Photovoltaic Array on a Distribution Feeder
Team Moquette

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EE416 - Spring
April 19th, 2017

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1. Executive Summary

This document is a final report of the senior design project, Photovoltaic Array on a Distribution Feeder. This report will cover the entirety of the project with detailed progress that team Moquette has made throughout the year(2016-2017). It will also include the results of the project, as well as limiting factors of design, recommendations for expanded projects, and future work that should be done.

The alpha prototype design was essentially targeting the solution approach to determine the maximum power that can be output by the PV array on a distribution feeder in Pullman (Turner 117). Team Moquette utilized the GE distribution management software (DMS) called e-terradistribution. The alpha prototype was a recreation in the DMS of an IEEE 37 node distribution feeder. This IEEE 37 node system contributed in understanding the contour of the project so that team Moquette could plan the beta prototype design.

The beta prototype design consisted of implementing the results obtained from the alpha prototype design to Turner 117 model already in place in WSU's DMS. The beta prototype design was a scaled-up version of the alpha prototype, as the Pullman feeder was significantly more complex than the self-created 37 node system. The key goals of the beta prototype design were to ensure the safety of distribution management system, acquire the real-time data, and write python code to enable VAR control at the PV level.

2. Introduction

The senior design team, Moquette, at Washington State University was tasked with the project of determining the maximum amount of photovoltaic (PV) generation that could theoretically be placed on Avista Utilities feeder, Turner 117 in Pullman, Washington. The team was given the project by the Energy System Innovation Center (ESIC). ESIC is a research organization whose goal it is to address the demand for clean, reliable energy.

With the increasing awareness of the negative anthropogenic effects caused by traditional electric power generation, interest in developing and efficiently integrating clean renewable sources of energy has risen. These renewable sources, like wind and solar, provide an electricity without the harmful carbon emissions. They are not without their drawbacks though. Beyond the political and economic issues that have become staples of renewable resource debates, there are a variety of technical issues that arise with the integration of renewables, especially with solar.

As solar technology has become more efficient and thus affordable, it has gained popularity as a source of distributed generation. The traditional radial structure of distribution systems was not designed to handle the multi directional power flow that occurs when placing generation sources downstream on a feeder. This has resulted in problems such as voltage regulation, improper protective coordination, and harmonic distortion among others. These are a few of the issues organizations like ESIC have set out to conquer.

When presenting the team with the task of determining the maximum theoretical PV generation for the Turner 117 feeder, ESIC left the scope of the project open ended, which left the team to decide what direction they wanted to take the project. Through meetings with industry mentors Dr. Jing Xie, and Dr. Adam Hahn, and background research performed by the team, it was decided that the focus of the project would be voltage regulation issues. Unlike a standard distribution feeder in which voltage will be lower at nodes further away from the substation due to voltage drop, when a generation source like a PV array is added, the current will flow in the opposite direction if enough power is injected, and voltage will begin to rise.
As the team headed into the project, there were two major questions they were going to focus on. What is the maximum amount of generation that can theoretically be produced on Turner 117 at the site of the existing solar array all while maintaining voltages within the required ±5% of the nominal voltage? And can we implement a solution to mitigate the voltage issues as load and generation change throughout the day using VAR control of the PV inverter?

3. Description of Culminating Design

The beta prototype for Moquette's Senior Design is a working semi-dynamic model of the Turner 117 Feeder located in Pullman Washington. This distribution feeder is of particular interest to the Energy Systems Innovation Center at WSU because it contains two distributed energy resources, a 72 kW PV array, and a 1 MW battery. This model was used to determine the theoretical maximum amount of solar generation that could be placed on the feeder. The features of the semi-dynamic model allow it to be used extensively for future research conducted by ESIC. Features of the Turner model include:

Integration with a Scripting Module: The DMS software allows the operator to write scripts that can automate power flow calculations multiple times throughout the day as well as manually modify set points. Of particular note is the ability to modify both the battery and PV array's generation value to determine how much solar should be integrated, and define when the battery should be charging or discharging.

Dynamic Load Schedules: Each load's P value follows a curve based on the unique characteristics of the feeder allowing for accurate voltage profiles and current flows throughout the system for all simulated hours of the day.

Voltage Control Strategy: Although not able to be effectively used on the Turner 117 model due to limitations described below, the beta prototype included the design of a power factor control algorithm to help mitigate voltage rise issues caused by high levels of PV integration. The effects of this control strategy can be seen in the validation section as it applied to the IEEE 37 node system.

Configurable Topology: The GE DMS allows breakers, and reclosers to be opened and closed to examine how the system will react to different disturbances. Due to the limitless possibilities of system topology all results for this project were completed assuming a normally operating system. However, the analysis of the PV array and 1 MW battery as a potential microgrid during a large-scale grid disturbance could be a point of interest for future projects.

4. Project Management

4.1. Timeline

The project's complexity coupled with the fact that under eight months was given to complete the project, made it clear that an organized and detailed timeline was needed. The projects abstract was presented in September. A team of five members was gathered together. Then, meetings were scheduled in which individual skills were getting familiar with the project. while at the same time meeting with industry and faculty mentors to discuss the project in further details. The team and the mentors agreed that a scheduled meeting every Tuesday from 2:00-3:00pm would be sufficient throughout the entire lifetime of the project. The team would research, work on the project, and report back to mentors informing them of the team's progress. After which the mentors would give suggestions on how to improve and move forward with future work. During the first months, much of the work done was reading and learning from articles, so the team decided that meeting up every day or every other day was not necessary. When the team had questions, or found something that could advance the work, it was posted on a private Facebook page where the entire team could read and reply. Towards the middle of the timeline the team was working towards completing the alpha prototype model which required creating a working model of a distribution feeder, and running tests. During this time the team found that meeting up every day was now necessary as topics and questions would be hard to answer or fully understand over social media. For more specific details regarding team member’s roles or dates of meetings of the overall project please see the Gantt Chart provided below.

Given the immense scope of the project, it was imperative the resources gathered by the team were used both frequently and effectively. The team's first resource was their industry and faculty mentors who developed the scope of the project beyond the initial abstract presented by the instructor. The mentors also helped organize and facilitate the timeline of the project allowing the team to meet specific deadlines with minimal obstruction. Alongside the mentors was Washington State University's own Energy Systems Innovation Center (ESIC) which served as the team’s main resource as it was the location of the server and provided all licensing and software needed to perform testing and analysis of the distribution system.

Secondary sources included Arjun Pedapati, a Power Systems Engineer for General Electric (GE) and scholarly articles. Arjun helped the group by providing a two-day workshop in which the team learned how to create a basic model of a distribution feeder and how to modify the model in order to fit the specifications of the team using the E-Terradistribution software used by ESIC and Washington State University. Research articles regarding voltage regulation and photovoltaic implementation allowed the team to develop the baseline knowledge needed to understand and identify solutions to ultimately reach our goal.

