ELEN 460
Computer Laboratory Exercise No: 6
Power Flow Analysis on Small and Medium Sized Systems

Objective:

Gain experience and insights on the power flow problem by running power flow studies on both a 37 bus system and a 2000 bus system. Observe the effects of changes in generator, transformer and shunt capacitor controls on the system bus voltages and transmission line flows.

Background on 37 Bus APL System

Assume that you are an operations engineer working for Aggieland Power and Light (APL). Your job is to provide engineering support for the real-time operations of your small, but beloved 37 bus power system which supplies Aggieland. This is a 345/138/69 kV system. As you start your shift, immediately there is a failure at the Kyle138 generator, resulting in a loss of 175 MW of generation in the heart of your system. This causes several line overloads. Seemingly by magic, your boss provides you with the current power flow solution for your system, whose oneline is shown in Figure 1. Immediately you focus in on two overloaded lines: the 138 kV line from HOWDY138 to WEB138 and the 69 kV line from TEXAS69 to REVEILLE69. You do wonder how their MW flow fields are already highlighted on the oneline, but that is a question best left for another day. Your boss asks for your recommendations on how to fix the system, but also insists that you follow the following procedure.

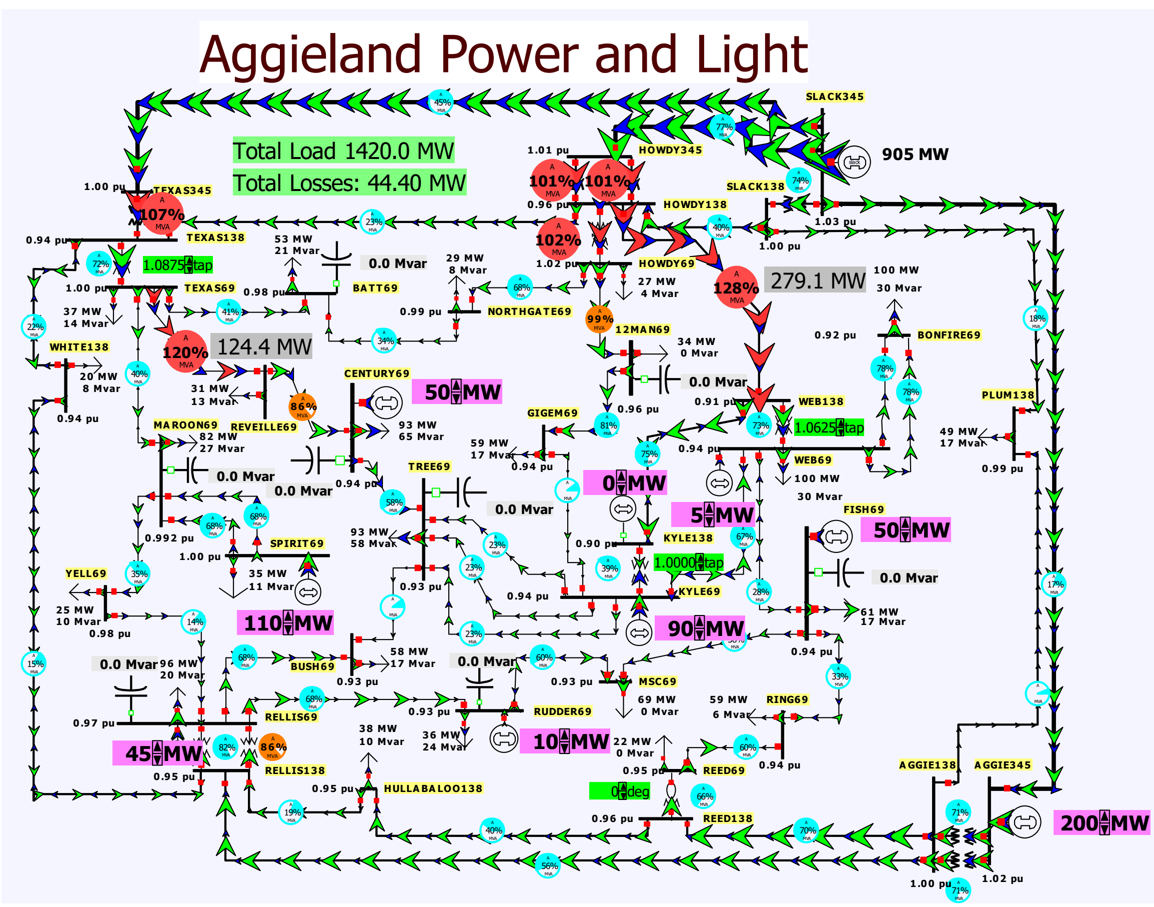

Figure 1: 37 Bus APL System

Procedure for 37 Bus System

0. You know your boss is a stickler for following procedure, so even though time is of the essence, you know you must read through the entire procedure for the 37 bus APL system before you start. You also know you'll need to prepare a report on what you've done afterward, so you need to keep a log of what you do.

