Impact of High Photo-Voltaic Penetration on Distribution Systems

DESIGN DOCUMENT

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1 Introduction

1.1 PROJECT STATEMENT

The amount of solar generation is increasing rapidly in Iowa, and the current systems are having problems (over-voltage, opposite direction power flow, the possibility of islanding, etc.) keeping up with all the additions. In this project, we are trying to assess the impact of high penetration solar power generation on distribution feeders and its effects on the power quality delivered to the consumer.

1.2 PURPOSE

The purpose of this project is to use computer-modeling systems to analyze the impacts of solar generation in the utility's distribution systems. This will be beneficial to the society because we will be able to find the adverse effects of high penetration solar generation before the implementation of the generation, so the customers never see the problems. Also, this project will allow for more solar power on distribution systems while limiting the problems seen.

1.3 GOALS

We have several goals that we would like to achieve. Our goals are shown below.

- Simulate an Alliant-owned distribution feeder while incorporating solar PV generation into the simulation to observe the effects
- Compare community PV generation and residential PV generation to determine the best way to incorporate solar power into distribution systems
- Find solutions that will prevent future problems relating to solar PV generation on the Alliant Energy Systems

2 Deliverables

The deliverables necessary in this project are listed below.

- Voltage profiles and other necessary plots from simulations
- Comparison of residential and community solar PV generation
- Results of simulation with solar PV in certain areas
- Possible solutions for modifications to distribution system
- Cost Estimations

3 Design

We have been using OpenDSS software to simulate an IEEE 34Bus distribution system with load shapes from different seasons throughout the year. Our latest task has been to introduce solar PV into the distribution system at certain points to figure out where it has the highest impact and where the voltage is out of bounds.

3.1. SYSTEM SPECIFICATIONS

3.1.1 Non-functional

- Can the current Alliant system support high solar penetration as it exists now?
    - What modifications will the system need?
- How much would modifications cost to the current system?
    - We are looking for the best solution with the lowest cost

3.1.2 Functional

- Analyze IEEE distribution systems.
    - Load profiles
    - Voltage magnitudes and angles
    - Voltage violations at busses
- Add Solar PV to the distribution models
    - Compare the load profiles to those from the base case
    - Compare the power flows to the base case
- Analyze the Alliant Energy bus system provided
    - Load profiles
    - Compare those when solar is added
- Determine what modifications need to be made to the current Alliant system for it to be feasible to add residential and community solar PV

3.2 PROPOSED DESIGN/METHOD

We will not be able to reach a consensus on what we will implement until we get to analyze the Alliant Energy system. This will be the goal of the next semester as we are introduced to the Alliant Energy system. So far, we have been doing our analysis on the IEEE 34Bus system that gives us a good idea of how a distribution system will react when solar PV is introduced at certain points in the system and analyzed at different times of the year. We plan on simulating the Alliant Energy System to the full extent if a possible amount of solar PV was added to it shortly. Our analysis and problem-solving methods should translate over fully from the IEEE test cases to the Alliant Energy distribution system.

3.3 DESIGN ANALYSIS

We have been working with IEEE test cases and so far have just begun introducing solar PV into the 34Bus system. We will do the same with the 123Bus system and simulate different scenarios with solar PV penetration during the summer and winter as well as during various times of the day. From this, we will discuss and plan to add voltage regulators and capacitor banks at specified locations in the system to regulate the voltage levels and keep them in bounds.

4 TESTING/DEVELOPMENT

4.1 INTERFACE SPECIFICATIONS

During our first meeting with our adviser, he explained which software we would be using for the entire project, which in our case is OpenDSS. We have could work with the software a lot over the course of the semester. It is the same software that we will eventually use to load in the Alliant Energy distribution system.

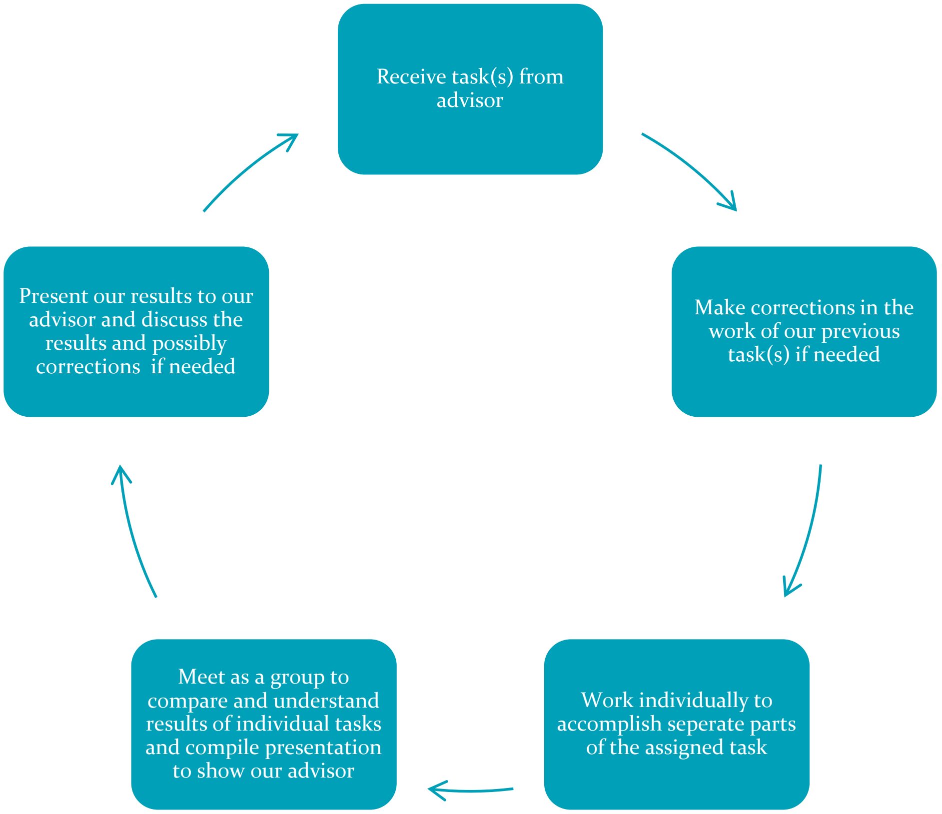
4.2 HARDWARE/SOFTWARE

We have been using OpenDSS and will continue to use it for the remainder of the project. It is the leading software that is used to simulate our scenario for the 34Bus and 123Bus systems that we will be simulating. Eventually, we will use the Alliant Energy distribution system with our simulation and use OpenDSS to run it.

