

EE 554 PROJECT ASSIGNMENT, SPRING 2023, DR. MCCALLEY

Due: April 27, 2023

Power System Simulation for Engineers: Stability Analysis

Your assignment is to perform an *operating study* for the **Diablo Canyon Nuclear Power Plant** using the power flow and stability data provided to you by the instructor. The objective of the study is to **determine the safe operating limits for the plant, in terms of MW output power**, under the NERC disturbance class P1 given in the NERC Planning Standards. You may assume that this criterion is condensed to “the system must perform satisfactorily for a **three-phase fault at the machine terminals followed by loss of a single circuit.**” To perform satisfactorily, the machine must be stable, and no first-swing transient voltage dip can fall below 0.75 per-unit.

There are three 500 kV lines emanating from the plant under “normal” conditions. You are to develop the MW operating limits for a “weakened” condition whereby one line is out on maintenance. Since two of the lines are identical, this means that you must develop two different operating limits: with lines A, B, C, and A and B identical, you must identify (1) the operating limit with A out (2) the operating limit with C out.

I expect that everyone will use the Siemens software PSS/E for power flow and time-domain simulation. I do not object if you want to use something else, but I may not be as able to help you with program issues if you do use something else.

The following provides instructions for using the PSS/E software. This software has both power flow and transient stability applications. Note that these instructions are meant to assist you as a guide, but one should not expect that they are perfect nor will they alleviate you from having to think. Rather, expect to apply good judgment when using the programs. When you come to a point that appears unclear to you, assess the situation as well as you can, make a decision, note your thinking on a pad of paper, and move on.

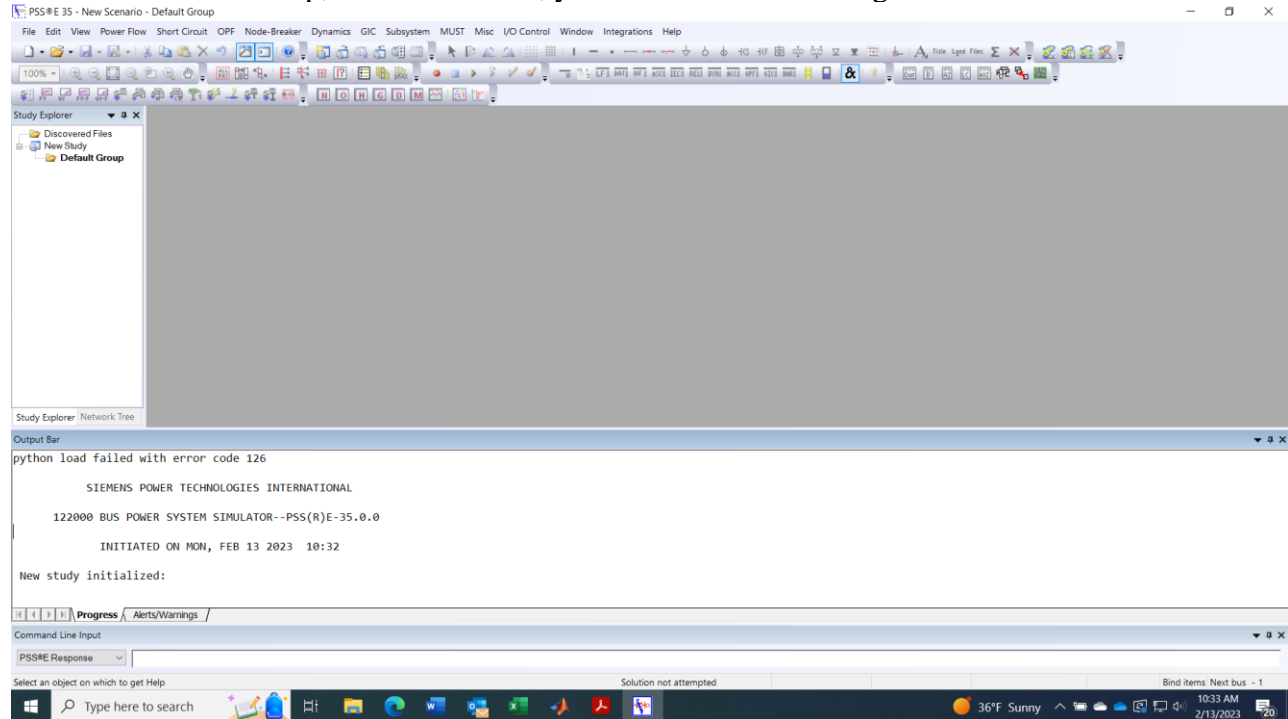
You can access PSS/E in any of the following Coover Hall teaching labs:

[1125](#) | [1313](#) | [2011](#) | [2014](#) | [2018](#) |

You can also access it remotely via the EE VDI virtual lab. Here is a link with info on VDI:

<https://etg.ece.iastate.edu/vdi/>.

Once you logged into a computer having PSS/E, the click on the start button, scroll down to find the “PSSE 35.3 folder, open the folder, and then click on the PSSE 35.3 icon. It might take a minute or so to come up, but once it does, you will see the following screen.



You can access manuals as a resource to clarify any problem you come across. Manuals can be found by using the “Help” button at the top right-hand-side of the menu and then selecting “PSS@E Documentation.” Page down the table of contents and you will see that this extensive manual includes information on use of PSS/E for AC power flow, DC power flow, contingency analysis, fault analysis, optimal power flow, probabilistic reliability, voltage stability, geomagnetic induced currents, node-breaker modeling, network reduction, and, of most importance to us, dynamic security analysis (DSA). The DSA material starts on p. 975 of the manual.

You are provided (on the website) with 4 data files:

- wecc179.raw: The power flow raw data file in PTI Version 30 format.
- wecc179.dyr: The machine data for all machines in the system.

These data files are from a test system which is *similar in structure* to the transmission system of the western U.S. However, I stress “similar” for two reasons:

1. The system is a product of gross approximation. Many essential features are omitted in order to keep the system relatively simple and small in terms of number of buses, lines, and machines. For example,

this system represents only 179 buses. Actual models of the western US grid typically have on the order of 30000 buses.

2. I do not have authority to provide accurate transmission models of the western US grid.

So one should understand that any results obtained using this model pertain only to this model and have little relevance to the actual western US grid.

