

Transient Stability Analysis with PowerWorld Simulator



T3: Transient Stability Basics



PowerWorld
Corporation

2001 South First Street
Champaign, Illinois 61820
+1 (217) 384.6330

support@powerworld.com
<http://www.powerworld.com>

Transient Stability Basics



- 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

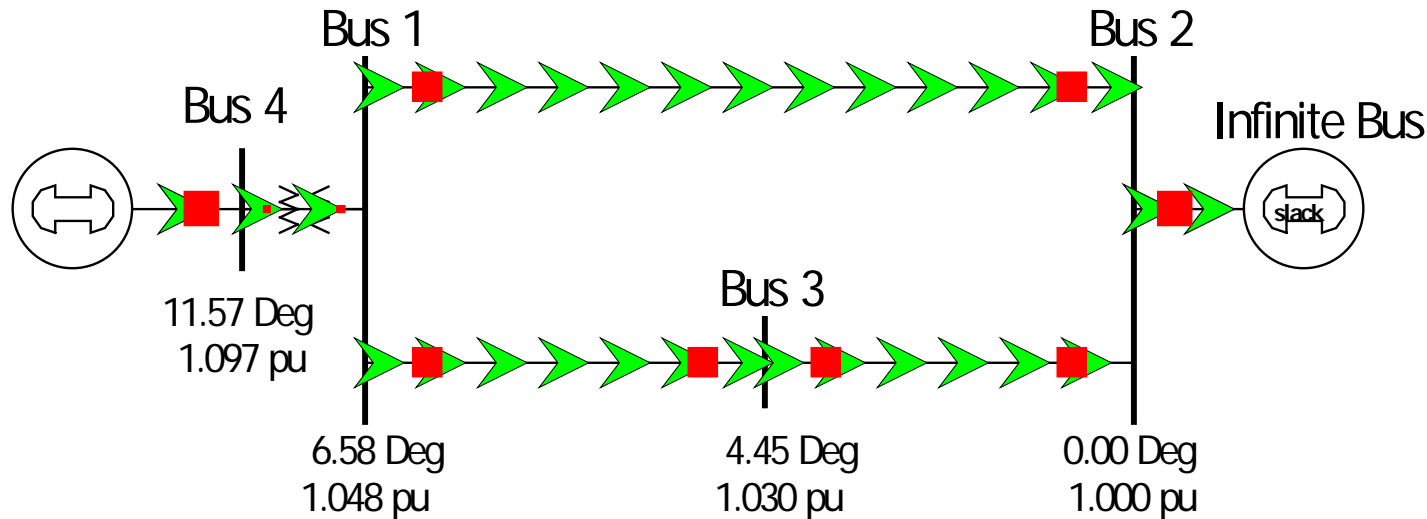


- The procedure for a “typical” transient stability study is straightforward
 - Study assumes that the transient stability models have been saved in the *.pwb file and storage/plotting variables of interest (up to and including every is already defined)
- Open *.pwb file, select “Add-Ons, Transient Stability”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

