ECEN 667
Power System Stability

Lecture 6: Transient Stability Intro, Synchronous Machine Models

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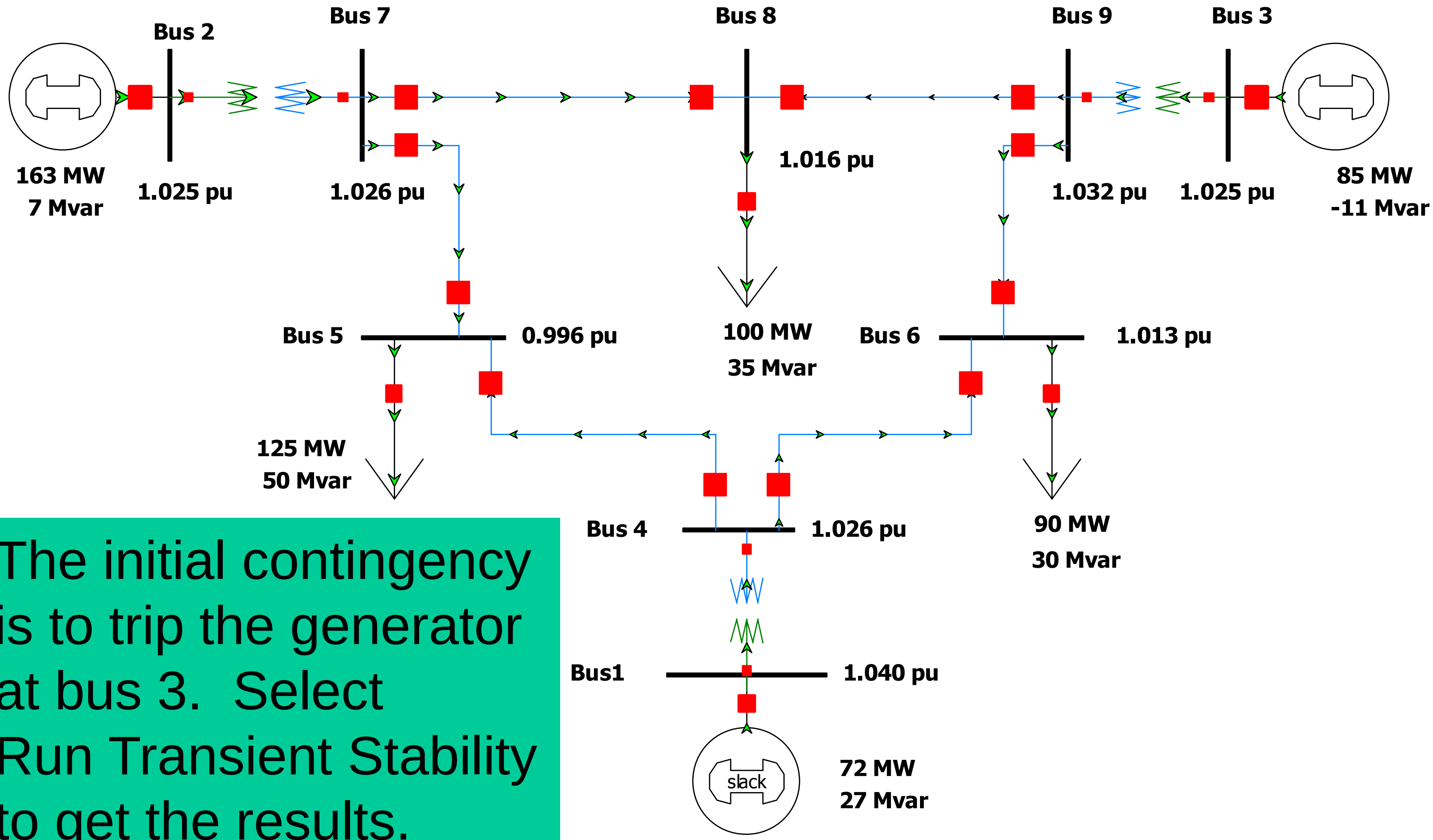
Announcements

- Read Chapter 3, skip 3.7 for now
- Homework 2, which is posted on the website, is due on Thursday Sept 21

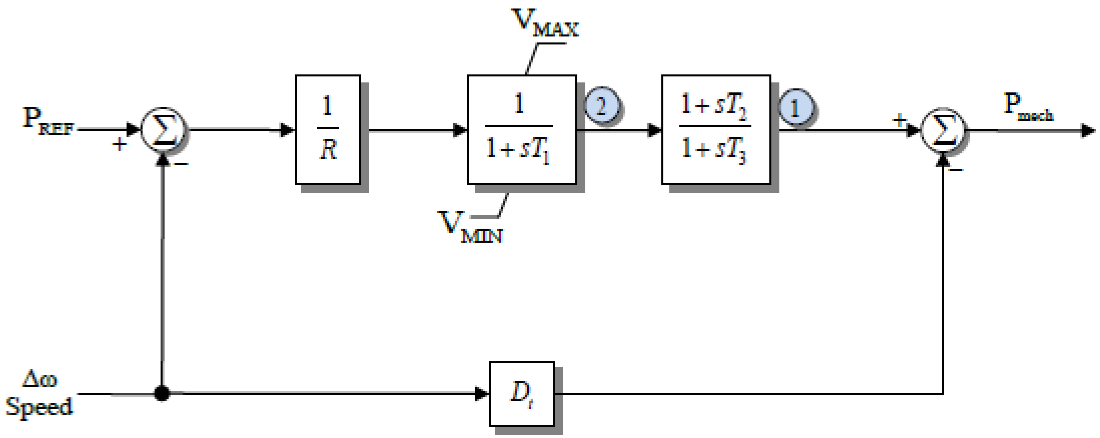
WSCC Case One-line



The initial contingency is to trip the generator at bus 3. Select Run Transient Stability to get the results.