We also use Excel to export data into organized files. This way, we can plot the data in graphs to explain what happened during the simulation clearly.

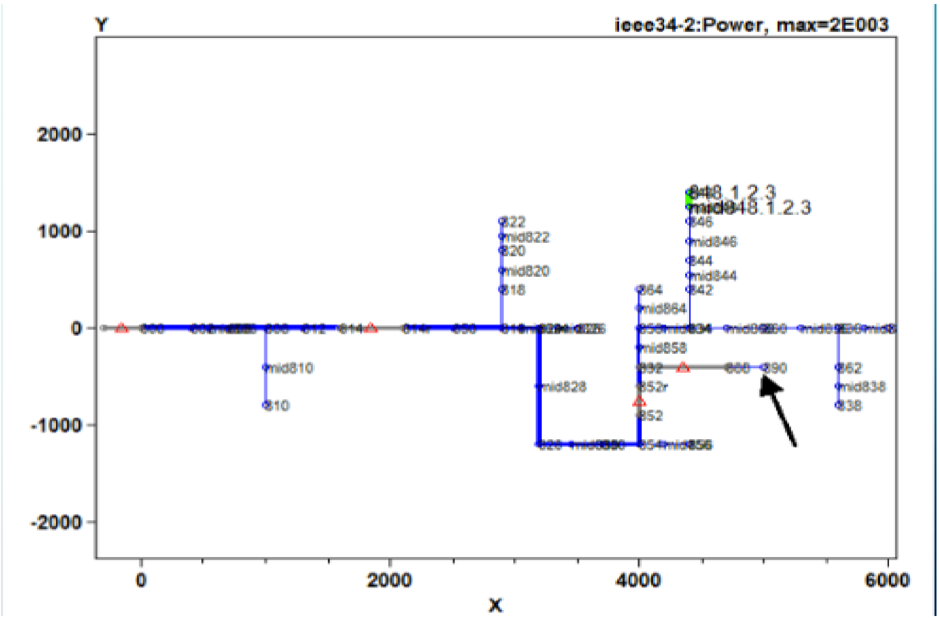
4.3 PROCESS

Shown below is our flow diagram:

