ECEN 667
Power System Stability

Lecture 4: Modeling Transmission Lines, Transient Stability Overview

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Announcements

- Start reading Chapters 3
- Homework 1 is assigned today. It is due on Thursday September 12
- Reference for modeling three-phase lines is W. Kersting, *Distribution System Modeling and Analysis*, 4th Edition, CRC Press, 2018

EMTP Network Solution

- The EMTP network is represented in a manner quite similar to what is done in the dc power flow or the transient stability network power balance equations or geomagnetic disturbance modeling (GMD)
- Solving set of dc equations for the nodal voltage vector **V** with

  $$\mathbf{V} = \mathbf{G}^{-1}\mathbf{I}$$

  where **G** is the bus conductance matrix and **I** is a vector of the Norton current injections

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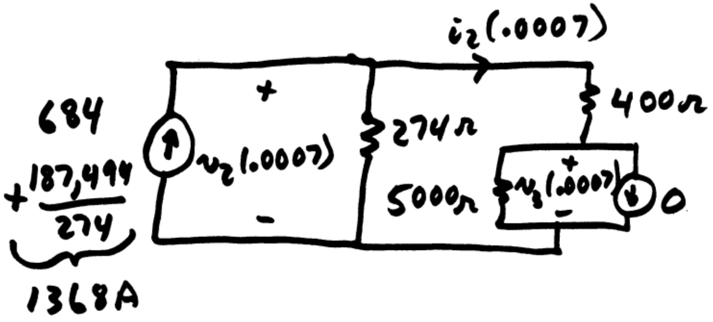
EMTP Network Solution

- Fixed voltage nodes can be handled in a manner analogous to what is done for the slack bus: just change the equation for node i to $V_i = V_{i,fixed}$
- Because of the time delays associated with the transmission line models **G** is often quite sparse, and can often be decoupled
- Once all the nodal voltages are determined, the internal device currents can be set
  - E.g., in example 2.1 one we know v_2 we can determine v_3



Three-Phase EMTP

- What we just solved was either just for a single phase system, or for a balanced three-phase system
  - That is, per phase analysis (positive sequence)
- EMTP type studies are often done on either balanced systems operating under unbalanced conditions (i.e., during a fault) or on unbalanced systems operating under unbalanced conditions
  - Lightning strike studies
- In this introduction to EMTP will just covered the balanced system case (but with unbalanced conditions)
  - Solved with symmetrical components

Modeling Transmission Lines

- Undergraduate power classes usually derive a per phase model for a uniformly transposed transmission line

$$L = \frac{\mu_0}{2\pi} \ln \frac{D_m}{R_b} = 2 \times 10^{-7} \ln \frac{D_m}{R_b} \ \text{H/m}$$

$$C = \frac{2\pi\varepsilon}{\ln {D_m}/{R_b^c}}$$

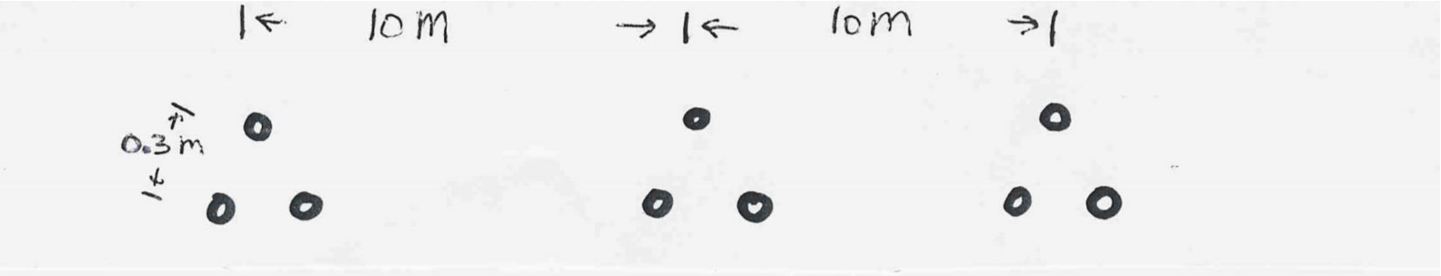
$$\mathrm{D_m} = \left[d_{ab} d_{ac} d_{bc}\right]^{1/3} \qquad R_b = (\mathrm{r}' d_{12} \cdots d_{1n})^{1/n}$$

$$\mathrm{R_b^c} = (r d_{12} \cdots d_{1n})^{1/n} \ \text{(note r NOT r')}$$

$$\varepsilon \text{ in air } = \varepsilon_{\mathrm{o}} = 8.854 \times 10^{\text{-12}} \ \text{F/m}$$

Modeling Transmission Lines

- Resistance is just the Ω per unit length times the length
- Calculate the per phase inductance and capacitance per km of a balanced 3ϕ, 60 Hz, line with horizontal phase spacing of 10m using three conductor bundling with a spacing between conductors in the bundle of 0.3m. Assume the line is uniformly transposed and the conductors have a 1.5 cm radius and resistance = 0.06 Ω/km



Modeling Transmission Lines

$$\mathrm{D_m} = (10\times10\times20)^{1/3} = 12.6\mathrm{m}$$

$$R_b = (0.78\times0.015\times0.3\times0.3)^{1/3} = 0.102\mathrm{m}$$

$$L = 2\times10^{-7}\ln\frac{12.6}{0.102} = 9.63\times10^{-7}\mathrm{H/m} = 9.63\times10^{-4}\mathrm{H/km}$$

$$R_b^c = (0.015\times0.3\times0.3)^{1/3} = 0.1105\mathrm{m}$$

$$C = \frac{2\pi\times8.854\times10^{-12}}{\ln 12.6/0{,}1105} = 1.17\times10^{-11}\mathrm{F/m} = 1.17\times10^{-8}\mathrm{F/km}$$

- Resistance is 0.06/3=0.02Ω/km
  - Divide by three because three conductors per bundle

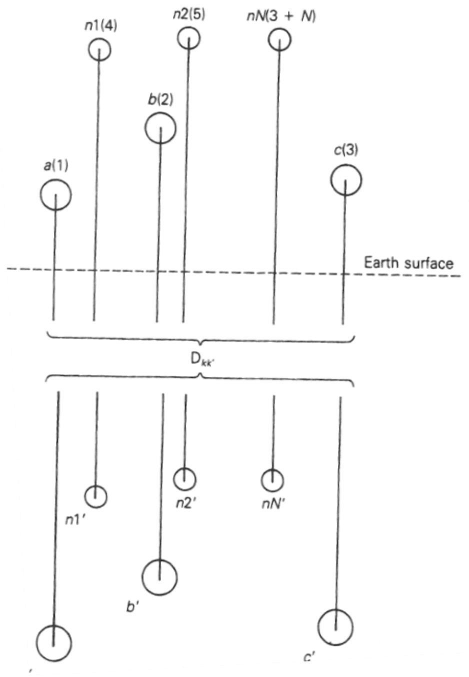
Untransposed Lines with Ground Conductors

- To model untransposed lines, perhaps with grounded neutral wires, we use the approach of Carson (from 1926) of modeling the earth return with equivalent conductors located in the ground under the real wires
  - Earth return conductors have the same GMR of their above ground conductor (or bundle) and carry the opposite current
- Distance between conductors is

$$D_{kk'} = 658.5\sqrt{\rho / f} \text{ m}$$

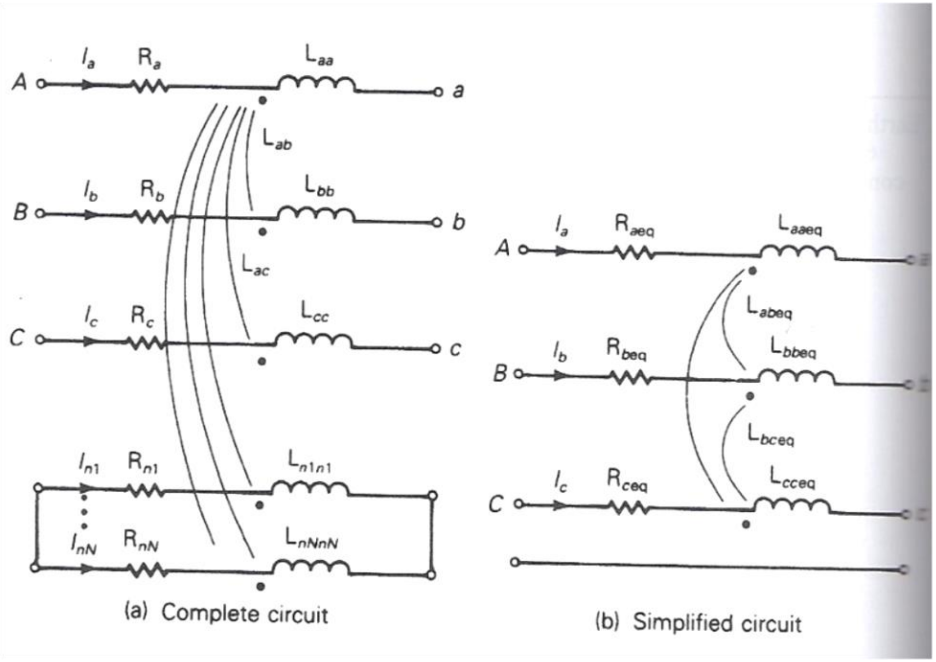
where ρ is the earth resistivity in Ω-m

with 100 Ω-m a typical value



Untransposed Lines with Ground Conductors

- The resistance of the equivalent conductors is $R_{k'}=9.869\times10^{-7}\times f$ Ω/m with f the frequency, which is also added in series to the R of the actual conductors
- Conductors are mutually coupled; we'll be assuming three phase conductors and N grounded neutral wires
- Total current in all conductors sums to zero



(a) Complete circuit

(b) Simplified circuit

Untransposed Lines with Ground Conductors

- The relationships between voltages and currents per unit length is
$$\begin{bmatrix} E_{Aa} \\ E_{Bb} \\ E_{Cc} \\ 0 \\ \vdots \\ 0 \end{bmatrix} = \left(\mathbf{R} + j\omega\mathbf{L}\right)\begin{bmatrix} I_a \\ I_b \\ I_c \\ I_{n1} \\ \vdots \\ InN \end{bmatrix}$$

- Where the diagonal resistance are the conductor resistance plus $R_{k'}$ and the off-diagonals are all $R_{k'}$
- The inductances are $L_{km} = 2\times 10^{-7} \ln\left(\frac{D_{km'}}{D_{km}}\right)$ with D_{kk} just the GMR for the conductor (or bundle)