Generator Governors

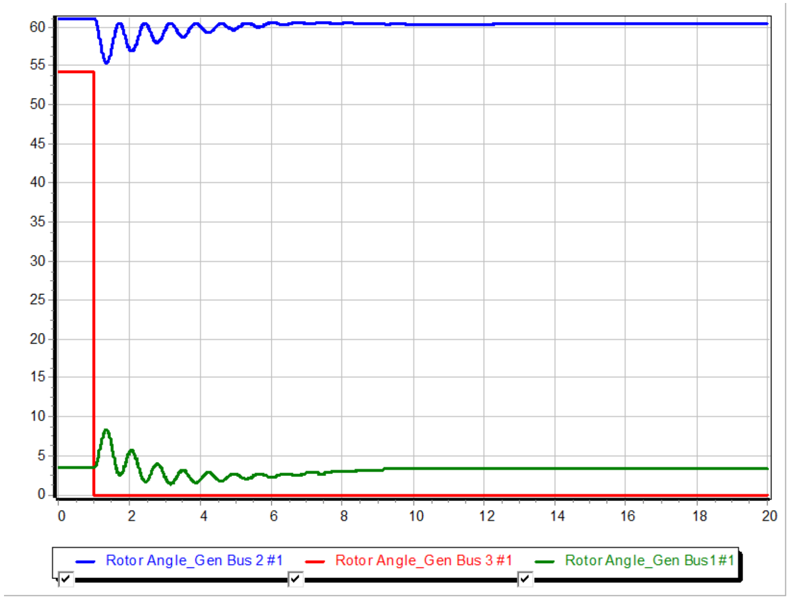
- Governors are used to control the generator power outputs, helping the maintain a desired frequency
- Covered in sections 4.4 and 4.5
- As was the case with machine models and exciters, governors can be entered using the Generator Dialog.
- Add TGOV1 models for all three generators using the default values.

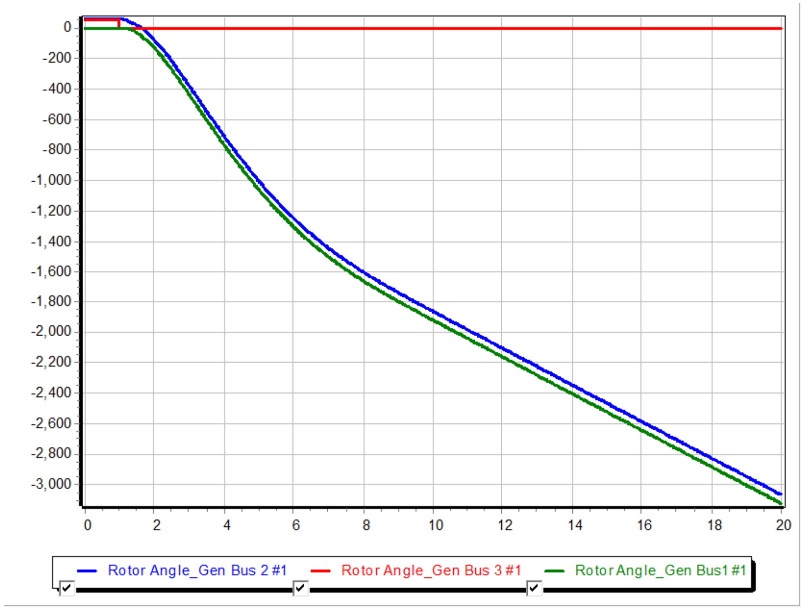


Additional WSCC Case Changes

- Use the “Add Plot” button on the plot designer to insert new plots to show 1) the generator speeds, and 2) the generator mechanical input power.
- Change contingency to be the opening of the bus 3 generator at time t=1 second. There is no “fault” to be cleared in this example, the only event is opening the generator. Run case for 20 seconds.
- Case Name: WSCC_9Bus_WithGovernors