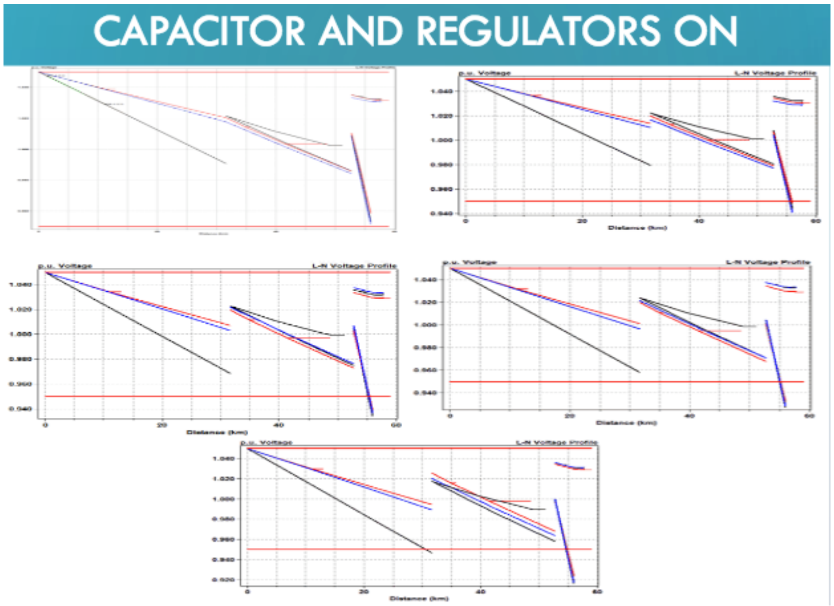


5 Results

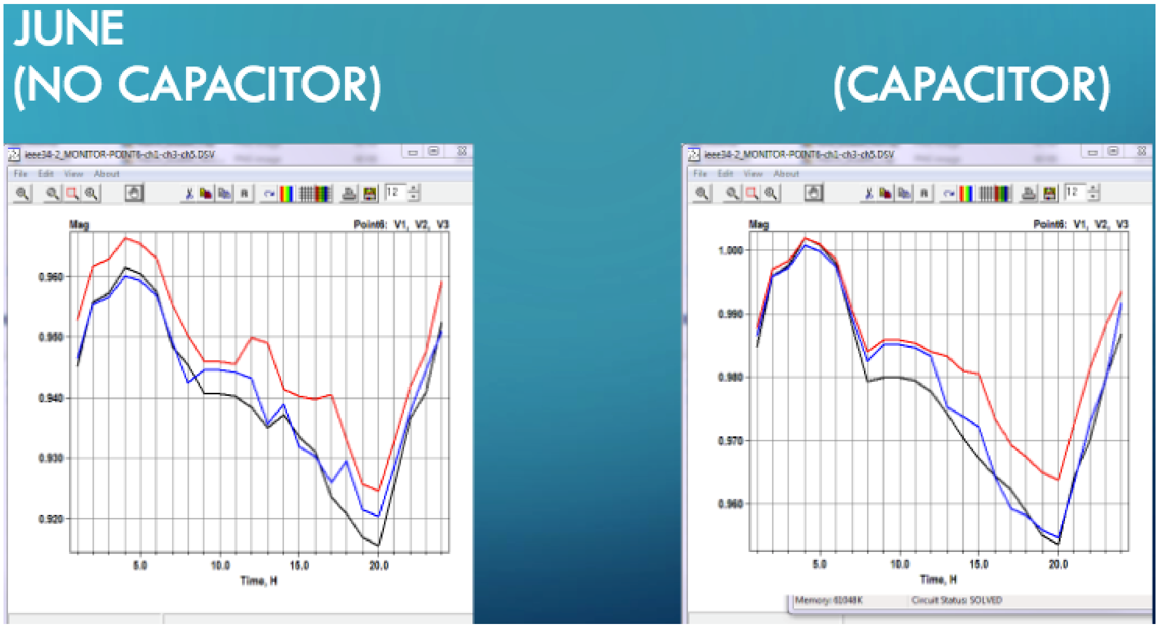
This is a 34-bus system, which we analyzed according to months and over period of 24 hours.



Shown below are the load voltage plots, each group member had to analyze load profiles for different loads and see how capacitors and regulators affect the system. There were four cases that we analyzed of capacitors switched on and off and same for regulators. We did the same thing for three more cases. We looked for voltage violations shown by the red lines on top and bottom.


CAPACITOR AND REGULATORS ON

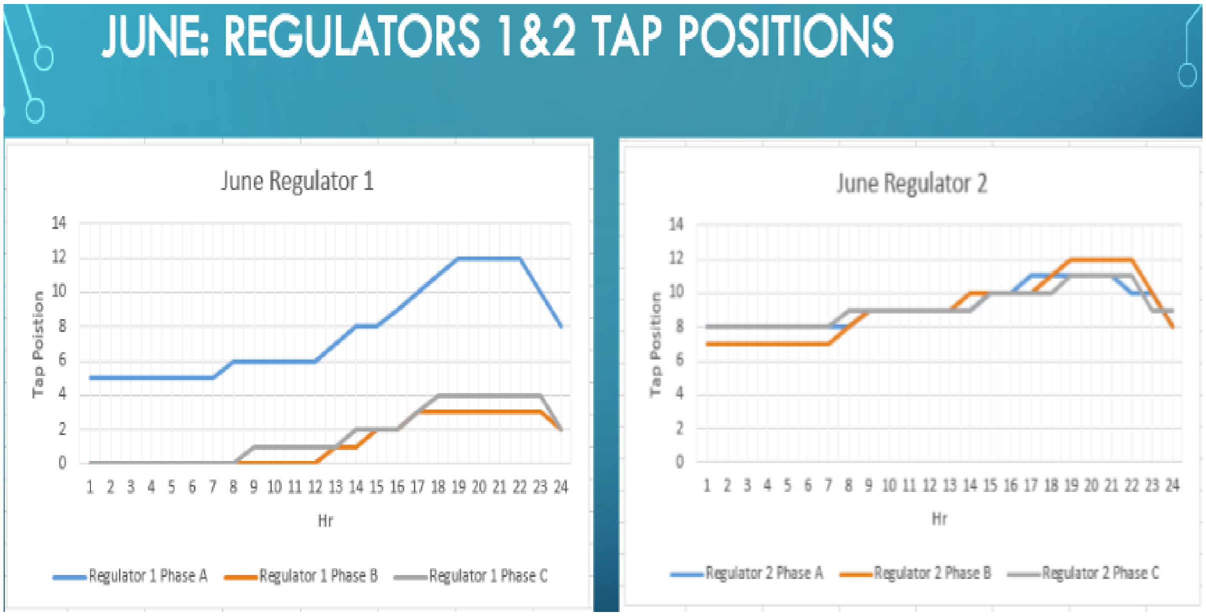
Below is an example of time series plots with an addition of capacitors. For this first, we had to calculate what capacitance value is required by the system to eliminate violations. Each member analyzed different month. We did see that December had the highest number violations and June had the highest standard deviation.



JUNE
(NO CAPACITOR)

(CAPACITOR)

