EE 455 Power System Dynamics and Protection

Final Project - Transient Stability Analysis and Design Problem

Final Report due March 14, 2013 2:30 PM to class drop box

100 points

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In this problem you will use a computer program called PowerViz to perform a transient stability analysis on the 9 bus system depicted in Figure 1, and modify the system to improve stability. The numbers on the lines and buses are those used in the data sets and in PowerViz displays. The MVA ratings on the transmission lines and transformers indicate the rated limit for that line or transformer. The complex numbers on the load buses are the complex loads at those buses in MVA.

The instructions that follow describe a very specific set of steps for you to follow in performing the stability analysis. You should follow these steps in your analysis and write up your results as a formal report. Your report organization need not be explicitly divided into these steps but the report should include the information asked for in some well-organized form. Your report should also conform to the usual structure of a formal report (see the Appendix for a sample report structure).

Turn in your report and presentation in electronic format (.pdf preferred) to the class drop box by 2:30 PM on March 14.

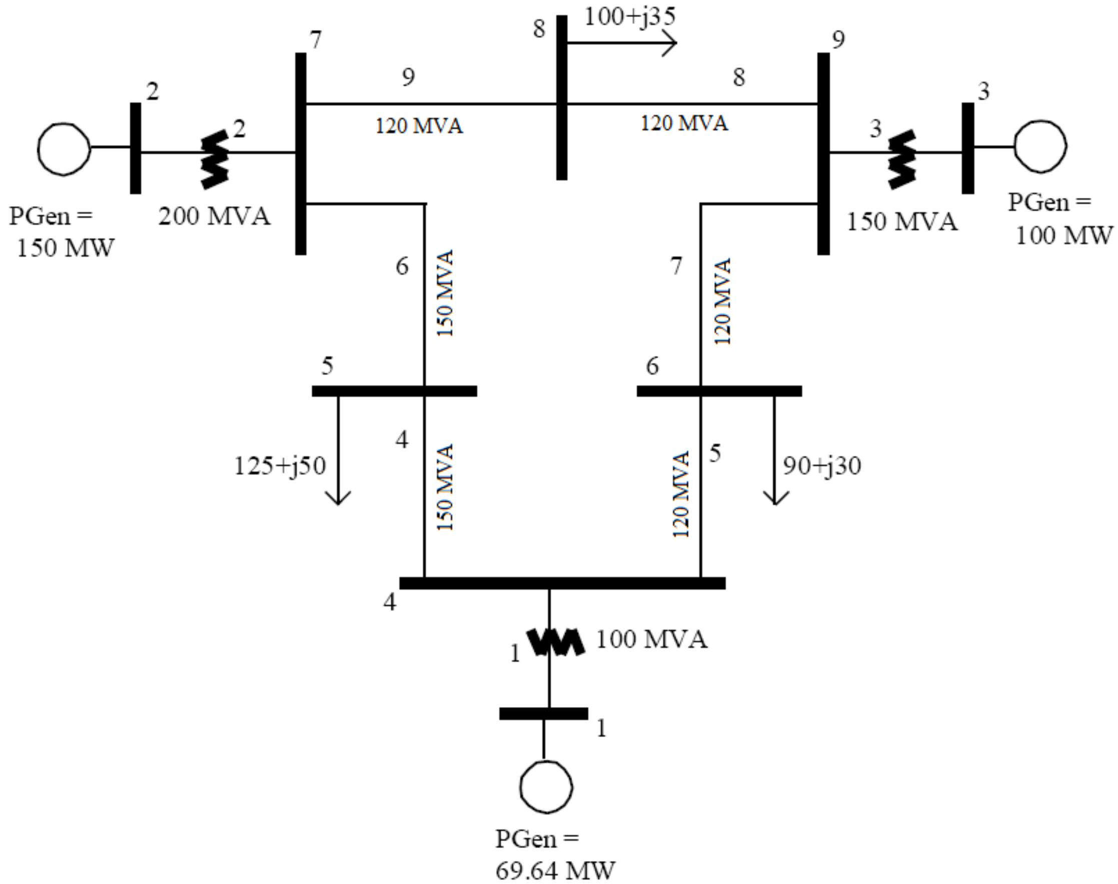

Figure 1. 9 bus 3 machine system.

(Modified from Anderson and Fouad, *Power System Control and Stability,* 1977).