Generator Angles on Different Reference Frames



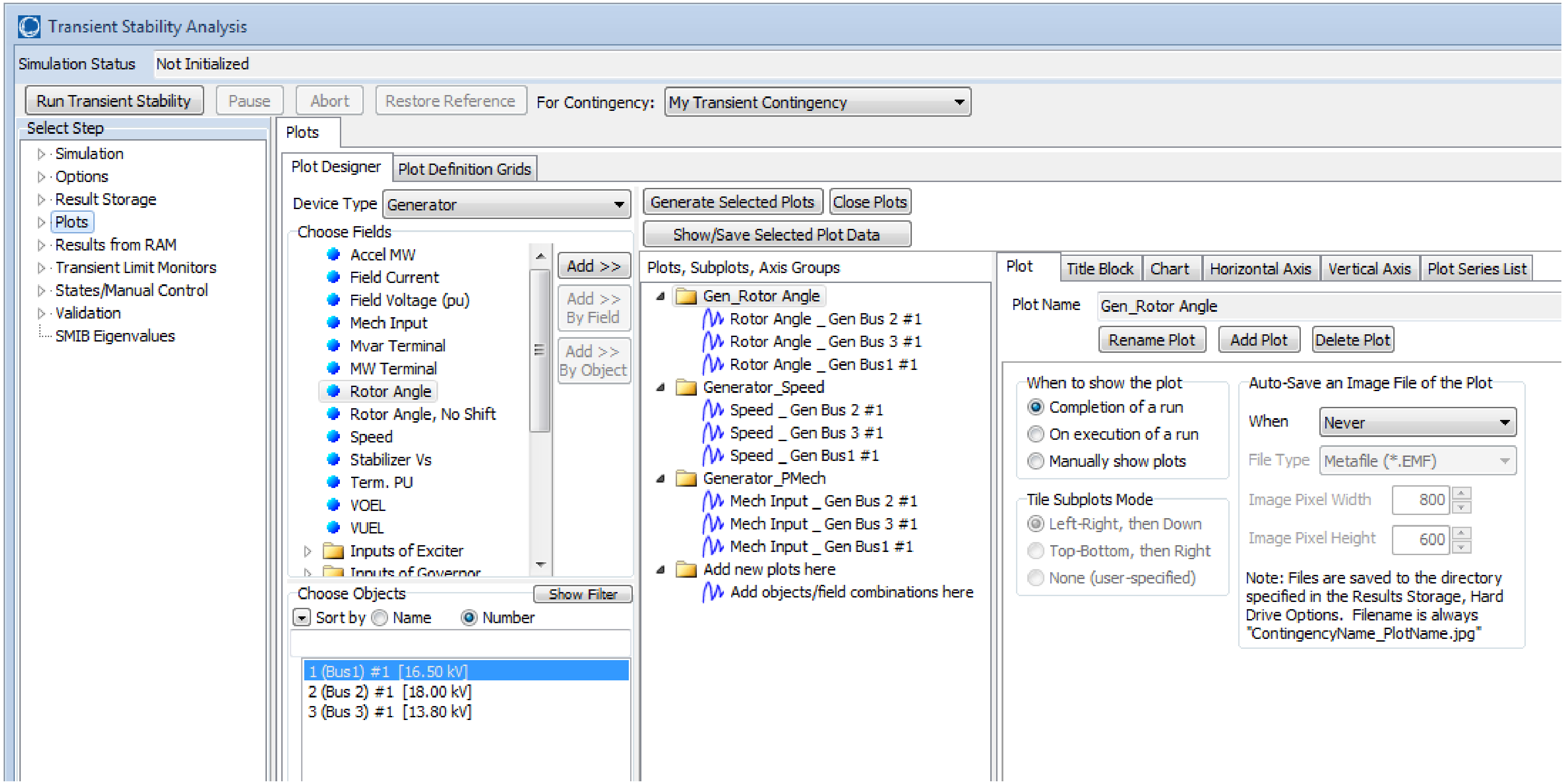


Average of Generator Angles Reference Frame

Synchronous Reference Frame

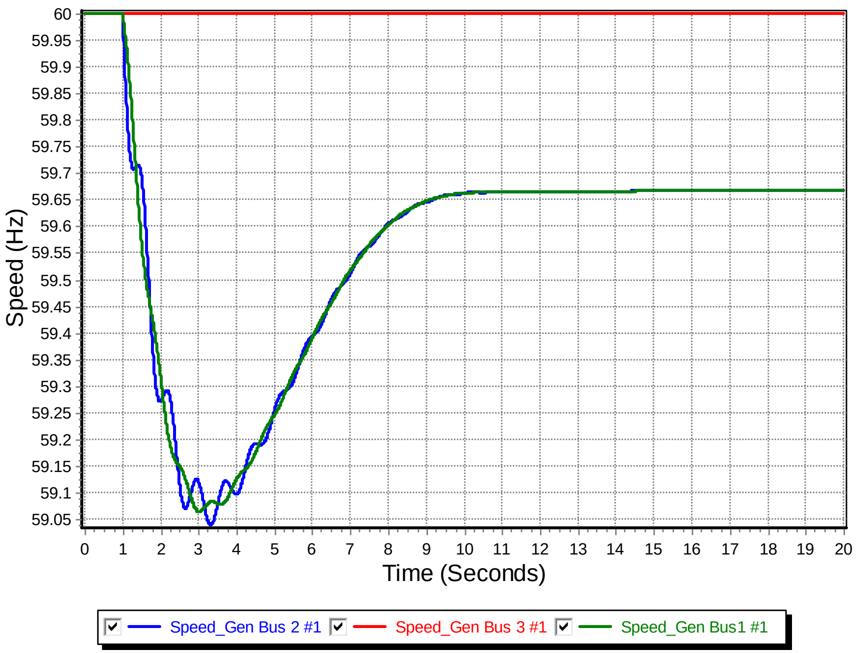
Both are equally "correct", but it is much easier to see the rotor angle variation when using the average of generator angles reference frame

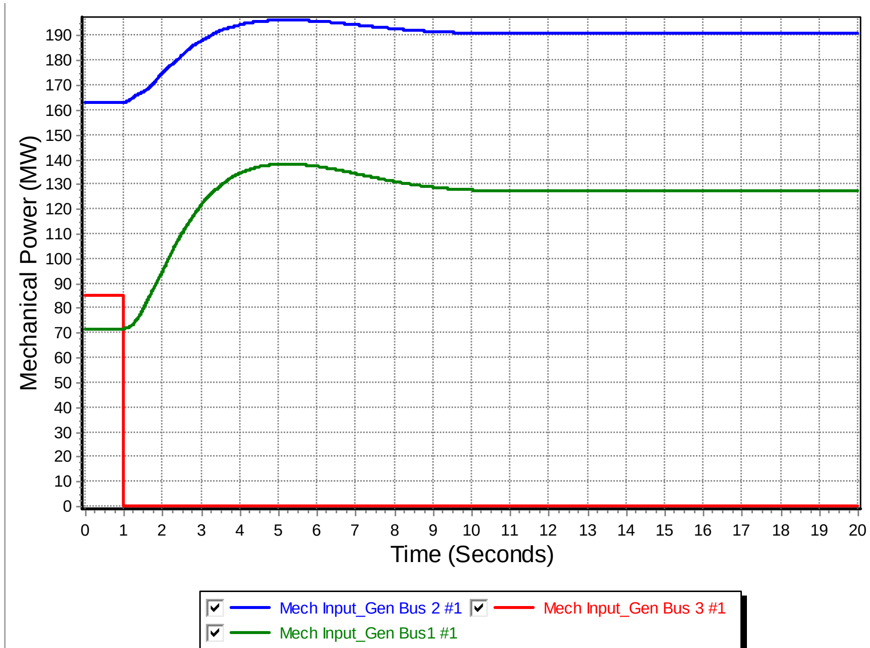
Plot Designer with New Plots



Note that when new plots are added using “Add Plot”, new Folders appear in the plot list. This will result in separate plots for each group