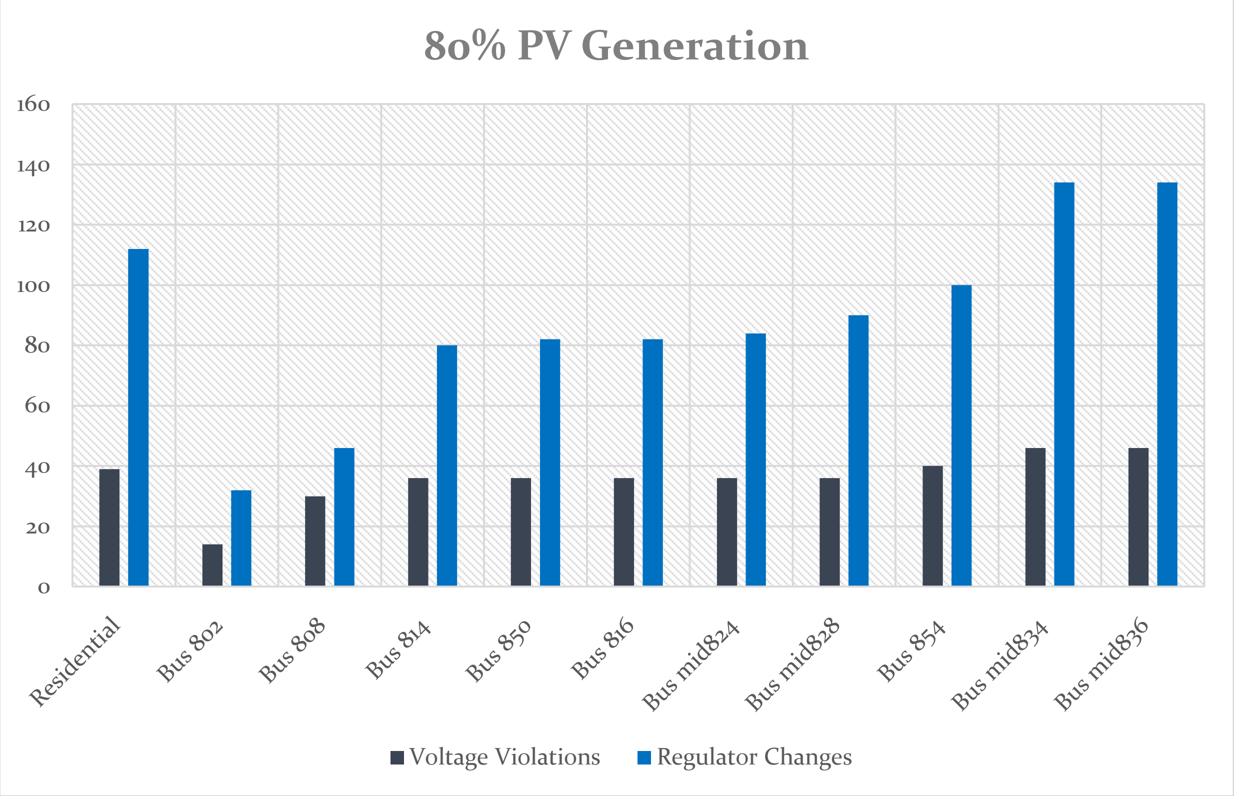
The graph below describes how regulator taps change over a period of 24 hours for the month of June. We analyzed for December as well and noticed how the regulator was reacting to different loads.



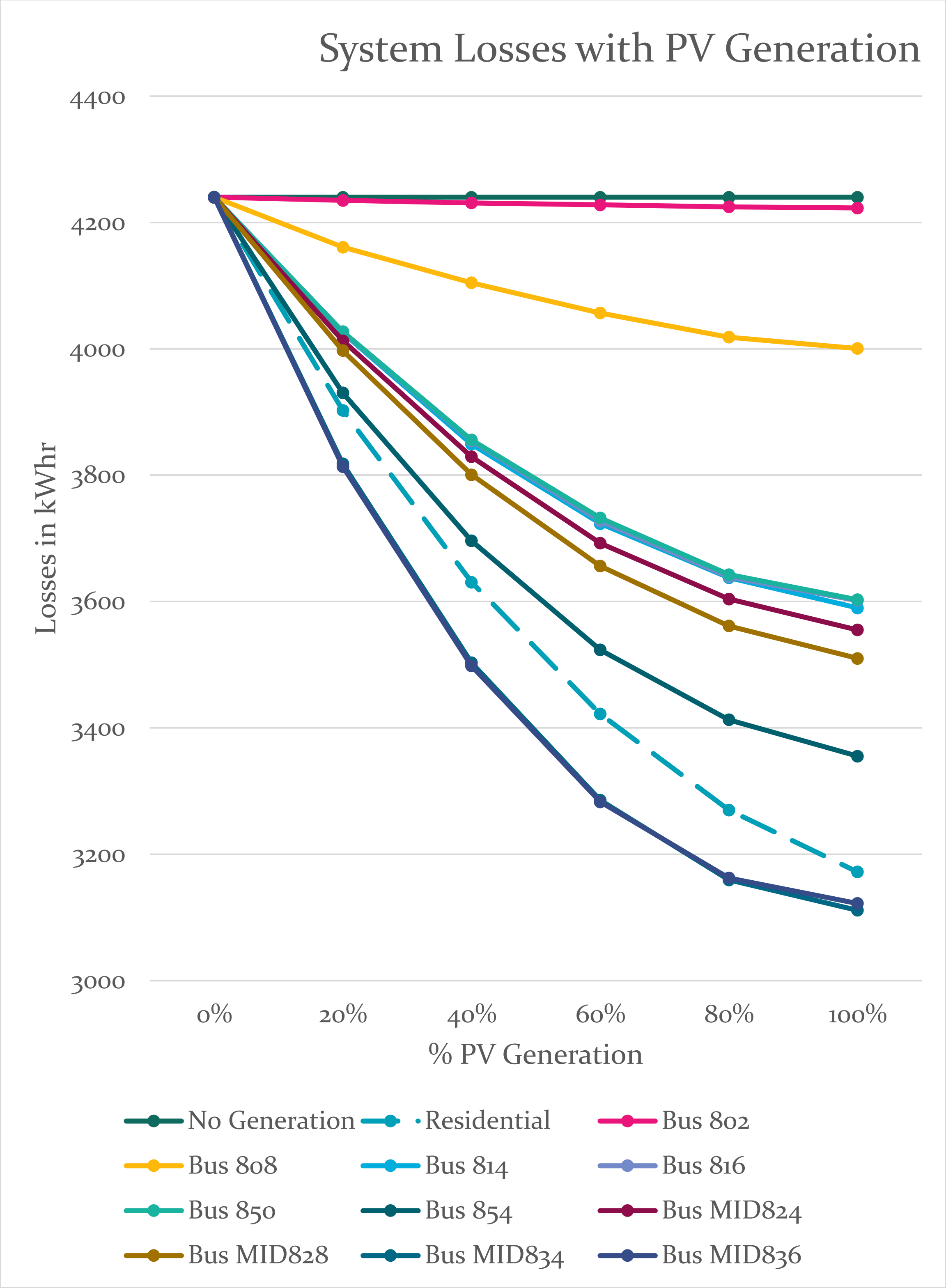
JUNE: REGULATORS 1&2 TAP POSITIONS

When adding solar PV at different locations along the system we looked at the load losses as a function of the solar source, voltage violations, and regulator changes. We analyzed this at 10 different buses with individual generation (community solar), and then again with a solar cell at each load on the system (residential solar). We also analyzed each one of these situations at different penetration levels of 20%, 40%, 60%, 80%, and 100%.