$D_{kk'}$ is large so
$D_{km'} \approx D_{kk'}$

Untransposed Lines with Ground Conductors

- This then gives an equation of the form

$$\begin{bmatrix} E_{Aa} \\ E_{Bb} \\ E_{Cc} \\ \hdashline 0 \\ \cdots \\ 0 \end{bmatrix} \left[\begin{array}{ccc:ccc} \multicolumn{3}{c}{\overbrace{\hphantom{Z_{11}\quad Z_{12}\quad Z_{13}}}^{Z_A}} & \multicolumn{3}{c}{\overbrace{\hphantom{Z_{14}\quad \cdots\quad Z_{1(3+N)}}}^{Z_B}} \\ Z_{11} & Z_{12} & Z_{13} & Z_{14} & \cdots & Z_{1(3+N)} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} & \cdots & Z_{2(3+N)} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} & \cdots & Z_{3(3+N)} \\ \hdashline Z_{41} & Z_{42} & Z_{43} & Z_{44} & \cdots & Z_{4(3+N)} \\ & & & & & \\ Z_{(3+N)1} & Z_{(3+N)2} & Z_{(3+N)3} & Z_{(3+N)4} & \cdots & Z_{(3+N)(3+N)} \\ \multicolumn{3}{c}{\underbrace{\hphantom{Z_{11}\quad Z_{12}\quad Z_{13}}}_{Z_C}} & \multicolumn{3}{c}{\underbrace{\hphantom{Z_{14}\quad \cdots\quad Z_{1(3+N)}}}_{Z_D}} \end{array}\right] \begin{bmatrix} I_a \\ I_b \\ I_c \\ \hdashline I_{n1} \\ I_{nN} \\ \vdots \end{bmatrix}$$

- Which can be reduced to just the phase values

$$\mathbf{E}_p = \left[\mathbf{Z}_A - \mathbf{Z}_B \mathbf{Z}_D^{-1} \mathbf{Z}_C\right] \mathbf{I}_p = \mathbf{Z}_p \mathbf{I}_p$$

- We'll use $\mathbf{Z}_\mathrm{p}$ with symmetrical components

Example (from 4.1 in Kersting Book)

- Given a 60 Hz overhead distribution line with the tower configuration (N=1 neutral wire) with the phases using Linnet conductors and the neutral 4/0 6/1 ACSR, determine $\mathbf{Z}_p$ in ohms per mile
  - Linnet has a GMR = 0.0244ft, and R = 0.306Ω/mile
  - 4/0 6/1 ACSR has GMR=0.00814 ft and R=0.592Ω/mile
  - $R_{k'}=9.869\times10^{-7}\times f\ \Omega/m$ is 0.0953 Ω/mile at 60 Hz
  - Phase R diagonal values are 0.306 + 0.0953 = 0.401 Ω/mile
  - Ground is 0.6873 Ω/mile

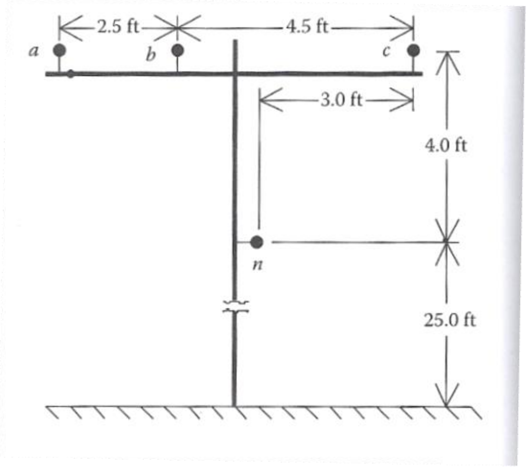


Figure 4.7 from Kersting

Example (from 4.1 in Kersting Book)

- Example inductances are worked with ρ = 100Ω-m

$$D_{kk'} = 658.5\sqrt{100/60}\ m = 850.1m = 2789 \text{ ft}$$

$$L_{km} = 2\times 10^{-7} \ln\left(\frac{D_{km'}}{D_{km}}\right) \approx 2\times 10^{-7} \ln\left(\frac{D_{kk'}}{D_{km}}\right)$$

- Note at 2789 ft, $D_{kk'}$ is much, much larger than the distances between the conductors, justifying the above assumption

Example (from 4.1 in Kersting Book)

- Working some of the inductance values

$$L_{aa} = 2\times10^{-7}\ \mathrm{ln}\left(\frac{2789}{0.0244}\right) = 2.329\times10^{-6}\ \mathrm{H/m}$$

- Phases a and b are separated by 2.5 feet, while it is 5.66 feet between phase a and the ground conductor

$$L_{ab} = 2\times10^{-7}\ \mathrm{ln}\left(\frac{2789}{2.5}\right) = 1.403\times10^{-6}\ \mathrm{H/m}$$

$$L_{an} = 2\times10^{-7}\ \mathrm{ln}\left(\frac{2789}{5.66}\right) = 1.240\times10^{-6}\ \mathrm{H/m}$$

Even though the distances are worked here in feet, the result is in H/m because of the units on μ_0

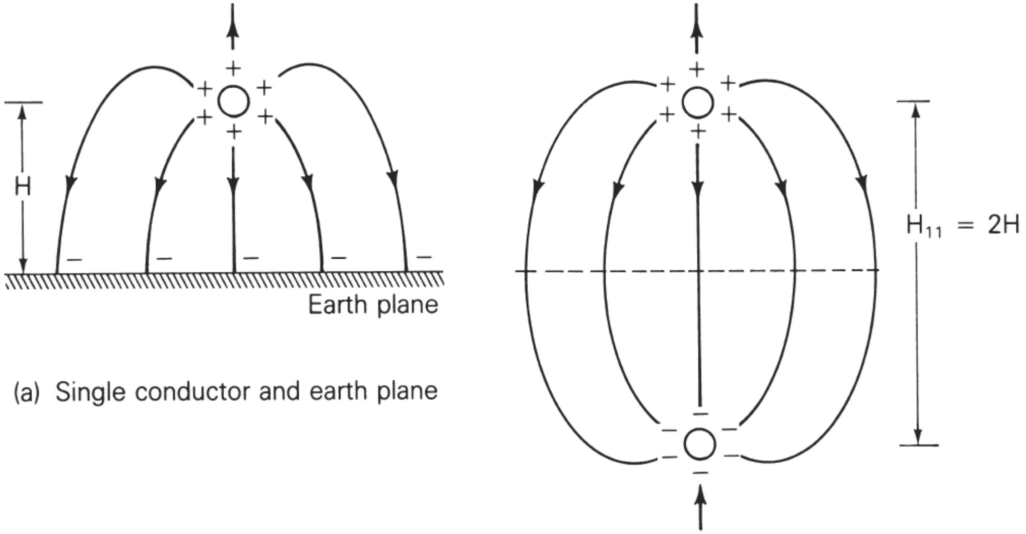
Example (from 4.1 in Kersting Book)

- Continue to create the 4 by 4 symmetric **L** matrix
- Then **Z** = **R** + jω**L**
- Partition the matrix and solve $\mathbf{Z}_p = \left[\mathbf{Z}_A - \mathbf{Z}_B\mathbf{Z}_D^{-1}\mathbf{Z}_C\right]$
- The result in Ω/mile is

$$\mathbf{Z}_p = \begin{bmatrix} 0.4576 + 1.0780 & 0.1560 + j0.5017 & 0.1535 + j0.3849 \\ 0.1560 + j0.5017 & 0.4666 + j1.0482 & 0.1580 + j0.4236 \\ 0.1535 + j0.3849 & 0.1580 + j0.4236 & 0.4615 + j1.0651 \end{bmatrix}$$

Modeling Line Capacitance

- For capacitance the earth is typically modeled as a perfectly conducting horizontal plane; then the earth plane is replaced by mirror image conductors
  - If conductor is distance H above ground, mirror image conductor is distance H below ground, hence their distance apart is 2H



(a) Single conductor and earth plane

FIGURE 4.23

Method of images

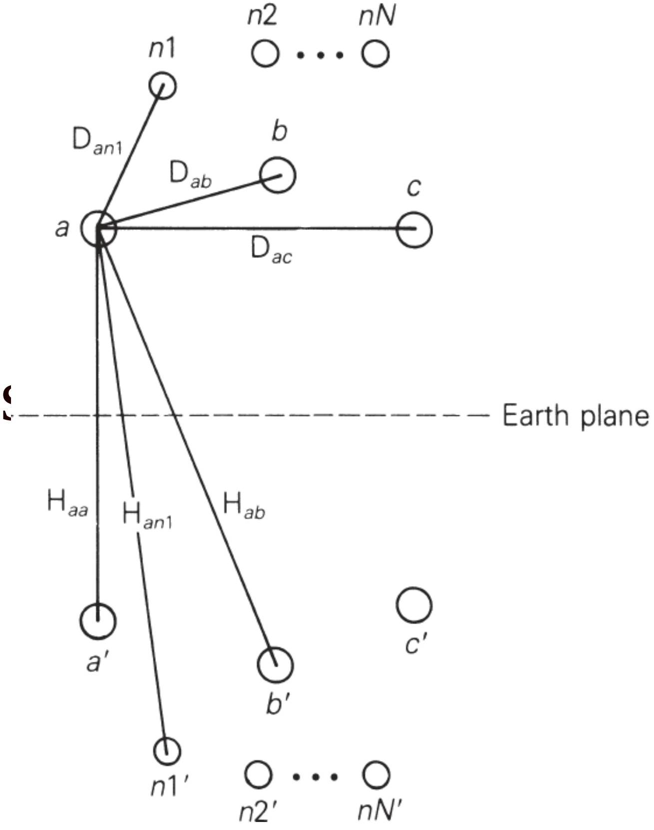
Modeling Line Capacitance

- The relationship between the voltage to neutral and charges are then given as

$$V_{kn} = \frac{1}{2\pi\varepsilon}\sum_{m=a}^{nN} q_m \ln\frac{H_{km}}{D_{km}} = \sum_{m=a}^{nN} q_m P_{km}$$

$$P_{km} = \frac{1}{2\pi\varepsilon}\ln\frac{H_{km}}{D_{km}}$$

- P's are called potential coefficients
- Where D_{km} is the distance between the conductors, H_{km} is the distance to a mirror image conductor and $D_{kk} = R_b^c$



Modeling Line Capacitance

- Then we setup the matrix relationship

$$\begin{bmatrix} V_{an}\\ V_{bn}\\ V_{cn}\\ \hline 0\\ \vdots\\ 0 \end{bmatrix} = \left[\begin{array}{c|c} \overbrace{\begin{matrix} \mathrm{P}_{aa} & \mathrm{P}_{ab} & \mathrm{P}_{ac}\\ \mathrm{P}_{ba} & \mathrm{P}_{bb} & \mathrm{P}_{bc}\\ \mathrm{P}_{ca} & \mathrm{P}_{cb} & \mathrm{P}_{cc} \end{matrix}}^{\mathbf{P}_A} & \overbrace{\begin{matrix} \mathrm{P}_{an1} & \cdots & \mathrm{P}_{anN}\\ \mathrm{P}_{bn1} & \cdots & \mathrm{P}_{bnN}\\ \mathrm{P}_{cn1} & \cdots & \mathrm{P}_{cnN} \end{matrix}}^{\mathbf{P}_B} \\ \hline \underbrace{\begin{matrix} \mathrm{P}_{n1a} & \mathrm{P}_{n1b} & \mathrm{P}_{n1c}\\ \vdots & & \\ \mathrm{P}_{nNa} & \mathrm{P}_{nNb} & \mathrm{P}_{nNc} \end{matrix}}_{\mathbf{P}_C} & \underbrace{\begin{matrix} \mathrm{P}_{n1n1} & \cdots & \mathrm{P}_{n1nN}\\ & & \\ \mathrm{P}_{nNn1} & \cdots & \mathrm{P}_{nNnN} \end{matrix}}_{\mathbf{P}_D} \end{array}\right] \begin{bmatrix} q_a\\ q_b\\ q_c\\ \hline q_{n1}\\ \vdots\\ q_{nN} \end{bmatrix}$$