Two high-level one-line diagrams of the overall system are given in Fig. 1 below, and Fig. 2 provides a more refined view of the portion of the system to be studied.

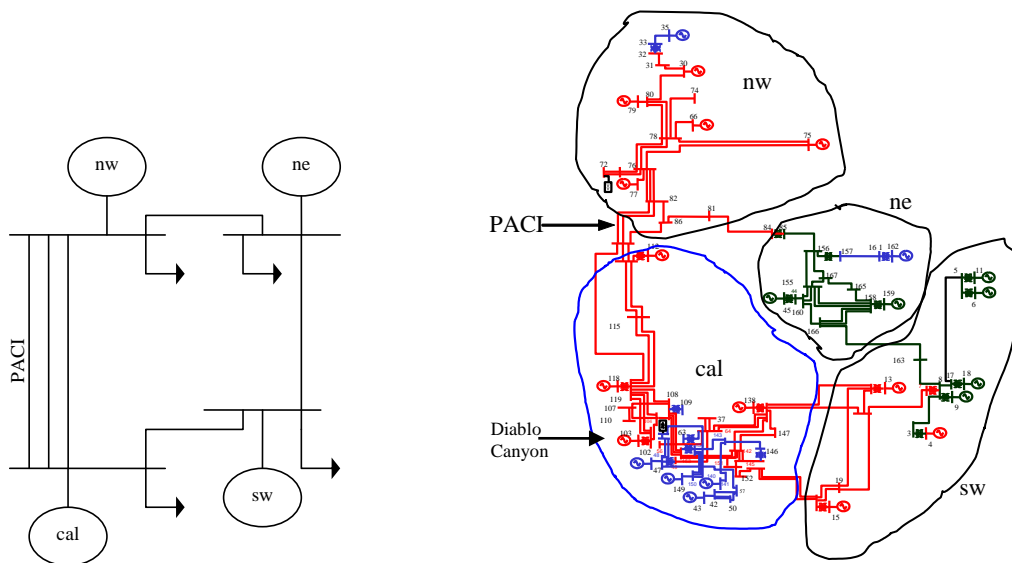


Fig. 1: High-level system one-line

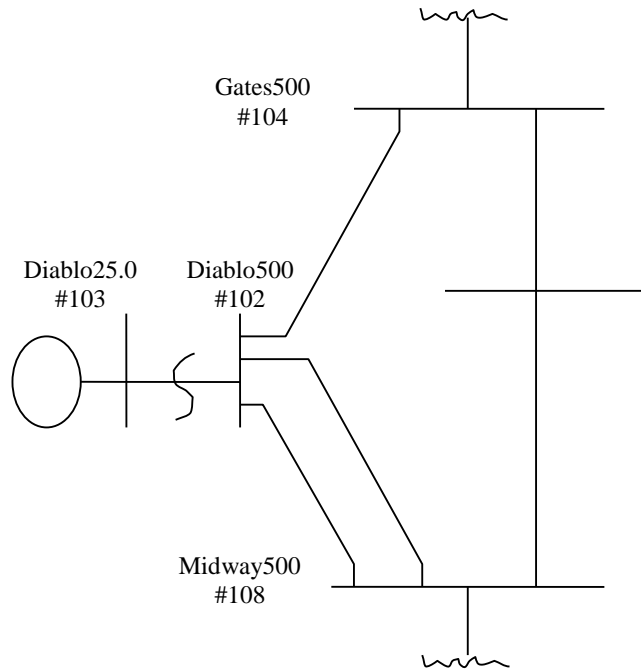


Fig. 2: Lower-level view of study area

You should be aware that there are two identical generating units at Diablo Canyon. Dynamic data for one of these plants are given below.

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THE BELOW CONTAINS STABILITY DATA FOR THE POWER PLANT OF INTEREST IN THE STUDY.
NOTE THAT THERE ARE TWO UNITS, BUT I HAVE ONLY PROVIDED DATA FOR ONE UNIT. YOU
MAY ASSUME THAT THE TWO UNITS ARE IDENTICAL. THE CORRSPONDING BUS NUMBER IN YOUR
POWER FLOW DATA IS 103. THERE IS DATA FOR THIS PLANT IN THE STABILITY DATA FILE
FOR YOUR SYSTEM, WHICH IS CALLED wecc179.dyr. YOU MUST CHECK THE DATA IN THE
FILE TO VERIFY THAT THE MACHINE DATA IS CORRECT IN RELATION TO THE BELOW. IF IT
IS NOT, THEN YOU MUST CORRECT IT. YOU NEED NOT BE CONCERNED ABOUT THE EXCITATION
DATA (CARDS FC AND FZ), THE PSS DATA (CARD SF), THE GOVERNOR DATA (CARD GS), OR
THE TURBINE DATA (CARD TB).
*****
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UT
NY O
IP W
I P TE N X'D X'Q T'DT'Q
MD < NAME ><KV>D<MVA> <F> <#> <> <> <> <> <> <> <>
MD DIABLO CYN 211340. 90 1 N PG+ 0.2810.281.043.124
```

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-----
I P Q MVA T'D T'Q SG10 SG12 D
MF < NAME ><KV>D<MWS ><%><%>< ><RA><X'D><X'Q><XD ><XQ >< ><XL >< >< >
MF DIABLO CYN 214650.01.01.0134000210.3460.9911.6931.6366.581.5 2280.07690.410.0
FC DIABLO CYN 21 .0000 0 0 40000 2 6.0 -6.0 1000 15
FZ DIABLO CYN 21 563 390 0 3850 40 10000.000 0
SF DIABLO CYN 21 0 020.00251000 20.322 0 0 0 0 .05 0
GS DIABLO CYN 211208.0 0.05 0.18 0.0 0.04 0.1 0.2
TB DIABLO CYN 210.200 0.30 5.0 0.70 0
```

However, the data in your system files (power flow and stability) represents only a single unit at the power plant. I have scanned the system data files and feel that the data for this plant is questionable. You need to check it to verify that it appropriately represents a single machine equivalent of the two machines given in the data below. Specifically, you need to check two things, one in pf data and one in dynamic data.

In what follows, Section A identifies how to modify the power flow data and how to run the power flow program. Section B identifies how to modify the dynamic data. Section C identifies how to run the time-domain simulation program.

