Electric Power Systems Project
Transient Stability and Power System Dynamics

Objective:

Gain experience and insights in the use the transient stability simulation software to determine critical clearing times, to look at the impact of generator losses on system frequency and to consider methods to prevent short-term voltage collapse.

Background on 37 Bus APL System:

The oneline diagram of the Aggieland Power and Light (APL) grid is shown in Figure 1.

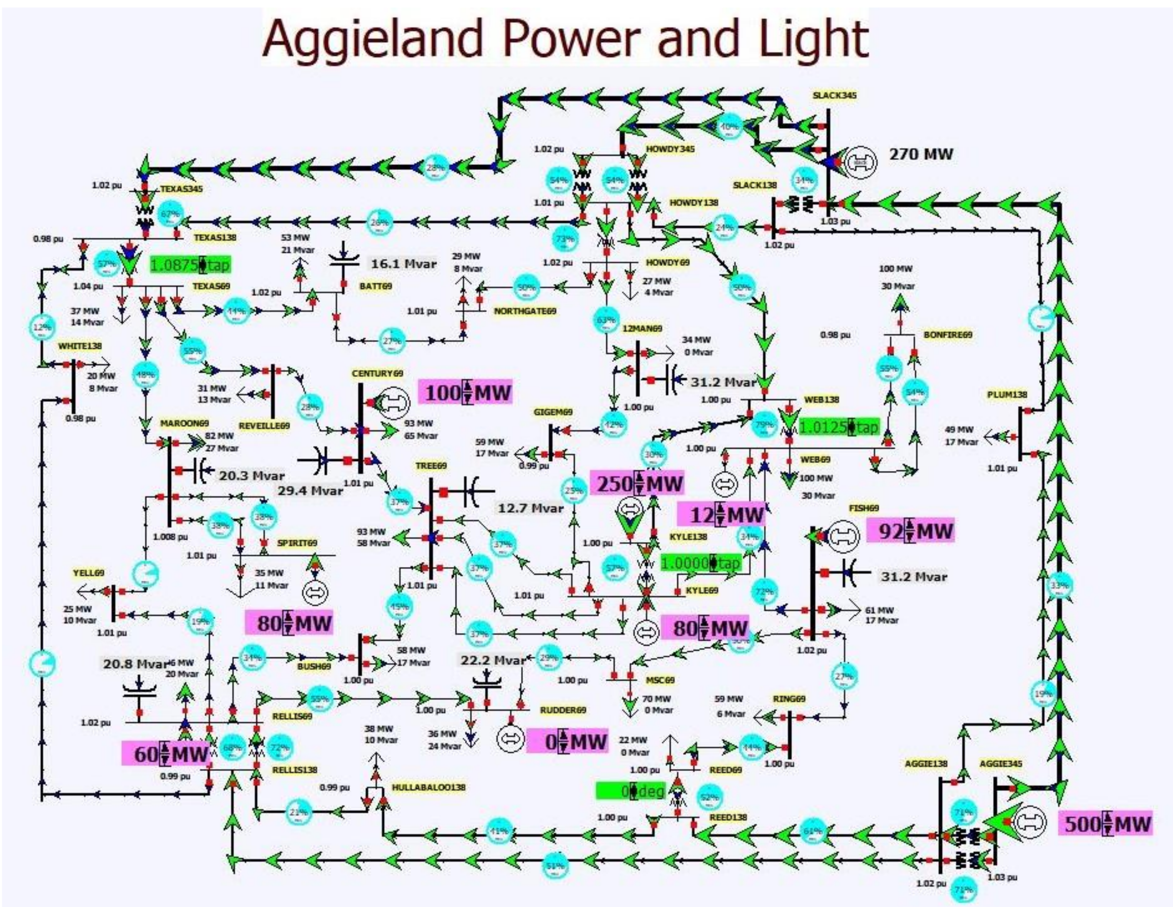


Figure 1: 37 Bus APL System

Procedure for Running Transient Stability on the APL System:

Start PowerWorld Simulator. Open the Project_2 case. The system has been setup to run transient stability with several contingencies predefined for the lab. Select **Add Ons, Transient Stability** to display the Transient Stability form. This will be used throughout the lab to do the transient stability simulations. This is shown in Figure 2.