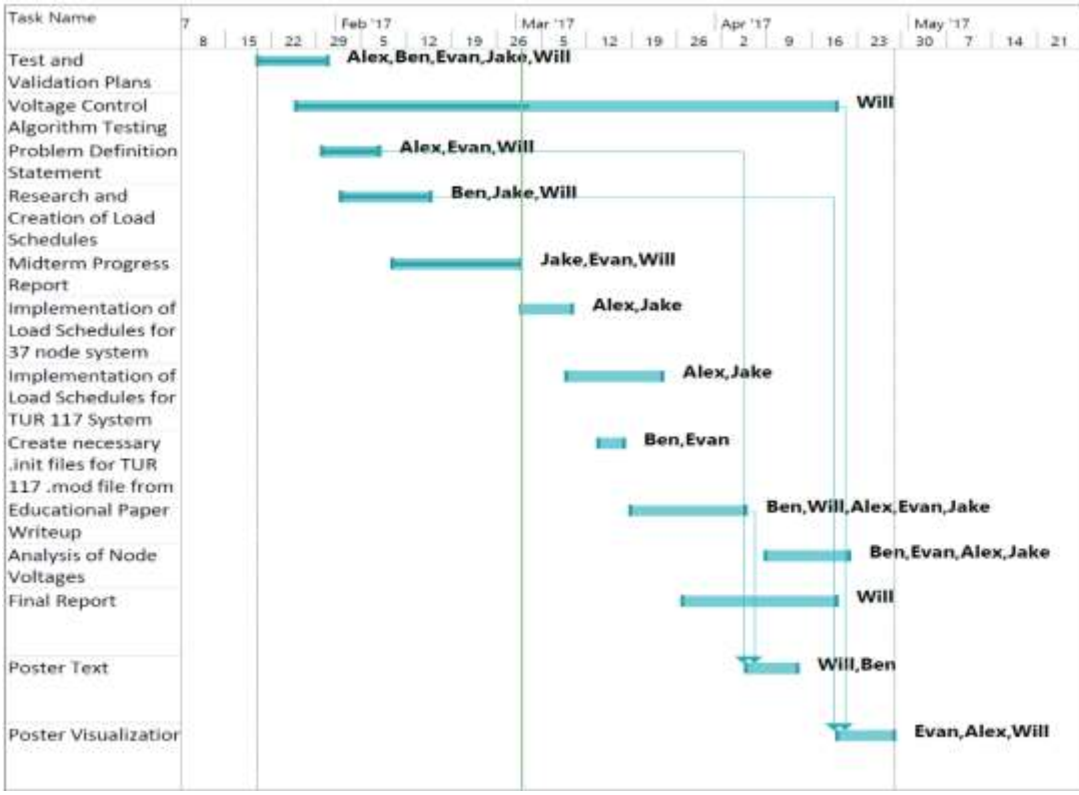

Figure 1: Gantt Chart for Spring 2017

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4.3. Project Challenges

- Getting a working base model - IEEE37Node
- The team ran into a roadblock with the implementation of the load and generation schedules on the Turner model due to an inability to change the model. It will require external assistance to acquire the resources to gain this capability, and the team is currently considering it.

5. Results

5.1. Analysis, Modeling and Simulation Results

Before the Beta Prototype was finalized the team utilized a smaller model composed of the IEEE 37 Node system for simulation to try and understand the expected problems to be faced on the larger Turner 117 distribution feeder. The simulation was done using static load values and the variable of interest for the project was the changing voltage levels as the nodes got further from the beginning of the distribution feeder and closer to the photovoltaic array. Below are several figures portraying the voltage of nodes versus the distance from the feeder start. Of particular note is the trendline of case #1 which shows the expected voltage drop over the length of the feeder. This can be compared to case #4 in which the voltage rises over the length of the feeder due to the real power being injected by the solar panel at node 11. The purpose of the control algorithm is to mitigate this voltage rise and can be seen in case #5 where the solar panels are still injecting a large amount of real power but consuming some reactive power to offset the voltage rise and bring the voltage of all nodes within the +/-5% specification. The purpose of the beta prototype's VAR control algorithm is to reduce the amount of reactive power being consumed/produced by the fuel cell to keep voltage within acceptable levels as load values change throughout a typical day.

A VAR control algorithm was explored because it was believed that the voltage rise due to the increase in PV array would be the limiting factor that the team would be able to mitigate. The other possible limits were not encountered in the early simulations but the possibility of harmonics problems and the current capacity of the lines were considered as possible avenues to explore engineering solutions to in early modeling. These were disregarded because they were facets of the power system outside of the control of the DMS system used for simulation and could be better explored by a project focusing on power electronics or the economic problems faced by the utilities.

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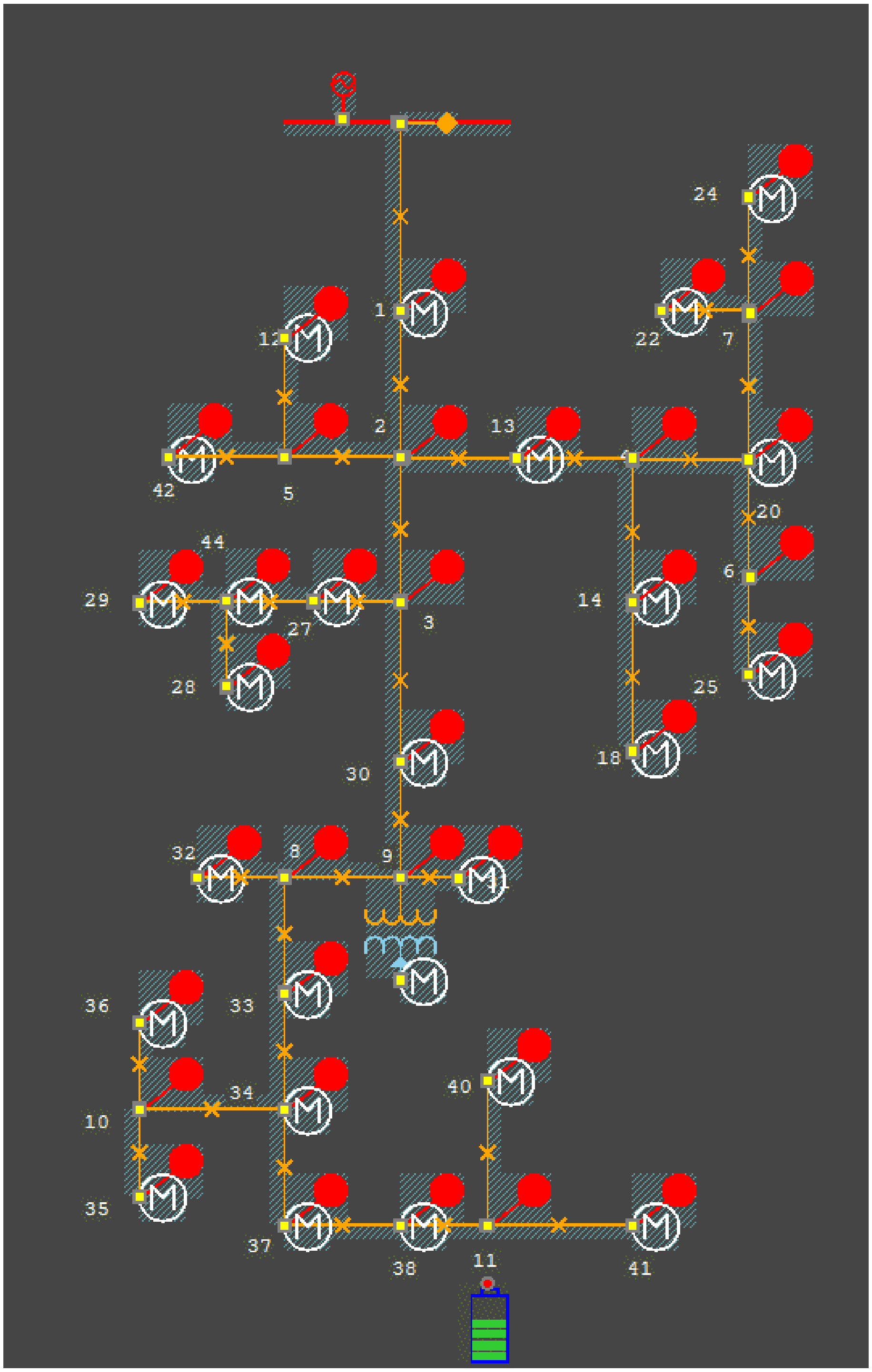