- And solve

$$\mathbf{V}_p = \left[\mathbf{P}_A - \mathbf{P}_B \mathbf{P}_D^{-1} \mathbf{P}_C\right] \mathbf{Q}_p$$

$$\mathbf{C}_p = \left[\mathbf{P}_A - \mathbf{P}_B \mathbf{P}_D^{-1} \mathbf{P}_C\right]^{-1}$$

Continuing the Previous Example

- In example 4.1, assume the below conductor radii

For the phase conductor $\mathrm{R}_b^c = 0.0300$ ft

For the neutral conductor $\mathrm{R}_n^c = 0.0235$ ft

- Calculating some values

$$\varepsilon_0 = 8.85\times 10^{-12}\ \mathrm{F/m} = 1.424\times 10^{-2}\ \mu\mathrm{F/mile}$$

$$P_{aa} = \frac{1}{2\pi\varepsilon_0}\ln\left(\frac{2\times 29.0}{0.0300}\right) = 11.177\ln\left(\frac{2\times 29.0}{0.0300}\right) = 84.57\,\mathrm{mile/\mu F}$$

$$P_{ab} = 11.177\ln\left(\frac{58.05}{2.5}\right) = 35.15\,\mathrm{mile/\mu F}$$

$$P_{an} = 11.177\ln\left(\frac{54.148}{5.6569}\right) = 25.25\,\mathrm{mile/\mu F}$$

Continuing the Previous Example

- Solving we get

$$\mathbf{P}_p = \left[\mathbf{P}_A - \mathbf{P}_B\mathbf{P}_D^{-1}\mathbf{P}_C\right] = \begin{bmatrix} 77.12 & 26.79 & 15.84 \\ 26.79 & 75.17 & 19.80 \\ 15.87 & 19.80 & 76.29 \end{bmatrix} \text{mile/}\mu\text{F}$$

$$\mathbf{C}_p = \left[\mathbf{P}_p\right]^{-1} = \begin{bmatrix} 0.0150 & -0.0049 & -0.0018 \\ -0.0049 & 0.0158 & -0.0030 \\ -0.0018 & -0.0030 & 0.0137 \end{bmatrix} \mu\text{F/mile}$$

Frequency Dependence

- We might note that the previous derivation for **L** assumed a frequency. For steady-state and transient stability analysis this is just the power grid frequency
- As we have seen in EMTP there are a number of difference frequencies present, particularly during transients
  - Coverage is beyond the scope of this class
  - An early paper is J.K. Snelson, "Propagation of Travelling on Transmission Lines: Frequency Dependent Parameters," IEEE Trans. Power App. and Syst., vol. PAS-91, pp. 85-91, 1972

Power System Overvoltages

- Line switching can cause transient overvoltages
  - Resistors (200 to 800Ω) are preinserted in EHV circuit breakers to reduce over voltages, and subsequently shorted
- Common overvoltage cause is lightning strikes
  - Lightning strikes themselves are quite fast, with rise times of 1 to 20 μs, with a falloff to ½ current within less than 100 μs
  - Peak current is usually less than 100kA
  - Shield wires above the transmission line greatly reduce the current that gets into the phase conductors
  - EMTP studies can show how these overvoltage propagate down the line

Insulation Coordination

- Insulation coordination is the process of correlating electric equipment insulation strength with expected overvoltages
- The expected overvoltages are time-varying, with a peak value and a decay characteristic
- Transformers are particularly vulnerable
- Surge arrestors are placed in parallel (phase to ground) to cap the overvoltages
  - They have high impedance during normal voltages, and low impedance during overvoltages; airgap devices have been common, though gapless designs are also used

Transient Stability Overview

- In next several lectures we'll be deriving models used primarily in transient stability analysis (covering from cycles to dozens of seconds)
- Goal is to provide a good understanding of 1) the theoretical foundations, 2) applications and 3) some familiarity the commercial packages
- Next several slides provide an overview using PowerWorld Simulator
  - Learning by doing!

PowerWorld Simulator

- Class will make extensive use of PowerWorld Simulator. If you do not have a copy of v21, the free 42 bus student version is available for download at http://www.powerworld.com/gloveroverbyesarma
- Start getting familiar with this package, particularly the power flow basics. Transient stability aspects will be covered in class
- Free training material is available at

http://www.powerworld.com/training/online-training

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 many 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.

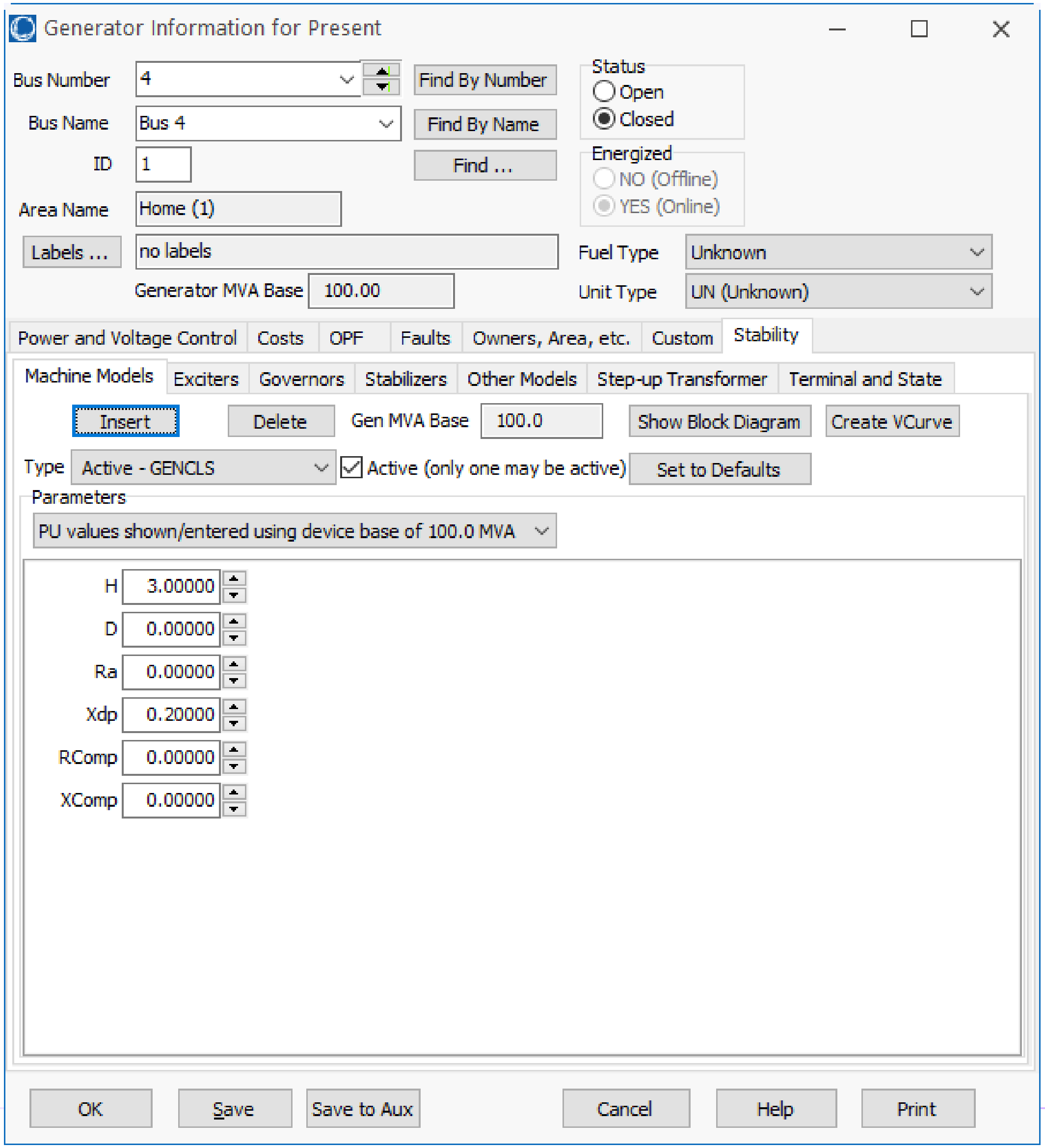
Power Flow vs. Transient Stability

- Power flow determines quasi-steady state solution and provides the transient stability initial conditions
- Transient stability is used to determine whether following a contingency the power system returns to a steady-state operating point
  - Goal is to solve a set of differential and algebraic equations, $d\mathbf{x}/dt = \mathbf{f}(\mathbf{x},\mathbf{y}),\ \mathbf{g}(\mathbf{x},\mathbf{y}) = \mathbf{0}$
  - Starts in steady-state, and hopefully returns to steady-state.
  - Models reflect the transient stability time frame (up to dozens of seconds), with some values assumed to be slow enough to hold constant (LTC tap changing), while others are still fast enough to treat as algebraic (synchronous machine stator dynamics, voltage source converter dynamics).