Step 0 – Obtain Program and Data Files

Download the 13 CHW2.zip file from the class web site. Unzip to obtain the PowerViz.exe file, and the data files 9bus_EE455.psd and 9busPlus10_EE455.psd in an appropriate folder. If you are working on a department machine, please delete your files when finished. You can always download and unzip again.

Step 1 – Base Case Power Flow

In this step you will run a "base case" power flow for the system and record the calculated results for each bus, line, and generator in a table. Include this table and a corresponding visual display in your report. To do this:

1. Run the PowerViz executable.
2. Choose "File:Open" on the menu and open the data file "9bus_EE455.psd".
3. The power flow will run automatically. The width of the arrows indicates the magnitude of power (MVA) flow through each line. The width of the gray shading indicates the line MVA limit.
4. Obtain a copy of the visual display using the "Edit:Copy View to Clipboard" function from the menu bar. Then paste the image into a Word file.
5. Open the power flow log file by choosing "View:Flow Log" from the menu. This will bring up a text file describing the system power flow results. Record the real and reactive power flow through each transmission line, the bus voltages, and the real and reactive generator outputs in a table. Note that there is now a corresponding flowlog.txt file in the directory. You may be able to edit this into a table. You can also view the numeric bus voltages or line flows by moving the mouse pointer over the bus or the line. The status bar in the lower left corner of the window shows the calculated values.
6. As the prompt at the bottom of the window indicates, you can easily change line, generator and bus properties and you can take lines out of service. Note that by double clicking on a line out of service, you can restore the line. This method of restoring a line is useful in the steps that follow. Feel free to experiment. Note that PowerViz, being developed by graduate students, is buggy, although it works well enough to do this assignment.

Step 2 – Simulate the Base Case Transient

In this step you will simulate a fault on the system and obtain graphs of the machine angles, bus injection powers, and bus voltages for the system. Specifically, the fault is at line number 6 (from bus 5 to bus 7) at (or near) bus 7. Assume that protective relaying clears the fault in 3 cycles (0.05 seconds). To do this:

1. From the power flow screen press the "SIM" button () on the toolbar. This will bring up the Simulation Table that defines the events that occur during the simulation run.
2. Verify or edit the Simulation Table. Leave the first event as "Start." Choose "Fault" as the second event type. Fill in 0.1 in the "At Time" box, "6" in the "Line Number" box and "7" in the "At Bus Number" box. Choose "TripLine" as the second event type and fill in "0.15" in the "At Time" box and "6" in the "Line Number" box. Choose "Finish" as the last event and fill in "3.0" as the finish time.
3. Choose the graphs you want PowerViz to produce. Check the boxes to the left of the table for "Machine Rotor Angles," "Machine Bus Voltages," and "Machine Electric Powers."
4. Click the "Run Simulation" button to run the simulation.
5. View the graphs. The graphs you selected will appear on the screen. The line colors on the graphs correspond to the bus colors that appear on the one-line display. You can move the graph windows to see the one-line.
6. Save the graphs. Click the "Save to MATLAB" button (for each graph). The program will prompt you for a file name for the data for this graph. Choose a MATLAB m-file name like "BaseMacAngles.m" for example. This data can be plotted and analyzed in more detail using MATLAB by running this m-file from the MATLAB command prompt. Include these graphs in your report.
7. In your report evaluate whether the system is stable or unstable and give reasons for your claim. Discuss any other interesting features of your results.

Step 3 – Find the Critical Clearing Time

Find the critical clearing time (considering the first swing only) for the fault from Step 2 by varying the time it takes the protective relaying system to clear the fault (the time between the “Fault” and “TripLine” events) and re-running the transient stability simulation. You will need to reconnect the transmission line that is taken out of service before running the simulation again. Double clicking on the line does this. Once you are close to the critical value, decrease the simulation time step (in the simulation dialog) to 0.001 sec and find the critical clearing time with that precision. Include plots of the machine angles for the marginally stable and marginally unstable cases in your report. Discuss how these plots could relate to the equal area criterion diagram for the system.

Note: The program has some problems writing the data to a MATLAB file when the number of points is large. If you are going to plot your system to MATLAB make sure there are less than 1,000 time steps in your simulation. Do this by lengthening the simulation interval to reduce the number of points once you understand the system behavior.