Figure 2: 37-Node Small-Scale Testing Model

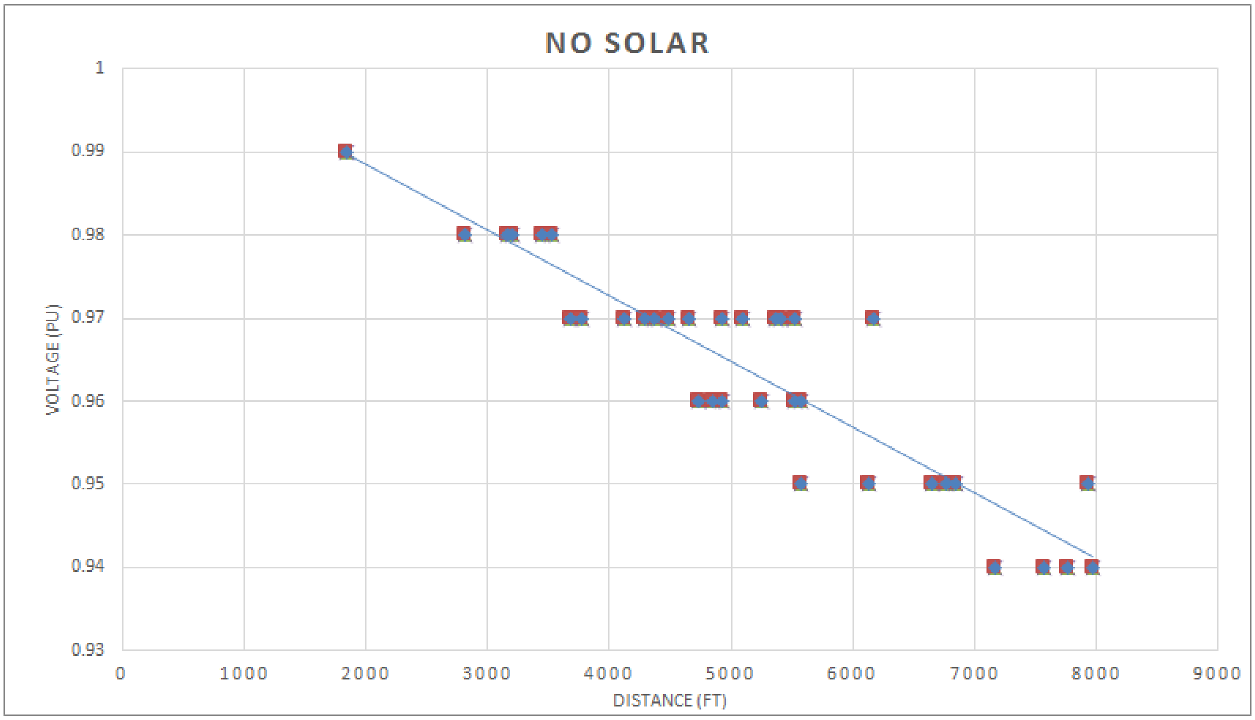

Figure 3: Case #1

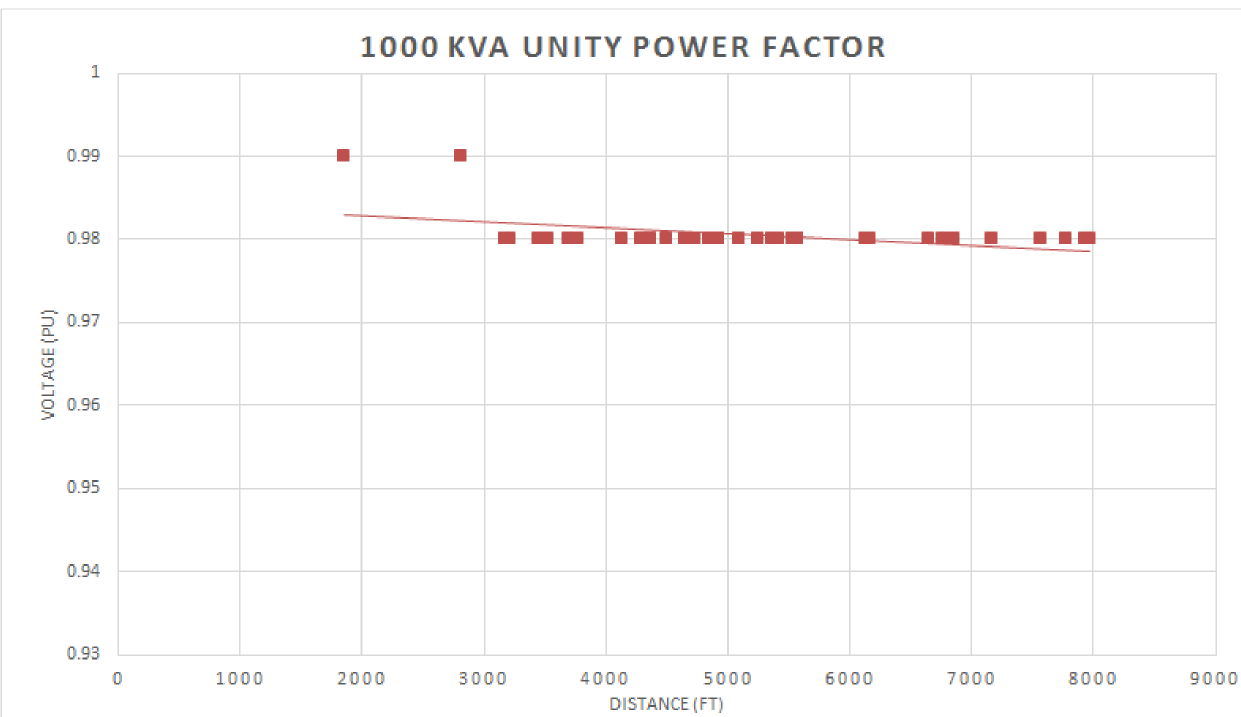

Figure 4: Case 2

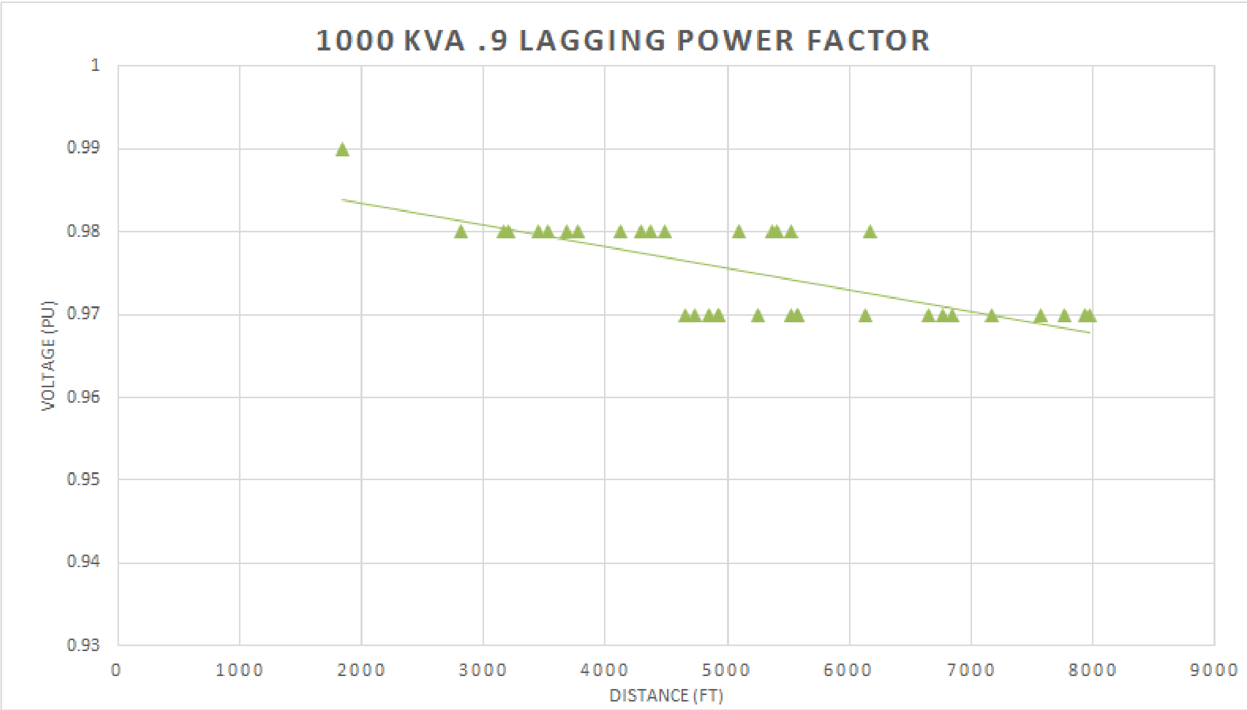

Figure 5: Case #3

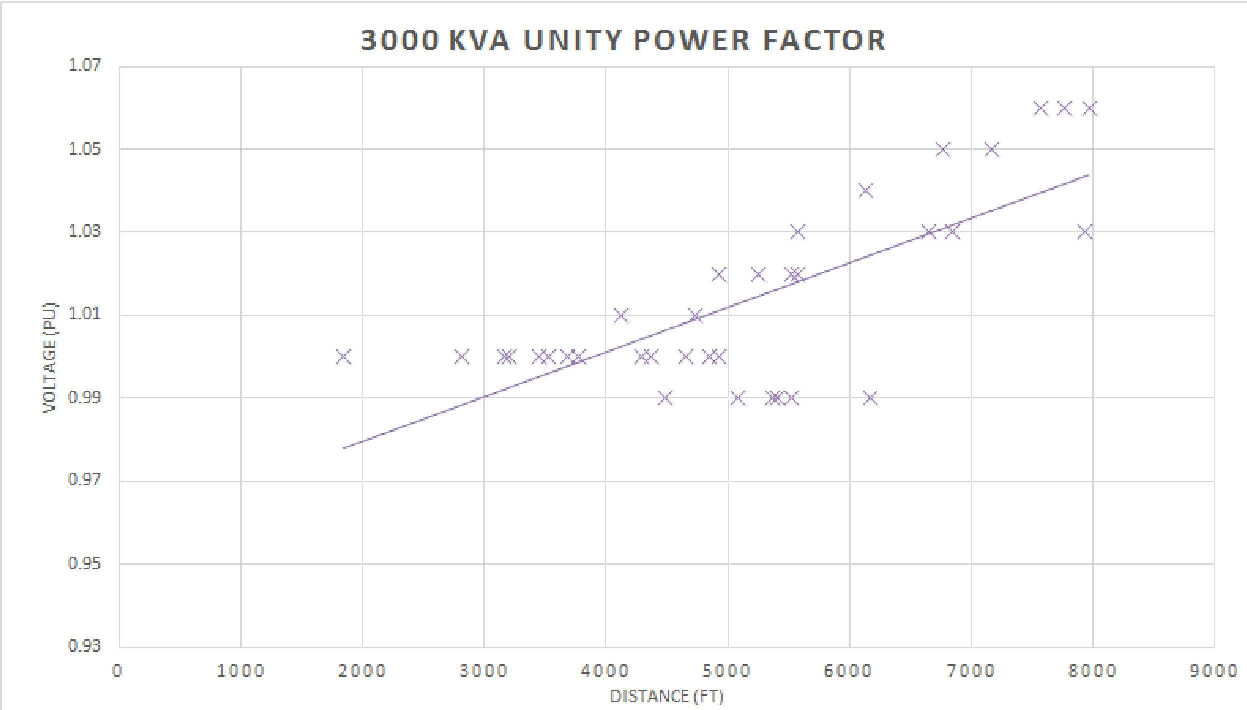

Figure 6: Case #4

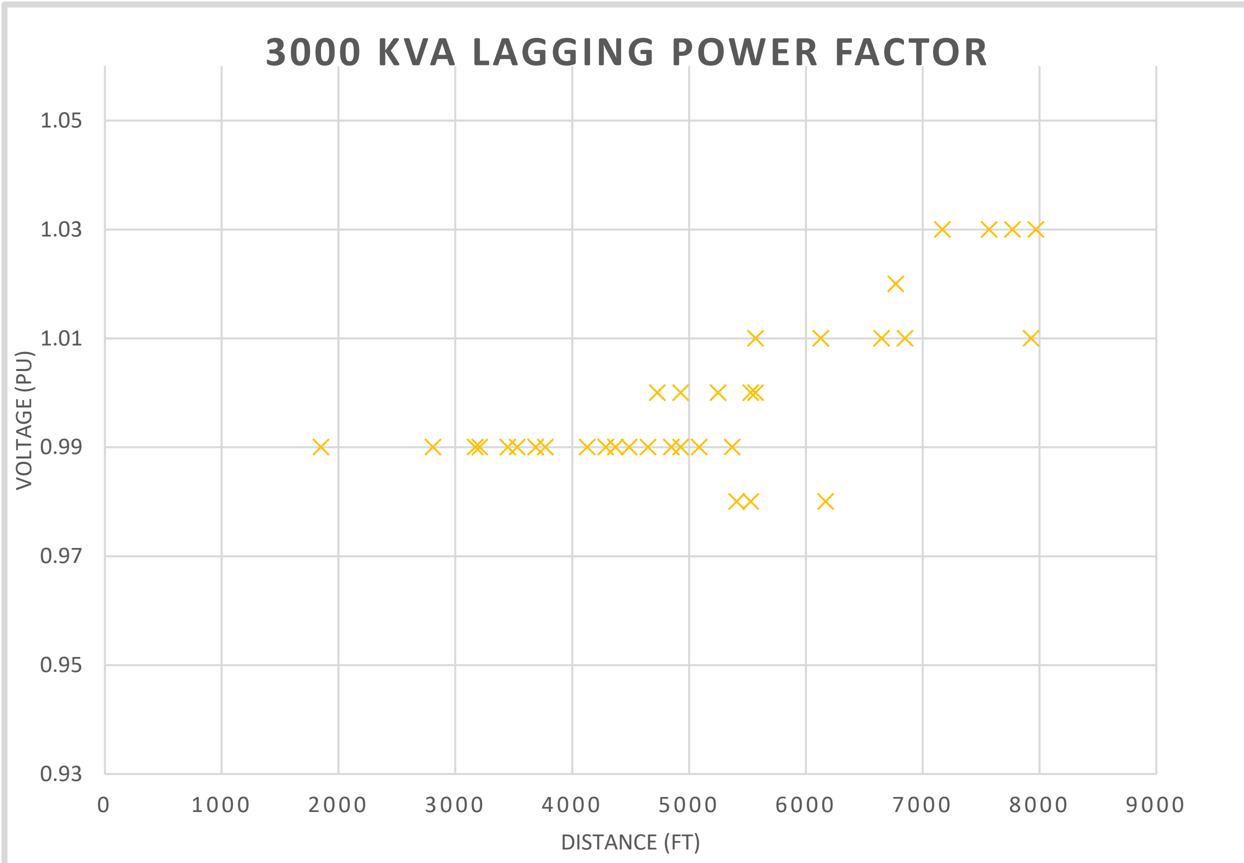

Figure 7: Case #5

5.2. Beta Prototype Test Results

Taking what was gained from the 37-node system, dynamic load schedules were applied to the Turner 117 model. Before any voltage regulation issues arose, the value of PV generation caused problem with power flow analysis. The system was able to handle approximately 1 MW of power before the system's power flow would not converge. This result flew in the face of our expected limit being the voltage. Even with the PV array injecting more than fourteen times its current theoretical maximum no voltage thresholds were reached and there was no need for the voltage control algorithm to act at all or for the PV array to produce at anything other than unity power factor. Figure 8 shows the selected nodes A-I whose voltage was examined throughout the course of a simulated day. Figure 6 and Figure 7 display the voltage of the selected nodes throughout the course of a simulated day without and with solar generation respectively. A table containing the raw data can be found in the Appendices.