1. Start PowerWorld Simulator. Open the Lab6_Bus37Start case. This power flow case represents the current situation with the KYLE138 generator out-of-service. The KYLE138 generators reports it has a severe failure so this generator is out for the duration. Now your boss asks that you select four other generators that could be used to fix the HOWDY138 to WEB138 and the TEXAS69 to REVEILLE69 line flow violations. In your report explain why you selected these four generators.

2. For each of the four generators selected in Step 1, experimentally calculate the sensitivities of the MW flow on each of the two overloaded lines (conveniently highlighted on the oneline) to the change in the output of each of the four generators you selected in Step 1. Then determine whether these sensitivities are relatively constant. That is, is there a nearly linear relationship between the change in the generation and the change in the line flows. Go in 5MW increments, and change the output of the generators by 25 MW total. In doing this calculation, assume that the change in the output of each generator is absorbed at the slack bus. Record all your results for your report.

3 You then remember that APL has recently installed a phase shifting transformer at REED substation, going between the 138 and 69 kV buses (shown at the bottom of the oneline). Starting with the initial power flow solution (which you can get by reloading the case), experimentally calculate the MW line flow sensitivities for a change in the phase shift across this transformer. Go in two degree increments (conveniently provided by the arrow in the degree field), and demonstrate the degree of linearity in this calculation. Of course all values are recorded in your report. The range on the phase shifter is between -30 and 30 degrees.

4. Develop the action plan to fix the overloads that you will shortly be providing to the system operator. Your boss wants your recommended fixes to require as little change in generation as possible, but you can feel free to change the phase shifter as much as desired (up to its limit and avoiding any other line overloads). The better plans are ones that require less change in total generation (you to not need to consider changes to the slack bus generation). While usually you would want your system to be N-1 reliable, now you just need to get the loading on all the lines back to 100% or less.

5. Implement you plan in the power flow. Save the case for your report, but in doing so be sure to use **SAVE CASE AS** to avoid overwriting the existing case. Then make a copy of the oneline diagram with the changes implemented. To save a online image, right-click on a blank portion of the oneline. This will display a local menu. Select **Export Image to File** and save it in one of your directories. You'll need to include this in your report.

6. You pass your recommendations on to your boss, who gets them to the system operator, thereby saving the system from disaster (assuming all your calculations are correct)! However, before you can celebrate, your boss notices that the reactive power loading on the system appears to be quite suboptimal. Somebody appears to have switched out all eight of the capacitor banks, and the taps on the three LTC transformers (shown in green

on the oneline) appear to be messed up, resulting in circulating vars (indicated by the blue arrows on the oneline). In particular there are circulating vars between the WEB and KYLE substations. Your boss asks for your recommendations on which capacitors to switch in and the tap ratios for the three LTCs, with the goal of minimizing total system losses. Luckily there is a procedure to follow.

7. Each of the three LTC transformers has taps that move between 0.9 and 1.1 off-nominal turns ratios in 0.00625 steps (hence a total of 33 steps). Starting with your solution from Step 6, for the transformer at WEB, create a graph showing how the total system losses change as you move the taps between 0.9 and 1.1. You can go in two tap increments, so your graph will have a total of 17 points.

8. Starting with your solution from step 6, for each of the eight capacitors record sequentially how the losses would change if that capacitor (and only that capacitor) was energized. Be sure to re-open each capacitor as you move to the next.

9 Pick one capacitor and close it. Then repeat Step 8 for the other seven capacitors. Comment on whether you think this is a linear relationship. That is, does superposition hold?

10 Using your engineering judgement coupled with experimentation, come up as closes as you can get to the optimal values for the three LTC transformer tap ratios, and the eight capacitor switch positions.

11 Save an image of the oneline with your changes; this should be included in your report.

12 In your report, provide a procedure that future engineers (who might not all be Aggies) can use to solve this type of problem.

Background on the 2000 Bus TSGC System

After a good early career at APL, you've now moved and are working for the Texas Synthetic Grid Company (TSGC). TSGC is charged with insuring that the Texas synthetic electric system is operated in a reliable manner. Your job is again to provide engineering support for the real-time operations of now a 2000 bus system. As luck would have it, again as you start your shift immediately there are problems. This time it is the loss of two 500 kV lines due to a tornado passing just east of San Antonio. Again you are provided with the current power flow solution for your system. Your focus is immediately on the San Antonio, Austin and Houston area, with the oneline shown in Figure 2. The two open 500 kV lines are indicated by the large green and black circles with the "X" through them. You know from your now vast experience that unless action is taken quickly the whole TSGC system could experience a cascading blackout. And that action will be a redispatch of the nearby real power generation. So you start working the following procedure to get the problem solved.