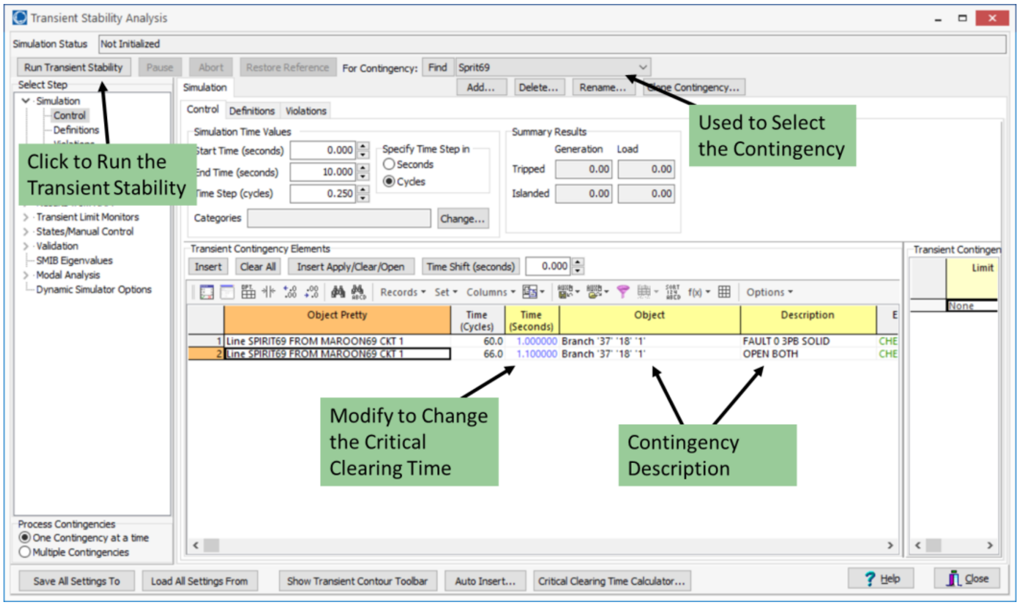


Figure 2: Transient Stability Form

Exercises:

1. For the first transient stability contingency, select the Sprirt69 contingency. This contingency applies a balanced three-phase fault at time equals 1.0 seconds right at the terminal of one of the 69 kV transmission lines going into the Spirit substation. After 0.1 seconds the fault is cleared by opening the transmission line. To do the transient stability run, click on the **Run Transient Stability** button. At the end of the simulation, a graph will appear showing the time-varying generator rotor angles. Save a copy of this graph for your report. Comment the results of the simulation.

2. Iteratively change the time the transmission line is opened to determine the critical clearing time for this fault (to an accuracy of 0.01 seconds – critical time is defined as the longest time the fault can be applied without one of the generators losing synchronism). The critical clearing time is the time difference between when the fault is applied (i.e., time = 1.0 seconds) and that largest clearing time. Save a copy of the rotor angle graph for the critical clearing time for your report and record the critical clearing time, explaining the result obtained.

3. Change the output of the Sprit69 generator from 80 to 40 MW and repeat the procedure of Exercise 2. In your report comment on why such a change result in a different critical clearing time.

4. Re-open the Project_2 case and the Transient Stability Form. Change the contingency to Kyle138, which simulates a fault on the 138 kV transmission line between the Kyle and WEB substations, which is also cleared by opening the line. Again, calculate the critical clearing time for this fault, saving a copy of the graph for your report and explain the results.

5. Next, change the assumed H value for the Kyle138 generator. There are several ways to do this. One is to right click on the generator on the oneline and select **Generator Information Dialog**. On the **Stability, Machine Models** page change the **H** value from 3.0 to 6.0. Select **OK** to save your change and close the dialog. Again, calculate the

critical clearing time for the Kyle138 contingency. Did the change in the critical clearing time match your expectations?

6. In the latter configuration of the grid, select the generators KYLE138, SPIRIT69, CENTURY69 and FISH69 and compute, one by one, the critical clearing time for a fault in a line leaving the generator bus, using the equal area criterion. Compare the results with those obtained using the time-domain simulation and comment the results obtained. Check the Frequently Asked Questions (FAQ) at the end of this document if you have doubts.

7. Open the Project_2 case and study generator contingencies. To do so, you need to model governors. Therefore, in Edit mode, select 5 large generators and activate governor model: for each generator open Stability, Governor and activate TGOV1 models. Then, simulate the loss of a small generator in the system. To do to, in Run mode, cut down line contingencies previously studied and insert generator contingencies. From Transient/Contingency elements select Insert/Generator. Select generator RUDDER69 (open contingency). Run the simulation and plot a graph showing the time-varying frequency at ten high voltage buses. (Plot/Device type: Bus/Add Plot). Plot also the per unit voltage magnitudes at the same busses. Make a note of the lowest frequency and ROCOF (Rate of Change of Frequency) and comment the results obtained. Save a copy of the graph showing the frequency and voltages at all the system buses for inclusion in your report. Check the Frequently Asked Questions (FAQ) at the end of this document if you have doubts.