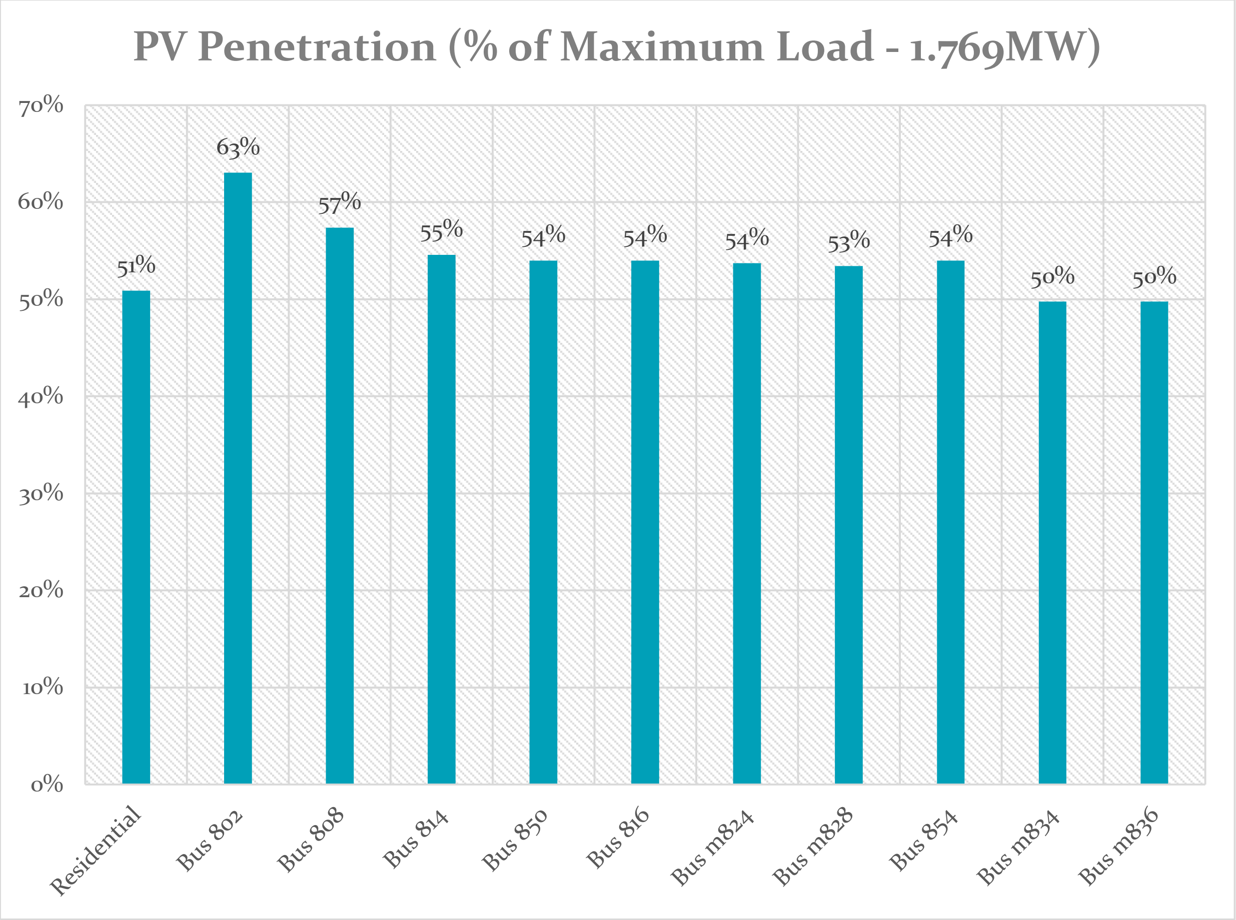
Here is the impact of solar on the voltage violations at regulator changes at 80% for all the different scenarios.



Then we ran an analysis to see what the line losses look like for all the different scenarios we described above.



This bar chart shows how much penetration is possible at each bus (assuming no other solar is present elsewhere on the system) before there will be voltage violations at the busses.



6 Conclusions

So far this semester we have worked on a couple of different distribution systems in OpenDSS. Most of the work has been with an IEEE 34-bus test system where we have been familiarizing ourselves with the various features and capabilities of the program. We have also started to add solar PV cells to different parts of the system to see how it will affect the entire distribution system. This will give us a chance to learn how to use OpenDSS more efficiently because when we move to a more advanced system next semester, we will need to know how to do everything as quickly and concisely as possible.

Our long-term goal going into next semester is to get an Aliant Energy system from a region in Iowa and do different solar penetration tests on it to determine what they will need to change in the system to be able to handle future residential and community solar expansion.

To accomplish these goals, we will continue to talk with our advisor, and familiarize ourselves with OpenDSS. It is a very powerful tool, and we continuing to dig deeper into the different features. We will also use different resources online and in print to better understand how adding solar to distribution systems can affect the stability and effectiveness of the system.