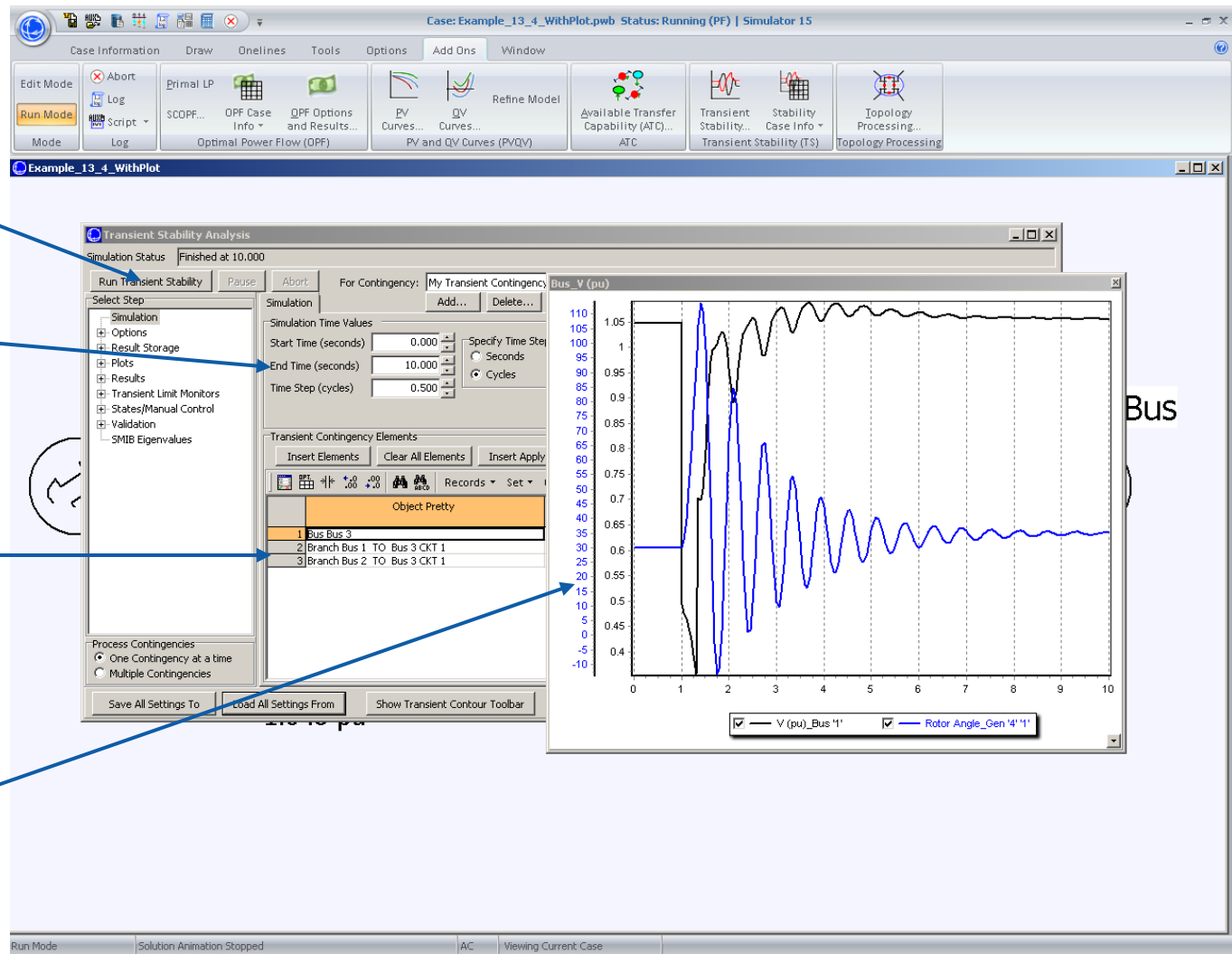


The most important button

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**.

The image displays two side-by-side screenshots of the 'Generator Information for Current Case' dialog box, showing the 'Stability' tab. Both screenshots show the same basic information: Bus Number 4, Bus Name 'Bus 4', ID 1, Area Name 'Home (1)', Fuel Type 'Unknown', and Unit Type 'UN (Unknown)'. The 'Generator MVA Base' is set to 100.00. The 'Status' is set to 'Closed'.

The left screenshot shows the 'Type' set to 'Active - GENROU'. The 'Parameters' section shows the following values:

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	0.0300		
Xdp	0.2000	Tqopp	0.0500		
Xqp	0.5000	S(1.0)	0.0000		

The right screenshot shows the 'Type' set to 'Active - IEEET1'. The 'Parameters' section shows the following values:

Tr	0.0000	Kf	0.0900
Ka	50.0000	Tf	1.4600
Ta	0.0200	Switch	0.0000
Vrmax	1.0000	E1	2.8000
Vrmin	-1.0000	SE(E1)	0.0400
Ke	-0.0600	E2	3.7300
Te	0.6000	SE(E2)	0.3300

Generator Dialog

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

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

	Object Pretty	Enabled	Time (Seconds)	Object	Description	Conting Name
1	Bus Bus 3	YES	1.0000	Bus '3'	FAULT 3PB SOLID	My Tran
2	Branch Bus 1 TO Bus 3 CKT 1	YES	1.3400	Branch '1' '3' '1'	OPEN BOTH	My Tran
3	Branch Bus 2 TO Bus 3 CKT 1	YES	1.3400	Branch '2' '3' '1'	OPEN BOTH	My Tran

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

Simulation Status: Not Initialized

Run Transient Stability | Pause | Abort

For Contingency: My Transient Contingency

Select Step

- Simulation
- Options
- Result Storage
- Plots
- Results
- Transient Limit Monitors
- States/Manual Control
- Validation
- SMIB Eigenvalues

