation voltages and helps speed up the solution
- Inner loop mismatch scalar
  - When network equation solutions are done as an intermediate part of the numerical integration method, allowing this scalar to be larger than 1 allows the network equation solution to have a larger mismatch

# Transient Stability Options: Power System Model - Common



- Integration Method
  - Second Order Runge-Kutta
  - Euler
- Infinite Bus Modeling
  - Model the island slack bus as a constant voltage and angle (essentially it is a generator with infinite inertia)
  - Infinite buses do not exist in real systems so normally this should NOT be done
  - Primarily intended for academic audiences
- Handling of Initial Limit Violations
  - There are many limits associated with dynamic models (exciters, governors, and over-excitation, etc...)
  - Theoretically, there should be no violations of these limits in the steady state solution
  - This option determines what Simulator does if there are violations in the initial conditions
  - Default action is to modify the limit value so that the system is initially in steady-state
- Include GIC Effects
  - This will include the Geomagnetically Induced Current effects into transient stability simulation

### Handling of Initial Limit Violations

- Modify Limits and Run
- Abort
- Run without Changing Limits

# Transient Stability Options: Power System Model



- Open the Power System Model page to the General tab

Options

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

General Power System Model Result Options Generic Limit Monitors User Defined Models Distributed Computing

Common Load Modeling Compatibility Options

Default Load Model

- Constant Impedance
- ZIP Model from Power Flow Model
- Constant Current
- Constant Current P, Impedance Q

When to use Complex Load Models

Minimum Load P (MW) 0.500

Minimum Load P/Q Ratio 0.25

Minimum Initial per unit voltage 0.00000

Complex Loads represent a composite of various of load types. Examples include CLOD, CPMLDW, MOTORW, and CompLoad. These filters are also used for Distribution Equivalent Models.

Distribution Equivalent Models Options

Min Nom kV for Transformer 0.00

Minimum Per Unit Voltages for Models with

Constant Power 0.700

Constant Current 0.500

Change

Default Load Model settings

# Transient Stability Options: Power System Model – Load Modeling



- Default Load Model
  - It is best to define a system-wide load model explicitly
  - This option is applied to loads with no specified dynamic model
- When to use Complex Load Models (CLOD, CMPLDW, MOTORW and CompLoad)
  - Minimum Load P (MW) to insert complex models
  - Minimum Load P/q Ratio
  - Minimum Initial per unit voltage
- Distribution Equivalent Models Options
  - Minimum Nominal KV to add the Transformer

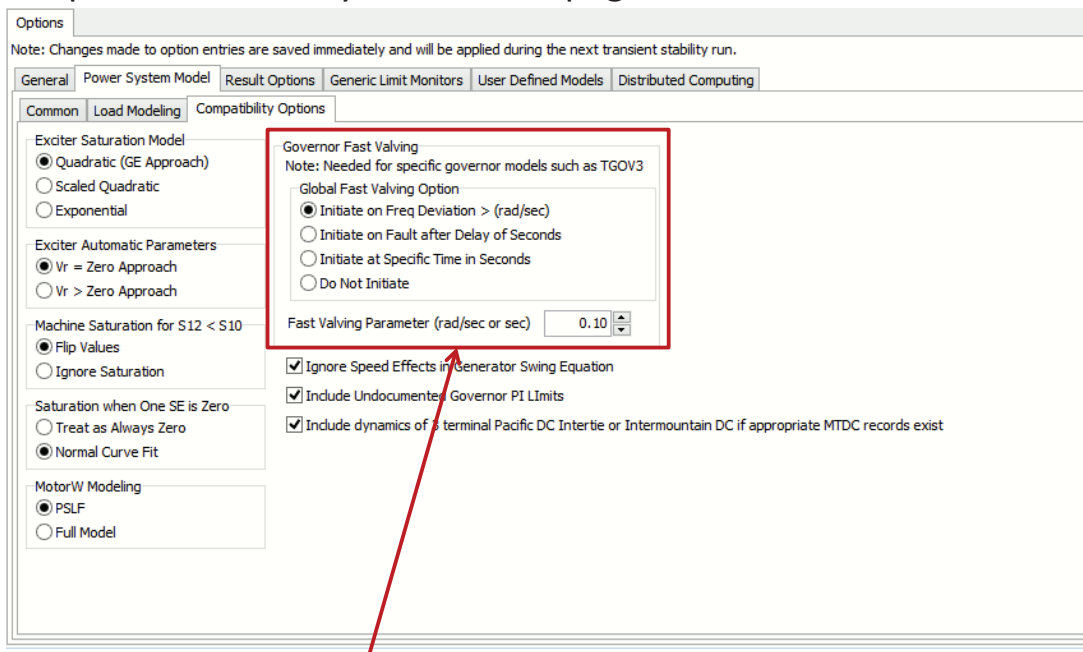
Default Load Model

- Constant Impedance
- ZIP Model from Power Flow Model
- Constant Current
- Constant Current P, Impedance Q

# Transient Stability Options: Power System Model – Compatibility



- Open the Power System Model page to the General tab



Special options for governors using Fast Valving such as TGOV3

# Transient Stability Options: Power System Model



- Exciter Saturation Model
  - Quadratic  $\rightarrow S(x) = B*(x - A)^2$  (GE PSLF)
  - Scaled Quadratic  $\rightarrow S(x) = B*(x - A)^2 / \text{input}$  (PTI PSS/E)
  - Exponential  $\rightarrow S(x) = B*x^A$  (BPA IPF)
- Exciter Automatic Parameters
  - Used to automatically calculate  $K_e$  when  $K_e = 0$
  - $V_r = 0$  approach  $\rightarrow K_e$  is set to force  $V_r = 0$  (GE PSLF)
  - $V_r > 0$  approach  $\rightarrow K_e$  is set to force  $V_r = V_{RMAX}/10$  (PTI PSSE)
- Machine Saturation when S12 < S10
  - This is bad data probably but you can request Simulator just flip the values
- Saturation when One SE is Zero
  - Treat always as zero, or Normal Curve Fit
- MotorW Modeling
  - Use PSLF modeling or Full Model

# Transient Stability Options: Power System Model



- Governor Fast Valving Option– When to Initiate
  - After a specified frequency deviation in rad/sec
  - After a fault
  - Specified time delay in seconds
  - Do not initiate
- Ignore Speed Effects in Generator Swing Equation
  - Generator swing equation includes a term that divides the  $P_{mech}$  by the per unit speed.
  - Normally you should not ignore this effect.
- Include Undocumented Governor PI Limits
  - Some limits are undocumented and model internally in PowerWorld
- Include dynamic 3 terminal Pacific DC Intertie or Intermountain DC
  - If appropriate MTDC record exist in the case.