Gen 3 Open Contingency Results

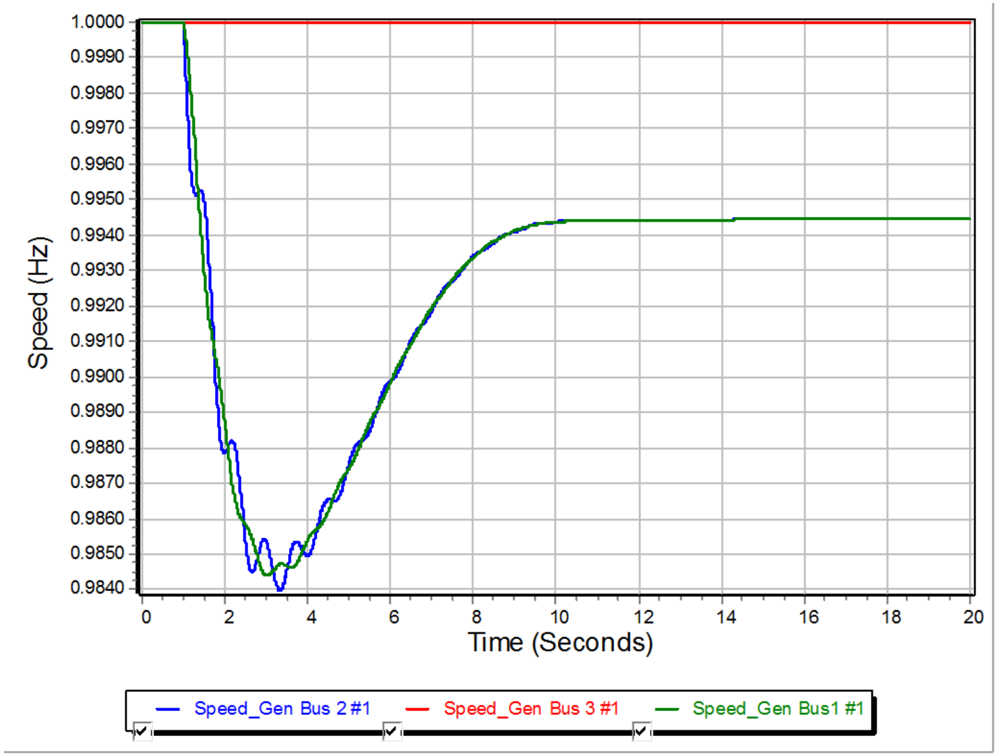




The left figure shows the generator speed, while the right figure shows the generator mechanical power inputs for the loss of generator 3. This is a severe contingency since more than 25% of the system generation is lost, resulting in a frequency dip of almost one Hz. Notice frequency does not return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

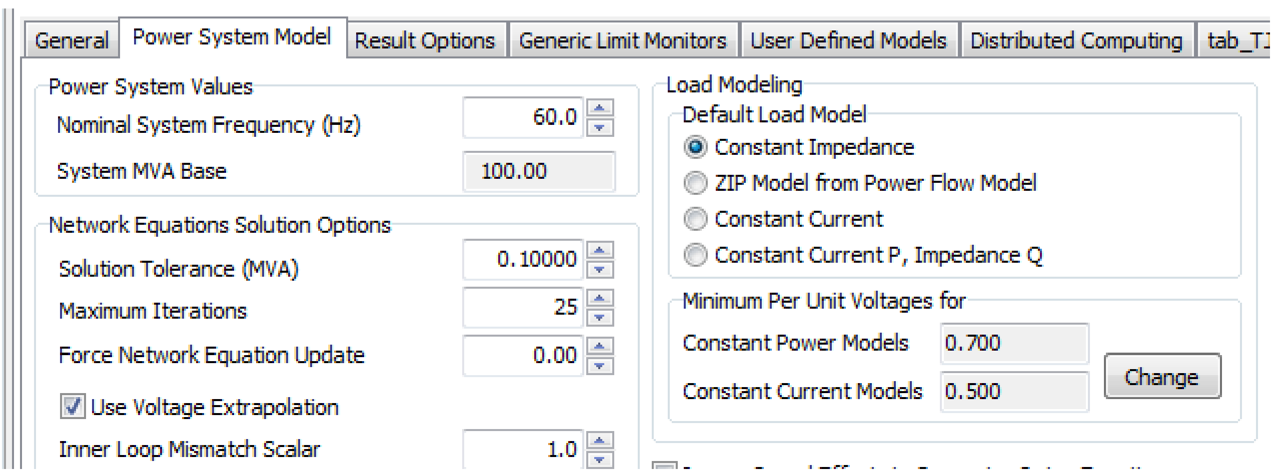
WSCC Frequency Recovery

- Notice that the frequency does not recovery exactly to 60 Hz; this is because of the governor "droop" characteristic
  - Full recovery is done in interconnected systems using AGC
  - Isochronous governors recover to a constant frequency for stand-alone systems



Load Modeling

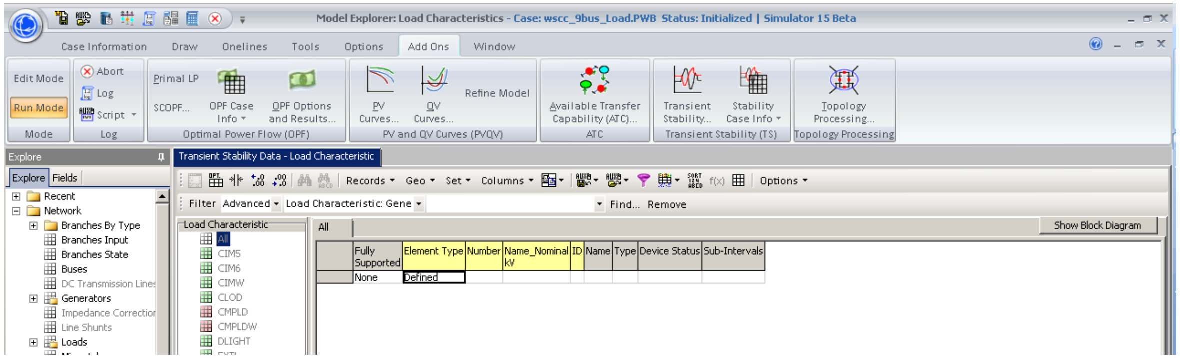
- The load model used in transient stability can have a significant impact on the results
- By default PowerWorld uses constant impedance models but makes it very easy to add more complex loads.
- The default (global) models are specified on the Options, Power System Model page.



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

Load Modeling

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



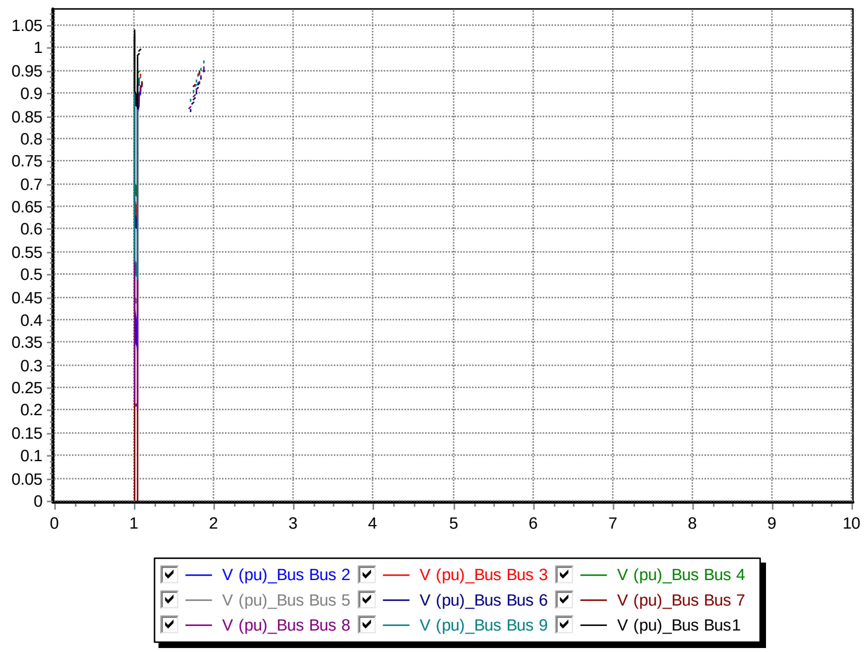
Right click here to get local menu and select insert.