Simulation Time Values

Start Time (seconds): 0.000

End Time (seconds): 10.000

Time Step (cycles): 0.500

Specify Time Step in

- Seconds
- Cycles

Transient Contingency Elements

Insert Elements | Clear All Elements | Insert Apply and Clear Fault

	Object Pretty	Enabled	Time (Seconds)	Object	Description	Conting Name
1	Bus Bus 3	YES	1.0000	Bus '3'	FAULT 3PB SOLID	My Tran
2	Branch Bus 1 TO Bus 3 CKT 1	YES	1.3400	Branch '1' '3' '1'	OPEN BOTH	My Tran
3	Branch Bus 2 TO Bus 3 CKT 1	YES	1.3400	Branch '2' '3' '1'	OPEN BOTH	My Tran

Process Contingencies

- One Contingency at a time
- Multiple Contingencies

Save All Settings To | Load All Settings From | Show Transient Contour Toolbar | Close

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

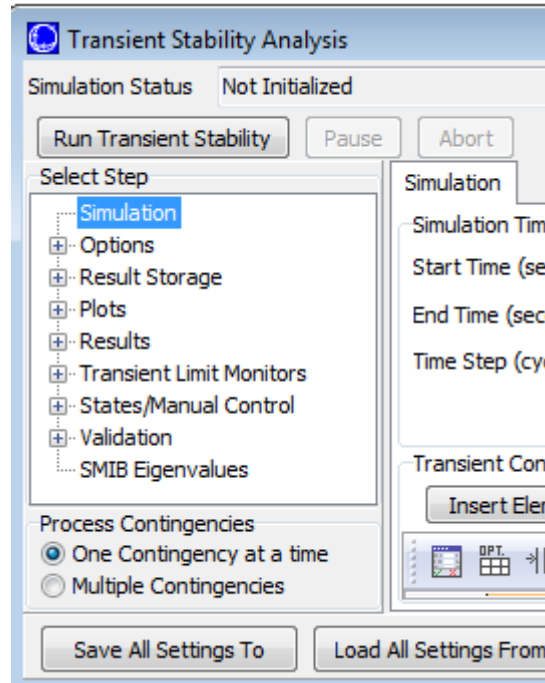
Specify what to store during the simulation for viewing, plotting, and contouring

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



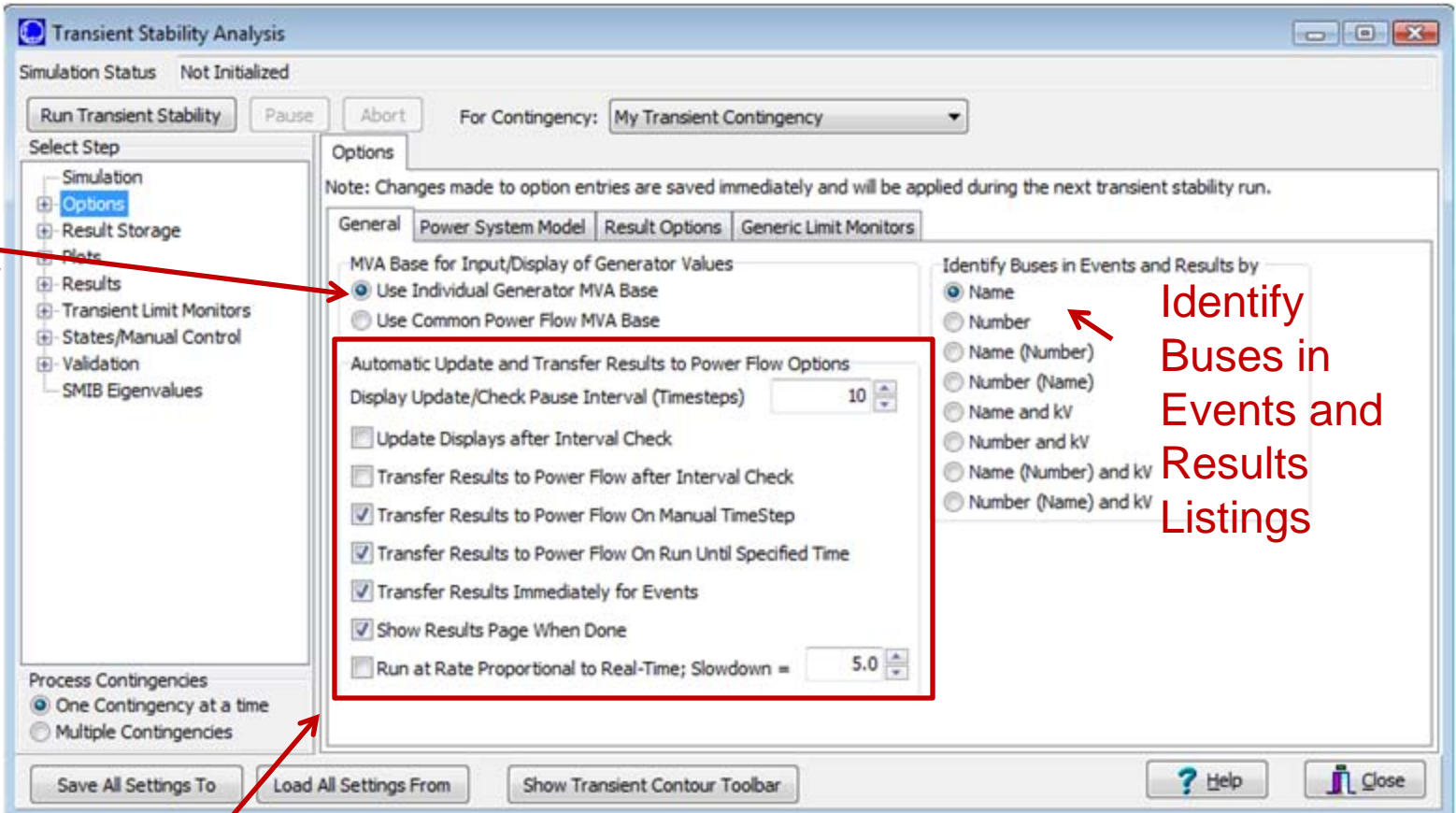
- Options to Transfer Results
 - Interval check
 - After manual time step
 - After manual control “Run Until Time”
 - Immediately after events
- Run at a Rate Proportional to Real-Time
 - Runs the simulation at a slower rate for educational/demonstrational purposes
 - i.e., to view a contour of transient 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 Status: Initialized ← Simulation is initialized