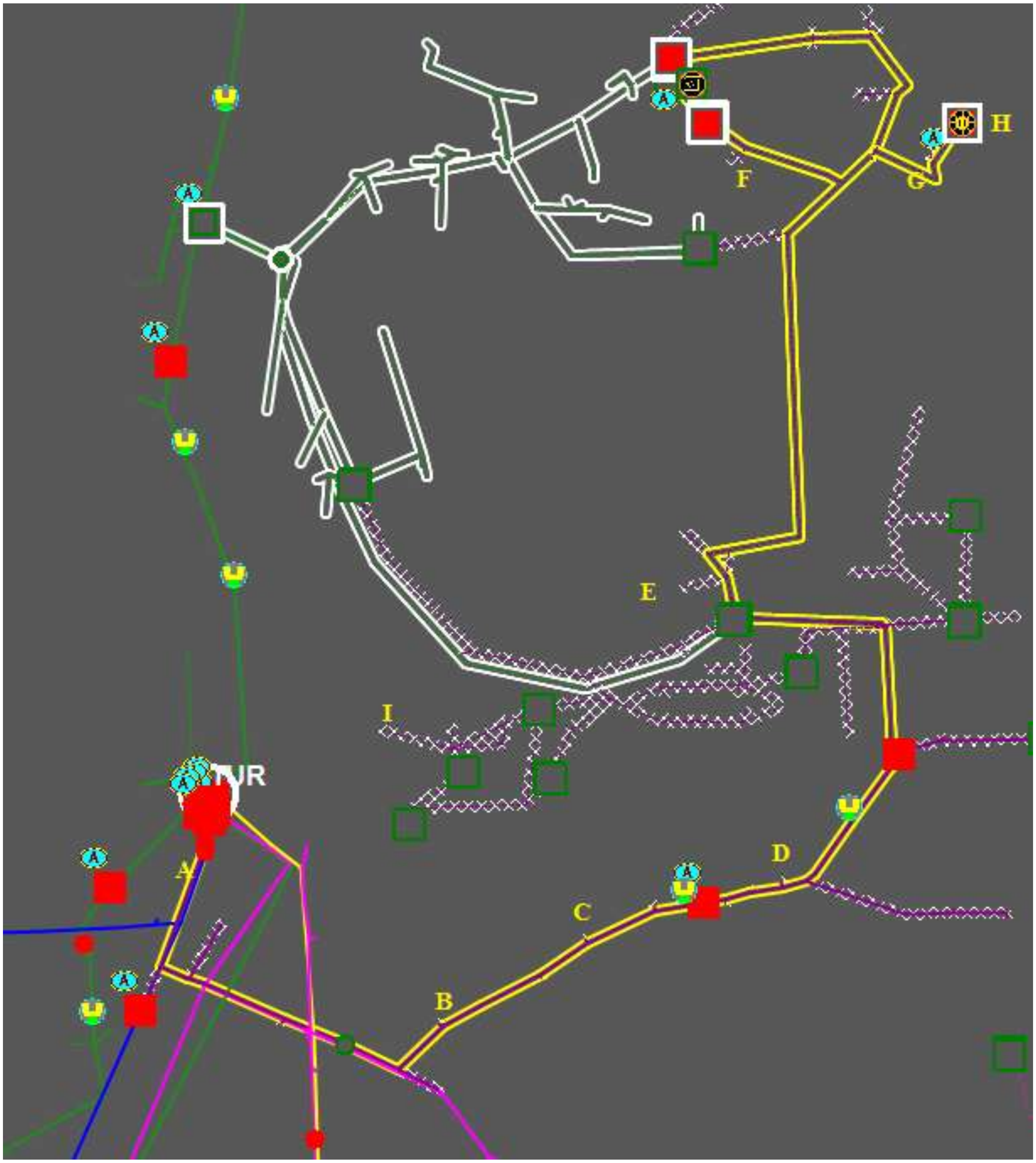

Figure 8: Turner 17 with Selected Nodes

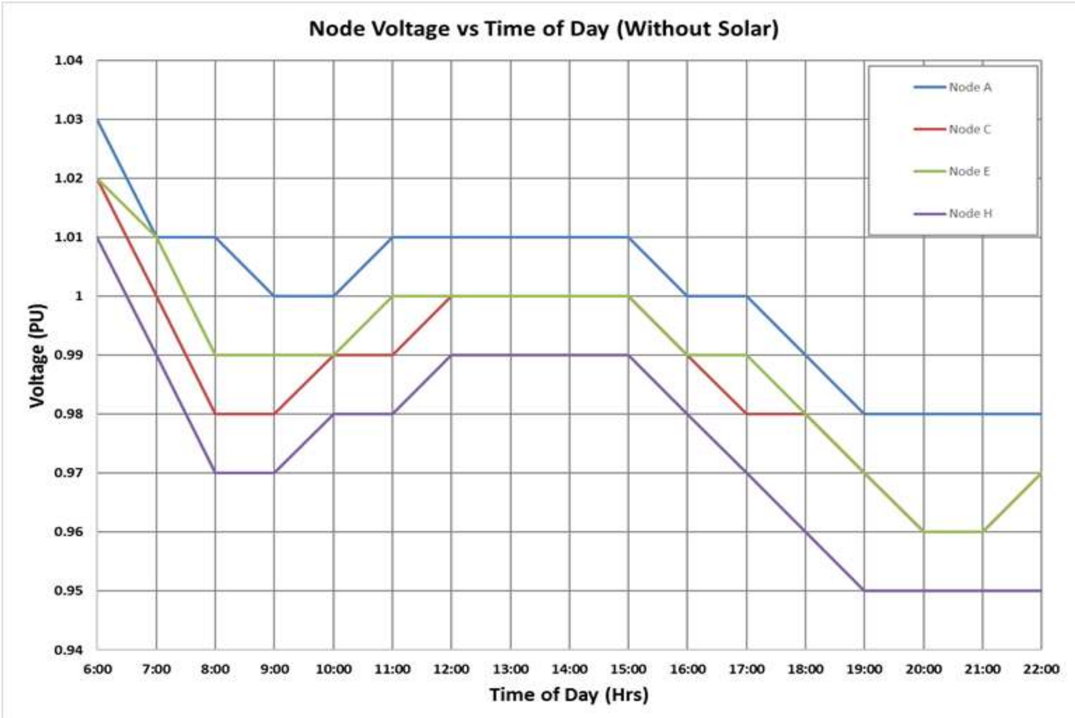

Figure 9: Case #6

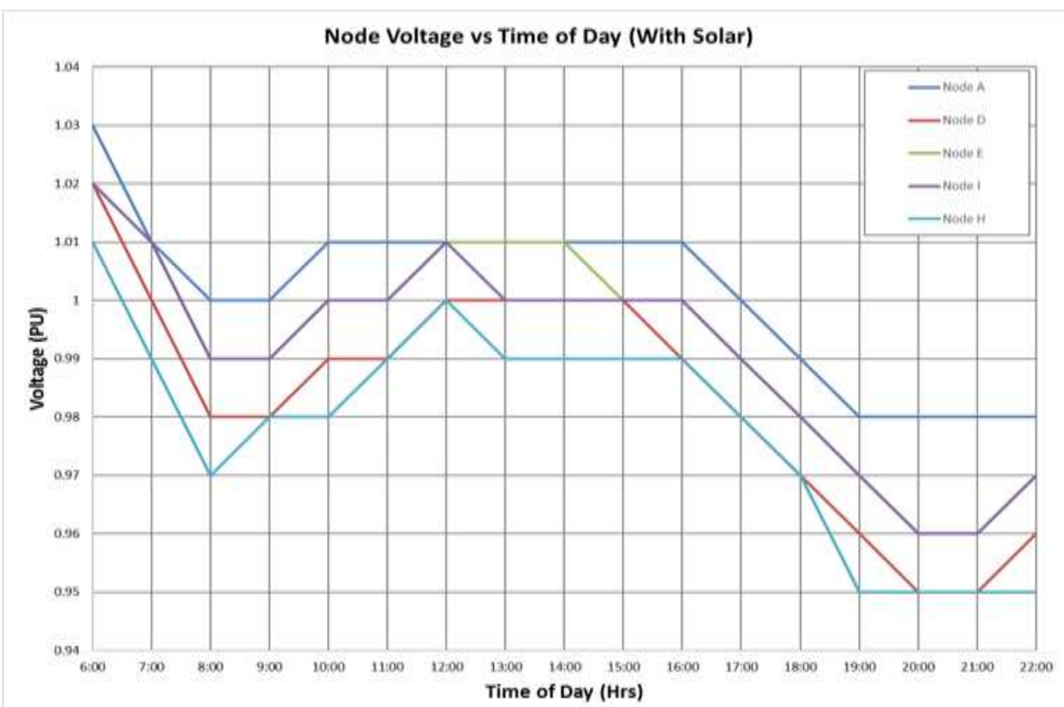

Figure 10: Case #7

5.3. Beta Prototype Validation Results

With the Turner 117 feeder not facing any voltage issues, the team had to turn back to the IEEE 37 node model to validate the voltage control strategy. The first step was to implement both dynamic load schedules and dynamic generation values on the existing model to examine the voltage profile for each of the node. A maximum solar generation of approximately 2500 kW was used because that was when the smaller model had begun to experience voltage issues. With the dynamic load and generation schedules there was not voltage problems at all times during the day and this allowed for the voltage control strategy to be of some use. Figure 9 shows the voltage at the PV array throughout the day without any voltage control strategies used.