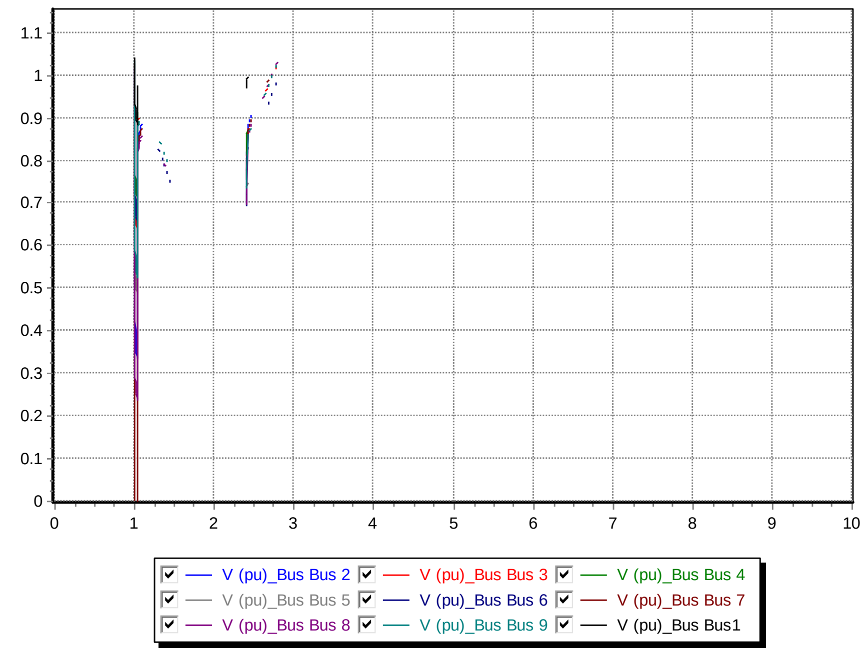
Dynamic Load Models

- Loads can either be static or dynamic, with dynamic models often used to represent induction motors
- Some load models include a mixture of different types of loads; one example is the CLOD model represents a mixture of static and dynamic models
- Loads models/changed in PowerWorld using the Load Characteristic Information Dialog
- Next slide shows voltage results for static versus dynamic load models
- Case Name: WSCC_9Bus_Load

WSCC Case Without/With Complex Load Models

- Below graphs compare the voltage response following a fault with a static impedance load (left) and the CLOD model, which includes induction motors (right)