A. Modifying pf data and running pf program

The power flow data, especially the transformer impedance (**the transformer impedance should be approximately 0.10 pu, when given on the machine base, but of course it must be converted to the 100 MVA system base when entered in the data**).

→ Note from the above “MF” card, we observe that the MVA base of the machine is 1340. If we are to represent two identical such machines, then the MVA base will be 2680. Assuming a transformer pu reactance on the machine base of 10% (0.1pu), then we will have the pu reactance of the transformer for the two-machine equivalent representation should be $0.1 \times (100/2680) = 0.00373$ pu. You need to modify the power flow data to account for this change. When you do, you should also check the power flow data to ensure that two units are modeled at the Diablo Canyon bus (103). Besides the transformer reactance, there are 2 additional things to check here:

- MVA rating: should be 2680MVA.
- Var limits: should be +660MVAR and -620MVAR.

Make sure you check the above 2 issues and make corresponding changes.

Let's first solve the power flow. To do this, follow these steps.

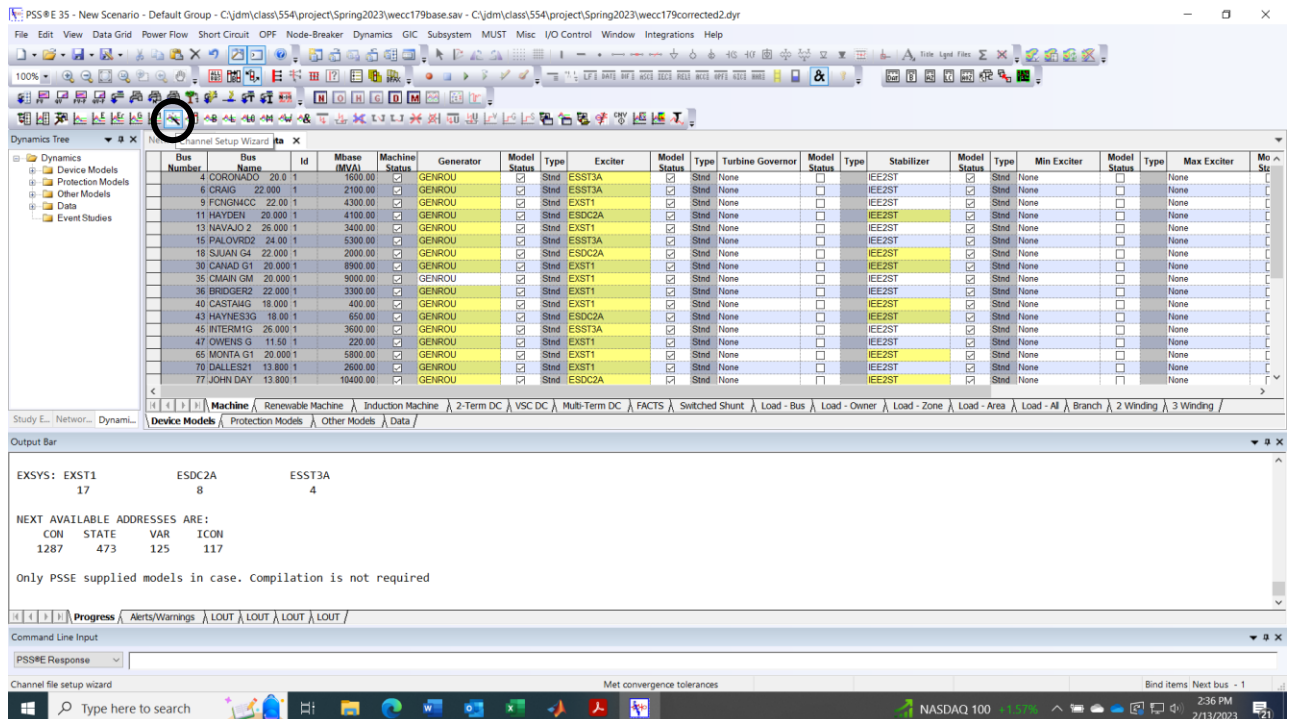
1. Click on the “File” button at the top left-hand-side of the menu..
2. Select “Open→File” and a dialogue box will appear.
3. Navigate to the folder where your data is located.
4. Select “wecc179.raw” and click “Open”. PSS\E will read the data.
5. Click on the “Power Flow” button in the top menu.
6. Select “Solution→Solve.” A dialogue box will open. You need not change any of these settings. Click “Solve” at the bottom of this dialogue box. You should then see some

reporting in the output bar at the bottom of the screen. Check to ensure it says “Reached tolerance,” that it has a reasonably small “largest mismatch” (perhaps 1 MW or less), and that the swing bus (John Day 13.8) generation is within its limit. If all this looks OK, then you have a solved power flow case. Click “Close” on the dialogue box.