7 References

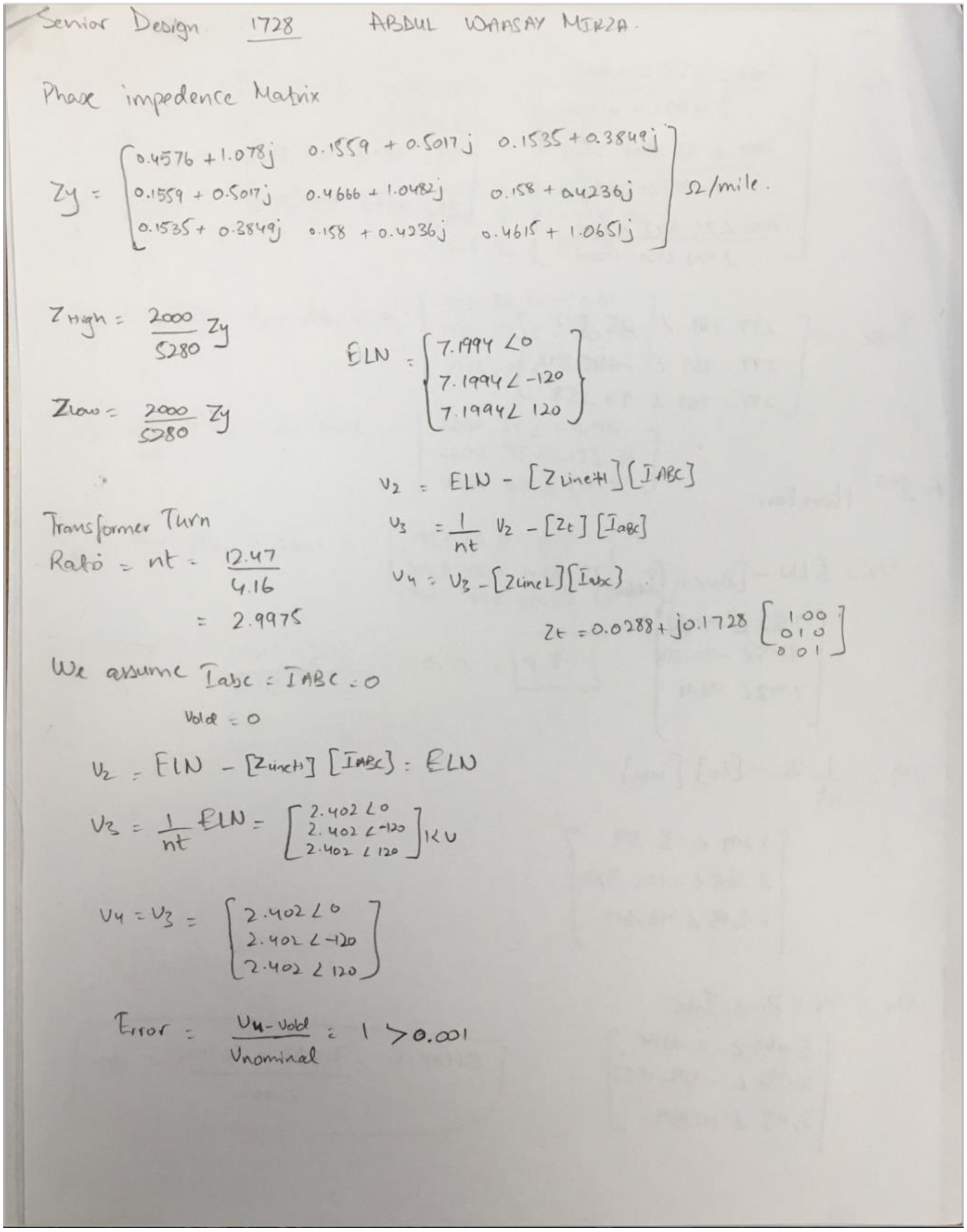
"EPRI | Simulation Tool – OpenDSS." *EPRI | Simulation Tool – OpenDSS*, Electric Power Research Institute, Inc., 1 Jan. 2011, smartgrid.epri.com/SimulationTool.aspx.

Kersting, William H. Distribution System Modeling and Analysis. Boca Raton: Taylor & Francis, 2012. Print.

Singhal, Ankit, and Venkataramana Ajjarapu. "Impact Assessment and Sensitivity Analysis of Distribution Systems with DG." *2015 North American Power Symposium (NAPS)*, 23 Nov. 2015, *IEEE*, doi:10.1109/naps.2015.7335218.

8 Appendix

4-bus system hand calculations:



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Phase impedence Matrix

$$Zy = \begin{bmatrix} 0.4576 + 1.078j & 0.1559 + 0.5017j & 0.1535 + 0.3849j \\ 0.1559 + 0.5017j & 0.4666 + 1.0482j & 0.158 + 0.4236j \\ 0.1535 + 0.3849j & 0.158 + 0.4236j & 0.4615 + 1.0651j \end{bmatrix} \Omega/\text{mile}.$$

$$Z_{High} = \frac{2000}{5280} Zy$$

$$Z_{low} = \frac{2000}{5280} Zy$$

$$ELN = \begin{bmatrix} 7.1994 \angle 0 \\ 7.1994 \angle -120 \\ 7.1994 \angle 120 \end{bmatrix}$$

$$V_2 = ELN - [Z_{lineH}][I_{ABC}]$$

$$V_3 = \frac{1}{nt} V_2 - [Z_t][I_{abc}]$$

$$V_4 = V_3 - [Z_{lineL}][I_{abc}]$$

$$Z_t = 0.0288 + j0.1728 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Transformer Turn Ratio $= nt = \frac{12.47}{4.16}$