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)

Gen MVA Base: 100.0

Type: Active - GENCLS

☑ Active (only one may be active)

Parameters

PU values shown/entered using device base of 100.0 MVA

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

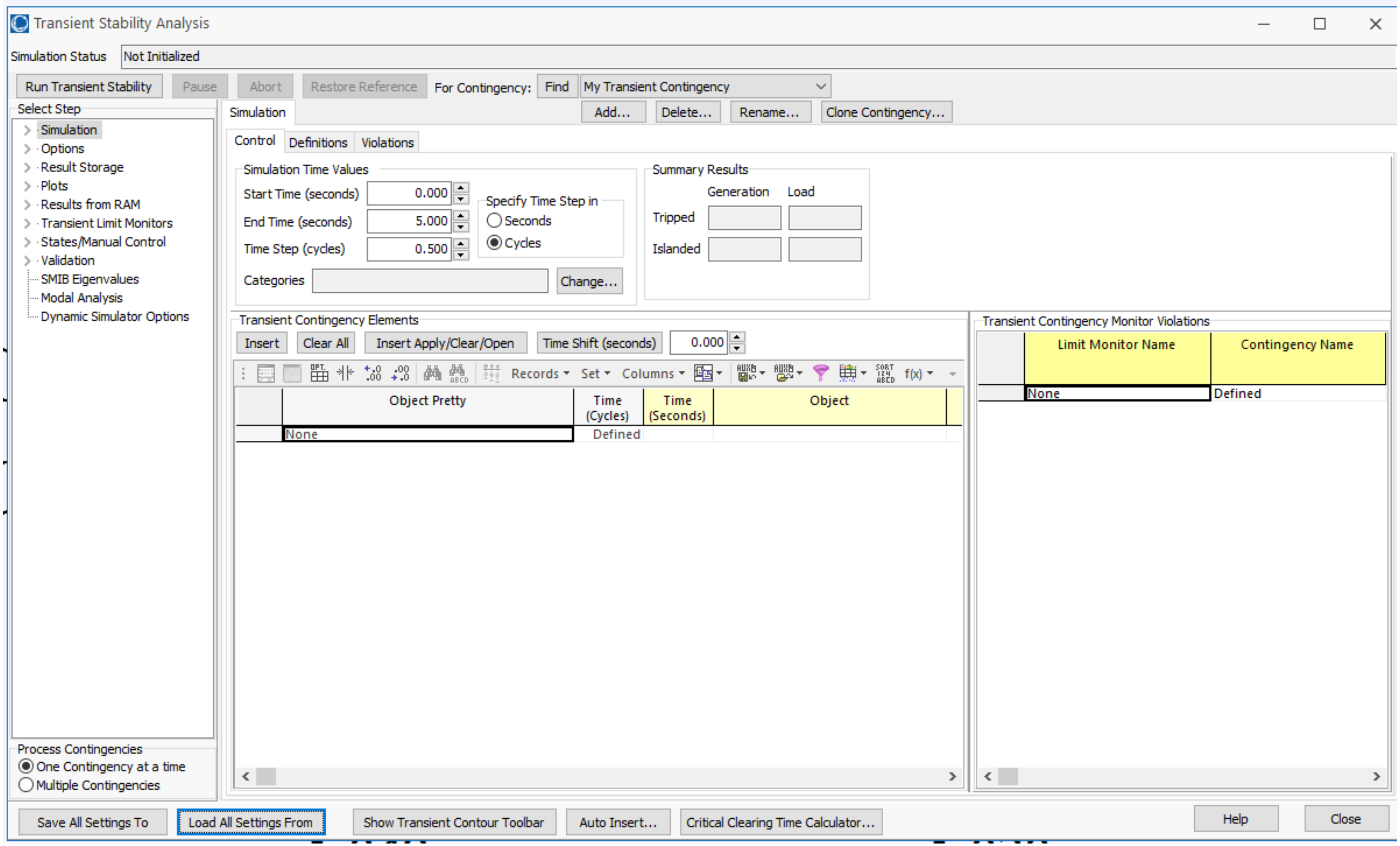
The GENCLS model represents the machine dynamics as a fixed voltage magnitude behind a transient impedance Ra + jXdp.

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
    - Plots: Used to plot results
    - Results: Used to view the results (actual numbers, not plots)

Transient Stability Overview Form



Simulation Status: Not Initialized

For Contingency: My Transient Contingency

Simulation Time Values

Start Time (seconds) 0.000

End Time (seconds) 5.000

Time Step (cycles) 0.500

Specify Time Step in: ○ Seconds ● Cycles

Categories

Summary Results

	Generation	Load
Tripped		
Islanded		

Time Shift (seconds) 0.000

Object Pretty	Time (Cycles)	Time (Seconds)	Object
None	Defined		

Limit Monitor Name	Contingency Name
None	Defined

Process Contingencies

● One Contingency at a time

○ Multiple Contingencies

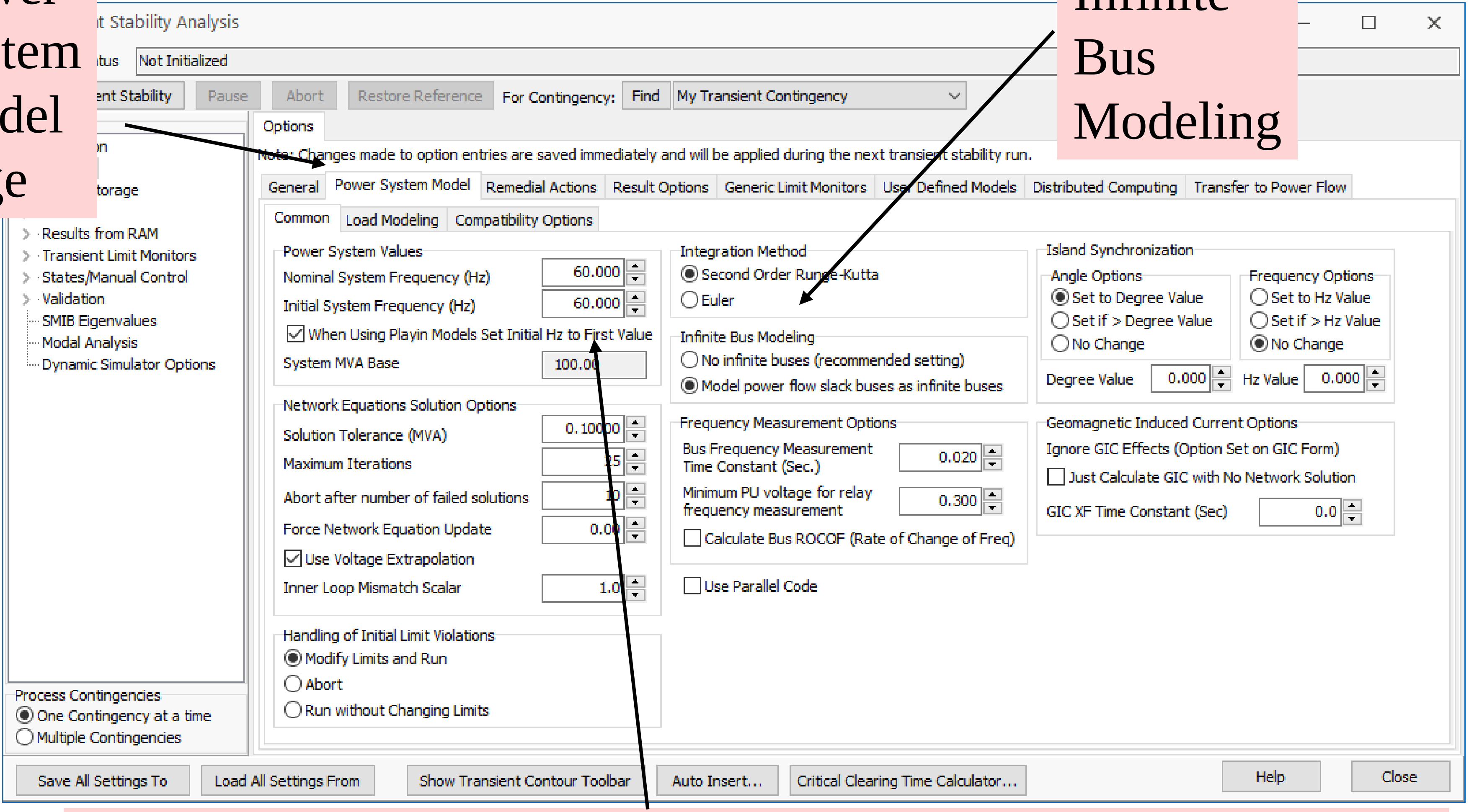
Infinite Bus Modeling

- 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 Options Page

Power System Model Page

Infinite Bus Modeling



Status: Not Initialized

For Contingency: My Transient Contingency

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

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

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

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

This page is also used to specify the nominal system frequency

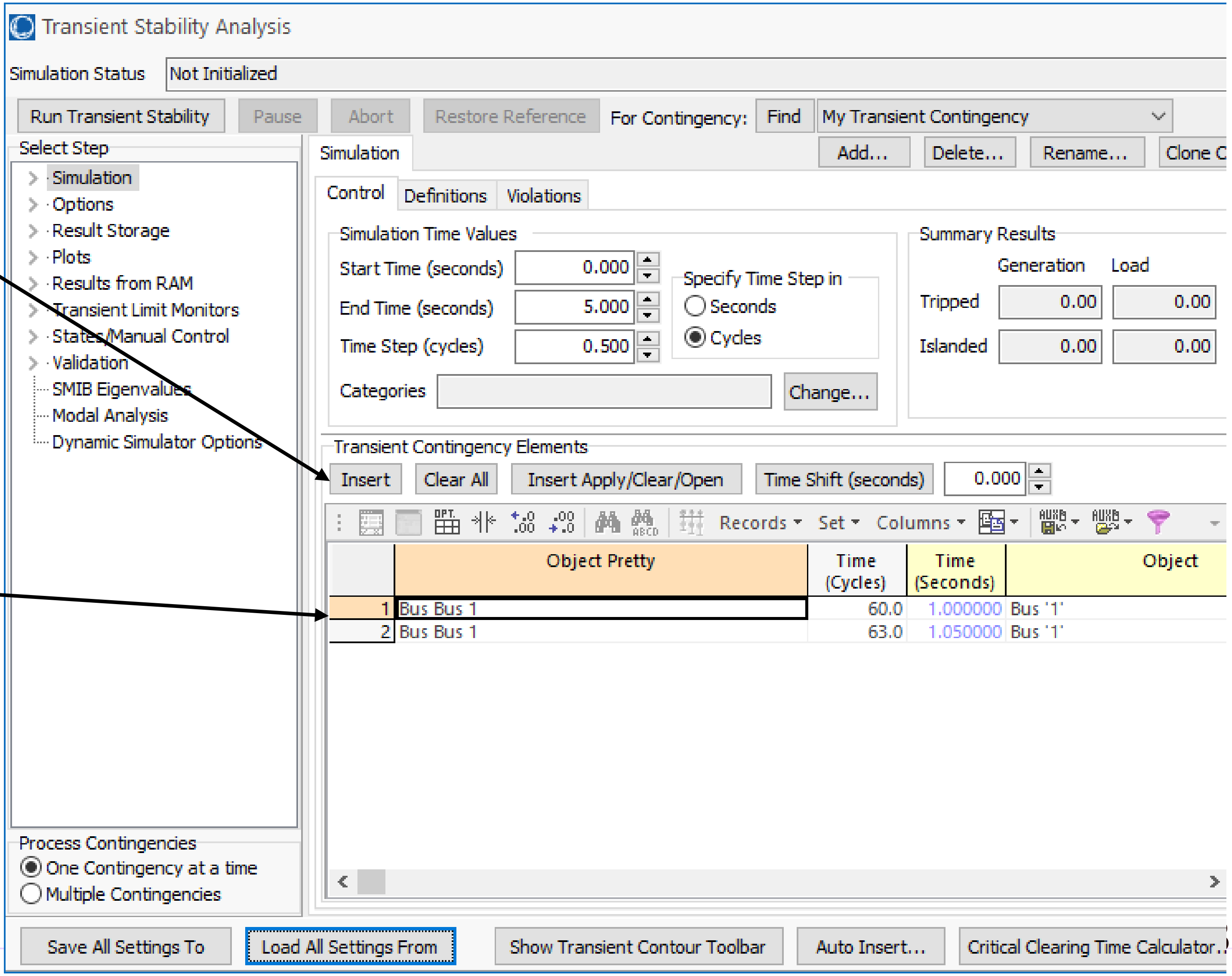
Specifying the Contingency Event

- 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 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 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 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 contingency and time of action