Run Transient Stability | Pause | Abort | For Contingency: My Transient Contingency

Select Step: Simulation, Options, Result Storage, Plots, Results, Transient Limit Monitors, **States/Manual Control**, Validation, SMIB Eigenvalues

States/Manual Control

Reset to Start Time | Transfer Present State to Power Flow

Run Until Specified Time: 0.000 | Run Until Time

Do Specified Number of Timestep(s): 1 | Number of Timesteps to Do

Restore Power Flow Model | Save Time Snapshot

All States | State Limit Violations | Generators | Buses | Transient Stability YBus

	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	NO	Angle	0.5244	0.0000000	0.0000000
2	Gen Synch. Mac	GENROU	4 (Bus 4) #1	NO	NO	Speed w	0.0000	0.0000000	0.0000000
3	Gen Synch. Mac	GENROU	4 (Bus 4) #1	NO	NO	Eqp	1.1995	0.0000000	0.0000000
4	Gen Synch. Mac	GENROU	4 (Bus 4) #1	NO	NO	PsiDp	1.1597	0.0000000	0.0000000
5	Gen Synch. Mac	GENROU	4 (Bus 4) #1	NO	NO	PsiQpp	0.2434	0.0000000	0.0000000
6	Gen Synch. Mac	GENROU	4 (Bus 4) #1	NO	NO	Edp	0.0000	0.0000000	0.0000000
7	Gen Exciter	IEEE1	4 (Bus 4) #1	NO	NO	EField	2.7098	0.0000000	0.0000000
8	Gen Exciter	IEEE1	4 (Bus 4) #1	NO	YES	Sensed Vt	1.0971	0.0000000	0.0000000
9	Gen Exciter	IEEE1	4 (Bus 4) #1	NO	NO	VR	-0.0743	0.0000000	0.0000000
10	Gen Exciter	IEEE1	4 (Bus 4) #1	NO	NO	VF	0.0000	0.0000000	0.0000000
11	Bus Frequency	Bus Frequency # 1 (Bus 1)		NO	NO	Frequency	0.0000	0.0000000	0.0000000
12	Bus Frequency	Bus Frequency # 2 (Bus 2)		NO	NO	Frequency	0.0000	0.0000000	0.0000000
13	Bus Frequency	Bus Frequency # 3 (Bus 3)		NO	NO	Frequency	0.0000	0.0000000	0.0000000
14	Bus Frequency	Bus Frequency # 4 (Bus 4)		NO	NO	Frequency	0.0000	0.0000000	0.0000000