8. Now, simulate the further loss of another generator in the system and plot the same graphs. Again, note the lowest bus frequency and lowest per unit bus voltage magnitude. Save a copy of the graphs showing the frequency at all buses for your report. Compare the two cases. Based on these two results, do the responses seem to be proportional to the amount of generation lost?

Report:

Provide a summary of the procedures you followed and the results you obtained.

Describe the strategy you used to solve the scenarios. What additional information would have been helpful to have in developing your optimal strategy?

Frequently Asked Questions (FAQ):

- **FAQ - About exercise 6:**

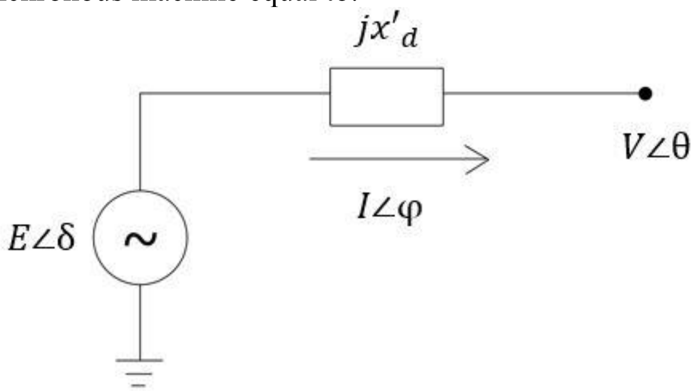
In the slides of the course, the following expressions were stated to define the critical clearing angle and the critical clearing time due to the Equal Area Criterion:

$$\delta_{cr} = arccos[-cos(\delta_0) + sin(\delta_0)(\pi - 2\delta_0)] \qquad (1)$$

$$t_{cr} = \sqrt{\frac{4H\,(\delta_{cr} - \delta_0)}{\omega_s P_m}} \qquad (2)$$

With δ in rad, H in s, P_m in p.u, $\omega_s = 2\pi f_s$ where f_s is the nominal frequency of the system in Hz.

These expressions (1) and (2) were stated considering the generated active power of a synchronous machine equal to:



$$P_e = \frac{VEsin(\delta - \theta)}{x'_d}$$

With the voltage angle of the terminal bus θ=0 considered as reference (θ=0). However, the terminal bus of the faulted generator in not automatically set as reference in the PowerWorld Simulator for every contingency simulated. So, what you need to do is to measure the angle θ and consider it in the expressions to calculate δ_{cr} and t_{cr}. The expressions (1) and (2) now become:

$$\delta_{cr} = arccos[-cos(\delta_0 - \theta_0) + sin(\delta_0 - \theta_0)(\pi - 2(\delta_0 - \theta_0))] \qquad (3)$$

$$t_{cr} = \sqrt{\frac{4H\,(\delta_{cr} - \delta_0 - \theta_0)}{\omega_s P_m}} \qquad (4)$$

In the PowerWorld simulator:

- To measure θ: 'Run mode > Add Ons > Trans. Stab. Sim. > Menu on the left, click on Plot, Plot Designer > Device type: Bus > V Angle (rad) > Choose the referred bus in the list> Click on Add new plots here> Click on Add > Run Transient Stability'
- To check f_s: 'Add Ons > Trans. Stab. Sim. > Menu on the left, click on Options > Nominal system frequency'.
- To check P_m and the referred base: 'Edit mode -> Double click on the generator'.

- **FAQ - About exercise 7:**

I) Understanding the frequency response:

To understand the frequency response of the system after the fault in the generator RUDDER69, investigate:

1) The power generated by the faulted generator.
2) The voltage behavior at the terminal buses.
3) The load behavior of the system. Plot the active power consumed by the load connected to the Bus RUDDER69.
4) With the three previous observations, can you understand what happened with the power imbalance of the system after the fault of this specific generator?

II) About plotting the ROCOF:

Some versions of the software are not plotting the ROCOF automatically. You can do it in many ways: one is to select the option "Derivative of actual value" in the 'Plot series' tab of the 'Plot designer' (please check the figure below). The other one is to export the frequency data to excel and treat it there or in Matlab.