Dipartimento di Energia

POLITECNICO DI MILANO

Electric Power Systems Project 2019-2020
Power Flow Analysis on Medium Sized Systems

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

Assume that you are an operations engineer working for PoliTSO Power and Light (PPL). Your job is to provide engineering support for the real-time operations of your small, but beloved 37 bus power system which supplies PoliMi. This is a 345/138/69 kV system. As you start your shift, immediately there is a failure at the SPIRIT69 generator, resulting in a loss of 110 MW of generation in the heart of your system. This causes several line and transformer overloads. 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 the overloaded lines and transformers. Your boss asks for your recommendations on how to fix the system, but also insists that you follow the following procedure. The procedure is based on using PowerWorld Simulator, which can be downloaded at https://www.powerworld.com/gloveroverbyesarma.

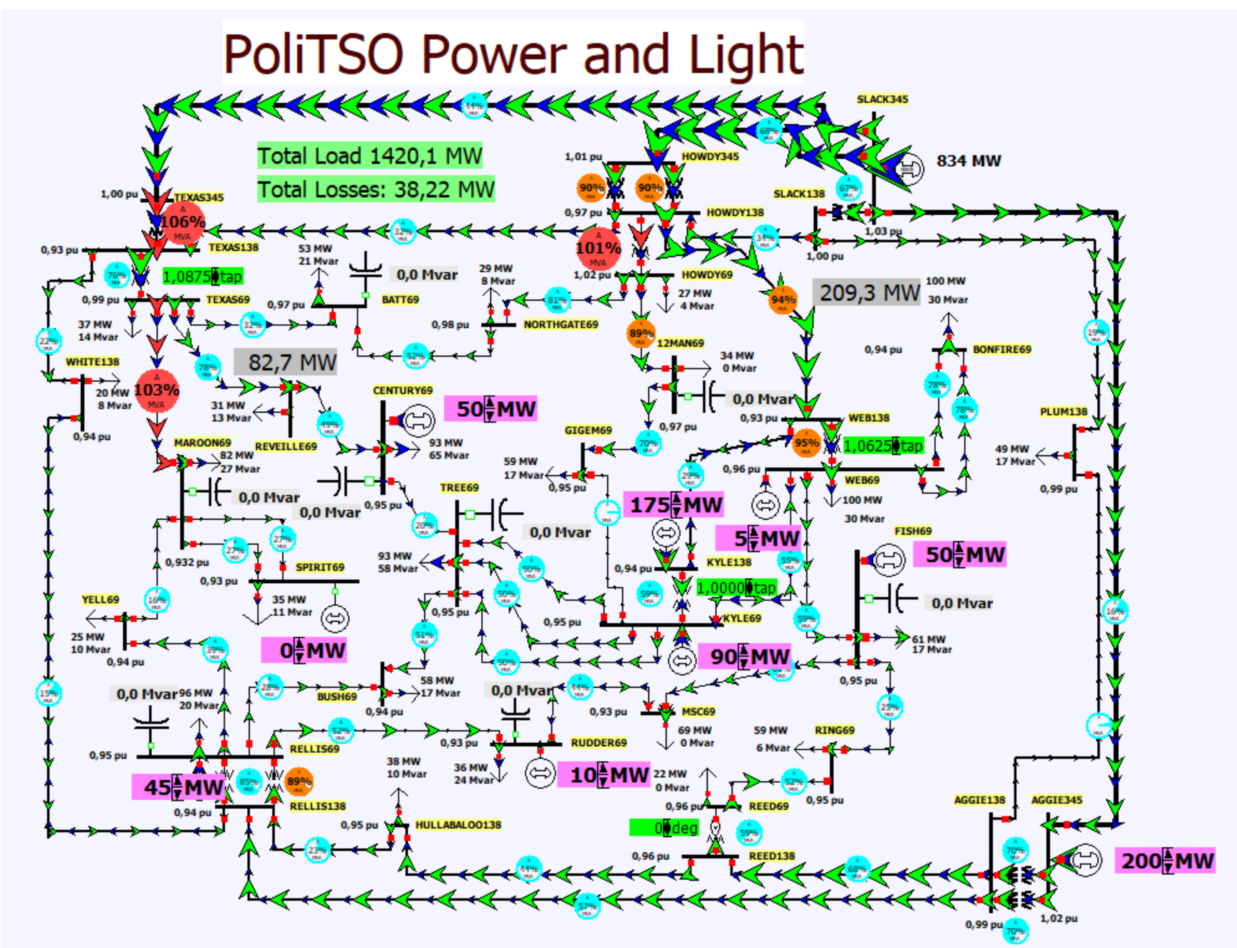

Figure 1: 37 Bus PPL System

Procedure for 37 Bus System

You know your boss is a stickler for following procedure. So you know you must read through the entire procedure 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 Pr_1_37Bus_Start case. This power flow case represents the current situation with the SPIRIT69 generator out-of-service because of a severe failure; so, this generator is out for the whole duration. Now your boss asks that you select <u>two</u> other generators that could be used to fix the power flow violations. In your report explain why you selected these two generators.
2. For each of the two generators selected in Step 1, experimentally calculate the sensitivities of the MW flow on each of the overloaded elements (conveniently highlighted on the oneline) to the change in the output of each of the two 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/transformer 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. Compare and comment results of Step 2 with the one from the PowerWorld Simulator tool *Sensitivities*. How the sensitivities change considering bus AGGIE345 as the new slack bus? Record all your results for your report.
4. You then remember that PPL 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/transformer 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.
5. 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 (only consider the <u>two</u> generators selected in Step 1), but you can feel free to change the phase shifter as much as desired (up to its limit and avoiding any other line/transformer overloads). The better plans are ones that require less change in total generation (you do 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 and transformers back to 100% or less.
6. Implement your 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 an 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.

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). 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.

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 5, 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 5, 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 from PoliMi) can use to solve this type of problem.
13. Determine what are, in the operating condition determined at Step 5, the critical contingencies (max branch [%], min volt, max volt) according to the ENTSO-e N-1 security criterion. List in a Table the main critical contingencies and why they are critical.

Report:

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.