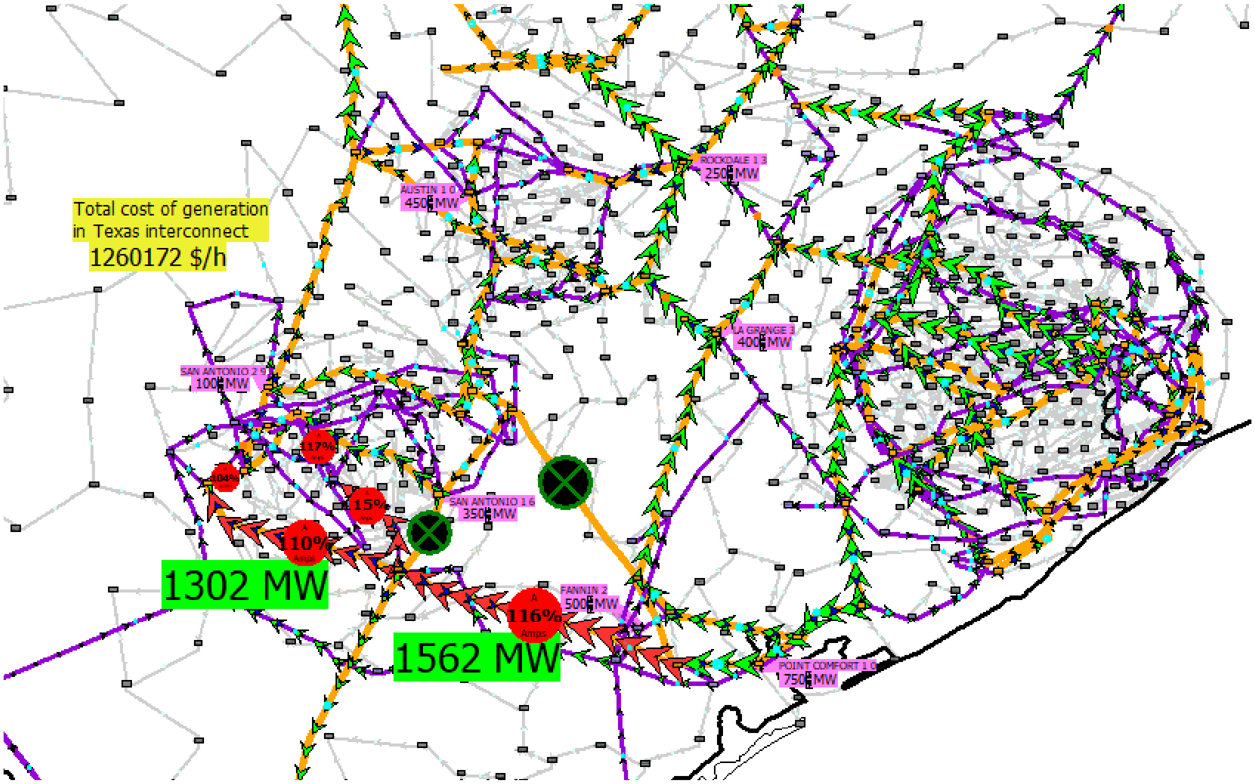

Figure 2: 2000 Bus TSGC System, San Antonio, Austin, and Houston Area

Procedure for TSGC System

1. Open up Lab6_Texas_Start. This is the TSGC power flow with the 500 kV lines shown in orange and the 230 kV lines in violet.
2. Seven generators are available to control, indicated by the magenta labels and MW set point fields. Collect some data on how the line overloads change with each generator's set points, and decide on a recommended course of action to fix the overloads that will involve the least total change in generation. Implement this plan in the power flow and adjust it as needed.
3. Save a copy of the oneline file image that you should include in your report.
4. The total cost of generation is given in the gold field on the oneline diagram. Note how your control actions affect the total cost and mention in your report. Since this is an emergency situation, cost is not a crucial concern right now so you do not need to elaborate on this in your report. However, this is something we'll return to the next experiment.

Report:

For both the 37 bus and 2000 bus systems, provide a step by step account of the procedure you followed and the results you have obtained. Your report should answer all of the questions raised in the procedure. As is fitting for engineering practice, document your recommended specific course of action and justify it with data you have collected. Be sure to include images of the systems and keep in mind that the executives reading your report will want it well written.