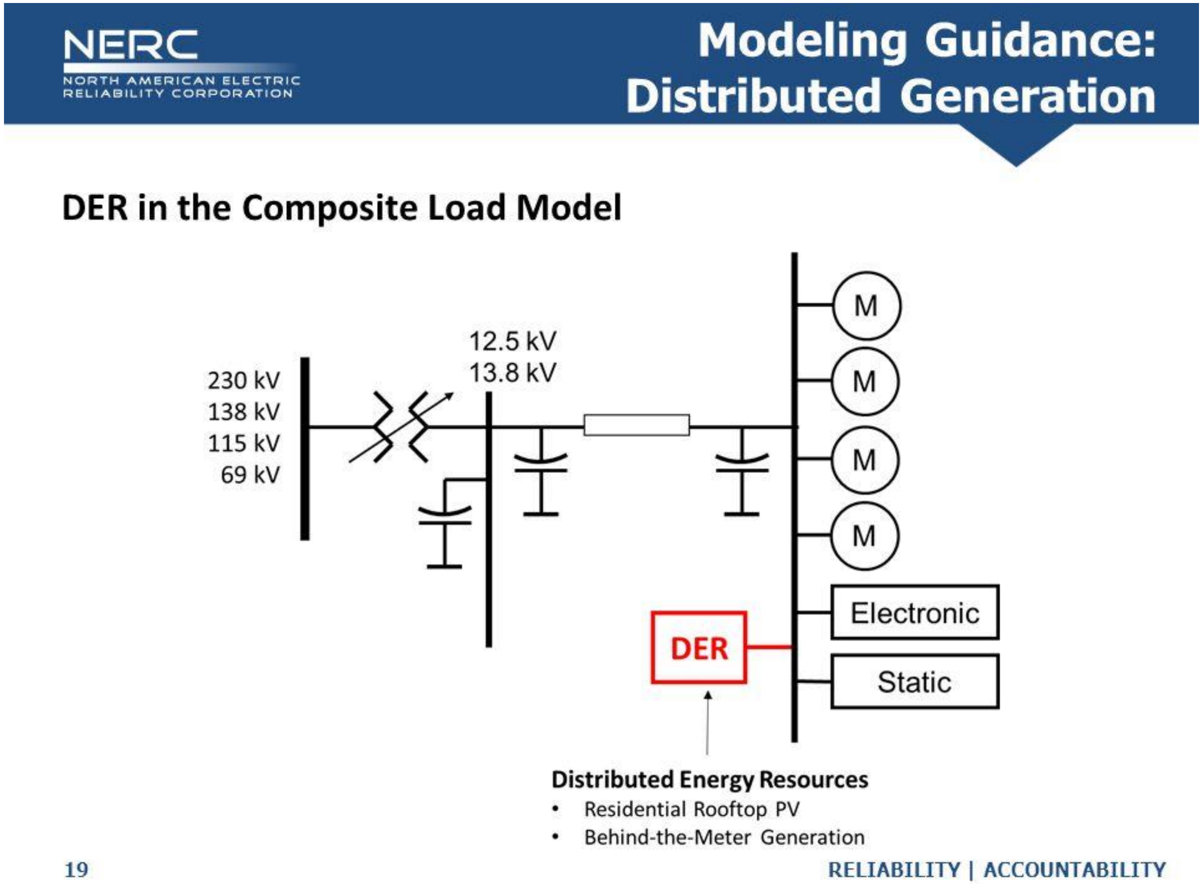


Under-Voltage Motor Tripping

- In the PowerWorld CLOD model, under-voltage motor tripping may be set by the following parameters
  - Vi = voltage at which trip will occur (default = 0.75 pu)
  - Ti (cycles) = length of time voltage needs to be below Vi before trip will occur (default = 60 cycles, or 1 second)
- In this example change the tripping values to 0.8 pu and 30 cycles and you will see the motors tripping out on buses 5, 6, and 8 (the load buses) – this is especially visible on the bus voltages plot. These trips allow the clearing time to be a bit longer than would otherwise be the case.
- Set Vi = 0 in this model to turn off motor tripping.

Composite Load Model

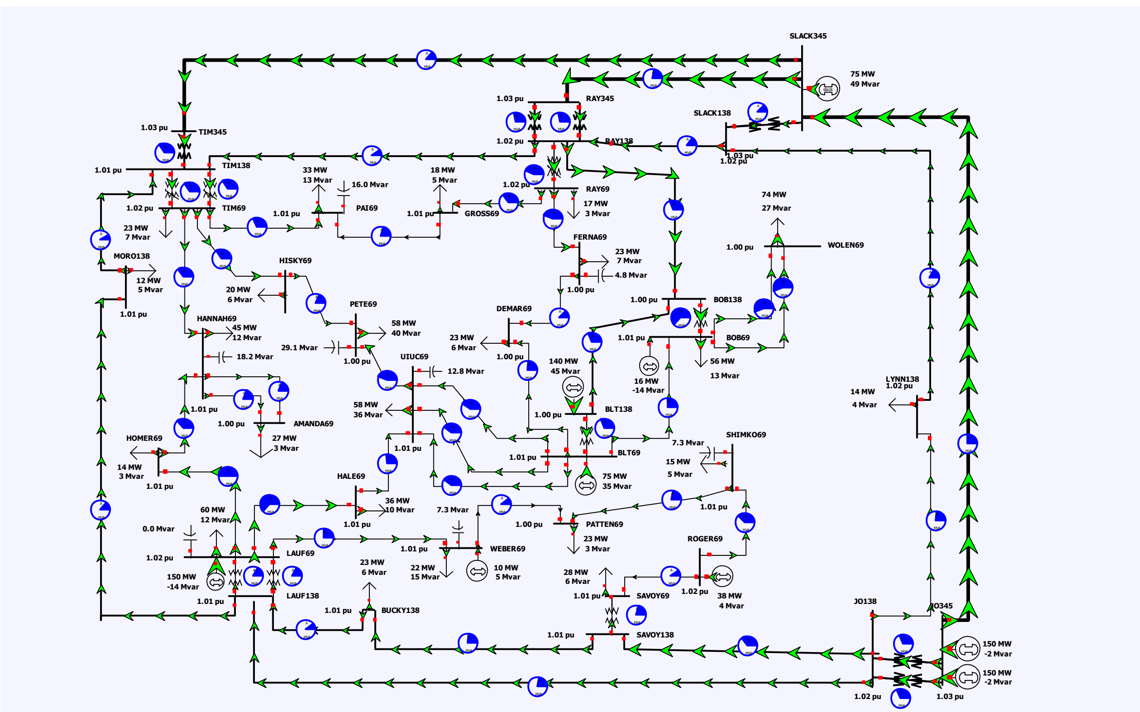
- General trend is towards more complex load models, sometimes with more than 100 parameters!



The composite load model includes up to four motors, other loads, and a simple distribution system (with an LTC)

37 Bus System

- Next we consider a slightly larger, 9 generator, 37 bus system. To view this system *open case GOS_37Bus*. The system one-line is shown below.



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

Transient Stability Case and Model Summary Displays

Transient Stability Model Summary Form | Generators | Load Characteristics

Records ▾ Set ▾ Columns ▾ f(x)

Filter Find... Remove

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

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

del Use

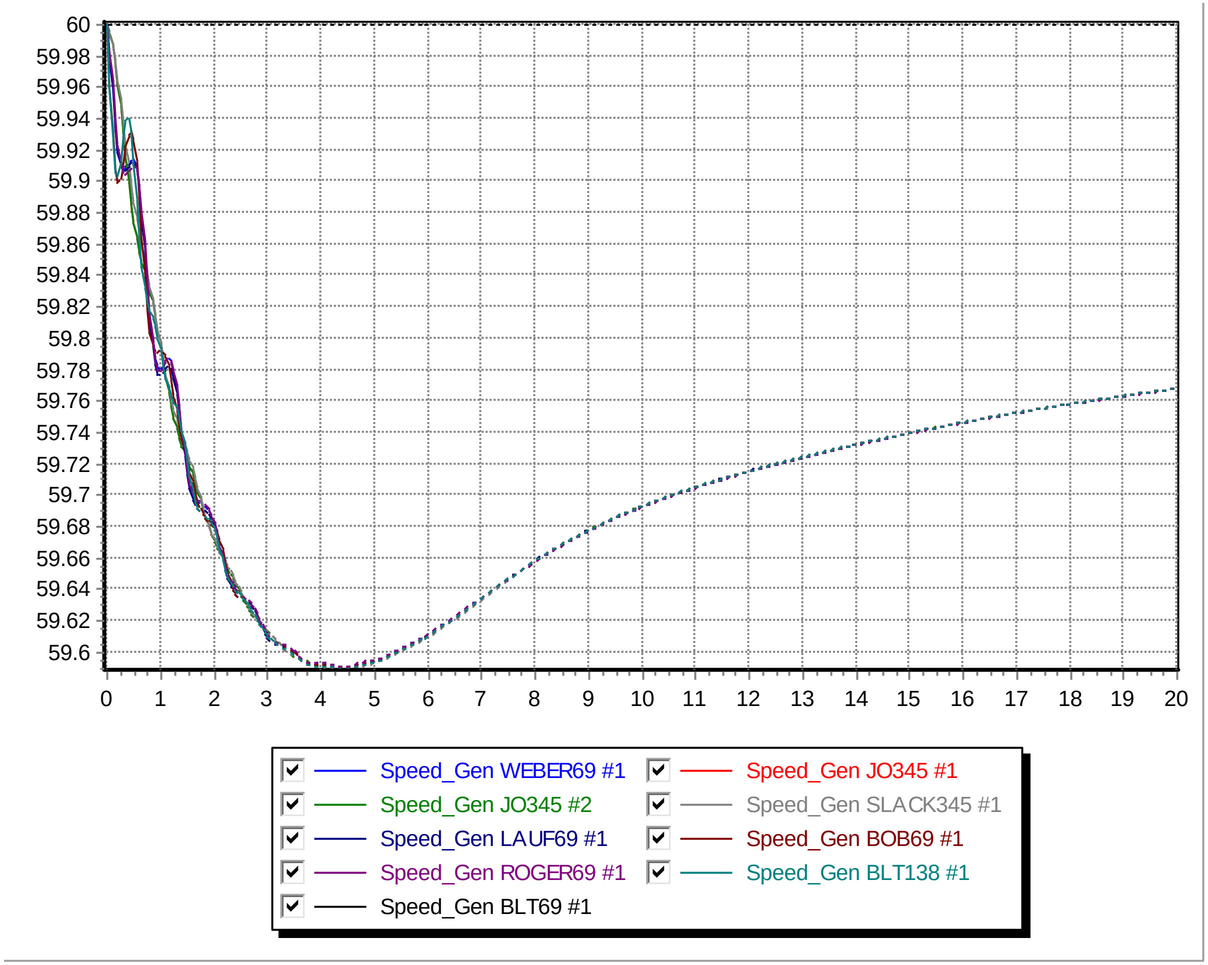
Generator Transient Stability Model Summary