Initial states and derivatives

Process Contingencies: One Contingency at a time, Multiple Contingencies

Save All Settings To | Load All Settings From | Show Transient Contour Toolbar | Close

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

Transient Stability Analysis
Simulation Status Paused at 0.008 ← Simulation is paused

Run Transient Stability Continue Abort For Contingency: My Transient Contingency

Select Step

- Simulation
 - Options
 - Result Storage
 - Plots
 - Results
 - Transient Limit Monitors
 - States/Manual Control
 - All States
 - State Limit Violations
 - Generators
 - Buses
 - Transient Stability YBus
 - Validation
 - SMIB Eigenvalues

States/Manual Control

Reset to Start Time Transfer Present State to Power Flow

Run Until Specified Time 0.000 Run Until Time Restore Power Flow Model

Do Specified Number of Timestep(s) 1 Number of Timesteps to Do Save Time Snapshot

All States State Limit Violations Generators Buses Transient Stability YBus

	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	0.0000000	0.0000000
2	Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Speed w	0.0000	0.0000000	0.0000000
3	Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Eqp	1.1995	0.0000000	0.0000000
4	Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	PsiDp	1.1597	0.0000000	0.0000000
5	Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	PsiQpp	0.2434	0.0000000	0.0000000
6	Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Edp	0.0000	0.0000000	0.0000000
7	Gen Exciter	IEEET1	4 (Bus 4) #1		NO	EField	2.7098	0.0000002	0.0000000
8	Gen Exciter	IEEET1	4 (Bus 4) #1		YES	Sensed Vt	1.0971	0.0000000	0.0000000
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	0.0000000	0.0000000
11	Bus Frequency	Bus Frequency #1 (Bus 1)			NO	Frequency	0.0000	0.0000000	0.0000000
12	Bus Frequency	Bus Frequency #2 (Bus 2)			NO	Frequency	0.0000	0.0000000	0.0000000
13	Bus Frequency	Bus Frequency #3 (Bus 3)			NO	Frequency	0.0000	0.0000000	0.0000000
14	Bus Frequency	Bus Frequency #4 (Bus 4)			NO	Frequency	0.0000	0.0000000	0.0000000

Process Contingencies

One Contingency at a time

Multiple Contingencies

Save All Settings To Load All Settings From Show Transient Contour Toolbar Close

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”

Transient Stability Analysis

Simulation Status Paused at 1.350 ← Simulation is paused after the fault is cleared

Run Transient Stability Continue Abort For Contingency: My Transient Contingency

Select Step

- Simulation
- Options
- Result Storage
- Plots
- Results
- Transient Limit Monitors
- States/Manual Control
- Validation
- SMIB Eigenvalues

States/Manual Control

Reset to Start Time Transfer Present State to Power Flow

Run Until Specified Time 1.350 Run Until Time Restore Power Flow Model

Do Specified Number of Timestep(s) 1 Number of Timesteps to Do Save Time Snapshot

All States State Limit Violations Generators Buses Transient Stability YBus

	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	1.8522	4.4611077	0.0420671
2	Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Speed w	0.0118	-0.1878478	-0.0015413
3	Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Eqp	1.0522	-0.4092526	-0.0034000
4	Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	PsiDp	0.9191	-0.0371895	0.0017903
5	Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	PsiQpp	0.2415	5.9211988	0.0663601
6	Gen Synch. Mac	GENROU	4 (Bus 4) #1		NO	Edp	0.0000	0.0000000	0.0000000
7	Gen Exciter	IEEET1	4 (Bus 4) #1		NO	EField	3.2706	1.3593989	0.0114713
8	Gen Exciter	IEEET1	4 (Bus 4) #1		YES	Sensed Vt	0.7268	0.0000000	0.0000000
9	Gen Exciter	IEEET1	4 (Bus 4) #1	High Limit	NO	VR	1.0000	0.0000000	0.0000000
10	Gen Exciter	IEEET1	4 (Bus 4) #1		NO	VF	0.0306	-0.0209724	-0.0001717
11	Bus Frequency	Bus Frequency M	1 (Bus 1)		NO	Frequency	0.0028	-0.1109212	-0.0012826
12	Bus Frequency	Bus Frequency M	2 (Bus 2)		NO	Frequency	0.0000	0.0000000	0.0000000
13	Bus Frequency	Bus Frequency M	3 (Bus 3)		NO	Frequency	0.0006	0.0000000	0.0000000
14	Bus Frequency	Bus Frequency M	4 (Bus 4)		NO	Frequency	0.0072	-0.2862825	-0.0034706