Simulation Status: Not Initialized

For Contingency: My Transient Contingency

Simulation Time Values

Start Time (seconds): 0.000

End Time (seconds): 5.000

Time Step (cycles): 0.500

Specify Time Step in
○ Seconds
● Cycles

Categories:

Summary Results

	Generation	Load
Tripped	0.00	0.00
Islanded	0.00	0.00

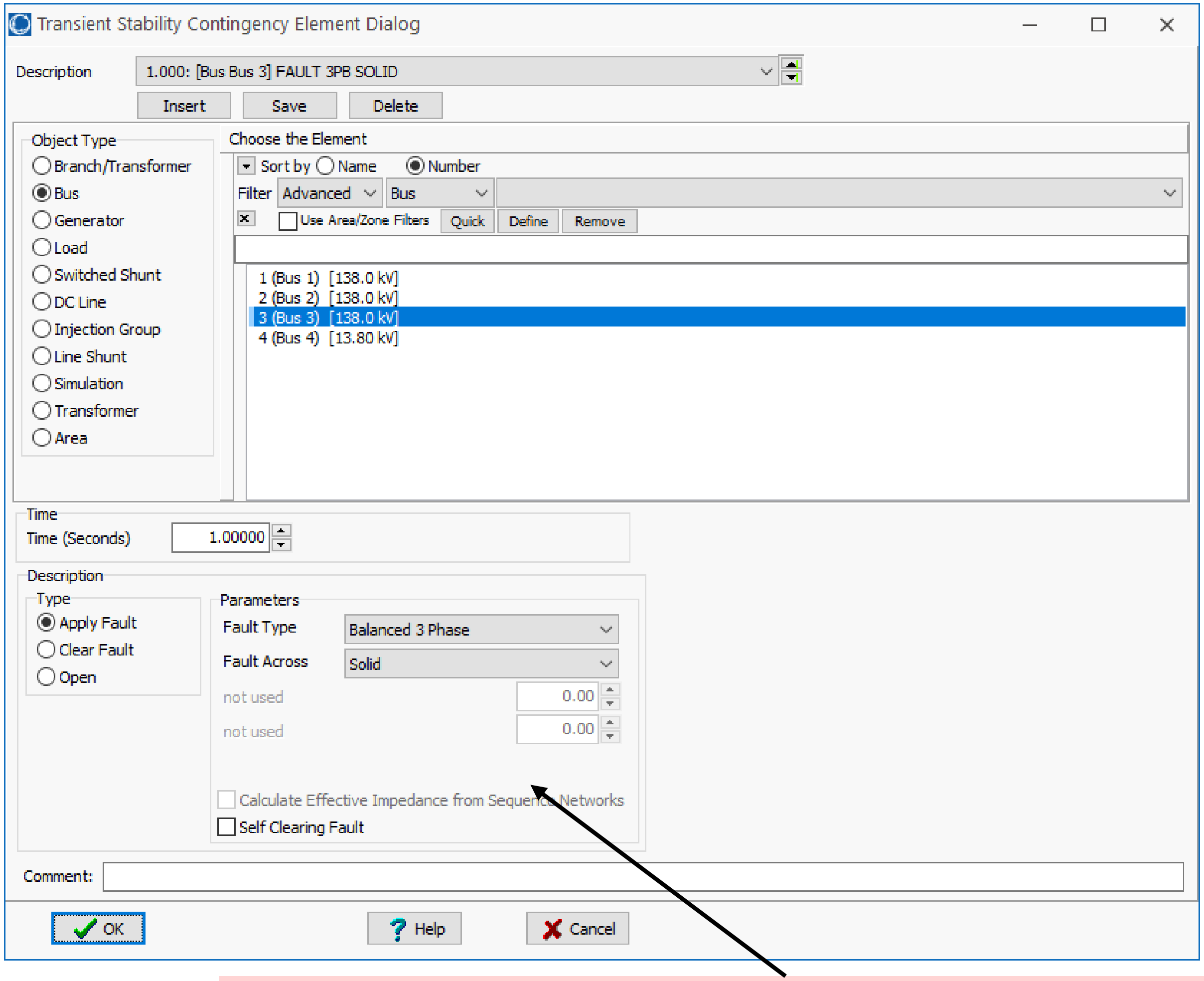
Transient Contingency Elements

Time Shift (seconds): 0.000

	Object Pretty	Time (Cycles)	Time (Seconds)	Object
1	Bus Bus 1	60.0	1.000000	Bus '1'
2	Bus Bus 1	63.0	1.050000	Bus '1'

Process Contingencies
● One Contingency at a time
○ Multiple Contingencies

Event Contingency Dialog



Transient Stability Contingency Element Dialog

Description: 1.000: [Bus Bus 3] FAULT 3PB SOLID

Object Type:
- ○ Branch/Transformer
- ● Bus
- ○ Generator
- ○ Load
- ○ Switched Shunt
- ○ DC Line
- ○ Injection Group
- ○ Line Shunt
- ○ Simulation
- ○ Transformer
- ○ Area

Choose the Element

Sort by ○ Name ● Number

Filter: Advanced, Bus

☐ Use Area/Zone Filters

1 (Bus 1) [138.0 kV]
2 (Bus 2) [138.0 kV]
3 (Bus 3) [138.0 kV]
4 (Bus 4) [13.80 kV]

Time

Time (Seconds): 1.00000

Description

Type:
- ● Apply Fault
- ○ Clear Fault
- ○ Open

Parameters

Fault Type: Balanced 3 Phase

Fault Across: Solid

not used: 0.00

not used: 0.00

☐ Calculate Effective Impedance from Sequence Networks

☐ Self Clearing Fault

Comment:

Available element type will vary with different objects

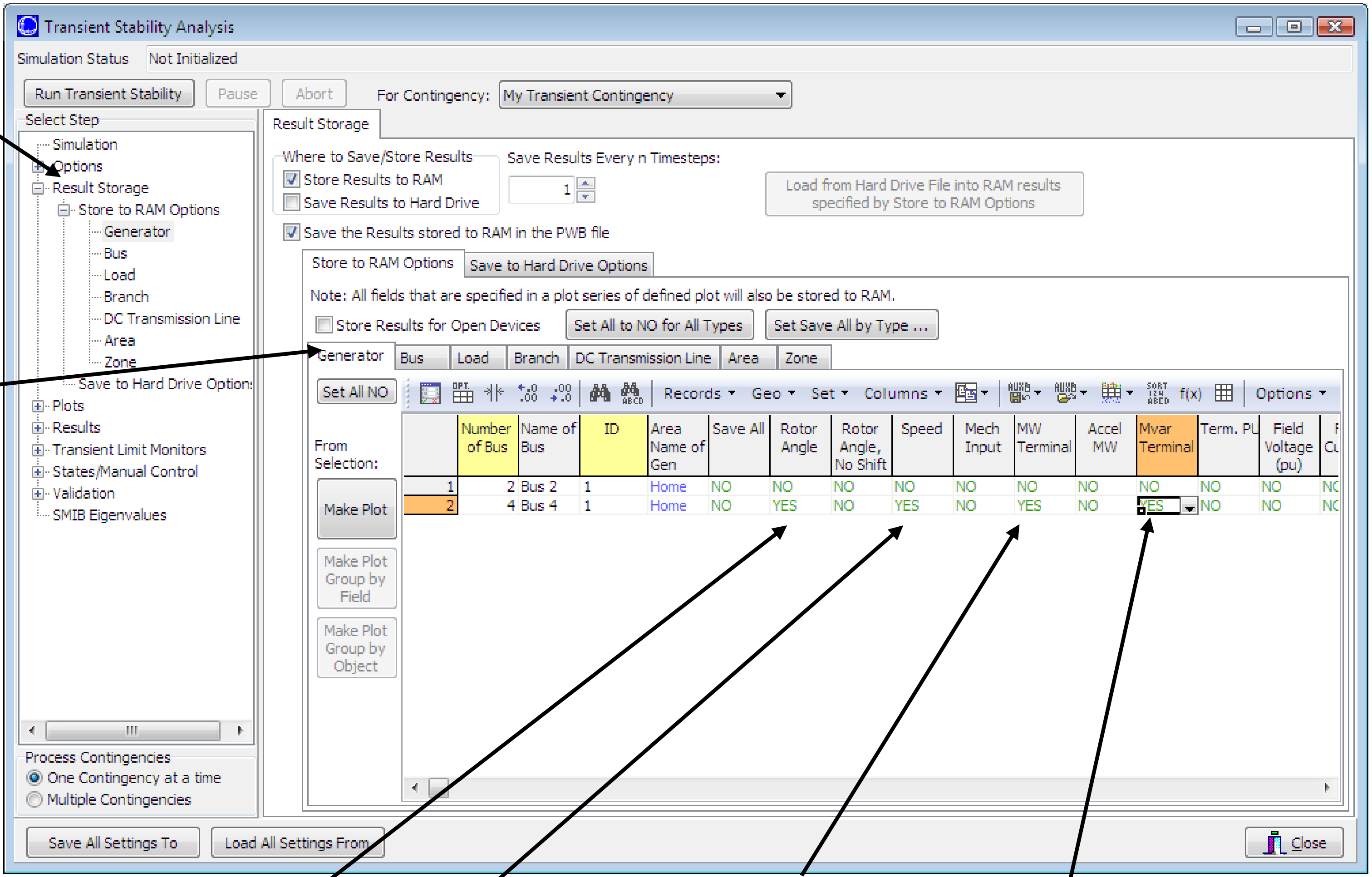
Determining the Results to View

- 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



Transient Stability Analysis

Simulation Status: Not Initialized

For Contingency: My Transient Contingency

Where to Save/Store Results

- ☑ Store Results to RAM
- ☐ Save Results to Hard Drive

Save Results Every n Timesteps: 1

☑ Save the Results stored to RAM in the PWB file

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

☐ Store Results for Open Devices

	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. PU	Field Voltage (pu)	F Cu
1	2	Bus 2	1	Home	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	N
2	4	Bus 4	1	Home	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	N