$= 2.9975$

We assume $I_{abc} = I_{ABC} = 0$

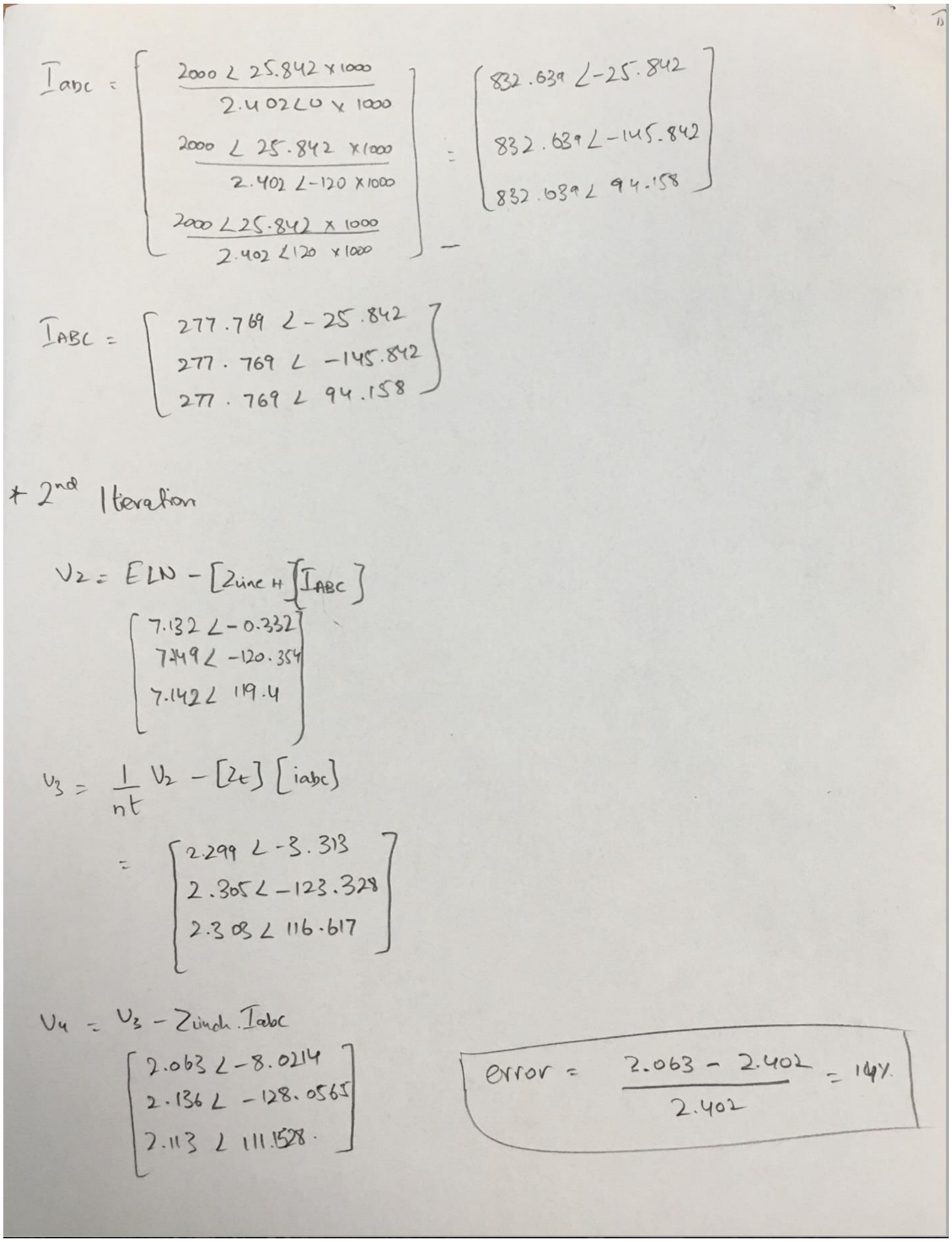
$V_{old} = 0$

$$V_2 = ELN - [Z_{lineH}][I_{ABC}] = ELN$$

$$V_3 = \frac{1}{nt} ELN = \begin{bmatrix} 2.402 \angle 0 \\ 2.402 \angle -120 \\ 2.402 \angle 120 \end{bmatrix} kV$$

$$V_4 = V_3 = \begin{bmatrix} 2.402 \angle 0 \\ 2.402 \angle -120 \\ 2.402 \angle 120 \end{bmatrix}$$

$$Error = \frac{V_4 - V_{old}}{V_{nominal}} = 1 > 0.001$$



$$I_{abc} = \begin{bmatrix} \dfrac{2000\angle 25.842 \times 1000}{2.402\angle 0 \times 1000} \\ \dfrac{2000\angle 25.842 \times 1000}{2.402\angle -120 \times 1000} \\ \dfrac{2000\angle 25.842 \times 1000}{2.402\angle 120 \times 1000} \end{bmatrix} = \begin{bmatrix} 832.639\angle -25.842 \\ 832.639\angle -145.842 \\ 832.639\angle 94.158 \end{bmatrix}$$

$$I_{ABC} = \begin{bmatrix} 277.769\angle -25.842 \\ 277.769\angle -145.842 \\ 277.769\angle 94.158 \end{bmatrix}$$

* 2nd Iteration

$$V_2 = ELN - [Z_{line\,H}][I_{ABC}]$$

$$\begin{bmatrix} 7.132\angle -0.332 \\ 7.149\angle -120.354 \\ 7.142\angle 119.4 \end{bmatrix}$$