Exciter state is at a limit

Process Contingencies

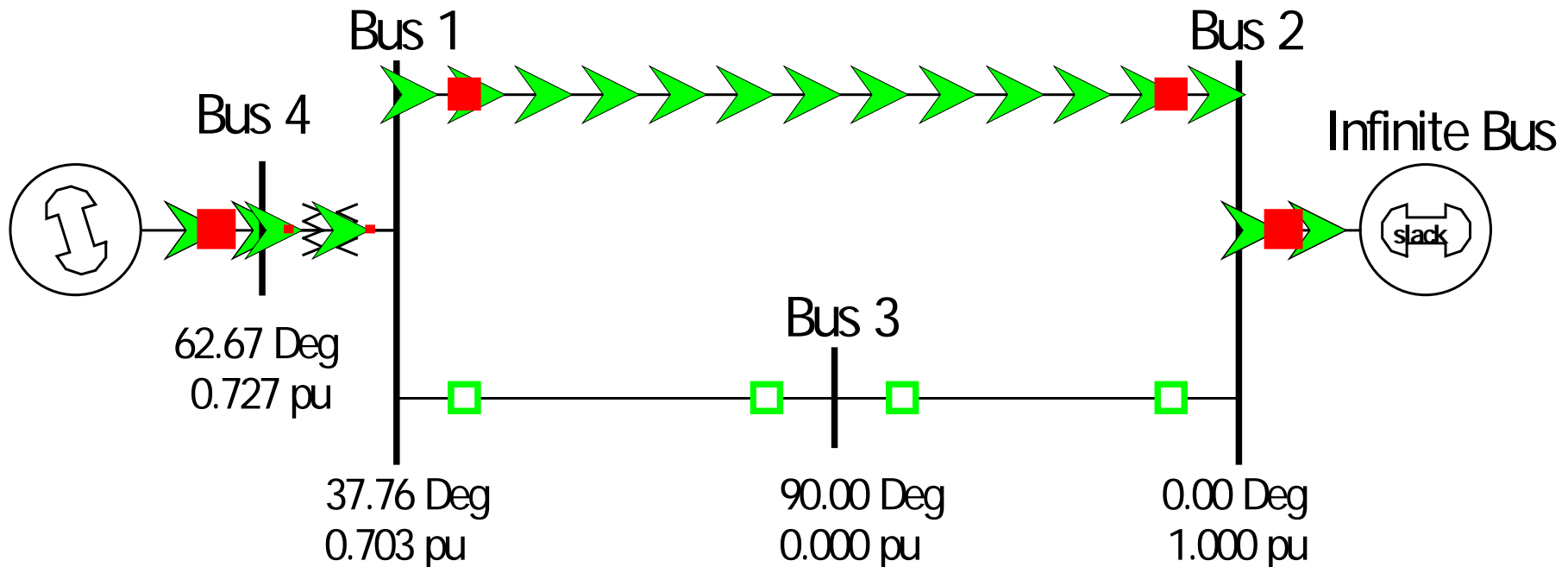
- One Contingency at a time
- Multiple Contingencies

Save All Settings To Load All Settings From Show Transient Contour Toolbar Close

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

Simulation Status Finished at 10.000

Run Transient Stability Pause Abort For Contingency: My Transient Contingency

Select Step

- Simulation
- Options
- Result Storage
- Plots
- Results
- Transient Limit Monitors
- States/Manual Control
- Validation
- SMIB Eigenvalues