Process Contingencies

- ● One Contingency at a time
- ○ Multiple Contingencies

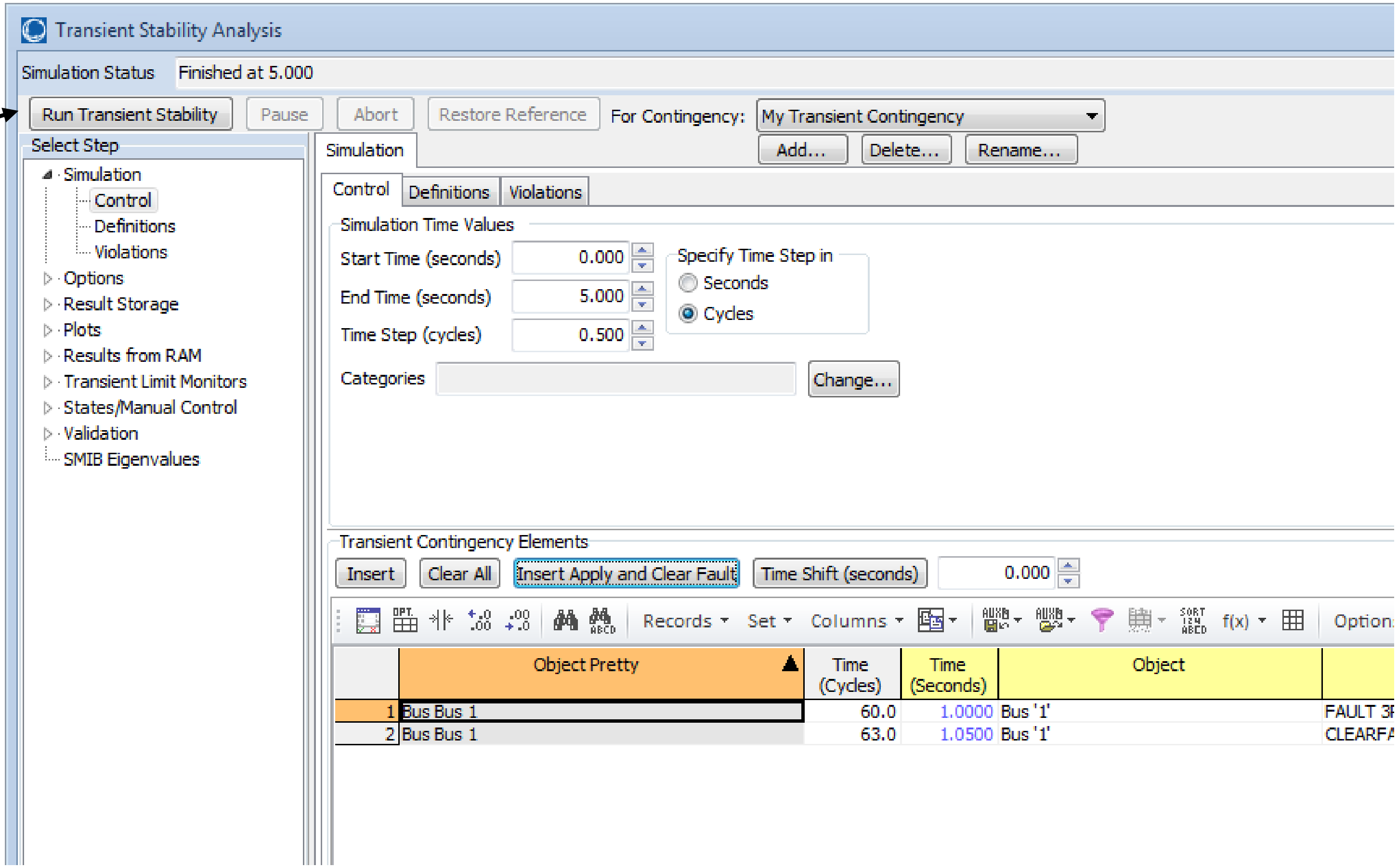
Double Click on Fields (which sets them to yes) to Store Their Values

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_WithCLSModel_ReadyToRun”
- Click on “Run Transient Stability” to solve.

Doing the Run

Click to run the specified contingency



Simulation Status: Finished at 5.000

For Contingency: My Transient Contingency

Start Time (seconds): 0.000

End Time (seconds): 5.000

Time Step (cycles): 0.500

Specify Time Step in: ○ Seconds ● Cycles

Categories:

Time Shift (seconds): 0.000

	Object Pretty	Time (Cycles)	Time (Seconds)	Object	
1	Bus Bus 1	60.0	1.0000	Bus '1'	FAULT 3F
2	Bus Bus 1	63.0	1.0500	Bus '1'	CLEARFA

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"

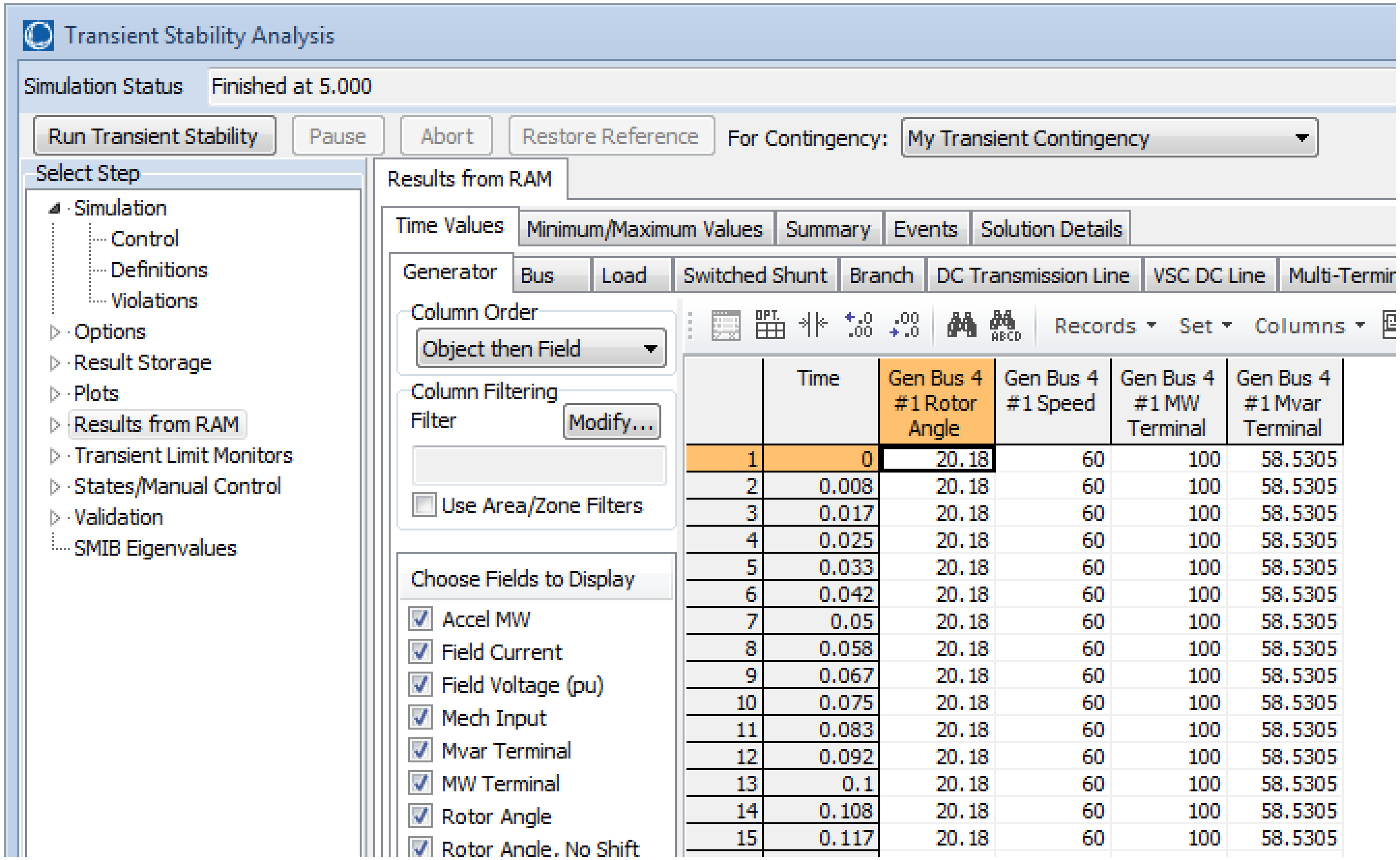
Continuing PowerWorld Simulator Example

- Class will make extensive use of PowerWorld Simulator. If you do not have a copy of v19, the free 42 bus student version is available for download at

  http://www.powerworld.com/gloveroverbyesarma
- Start getting familiar with this package, particularly the power flow basics. Transient stability aspects will be covered in class
- Open Example_13_4_WithCLSModelReadyToRun
  - Cases are on the class website

Results: Time Values

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



Simulation Status: Finished at 5.000

For Contingency: My Transient Contingency

Column Order: Object then Field

Filter

☐ Use Area/Zone Filters

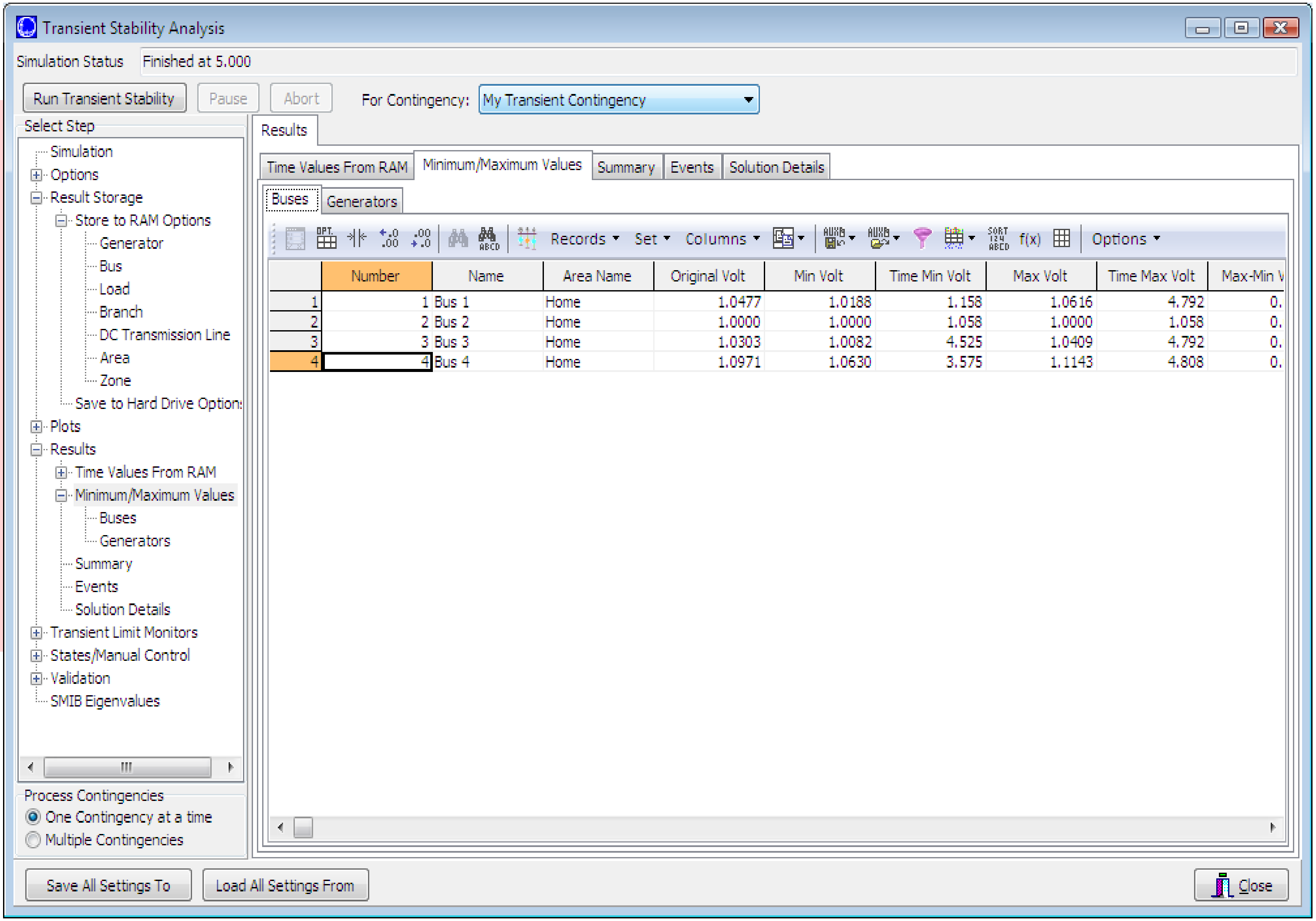
☑ Accel MW
☑ Field Current
☑ Field Voltage (pu)
☑ Mech Input
☑ Mvar Terminal
☑ MW Terminal
☑ Rotor Angle
☑ Rotor Angle, No Shift