Records ▾ Geo ▾ Set ▾ Columns ▾ f(x) Optic

Filter Advanced ▾ Generator ▾ Find... Remove

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

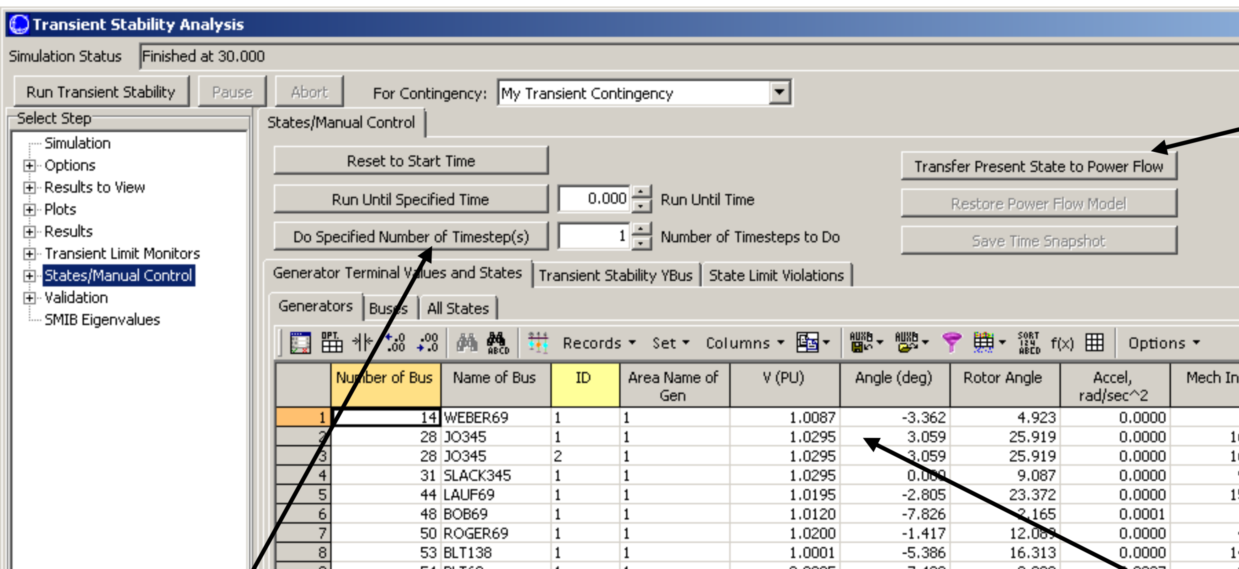
37 Bus Case Solution



Graph shows the generator frequency response following the loss of one generator

Stepping Through a Solution

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



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

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

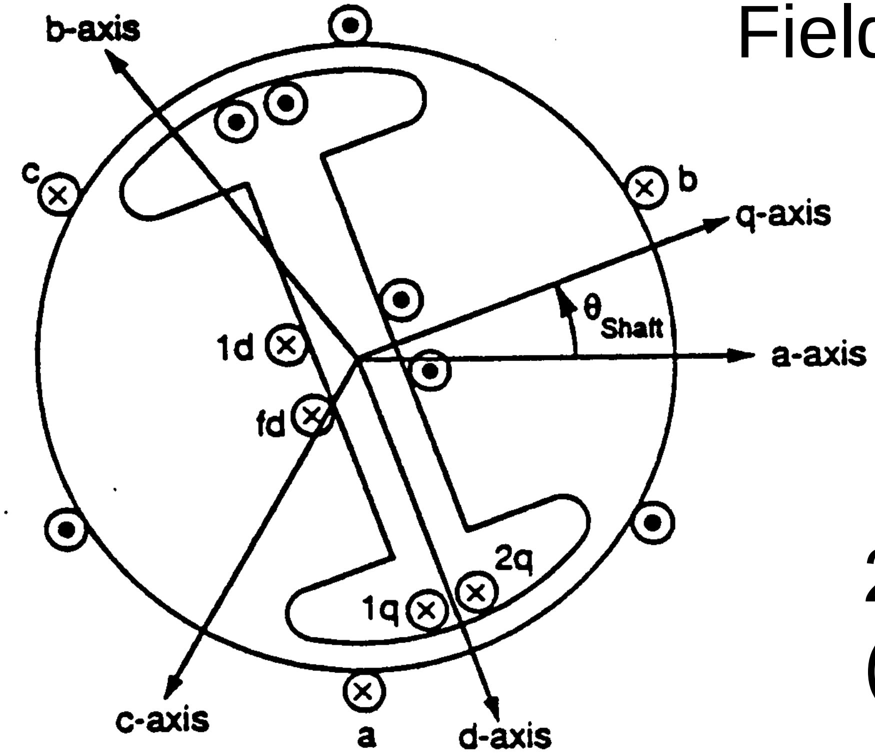
See detailed results at the Paused Time

Synchronous Machine Modeling

- Electric machines are used to convert mechanical energy into electrical energy (generators) and from electrical energy into mechanical energy (motors)
  - Many devices can operate in either mode, but are usually customized for one or the other
- Vast majority of electricity is generated using synchronous generators and some is consumed using synchronous motors, so that is where we'll start
- Much literature on subject, and sometimes overly confusing with the use of different conventions and nominclature