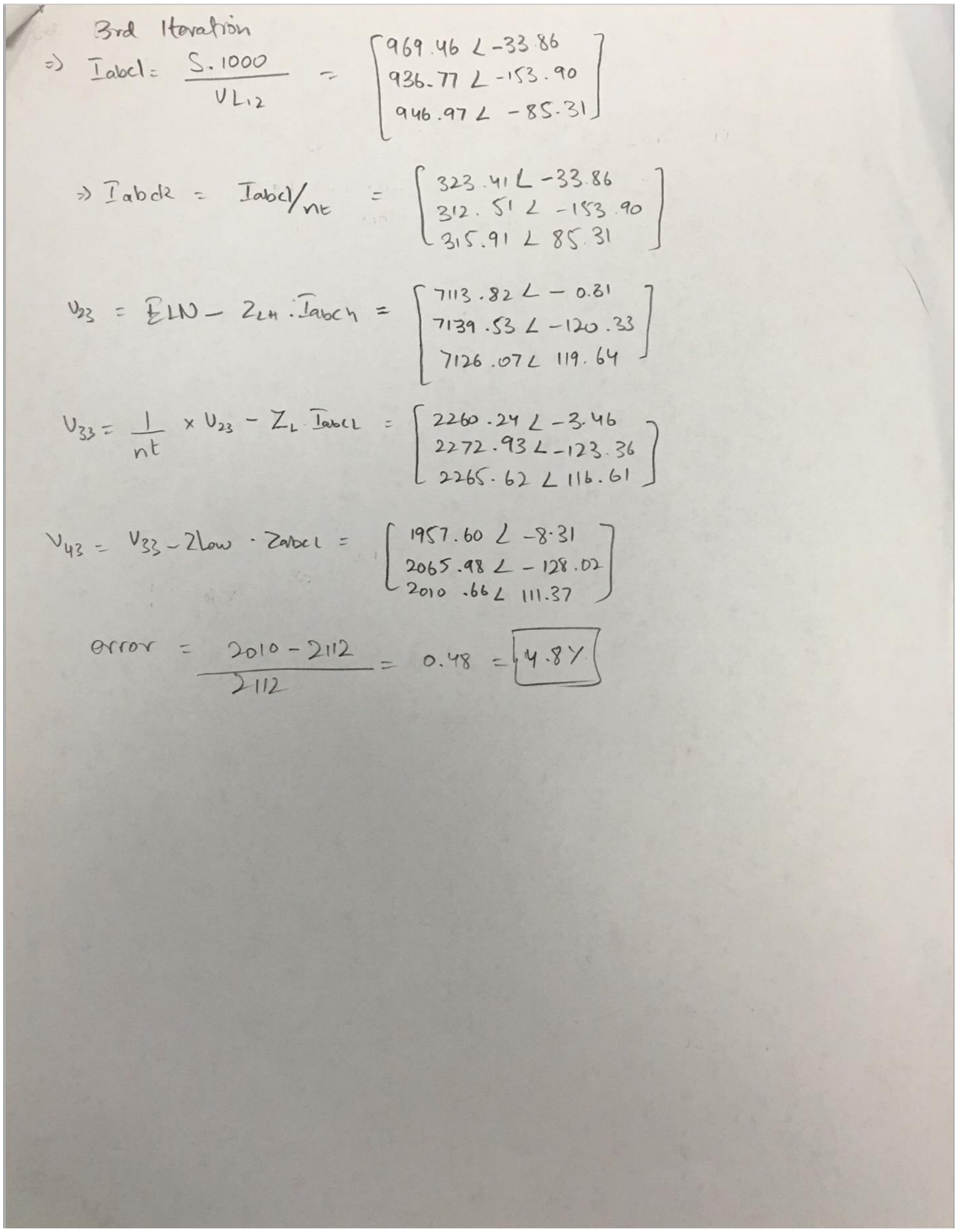
$$V_3 = \frac{1}{nt} V_2 - [Z_t][i_{abc}]$$

$$= \begin{bmatrix} 2.299\angle -3.313 \\ 2.305\angle -123.328 \\ 2.308\angle 116.617 \end{bmatrix}$$

$$V_4 = V_3 - Z_{inch} . I_{abc}$$

$$\begin{bmatrix} 2.063\angle -8.0214 \\ 2.136\angle -128.0565 \\ 2.113\angle 111.528 \end{bmatrix}$$

$$\boxed{\text{error} = \frac{2.063 - 2.402}{2.402} = 14\%}$$



3rd Iteration

$$\Rightarrow I_{abc1} = \frac{S \cdot 1000}{V_{L12}} = \begin{bmatrix} 969.46 \angle -33.86 \\ 936.77 \angle -153.90 \\ 946.97 \angle -85.31 \end{bmatrix}$$

$$\Rightarrow I_{abc2} = I_{abc1}/n_t = \begin{bmatrix} 323.41 \angle -33.86 \\ 312.51 \angle -153.90 \\ 315.91 \angle 85.31 \end{bmatrix}$$

$$V_{23} = E_{LN} - Z_{LH} \cdot I_{abcH} = \begin{bmatrix} 7113.82 \angle -0.81 \\ 7139.53 \angle -120.33 \\ 7126.07 \angle 119.64 \end{bmatrix}$$

$$V_{33} = \frac{1}{n_t} \times V_{23} - Z_L \, I_{abcL} = \begin{bmatrix} 2260.24 \angle -3.46 \\ 2272.93 \angle -123.36 \\ 2265.62 \angle 116.61 \end{bmatrix}$$

$$V_{43} = V_{33} - Z_{Low} \cdot Z_{abcL} = \begin{bmatrix} 1957.60 \angle -8.31 \\ 2065.98 \angle -128.02 \\ 2010.66 \angle 111.37 \end{bmatrix}$$

$$\text{error} = \frac{2010 - 2112}{2112} = 0.48 = \boxed{4.8\%}$$