7. Now check the generation at Diablo. To do this, click on the “Buses and Equipment” in the middle of the screen, and then select “Machine” in that menu location. Then scroll down the list of bus number/names until you see Bus Number 103 (Diablo01 25.0). Move the slider over to the right until you can see the columns titled “VSched (pu)”, “PGen (MW)” and “QGen (MVAR)”. Note their values should be 0.98 pu, 765 MW and -206.26 MVAR, respectively. We will be making power flow changes, and inspecting these values will confirm that we indeed made the change we intended.
8. Now we will modify the power flow data to adjust the Diablo transformer reactance. To do this, click on the “Branch” button in the middle of the screen. Then click on “2 Winding” and then find the Diablo 500 to Diablo1 25.0 transformer (it will be bus 102 to bus 103). Identify this transformer’s “Specified X (pu).” You should see that it is 0.0098. This is larger than it should be – change it to 0.00373 by simply typing the correct value into the cell containing the incorrect value.
9. Repeat steps 5 and 6 above.
10. Repeat step 7 above. You should see that the “Vsched (pu)” and “PGen (MW)” remain as 1.0 and 765 MW for Diablo1 25.0 (these are both inputs to the power flow program), but the “QGen (MVAR)” (an output of the power flow program) has increased significantly in the negative direction. Identify how much it has increased and explain why that happened. Do you think the change that caused this (xfmr reactance) is important for our stability-study objective? Why or why not?
11. The 0.98 pu voltage at Diablo1 25.0 is a little low. Let’s change it to 1.0pu by simply typing “1.0” into the cell containing the VSched for Diablo1 25.0.
12. Repeat steps 5 and 6 above.
13. Repeat step 7 above. You should see that the “QGen (MVAR)” has increased in the positive direction. Identify how much it increased. Do you think the change that caused this (increasing Vsched) is important for our stability study objective? Why or why not?
14. Note that you are not yet ready to perform the desired operating study, because to do so, you will have to make one more change to the power flow case (remove a line to create the “weakened condition” by removing from the power flow either “Line A” or “Line B.” Before doing that, let’s investigate the stability behavior of Diablo1 25.0 in the transmission system normal state. If the system is well-planned, we should see that the machine is stable even when generating at its maximum level of 2680 MW. To investigate this, change the generation level at Diablo1 25.0 from its current value of 765 MW to its maximum value of 2680 MW. If you make no other generation change in the network, then the swing bus (John Day 13.8) generation will compensate for this change. We will allow this in our study, under the condition that John Day 13.8 always remains within its MW limits. However, as a stability engineer, you should be aware of (i) whether this change is realistic and (ii) whether it is having positive or negative impact on the stability behavior you intend to study. (John Day 13.8 is in Oregon, and Diablo1 25.0 is about 230 miles south of San Francisco and about 180 miles north of Los Angeles, and with about 3000 MW being transferred from Oregon into California via lines 169-114, 171-114, and 173-111, increasing Diablo1 25.0 and decreasing John Day 13.8 will reduce the flow into California,

shifting some of the generation closer to the heavy Southern California load centers, having what might be a stabilizing influence on the entire interconnection, as long as Diablo1 25.0 itself remains stable for disturbances local to it). Click on “Buses and equipment” and then “Machine”, find Diablo1 25.0, and change its PGen (MW) to 2680.

15. Repeat steps 5 and 6 above. You should see that John Day 13.8 decreased by about the same amount that you increased Diablo1 25.0.
16. Repeat step 7 above. You should see that QGen (MVARs) increased in the positive direction.
17. Save the power flow case by clicking on “File→Save case as.” You will have opportunity to navigate to the directory of choice; then click on “OK”.
18. Now you are ready to run the transient stability time domain simulation application. Before doing so, I suggest that you watch a short video here: www.youtube.com/watch?v=UxTgYoCOI8E.
19. Read in your dynamics machine data by clicking on “File” on the left-hand-side of the top menu, and then select “Open→File”. Navigate to the directory containing your dynamics data “wecc179corrected2.dyr” and select it. A dialogue box will open. Click “OK”.
20. Make sure your toolbar contains the dynamics features. To do this, click on “View” in the top menu bar (left-hand-side) and select “Toolbars→Dynamics Simulation.”
21. Define the plot variables to be viewed after the simulation. To do this, go to the dynamics icon row, which is the fourth icon row from the top. Click on the “Channel wizard setup,” which is the 9th icon from the left in the dynamics icon row. In the below screenshot, this icon is circled.

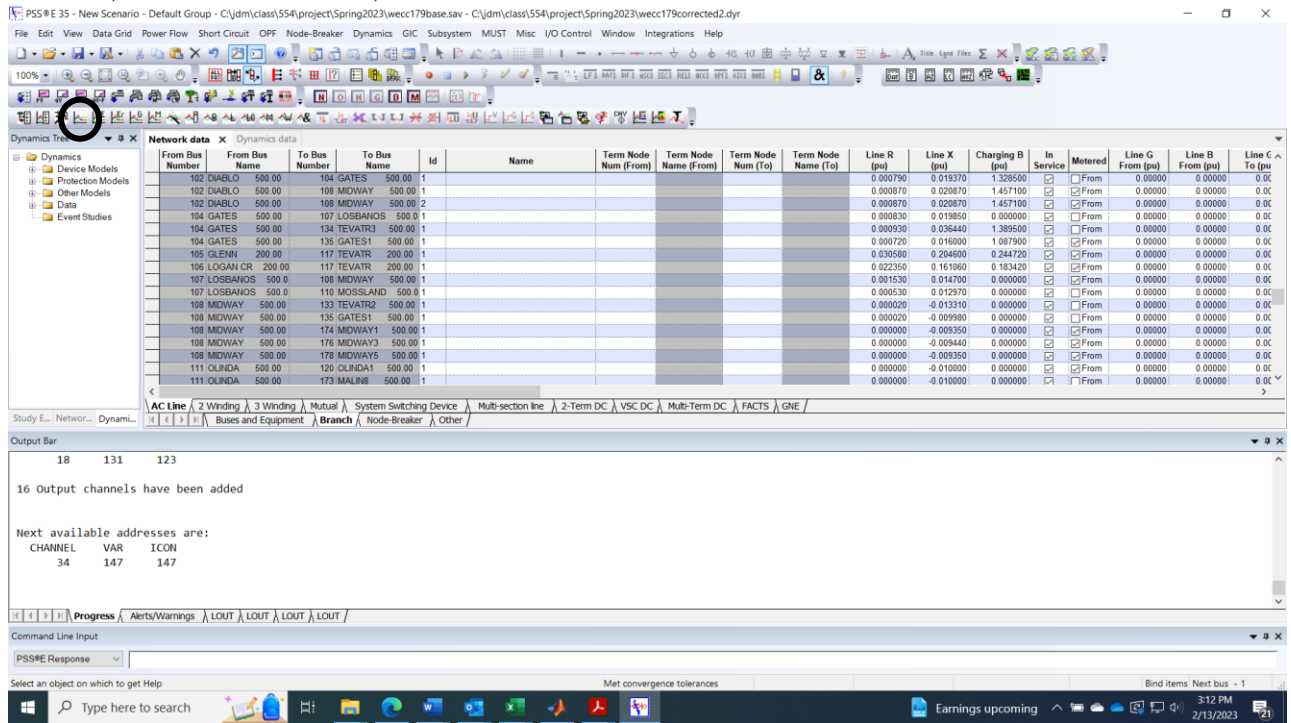


A dialogue box will open providing you with options on what you want to be available to you for plotting. A “Basic” selection is already made for you, and I suggest to use it with one additional selection. On the right-hand-side of the dialogue box, click in the “BsFreq” checkbox.