Synchronous Machine Modeling

3ϕ bal. windings (a,b,c) – stator



Field winding (fd) on rotor

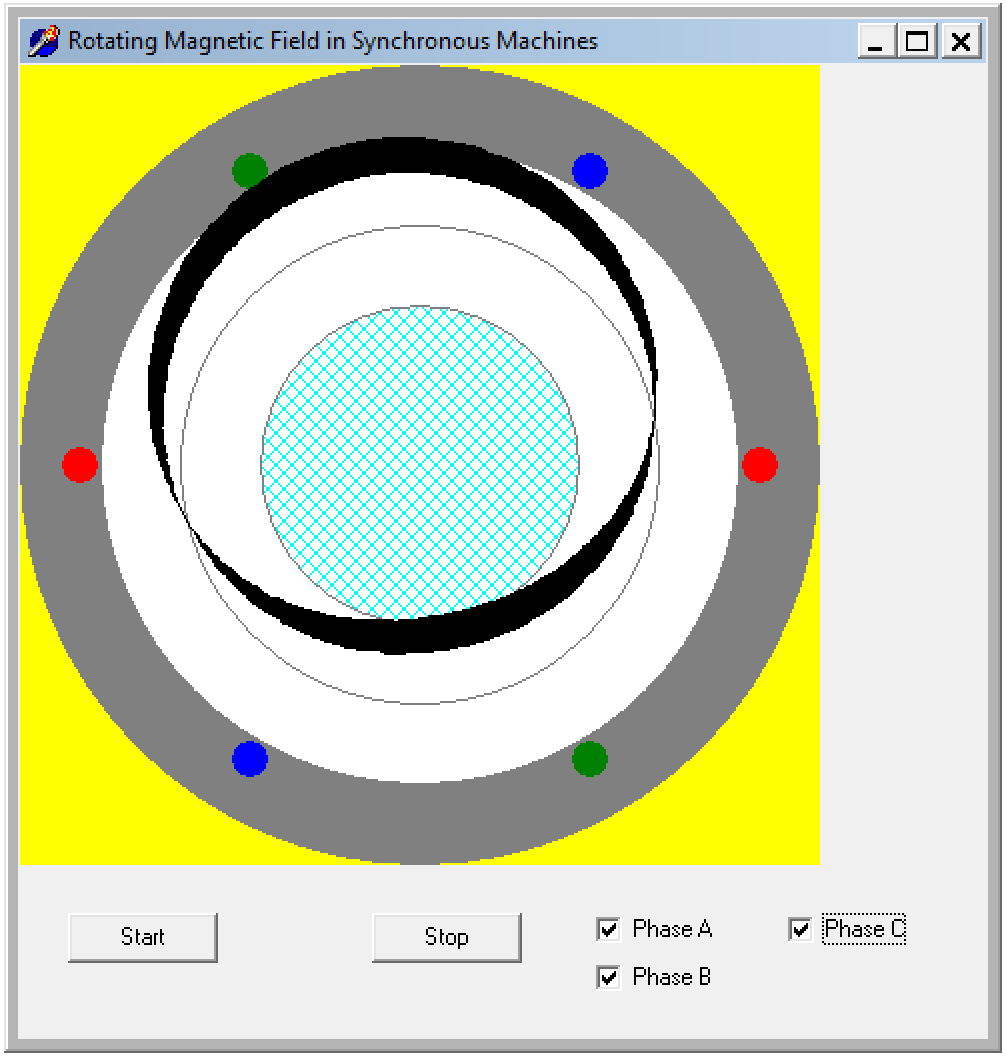
Damper in “d” axis (1d) on rotor

2 dampers in “q” axis (1q, 2q) on rotor

Two Main Types of Synchronous Machines

- Round Rotor
  - Air-gap is constant, used with higher speed machines
- Salient Rotor (often called Salient Pole)
  - Air-gap varies circumferentially
  - Used with many pole, slower machines such as hydro
  - Narrowest part of gap in the d-axis and the widest along the q-axis

Rotating Magnetic Field Demo



Dq0 Reference Frame

- Stator is stationary, rotor is rotating at synchronous speed
- Rotor values need to be transformed to fixed reference frame for analysis
- Done using Park's transformation into what is known as the dq0 reference frame (direct, quadrature, zero)
  - Parks' 1929 paper voted 2^{nd} most important power paper of 20^{th} century (1^{st} was Fortescue's sym. components paper)
- Convention used here is the q-axis leads the d-axis (which is the IEEE standard)
  - Others (such as Anderson and Fouad) use a q-axis lagging convention

Fundamental Laws

Kirchhoff's Voltage Law, Ohm's Law, Faraday's Law, Newton's Second Law

Stator

$$v_a = i_a r_s + \frac{d\lambda_a}{dt}$$

$$v_b = i_b r_s + \frac{d\lambda_b}{dt}$$

$$v_c = i_c r_s + \frac{d\lambda_c}{dt}$$

Rotor

$$v_{fd} = i_{fd} r_{fd} + \frac{d\lambda_{fd}}{dt}$$

$$v_{1d} = i_{1d} r_{1d} + \frac{d\lambda_{1d}}{dt}$$

$$v_{1q} = i_{1q} r_{1q} + \frac{d\lambda_{1q}}{dt}$$

$$v_{2q} = i_{2q} r_{2q} + \frac{d\lambda_{2q}}{dt}$$

Shaft

$$\frac{d\theta_{\text{shaft}}}{dt} = \frac{2}{P}\omega$$

$$J\frac{2}{P}\frac{d\omega}{dt} = T_m - T_e - T_{f\omega}$$