To alleviate the voltage issues the power factor of the solar panel was dynamically changed. Instead of continuously changing the power factor and causing a situation where the it could oscillate continuously a series of dead bands was created in which the amount of reactive power consumed was increased when voltage surpassed a threshold, 1.04 pu, but was not reduced until the voltage was lower than a different threshold, 1.02 pu. Figure 9 shows the voltage with the voltage control strategy implemented. The use of a dynamic power factor instead of a static lagging power factor increases the amount of power the inverter can push when there are no voltage problems in the system. It also has the ability to be integrated as part of a larger system in which other voltage control elements, capacitor banks or tap changing transformers, can have an efficient control mechanism. It was assumed that the inverters of the PV array were rated to produce reactive power in addition to the currently supplied kW. If the inverters were at maximum rated power at any point the real power would need to be reduced to accommodate the needed reactive consumption. Figure 10 shows the reactive power throughout the day as needed by the voltage control algorithm.

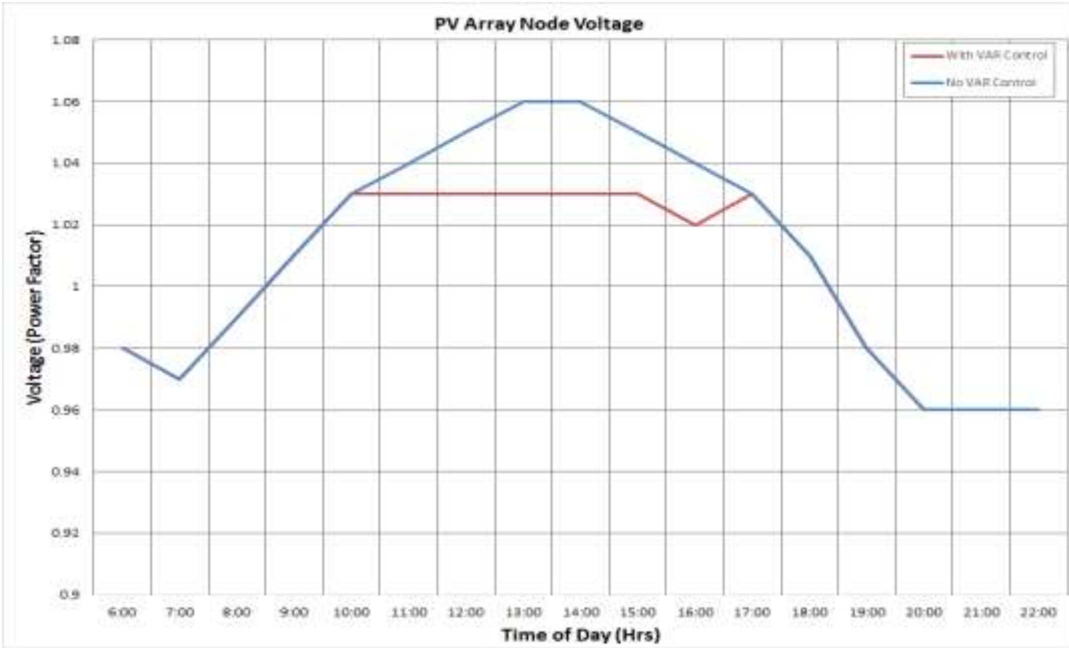

Figure 11: Graph comparing node voltage with and without VAR control

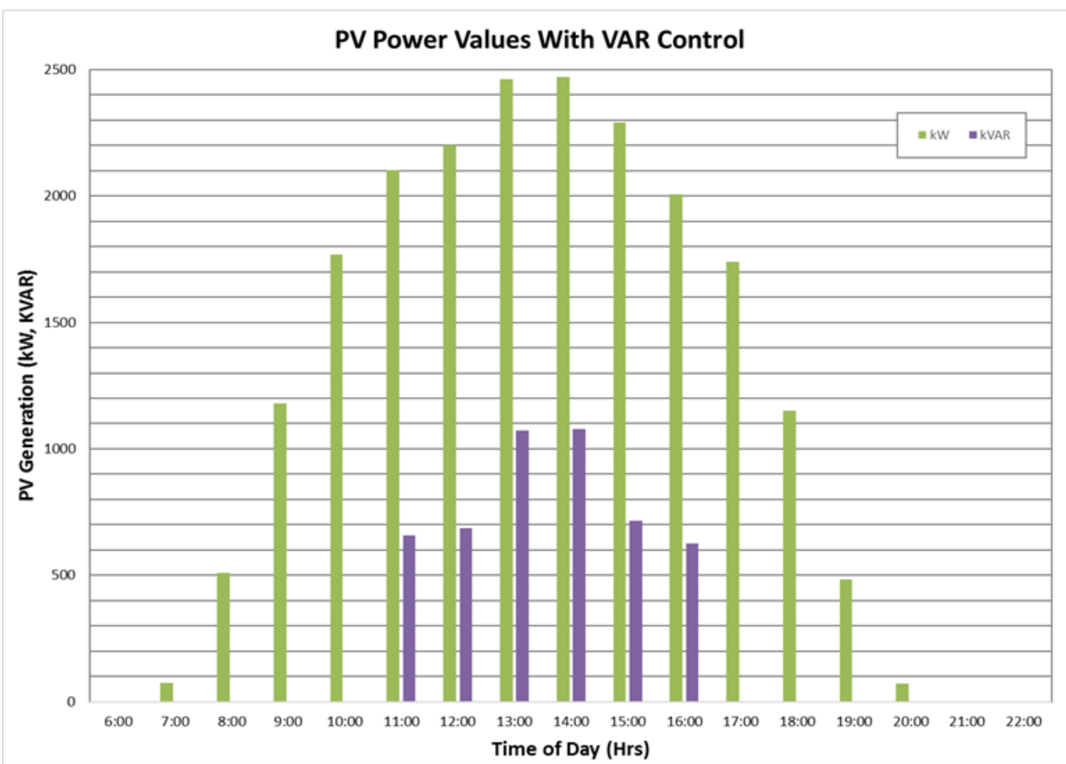

Figure 12: Graph showing the increase in VAR production during peak hours

5.4. Broader Impacts and Contemporary Issues

PV array has a long history of development. Thanks to the scientists whose work contributed to the development of PV array. It all started with the French scientist, Alexandre Edmond Becquerel who discovered the photovoltaic effect in 1839 [1]. Then, in 1905 [1] Albert Einstein published a paper explaining how the photoelectric works based on the principle of quantum theory of light. In 1954 [1], Daryl C. et al. developed the silicon photovoltaic (PV) cell at Bell Laboratories, and this was the turning point. From this date, photovoltaic has evolved to become an alternate source of energy. It is this major milestone that led the research laboratories and the technology industry to push the boundary of renewable energy. In this modern era, PV array is not a myth anymore, it has become predominant in the spectra of renewable energy. According to the Solar Energy Industry Association (SEIA) [2], the U.S. has reached a total of 42.4 gigawatts installed capacity of solar PV in 2016 which represents enough energy to power up about 8.3 million American homes. This report included rooftop and ground-mounted solar PV installed in residential, commercial and utility. Furthermore, the solar energy growth is widely spreading across the U.S. with California State ranking at the top.