States/Manual Control

Reset to Start Time

Run Until Specified Time 0.000 Run Until Time

Do Specified Number of Timestep(s) 1 Number of Timesteps to Do

Transfer Present State to Power Flow

Restore Power Flow Model

Save Time Snapshot

All States State Limit Violations Generators Buses Transient Stability YBus

	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	NO	Angle	0.6130	-0.0533424	-0.0004114
2	Gen Synch, Mac	GENROU	4 (Bus 4) #1	NO	NO	Speed w	-0.0001	-0.0011993	-0.0000109
3	Gen Synch, Mac	GENROU	4 (Bus 4) #1	NO	NO	Eqp	1.1827	-0.0016538	-0.0000150
4	Gen Synch, Mac	GENROU	4 (Bus 4) #1	NO	NO	PsiDp	1.1462	0.0000281	-0.0000022
5	Gen Synch, Mac	GENROU	4 (Bus 4) #1	NO	NO	PsiQpp	0.2520	-0.0117325	-0.0000887
6	Gen Synch, Mac	GENROU	4 (Bus 4) #1	NO	NO	Edp	0.0000	0.0000000	0.0000000
7	Gen Exciter	IEEET1	4 (Bus 4) #1	NO	NO	EField	2.5575	0.0318338	0.0002764
8	Gen Exciter	IEEET1	4 (Bus 4) #1	YES	NO	Sensed Vt	1.0972	0.0000000	0.0000000
9	Gen Exciter	IEEET1	4 (Bus 4) #1	NO	NO	VR	-0.0753	-0.0961425	-0.0007238
10	Gen Exciter	IEEET1	4 (Bus 4) #1	NO	NO	VF	-0.0001	0.0000849	0.0000008
11	Bus Frequency	Bus Frequency N 1	(Bus 1)	NO	NO	Frequency	0.0000	0.0018188	0.0000133
12	Bus Frequency	Bus Frequency N 2	(Bus 2)	NO	NO	Frequency	0.0000	0.0000000	0.0000000
13	Bus Frequency	Bus Frequency N 3	(Bus 3)	NO	NO	Frequency	0.0006	0.0000000	0.0000000
14	Bus Frequency	Bus Frequency N 4	(Bus 4)	NO	NO	Frequency	-0.0001	0.0026308	0.0000192

Process Contingencies

Save All Settings To Load All Settings From Show Transient Contour Toolbar Close

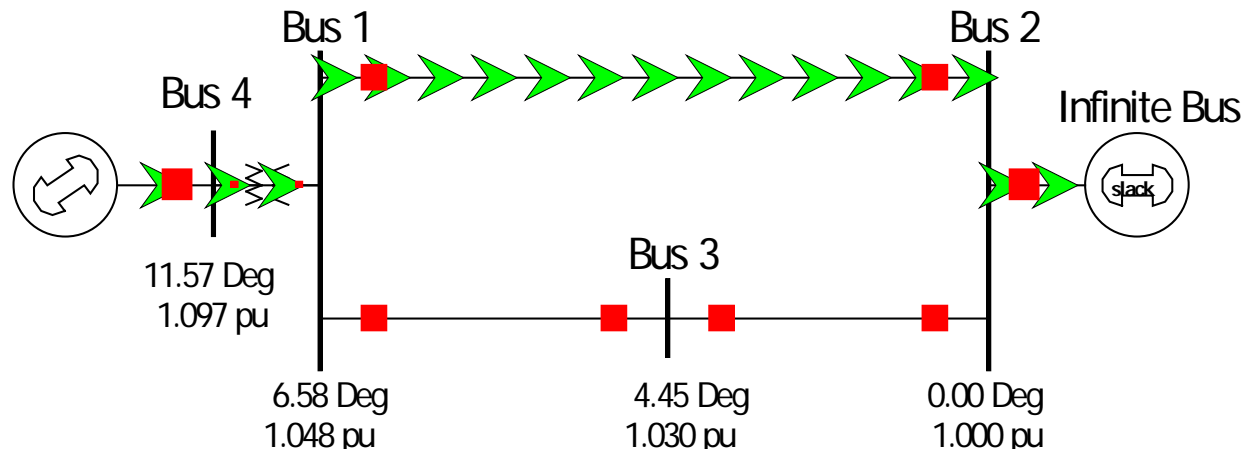
Option to restore state prior to transient stability run