- Then, at the bottom of the dialogue box, you could click on “All buses” to make all buses and machines available to you for plotting.
- Alternatively, if you feel you don’t need to consider all buses, enter a more limited number, e.g., just the buses close to Diablo Canyon; for this, enter the following bus numbers at the bottom of the dialogue box, in the entry “The following buses:”, type: 102, 103, 104, 108. This will make machine variables available for bus 103 (Diablo1 25.0) and bus variables available for all four (buses are Diablo 500, Diablo1 25.0, Gates 500, and Midway 500).

Click “Finish” in the channel setup wizard dialogue box.

22. To run a simulation, select the dynamic simulation toolbar icon, which is in the fourth row of icons, fourth from the left, and is circled in the screenshot below.



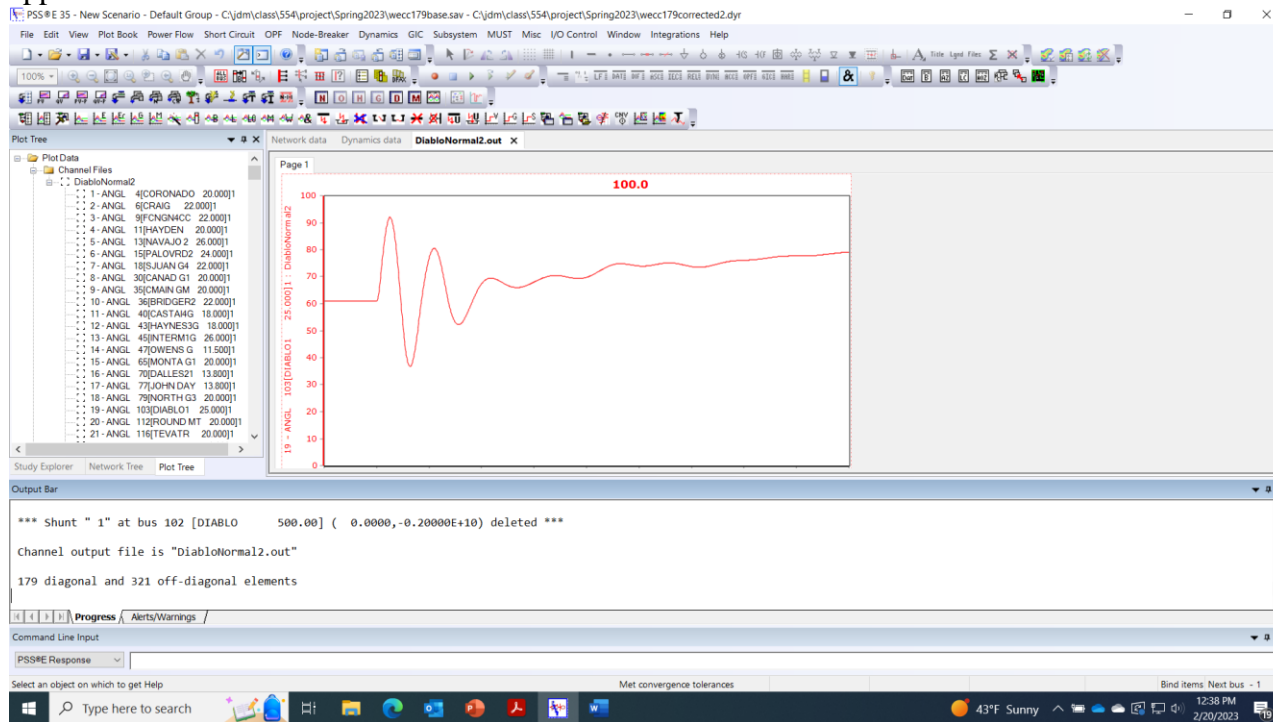
A dialogue box will appear to convert power flow loads, which are constant power loads, into the form you desire for dynamic simulation. I suggest to use the default settings already populating this dialogue box (P is 100% constant current and Q is 100% constant impedance). Click “OK” to close this dialogue box.

23. When you close the load conversion dialogue box in step 22, another dialogue box will open to initialize and run the simulation.

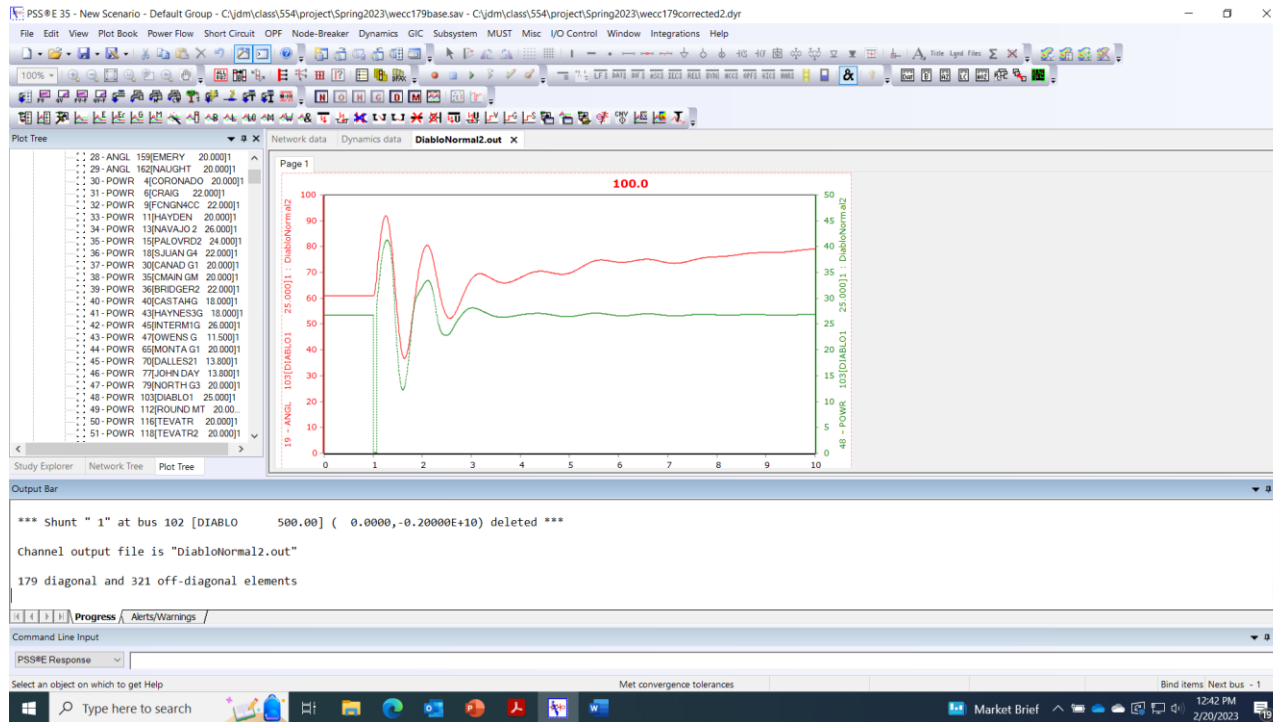
- First, you should specify the name of the plot output file, e.g., DiabloNormal. Doing so will write the plot output to the directory containing your power flow and stability data in a file called DiabloNormal.out. (Note that the program will not let you re-use an existing output file, and so repetitions of this step will require using a new name for the output file, e.g., DiabloNormal1, DiabloNormal2, etc.) Then click on the button “Initialize.”
- Next, change the “Print every” value from the default of “1” to “0.” (If you do not do this, you will have all output printed to screen, an action which will dramatically slow the simulation speed).
- Next, change the “Plot every” value from the default of “0” to “1.”