U.S. are not the only countries in this growth interest in PV array. Among the many countries investing in PV systems, per the International Energy Agency (IEA) 2016 report [3], there are few that standout: China, Germany, Japan, Italy, United Kingdom, France, Spain, Australia and India [4]. This growth interest in renewable energy does not go alone without difficulty. Although the long existing traditional power grid has been getting updated with new standards and improvement, renewable energy such as PV array is bringing more complexity as it is being integrated into the electrical grid. A typical example is the current 72 kW PV array project carries out by the ESIC located in Washington State University Pullman, WA. This project found issues such as overvoltage, undervoltage and voltage imbalance. Also, there are some other issues associated with the integration of PV system into the electrical grid such as intermittence of sunlight, harmonic pollution and the communication system. Many research institutes are working hard to find solutions caused by PV system. Among these solutions, there are three with greater effect: reconducting, energy storage, reactive power source [5].
Therefore, overcoming these issues will improve the integration of PV array into the electrical grid. Apart from these issues, regulations for PV array is making a solid progress. This solid progress is motivated by countries willing to invest in sustainable environment and pushing the climate change agenda. In fact, the U.S department energy (DOE) [6], [7] offers a Loan Guarantee Program that contribute to reduce the financial cost associated with large energy

project. This program is a stimulus for private investors in solar energy generation and renewable energy. Qualified private investors from this program will be supported with getting loan from private lender. The DOE guarantees the debt in case of default loan payment by stepping in to repay the remaining balance. Since the program was created in 2005, more than $25 billion in private investment has been supported.

Another incentive program is the 1603 Treasury Program [8] also known as the §1603 American Recovery and Reinvestment Tax Act (ARRTA) program. The 1603 Treasury Program offers renewable energy project developers a direct federal grant in lieu of the Section 48 Investment Tax Credit (ITC). This program funds about 30% of the total cost for eligible project in most case. Since July 31st, 2009 to March 31st, 2017 about 105,972 projects have been funded with total spending of $25.7 billion and 34.5 GW of total installed capacity. The impact of the 1603 Treasury Program on the households is significant, with a total estimated annual electricity generation of 91.2 TWh which represents roughly about 8,440,000 homes. In this report, Washington state received about $975.7 million total funding for 160 projects and 1,469.67 MW of installed capacity [8].

There are many other incentive programs such as feed-in-tariff (FIT), renewable portfolio standard (RPS), pricing laws, production incentives, quota requirements, trading systems [9], [10] etc. All these programs couple with climate change agenda are energy-driven for the development and implementation of renewable energy systems in general and subsequently PV system. Finally, the development of PV systems has generated a new way of doing things called net metering. Net metering [11] is a policy that allows distributed generation customers to get credit for the excess solar energy produced and added into the electrical grid. This practice is widely spread across the U.S. territory. This practice also alleviates the burden on the utilities by bringing down the maintenance cost and consumers demand. For example, in Washington state, the program has been running since 2007 allowing investor-owned electric utilities to offset the billing for customer-generators with the excess renewable energy generated and added into the grid at the maximum capacity of 100 KW [12].

6. Limitations and Recommendations

6.1 Limitations

There were a variety of factors that lead to limitations in the design for this project. For the most part these limitations revolved in one way or another around the technological capabilities, with the most glaring barrier to progress being a fundamental lack of understanding and resources to fully understand the DMS system that was used in this project.

Every one of the team members came into the project with no understanding of the GE eterra DMS. The team was reliant on the instruction of the mentors to provide us with a knowledge base. Unfortunately, the mentors and even the other students who worked with the DMS system had a very limited knowledge of its capabilities and were not able to provide the team much clarity on its function. This resulted in the team often having to rely on outside resources, such as Arjun Pedapadi of GE, to receive help when problems arose. Having to rely on outside resources delayed the team's progress numerous times as a response was not always quickly received. These delays caused the team to not get as far into the analysis as they hoped.

Another limitation of this project was the restricted conditions under which the team could work. Due to the cost of the DMS software that was used, the school had only one license for it. This meant that the team could only have one person working with the DMS at any given time, and that person had to be in the lab at school. The lab was also widely used by other students which limited the times that the team could go into the lab to work. Also on multiple occasions, one of the other students in the lab had altered files used by the team so that the next time the team went to work they had to identify and reverse these alterations. These limitations again resulted in delays in the team's ability to complete their work and prevented them from achieving the level of analysis they hoped for.

When implementing the load schedules, the team was hoping to find that the loads of the Turner model would be predefined as either a residential, commercial or industrial load. This was not the case. Every load was defined as "RES" signaling it was a residential load even though it was known that there were commercial and industrial loads on the feeder. This lead the group to determine to take the general load curve of the feeder and apply it to each load. This provided a reasonable representation of the overall function of the feeder, though does not mimic the reality of the individual load behaviors.

As mentioned in the Results section of this paper, the team was not able to obtain the desired data on the Turner 117 model due to a lack of power flow convergence at PV generation values greater than 1MW. The team was not able to push generation values that caused voltage regulation issues on the feeder and thus didn't provide very meaningful information on what was the key point of this project.

6.2 Recommendations

After spending time working on this project, the team identified several areas that could be further explored in relation to this project. From the start the team decided to focus solely on issues pertaining to voltage regulation, but there are so many more issues that result from adding distributed generation sources on distribution feeders. If the generation sources are large, as they were in this theoretical simulation, then line capacity would become a factor. A project looking at reconductoring and over loaded feeder could be done. Also, re-coordinating protective devices including fuses and reclosers to properly implement bidirectional power flow protection would be an interesting study.

The structure of both Turner 117 and the IEEE 37 node feeder were simple, linear designs. While the linear nature of these two feeders allowed for an easy analysis of the effects of reversed power flow causing overvoltage issues, these issues would be easily mitigated by stepping the system voltage down using a voltage regulator at the substation. A more complicated non-linear structure could cause overvoltage issues on only one segment of the the feeder, and thus a simple fix of substation voltage regulation would not necessarily be the solution. A study on different feeder structures would produce different results.

7. Conclusions and Future Work

7.1 Conclusions

Team moquette has been working hard to complete the senior design project, Photovoltaic Array on a Distribution Feeder Team Moquette. The goal of the senior design project was about to determine the maximum power that can be output by a 72 kW PV array located on the feeder, turner 117. The 72 KW PV array is an ongoing project carried out by the Energy Systems Innovations Center (ESIC) in collaboration with Avista Utilities who owns the feeder. Team moquette successfully determined the maximum power to be 2.00 MW. This maximum power was reached with minimal instability in the system.

To accomplish this finding, the design project was organized in two phases (1&2). Phase 1 was about designing the alpha prototype. During this phase, team moquette with the contribution of a professional engineer from General Electric built a IEEE 37 nodes system eterradistribution software. This first solution approach helped in modeling the 72 kW PV array in a simulation case scenario. Phase 2 was about designing the beta prototype. During this phase 2, the IEEE 37 node systems was merged into the distribution management system, a real time data generated by the 72 kW PV array, and a control algorithm (python script) was developed to enable the modification of the reactive power at the inverter location. This was an interesting design project as team moquette was empowered with the difficulty associated with integrating the PV array into the traditional electrical grid.

7.2 Future Work

There is no doubt about growth interest in PV systems in general and subsequently to renewable source energy. This is growth interest in PV system will shift in the nearest future the traditional power grid to smart grid. In fact, ESIC is carrying out this 72 KW PV array with vision to turn the Pullman distribution system into smart-city. Thus, the future work will involve bringing up the 72 KW PV array to 2.0 MW. This next phase could involve a senior design team from ECCS/WSU. Then, another project could involve mitigating the non-convergence of the power on feeder, turner 117 and designing a protection schemes that accommodate the smart-grid factors.

8. Acknowledgements

Team Moquette would like to thank all the contributors to this project. First, team Moquette would like to pay a special thank you to the client, ESIC represented by the director, Dr.Chen-Chen Liu. Another special thank you goes to the industry mentor Dr. Jing Xie, co-mentor Dr. Adam Hahn and faculty mentor Dr. Anamika Dubey for all the technical assistance and guidance. Finally, a special thank you goes to Dr. Patrick Pedrow who was not just an instructor but assisted team Moquette to overcome many encountered obstacles and to be successful in this senior design project.