States/Manual Control

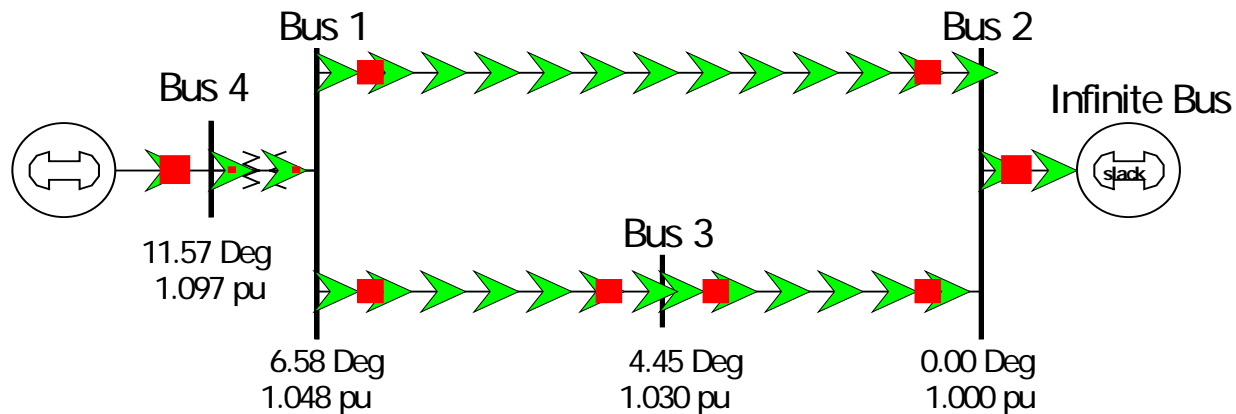


- Click “Restore Power Flow Model” to restore the power flow state of the system before the transient stability run

Restored model, unsolved



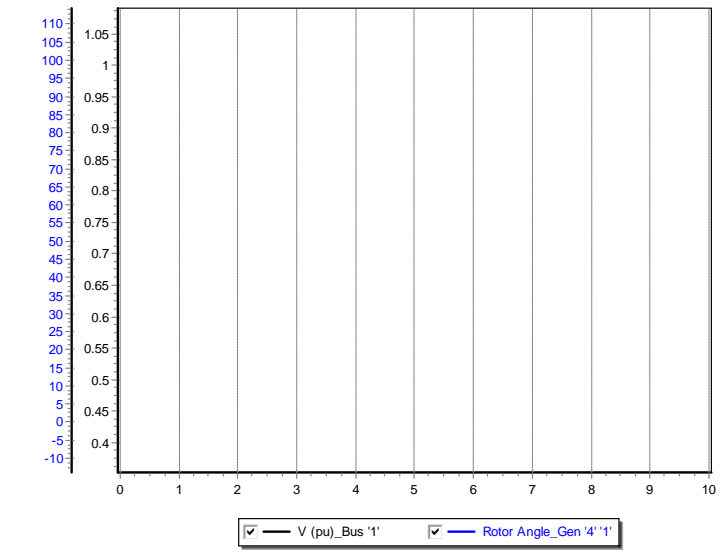
Restored model after a power flow solution



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

Nominal Frequency
(Typically 60 Hz or 50 Hz)

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 Distributed Computing

Power System Values

Nominal System Frequency (Hz) 60.0

System MVA Base 100.00

Network Equations Solution Options

Solution Tolerance (MVA) 0.10000

Maximum Iterations 25

Force Network Equation Update 0.00

Use Voltage Extrapolation

Inner Loop Mismatch Scalar 1.0

Infinite Bus Modeling

No infinite buses (recommended setting)

Model the power flow slack buses as infinite buses

Handling of Initial Limit Violations

Modify Limits and Run

Abort

Run without Changing Limits

Load Modeling

Default Load Model

Constant Impedance

ZIP Model from Power Flow Model

Constant Current

Constant Current P, Impedance Q

Minimum Per Unit Voltages for

Constant Power Models 0.700

Constant Current Models 0.500

Change

Exciter Saturation Model

Quadratic (GE Approach)

Scaled Quadratic

Exponential

Exciter Automatic Parameters

Vr = Zero Approach

Vr > Zero Approach

Machine Saturation for S12 < S10

Flip Values

Ignore Saturation

Integration Method

Second Order Runge-Kutta

Euler

Governor Fast Valving

Note: Needed for specific governor models such as TGOV3

Global Fast Valving Option

Initiate on Freq Deviation > (rad/sec)

Initiate on Fault after Delay of Seconds

Do Not Initiate

Fast Valving Parameter (rad/sec or sec) 0.1

Special options for governors using Fast Valving such as TGOV3

Transient Stability Options: Power System Model



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



- 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

Handling of Initial Limit Violations

Modify Limits and Run

Abort

Run without Changing Limits

Transient Stability Options: Power System Model



- 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
- 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.
- Governor Fast Valving Option– When to Initiate
 - After a specified frequency deviation in rad/sec
 - After a fault and a specified time delay in seconds
 - Do not initiate

Default Load Model

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

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
- Integration Method
 - Second Order Runge-Kutta
 - Euler