	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



Simulation Status: Finished at 5.000

For Contingency: My Transient Contingency

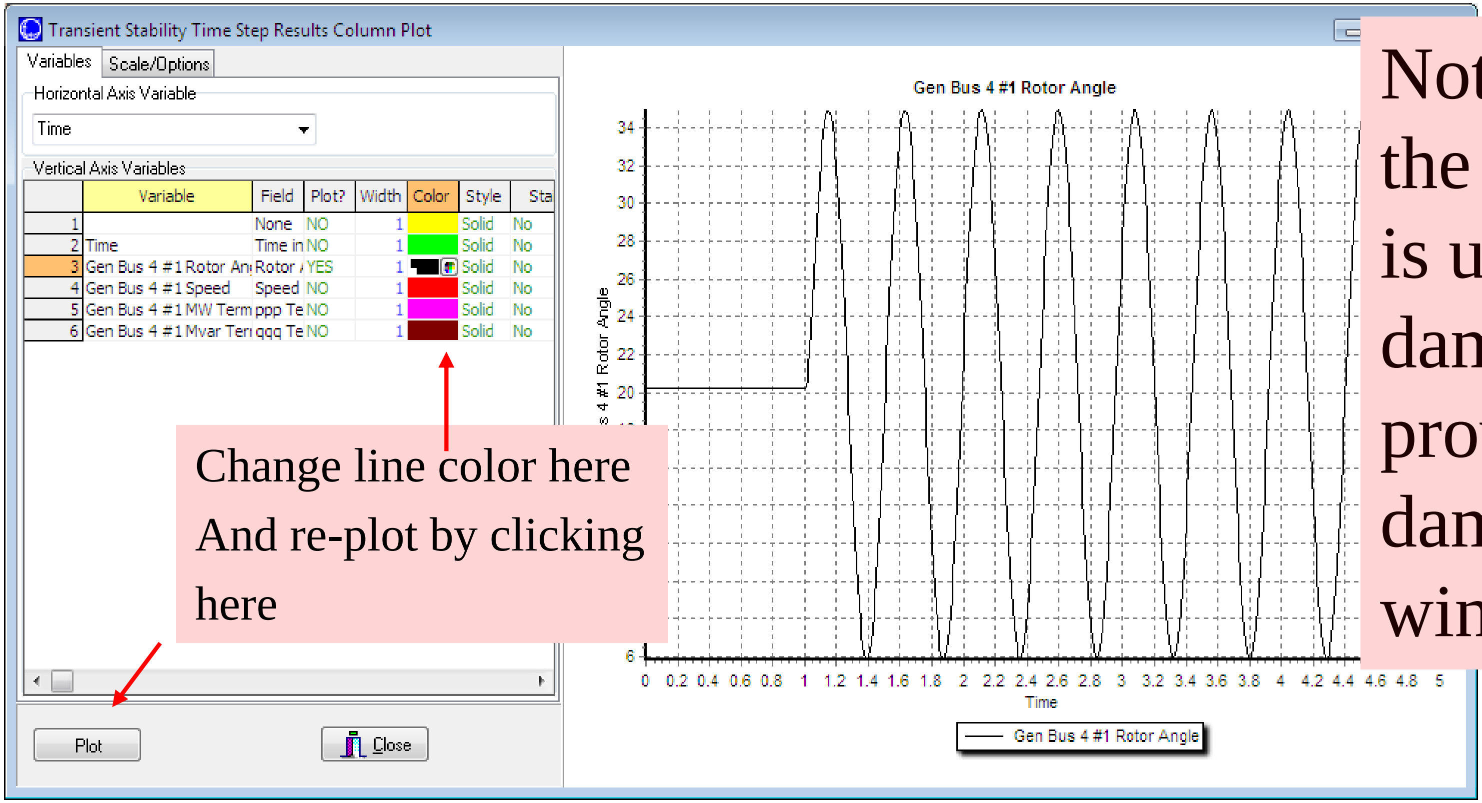
Process Contingencies
● One Contingency at a time
○ Multiple Contingencies

	Number	Name	Area Name	Original Volt	Min Volt	Time Min Volt	Max Volt	Time Max Volt	Max-Min
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



Time

	Variable	Field	Plot?	Width	Color	Style	Sta
1		None	NO	1	🟨	Solid	No
2	Time	Time in	NO	1	🟩	Solid	No
3	Gen Bus 4 #1 Rotor An	Rotor /	YES	1	⬛	Solid	No
4	Gen Bus 4 #1 Speed	Speed	NO	1	🟥	Solid	No
5	Gen Bus 4 #1 MW Term	ppp Te	NO	1	🟪	Solid	No
6	Gen Bus 4 #1 Mvar Ter	qqq Te	NO	1	🟫	Solid	No

Change line color here

And re-plot by clicking here

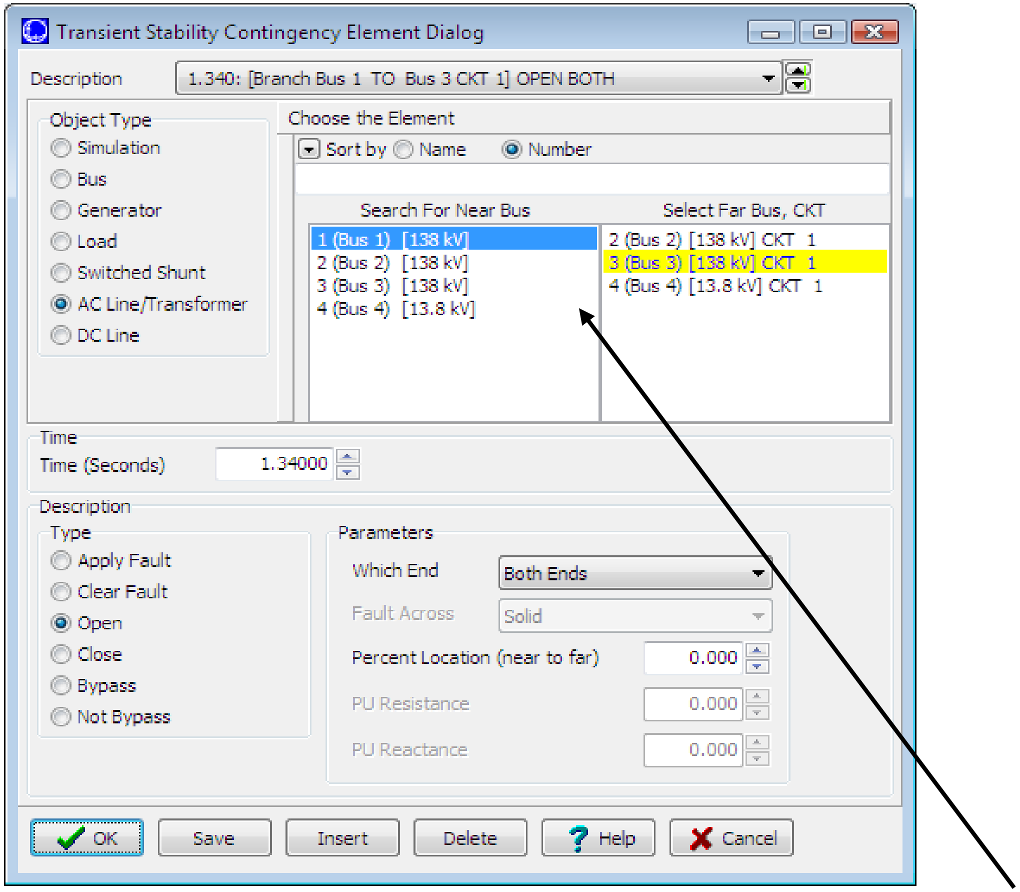
Notice that the result is undamped; damping is provided by damper windings

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 Contingency Elements



Transient Stability Contingency Element Dialog

Description: 1.340: [Branch Bus 1 TO Bus 3 CKT 1] OPEN BOTH

Object Type

- ○ Simulation
- ○ Bus
- ○ Generator
- ○ Load
- ○ Switched Shunt
- ● AC Line/Transformer
- ○ DC Line

Choose the Element

Sort by ○ Name ● Number

Search For Near Bus

- 1 (Bus 1) [138 kV]
- 2 (Bus 2) [138 kV]
- 3 (Bus 3) [138 kV]
- 4 (Bus 4) [13.8 kV]

Select Far Bus, CKT

- 2 (Bus 2) [138 kV] CKT 1
- 3 (Bus 3) [138 kV] CKT 1
- 4 (Bus 4) [13.8 kV] CKT 1