- Next, run the simulation without a disturbance (“flat”) for 1 second; you can do this by entering “1.0” into the selection box “Run to”. Then click “Run” in the dialogue box. Click “Close” in this dialogue box.
24. To apply a disturbance, select “Dynamics” in the top menu, and click on “Disturbances→Bus Fault,” and a dialogue box will appear. You can use the “Select” button to select Bus 102 (which is the Diablo 500 kV bus). You can leave the default values under “R” and “X” (these are specified in MW and MVAR at the nominal voltage, with MW=0 and MVAR=2E9, it means the susceptance is $B=2E9*1E6/500000=4E9$. This is a very large susceptance, which means it is a very small reactance, i.e., it looks like a short circuit). Now close the dialogue box by clicking on its “OK” button.
 25. Now you need to simulate for the fault-on period. Assume this period is 4cycles=0.0667sec. As in step 22, click on the dynamic simulation toolbar icon again, and change the “Run to” value from 1.0 to 1.0667. Then click the “Run” button at the bottom of this dialogue box. Then click “Close” at the bottom of this dialogue box.
 26. Now, similar to step 24 (where you applied the fault) now you need to remove the fault. Select “Dynamics” in the top menu, and click on “Disturbance→Clear Fault,” and a dialogue box will appear. The dialogue box will instruct you to “Select existing fault,” but there will only be one fault, and it will be already selected. You just need to click on “Go” at the bottom of the dialogue box.
 27. Now we need to remove a line. Note that in simulation, the fault-clearing of step 26 and the line removal are two steps, but in reality, these two things are usually the same thing. But here we are doing this via simulation, and so we must remove the line separately. To do this, again select “Dynamics” in the top menu, and click on “Disturbance→Trip Line.” A “Trip a Line” dialogue box will appear. Leave the default seeing “Trip a Branch” selected (i.e., do not select “Trip a 3-Winding Transformer”). On the right-hand-side of the dialogue box, click “Select”. A “Branch Selection” dialogue box will appear. Page down using the slider until you see Bus 102 (Diablo 500). Left click on that bus. When you do, you will see four other buses appear in the right-hand window of the dialogue box. Click on “104[Gates 500]”, which will model tripping of the Bus 102-Bus 104 (Diablo to Gates 500 kV) line. Click “OK” at the bottom of the dialogue box. This will return you to the “Trip a Line” dialogue box, where you can click “OK.”
 28. Now you need to simulate for the post-fault period. We will consider this period to be 10 seconds. As in step 25, click on the dynamic simulation toolbar icon again, and change the “Run to” value from 1.0667 to 10.0. Then click the “Run” button at the bottom of this dialogue box. Then click “Close” at the bottom of this dialogue box. The simulation will be very fast (unless you are “Printing” to screen in which case you should select “0” as the choice for “Print every” in the dynamic simulation toolbar icon – see step 23-b above). Once the simulation is complete, then click the “Close” button on the dynamic simulation dialogue box.
 29. You can view and copy plots as follows:
 - a. First, click on “File” in the top menu, left-hand-side, and then selecting “Open”. A dialogue box will appear and will show the directory containing the output file you created in step 23 above (in these notes, we called it “DiabloNormal,” and if you used the same name, you should see the file called “DiabloNormal.out”). Select this file and then click “Open.” This action will result in a “Channel Plot” box appearing in your middle right-hand pane.