Step 4 – Reclosing

Suppose that the utility finds that their circuit breaker/relay systems cannot reliably clear faults in 3 cycles (3/60 = 0.05 sec). Simulate the fault from step 2 again, but change the clearing time to 4 cycles (0.0667 sec). Show that the system is either stable or unstable. Now use the following procedure to cause line 6 to reclose 0.3 seconds after the fault.

1. Open the simulation dialog by clicking the “SIM” button.
2. Check that the clearing time is 0.0667 seconds, i.e the “TripLine” event “At Time” box has 0.1667 in it.
3. Change the next event type to “RecloseLine” using the drop-down box.
4. Enter “6” in the “Line Number” box and “0.4” in the “At Time” box.
5. Enter “3” in the “Finish Time” box.
6. Run the simulation and plot graphs of the machine angles and power injections.

<u>In your report, use equal area criteria diagrams</u> to discuss why stability increased with the addition of reclosing. Find and report the critical reclosing time for this fault.

Step 5 – Explore Impact of Other Factors on Stability

To understand the behavior of this system better, <u>explore the impact of other factors on stability</u> by examining the changes in the results of Step 3 above when changing:

1. Generator inertia constants, H.
2. Generator voltage setpoints.
3. Generator real power output (Note: Generator 1 is the swing bus. Its real power output is automatically set to load plus losses minus other generation.)
4. Line reactances.
5. Other.

The change in critical clearing time (step 3) is a common measure of the relative stability of the system before and after such changes.

These items are altered in the dialog boxes that appear when you “right-click” on the object of interest. For example, a right-click on a generator will yield a box where you can change the voltage set point. If in that box you left-click on the generator symbol, a second dialog box appears where you can change H. To change the line parameters, a right-click on a line yields the appropriate dialog box. To change the line capacity, you must change the line reactance. Changing the number in an “MVA limit” box has no effect on the electrical characteristics of the line.

For each of your experiments, your report should include an explanation of why the behavior you discover is to be expected.

The understanding you obtain from this exercise may help you in the next step.

Step 6 – Generation Scheduling Based on Stability Criteria

In this step you will set generator outputs to achieve stability. The power system is experiencing a cold day in which all loads increase by 10%, creating possible overload and stability problems. This case is found in file 9busPlus10_EE455.psd.

Your goal is to schedule generation so that the transmission lines are not overloaded, and so that the power system will survive a fault on any transmission line. Thus, the following contingencies must be (separately) simulated in order to ensure that the system is secure:

1. A fault at bus 7 on line 6.
2. A fault at bus 7 on line 9.
3. A fault at bus 4 on line 4.
4. A fault at bus 4 on line 5.
5. A fault at bus 9 on line 7.
6. A fault at bus 9 on line 8.

Assume all faults are 3-phase to ground, and that each of the above faults is cleared in 4 cycles (0.0667sec). Find one set of values for the real power output P_g for each of the three generators such that none of the above contingencies cause overloads (post fault, the emergency limits apply. Prefault, the normal limits apply) or a stability problem for that set. Include in your report the results of the rescheduled power flow (showing that the transmission lines are not overloaded) and plots of the machine angles for at least some of the above contingencies showing that the system is stable. Note that the one set of generator outputs must satisfy the stability and overload criteria for all of the faults.

The following procedure is suggested to find a secure operating point:

1. Simulate the first fault.
2. Adjust P_{g2} and P_{g3} to a point that does not cause any overloads and simulate the fault again (note that P_{g1} need not be changed since it is the swing bus, and is automatically set to load minus other generation). If the new system is still unstable, adjust the generation and repeat the simulation. Use equal area criteria considerations to guide your search!
3. Once an operating point has been found for the initial fault, simulate the other faults. If these faults cause the system to become unstable, adjust the generation until a new stable operating point is found.

Explain your search process in your report, and in your presentation.

A major factor that is ignored in this design process is the cost of making changes in generation. Discuss in your report the probable consequences to generation cost of achieving stability.

Appendix - Technical Report Format

Your project report should be in the form of a formal technical report. While there is no single structure required, it could contain sections similar to the following.

- Abstract
- Introduction / Problem statement
- Technical approach
- Accomplishments / Difficulties
- Results / Examples / User session log
- Evaluation
- Conclusions / Possible future work, alterations
- Appendices with details

Your report should convey professional competence through its appearance, organization, formatting, writing style, spelling, grammar and, yes, even punctuation and page numbering.