Time

Time (Seconds): 1.34000

Description

Type

- ○ Apply Fault
- ○ Clear Fault
- ● Open
- ○ Close
- ○ Bypass
- ○ Not Bypass

Parameters

Which End: Both Ends

Fault Across: Solid

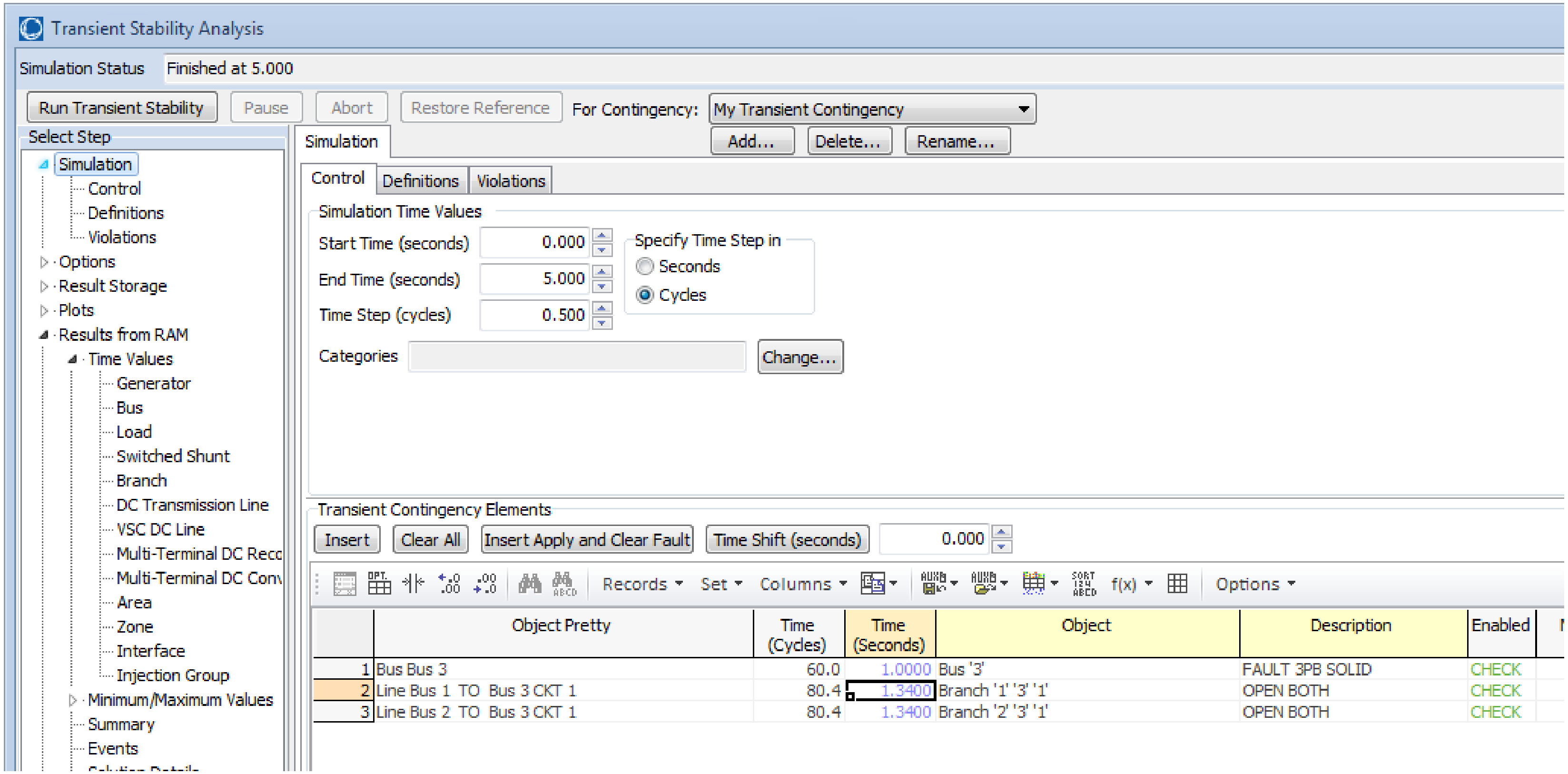
Percent Location (near to far): 0.000

PU Resistance: 0.000

PU Reactance: 0.000

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

For Contingency: My Transient Contingency

Simulation Time Values

Start Time (seconds): 0.000

End Time (seconds): 5.000

Time Step (cycles): 0.500

Specify Time Step in
○ Seconds
● Cycles

Categories:

Transient Contingency Elements

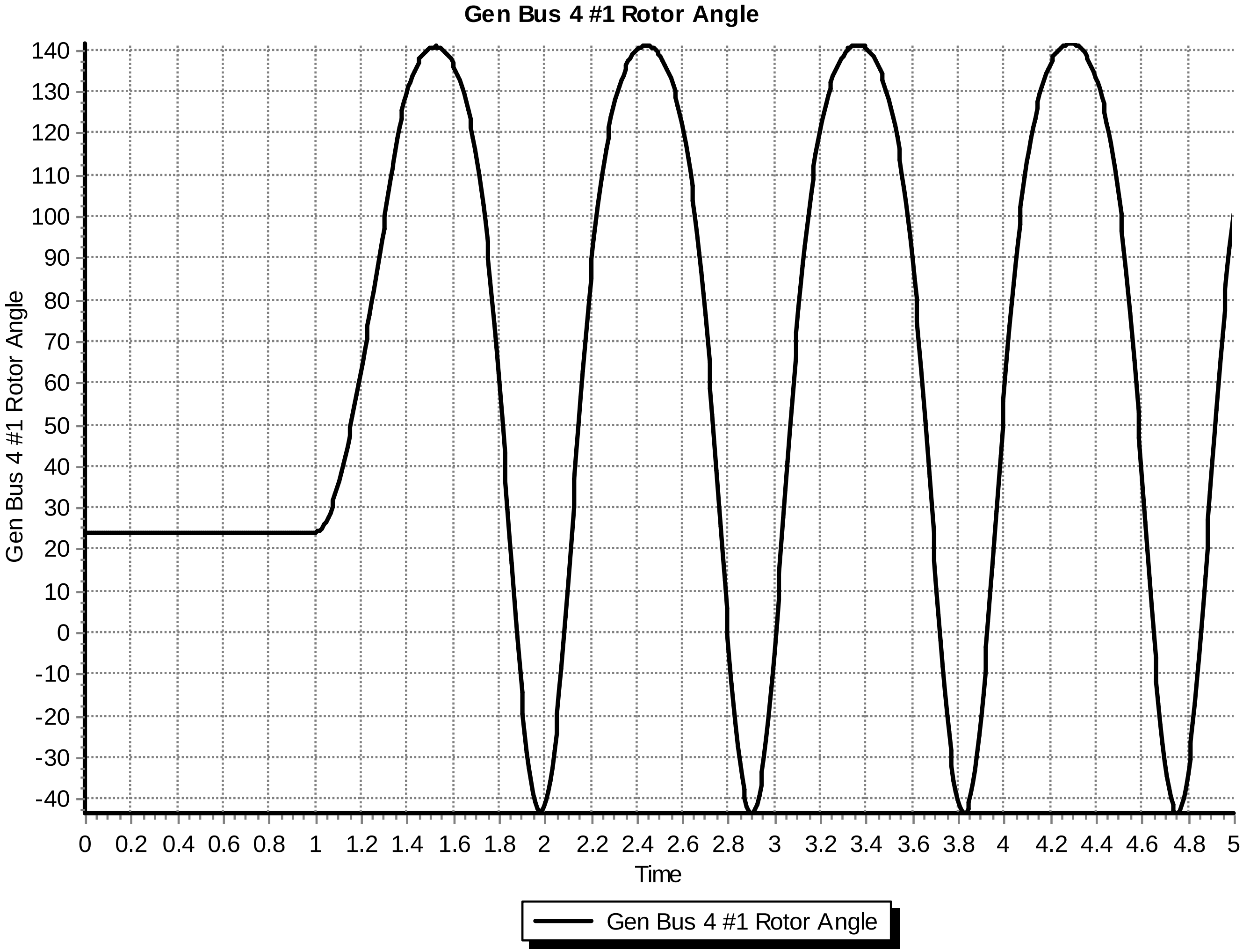
Time Shift (seconds): 0.000

	Object Pretty	Time (Cycles)	Time (Seconds)	Object	Description	Enabled
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

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

Case Name: Example_13_4_Bus3Fault

Results: On Verge of Instability

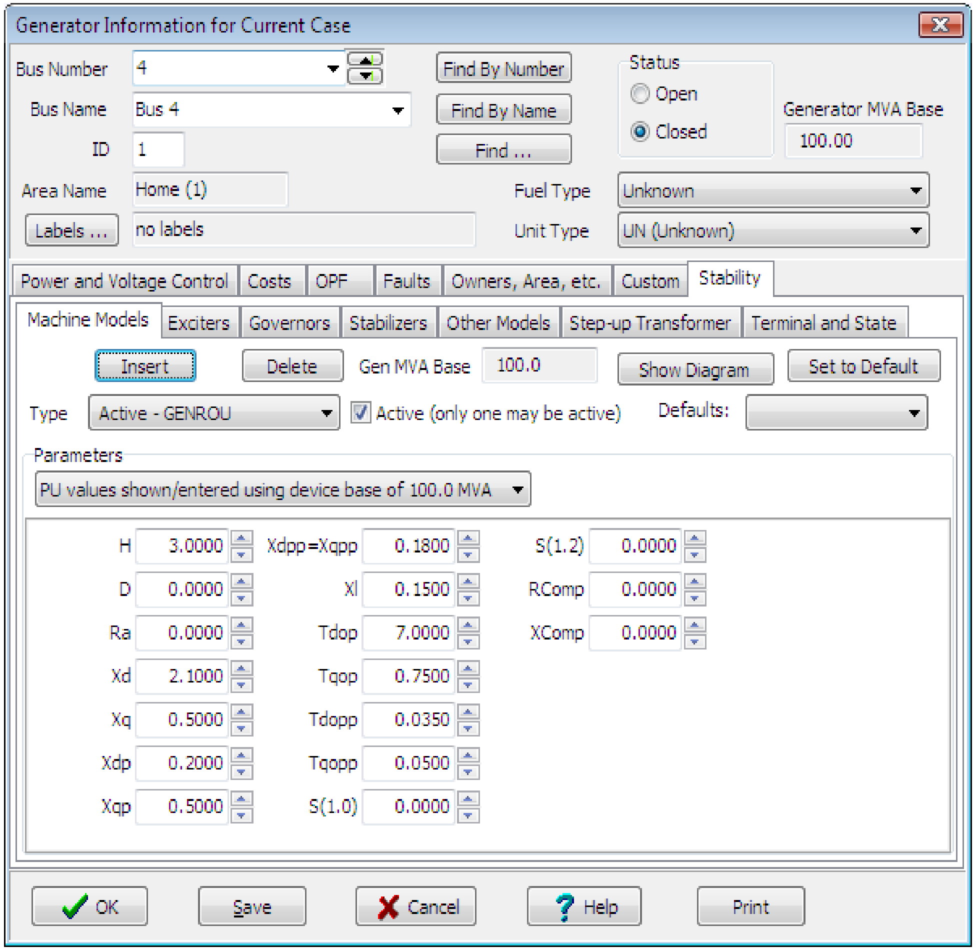


Also note that the oscillation frequency has decreased

A More Realistic Generator Model

- The classical model is consider 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



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)

Gen MVA Base: 100.0

Type: Active - GENROU

☑ Active (only one may be active)

Defaults:

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.