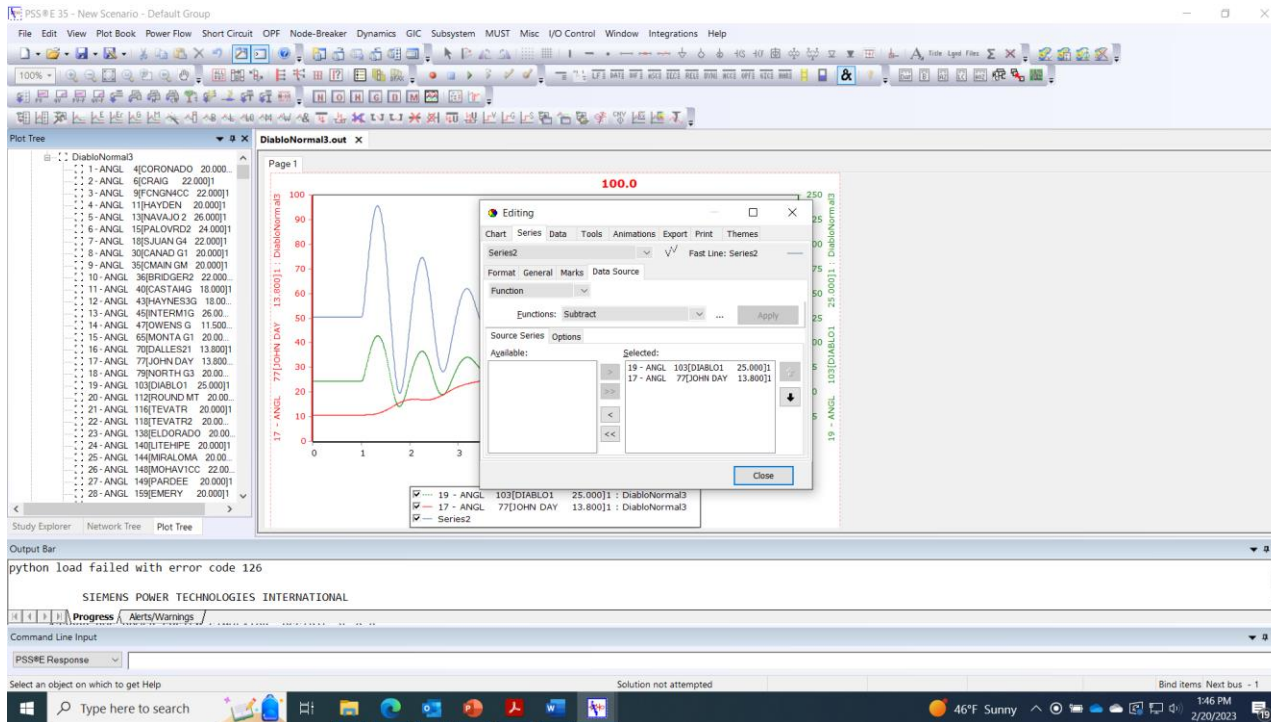
- b. Now you need to show the “Plot Data” in the middle left-hand pane. To do this, click on “View” from the top menu and select “Plot Tree.” Double click on the folder icon called “Channel Files.” Then click on the icon having the name of your “out” file. This will open your choices for plotting [your choices for plotting will depend on your decision in above step 21 (where you chose either 21a or 21b)].
- c. Choose a desired variable to plot from the middle left-hand pane, e.g., “ANGL 103[DIABLO1 25.000]1. Left-click on this variable in the middle left-hand pane, and drag to the middle right-hand pane. Once you do this, the PSS/E screen should appear as below.



- d. We may like to plot another variable, e.g., real power. To do this, drag the slider for the middle left-hand pane down until you see “POWR 103[DIABLO1 25.000]1.” Then left-click on this variable in the middle left-hand pane, and drag to the middle right-hand pane. Once you do this, the PSS/E screen should appear as below. Observe that the first variable (angle) has its scale on the left-hand axis, and the second variable (power) has its scale on the right-hand axis.

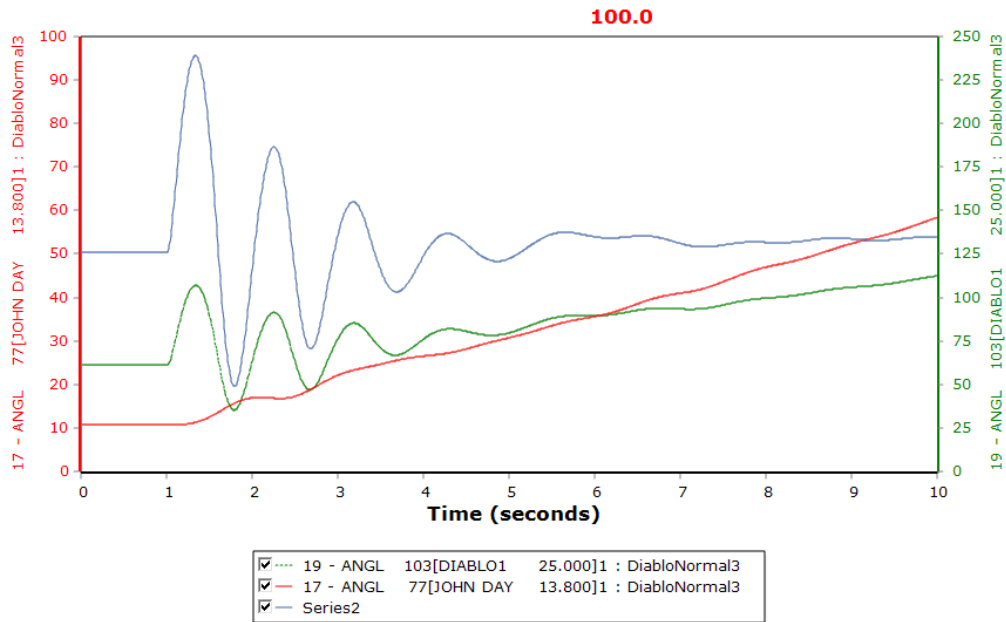


- e. You might like to plot relative rotor angle. To do this, let's start over. Right-click in on top of the plot shown in the middle right-hand pane and click on "Delete series." A dialogue box will appear – click "Delete" and then it will ask you "Do you really want to delete..." and you should click "OK." Repeat this "Delete series" process until you no longer have any plots showing on your middle-right-hand-side screen. Then drag "ANGL 77[John Day 13.800]1" from the middle left-hand pane to the middle right-hand pane. Repeat for "ANGL 103[Diablo1 25.000]1." Then left-click in the middle right-hand pane, and select "Show editor." The "Editing" dialogue box will appear; click the "Add" button on the right-hand-side. A "Tee-chart gallery" dialogue box will appear; at the top, you will see menu tables "Series Functions Templates." Click on "Functions." The dialogue box will change form, and you will see a list of functions on the left. Use the slider to move down the list until you see "Subtract." Click on "Subtract" and then click on "OK." This will take you back to the "Editor" dialogue box. Use the ">" function in the middle to move the two buses to the right-hand-pane of the dialogue box, and then click on "Apply," after which it should appear as shown below.