9. References

[1] Sunlight Electric, LLC., 2002-2013. [Online]. Available: http://www.sunlightelectric.com/pvhistory.php .

[2] Solar Energy Industries Association, "Research & Resources," 09 March 2017. [Online]. Available: http://www.seia.org/research-resources/us-solar-market-insight.

[3] U.S. Energy Information Administration, "Wind and Solar Projections from the U.S. Energy Information Administration: Past Performance and Ongoing Enhancements," https://www.eia.gov/outlooks/aeo/supplement/renewable/pdf/projections.pdf, Washington, DC 20585, 2016.

[4] I. E. Agency, "Snapshot of Global Photovoltaic Markets:2015," International Energy Agency, Global, 2016.

[5] A. S. Mubaraki, "IMPACT OF PHOTOVOLTAIC SYSTEM PENETRATION ON THE OPERATION OF VOLTAGE REGULATOR EQUIPMENT," http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=2034&context=theses, San Luis Obispo, CA, June 2013.

[6] U.S. Department of Energy, "LOAN GUARANTEE PROGRAM," https://energy.gov/savings/us-department-energy-loan-guarantee-program, Washington DC 20585, 2016.

[7] N. C. E. T. Center, "Loan Guarantee Program," DSIRE,N.C. Clean Energy Technology Center, Washington, DC 20585, 2016.

[8] U.S. Department of the Treasury, "Overview and Status Update of the §1603 Program," U.S. Department of the Treasury, Washington D.C, 2017.

[9] N. R. J. S. K. S. S.M. Moosavian, "Energy policy to promote photovoltaic generation," *Elsevier Ltd,* vol. 25, no. 0, p. 46, 12 May 2013.

[10] T. C. a. C. K. Karlynn Cory, "Feed-in Tariff Policy: Design, Implementation, and RPS Policy Interactions," National Renewable Energy Laboratory, Golden, 2009.

[11] N. C. o. S. Legislatures, "STATE NET METERING POLICIES," NCSL.org, Washington, D.C, 2016.

[12] W. U. a. T. Commission, "Net Metering," utc.wa.gov, Olympia, 2016.

10. Appendixes

Table 1: Raw Data of IEEE 37 Node with Multiple Cases

Case Type		No Solar Voltage	Unity (1000 kVA) Voltage	.92 PF Lagging (1100 kVA) Voltage	Unity (3000 kVA) Voltage	.92 PF Lagging (3200 kVA) Voltage
Node #	**Distance**	1	1	1	1	1
1	1850	0.99	0.99	0.99	1	0.99
2	2810	0.98	0.99	0.98	1	0.99
13	3170	0.98	0.98	0.98	1	0.99
5	3210	0.98	0.98	0.98	1	0.99
12	3450	0.98	0.98	0.98	1	0.99
42	3530	0.98	0.98	0.98	1	0.99
4	3690	0.97	0.98	0.98	1	0.99
14	3770	0.97	0.98	0.98	1	0.99
3	4130	0.97	0.98	0.98	1.01	0.99
18	4290	0.97	0.98	0.98	1	0.99
27	4370	0.97	0.98	0.98	1	0.99
20	4490	0.97	0.98	0.98	0.99	0.99
44	4650	0.97	0.98	0.97	1	0.99
30	4730	0.96	0.98	0.97	1.01	1
28	4850	0.96	0.98	0.97	1	0.99
9	4930	0.96	0.98	0.97	1.02	1
29	4930	0.97	0.98	0.97	1	0.99
6	5090	0.97	0.98	0.98	0.99	0.99
8	5250	0.96	0.98	0.97	1.02	1
25	5370	0.97	0.98	0.98	0.99	0.99
7	5410	0.97	0.98	0.98	0.99	0.98
22	5530	0.97	0.98	0.98	0.99	0.98
31	5530	0.96	0.98	0.97	1.02	1
32	5570	0.96	0.98	0.97	1.02	1
33	5570	0.95	0.98	0.97	1.03	1.01
34	6130	0.95	0.98	0.97	1.04	1.01
24	6170	0.97	0.98	0.98	0.99	0.98
10	6650	0.95	0.98	0.97	1.03	1.01
37	6770	0.95	0.98	0.97	1.05	1.02
35	6850	0.95	0.98	0.97	1.03	1.01
38	7170	0.94	0.98	0.97	1.05	1.03
11	7570	0.94	0.98	0.97	1.06	1.03
40	7770	0.94	0.98	0.97	1.06	1.03
36	7930	0.95	0.98	0.97	1.03	1.01
41	7970	0.94	0.98	0.97	1.06	1.03

Table 2: Raw Data of Turner 117 without Solar

Time	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00
Node A	1.03	1.01	1.01	1	1	1.01	1.01	1.01	1.01	1.01	1	1	0.99	0.98	0.98	0.98	0.98
Node B	1.02	1	0.99	0.99	0.99	1	1	1	1	1	0.99	0.99	0.98	0.97	0.96	0.96	0.97
Node C	1.02	1	0.98	0.98	0.99	0.99	1	1	1	1	0.99	0.98	0.98	0.97	0.96	0.96	0.97
Node D	1.02	1	0.98	0.98	0.99	0.99	1	0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.95	0.95	0.96
Node E	1.02	1.01	0.99	0.99	0.99	1	1	1	1	1	0.99	0.99	0.98	0.97	0.96	0.96	0.97
Node F	1.03	1.01	1	1	1	1	1.01	1.01	1.01	1.01	1	1	0.99	0.98	0.98	0.98	0.98
Node G	1.03	1.01	1	1	1	1.01	1.01	1.01	1.01	1.01	1	1	0.99	0.98	0.98	0.98	0.98
Node H	1.01	0.99	0.97	0.97	0.98	0.98	0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.95	0.95	0.95	0.95
Node I	1.02	1	0.99	0.99	0.99	1	1	1	1	1	0.99	0.99	0.98	0.97	0.96	0.96	0.97

Table 3: Raw Data of Turner 117 with Solar

Time	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00
Solar kW	0	20	192	472	708	884	924	992	988	1008	856	704	464	196	28	0	0
Node A	1.03	1.01	1	1	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1	0.99	0.98	0.98	0.98	0.98
Node D	1.02	1	0.98	0.98	0.99	0.99	1	1	1	1	0.99	0.98	0.97	0.96	0.95	0.95	0.96
Node E	1.02	1.01	0.99	0.99	1	1	1.01	1.01	1.01	1	1	0.99	0.98	0.97	0.96	0.96	0.97
Node I	1.02	1.01	0.99	0.99	1	1	1.01	1	1	1	1	0.99	0.98	0.97	0.96	0.96	0.97
Node H	1.01	0.99	0.97	0.98	0.98	0.99	1	0.99	0.99	0.99	0.99	0.98	0.97	0.95	0.95	0.95	0.95

Table 4: Raw Data of IEEE 37 Node with Dynamic Load Schedules

Time	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00
IEEE 37 Node With Dynamic Loads And No VAR Control																	
kw	0	74.6	509.52	1178.97	1769.05	2101.59	2201.98	2461.9	2471.03	2290.08	2005.56	1738.49	1150.4	483.73	71.83	0	0
kVAR	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0
V	0.98	0.97	0.99	1.01	1.03	1.04	1.05	1.06	1.06	1.05	1.04	1.03	1.01	0.98	0.96	0.96	0.96
IEEE 37 Node With Dynamic Loads And VAR Control																	
PF	1	1	1	1	1	0.95	0.95	0.9	0.9	0.95	0.95	1	1	1	1	1	1
kW	0	74.6	509.52	1178.97	1769.05	2101.59	2201.98	2461.9	2471.03	2290.08	2005.56	1738.49	1150.4	483.73	71.83	0	0
kVAR	0	0	0	0	0	656.2213	687.568	1073.117	1077.097	715.0773	626.2359	0	0	0	0	0	0
V	0.98	0.97	0.99	1.01	1.03	1.03	1.03	1.03	1.03	1.03	1.02	1.03	1.01	0.98	0.96	0.96	0.96