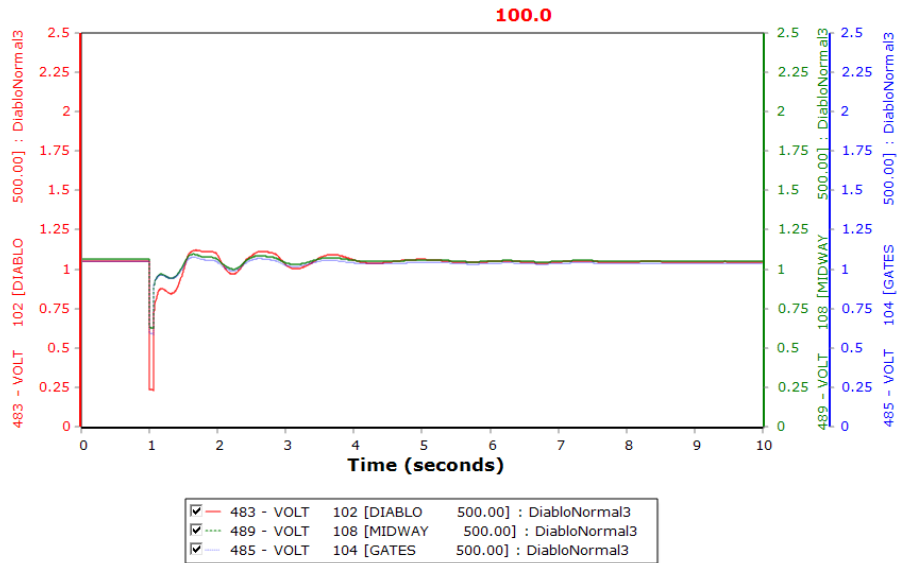


Click “Close” in the “Editing” dialogue box, and you will see the three plots (the two angle plots for Diablo1 and John Day, and the relative rotor angle plot called “Series 2” which is the angle of Diablo1 relative to John Day. Note that John Day is a useful reference to use because (i) it is large and (ii) it is pretty far from Diablo.

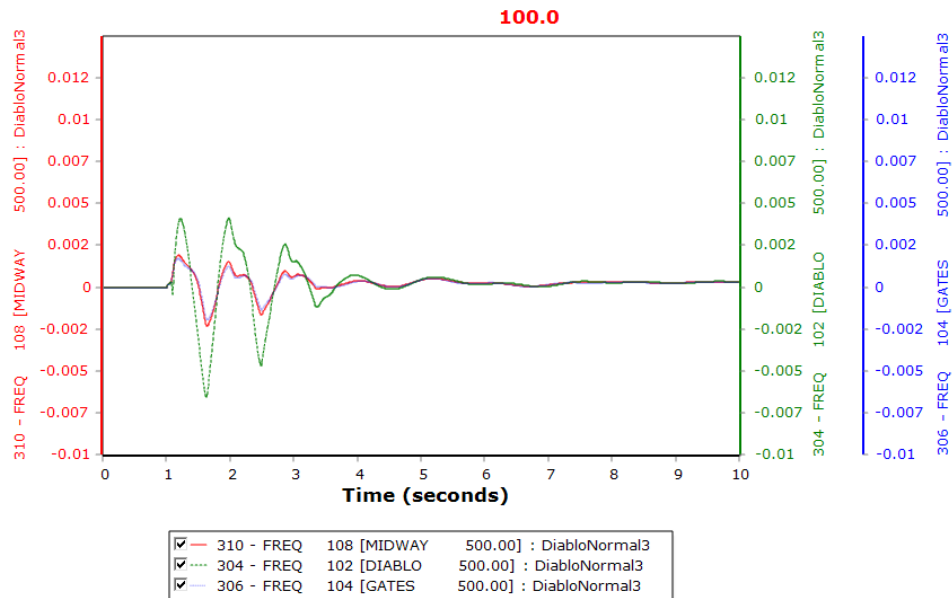
- f. Now you can copy the plot you have just made (or any of the above plots you made) by clicking on the “Plot Book” selection in the upper menu. Select “Copy to Clipboard→Bitmap”. Then you can paste that plot into a word file, which should appear as below. One useful conclusion of this work is that the case is clearly stable, as indicated by the Diablo relative rotor plot.



- g. It is suggested to also check the voltage plots for the three 500 kV buses at Diablo, Gates, and Midway, to ensure they do not dip below 0.75 pu. These plots will appear as below.



- h. For simulations where we are dropping significant amounts of generation, then it may also be important to plot bus frequencies, as shown below (and we would want to see bus frequencies above 59.5 Hz to avoid underfrequency load shedding). However, for this project, where you will only be tripping lines, bus frequency plots are not too important.



30. The above 30 steps should put you into a position where you can complete this project. After you are comfortable with the above 30 steps, then the effort associated with performing the project should be relatively modest. To proceed from this point, you should realize that you will perform three separate operating studies:

- a. Find the Diablo generating limit with Diablo – Gates out of service. This requires studying various levels of Diablo generation output to find the maximum value for which Diablo is stable for loss of one Diablo – Midway line.
- b. Find the Diablo generating limit with one Diablo – Midway line out of service. This requires
 - i. studying various levels of Diablo generation output to find the maximum value for which Diablo is stable for loss of the remaining Diablo – Midway line, and
 - ii. studying various levels of Diablo generation output to find the maximum value for which Diablo is stable for loss of the Diablo – Gates line.

For each of the above three studies, you will need to (A) guess a Diablo generation level; (B) run the appropriate simulation; (C) judge whether the case is stable with acceptable performance. Step (A) will be initially a guess, but subsequent Steps (A) would be “guided guesses,” e.g., if the MVA rating of the unit is 2680 MW, then, with one line out, one might guess at first that the limit is 1800 MW. To check the guess, then one needs to modify the power flow accordingly and resolve it, and then initiate the stability simulation with that resolved power flow. If the result is stable with acceptable performance, then one would try a higher value. If the result is unstable or it has unacceptable performance, then one would try a lower value. It is reasonable to identify the stability limit to the nearest 50 MW.

31. ...

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You should develop a report to the WECC Operating Committee providing safe operating guidelines for Diablo Canyon Nuclear Power Plant for one of its 500 kV lines out of service. Your report should contain the following information:

- A. An “Executive Summary” briefly (1 paragraph) describing the project objective together with the significant conclusions.
- B. An “Introduction” describing the problem and the objective together with the structure of the report.
- C. A “Methodology” section describing the approach taken and the tools used.
- D. A “Results” section which provides an overview of a table summarizing all results, the table itself, and relevant plots to support the result summary in the table. If there are a very large number of plots, then it might make sense to only provide a few representative plots in this section, and include the rest of them in an appendix.
- E. A “Conclusions” section which identifies the significant conclusions in relation to the project objective together with comments on any other observations made related to future operation of the Diablo Canyon Nuclear Power Plant.