Impact of High Photovoltaic Penetration of Distribution Systems

PROJECT PLAN

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Client: Alliant Energy

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List of Figures

List of Tables

List of Definitions

ANSI: American National Standards Institute

IEEE: Institute of Electrical and Electronics Engineering

PV: Photovoltaic.

1 Introductory Material

1.1 Acknowledgement

We would like to thank our advisor Professor Dr. Ajjarapu for his constant support and guidance. We as a team have worked on this project for one year and this has been a great opportunity for all of us to learn and grow as better electrical engineers.

1.2 Problem Statement

Solar energy is making advances very rapidly in today's world. Specially in a place like Iowa the solar generation and solar power plants are seen as a major source for power, to satisfy the needs of people.

In this project we are trying to assess the impact of high penetration solar power generation on a specific distribution feeder and its effect on the power delivered to the consumers. When overvoltage and reverse power flow occur, we will implement a solution.

1.3 Intended Users and Intended Uses

Power delivery is essential for constant development and easy living conditions for people in general. In our project we are trying to find an effective manner in which the power generated by the solar can reach household. The main intended audience, or the users, are the general public.

1.4 Assumptions and Limitations

To computer modulate the systems and to understand the impact of the solar generation in the utility systems we will be using the GridLab software. We are operating under the assumption that the load values given by Alliant Energy will not change much in the future, nor will any new loads be added. One of the limitations of this project is that any created solutions cannot be directly implemented to other distribution systems, but will provide ideas on how to solve similar problems.

1.5 Expected End Product

The expected result of our project are listed below.

- Simulate an Alliant Energy-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 system

2 Proposed Approach and Statement of Work

2.1 Objective of the Task

Our task is to simulate an Alliant Energy system, and determine methods of averting the problems that come with high PV penetration from solar energy. Some of the main complications that can arise due to high PV penetration are opposite direction power flow, and over-voltage. In researching the impact on distribution systems, we can find potential solutions to these problems.

2.2 Functional Requirements

The team has to deliver suggestions for avoiding problems due to high PV penetration in the implementation of solar energy into an Alliant Energy distribution system. These suggestions have to be substantiated by the team’s findings in GridLab. This will involve accompanying graphs and voltage profiles that are verifiable. The recommendations will also have to be applicable in multiple situations, and not just pertain to a particular situation.

2.3 Constraints Considerations

Profitability - The team's recommendations for implementing solar energy into an Alliant Energy distribution system have to be financially justifiable. The application of the solutions has to mitigate enough energy loss to validate creating the infrastructure necessary for them.

Current Infrastructure - The team's solutions for adding solar energy to an Alliant Energy distribution system has to account for the infrastructure that is already in place. Unless the findings are significant enough to rationalize rebuilding components of the distribution system that are already in place, the recommendations have to account for infrastructure already in place.

Climate - In Iowa, the climate isn't ideal for solar energy. The team's findings have to be acclimatable for all of the seasons.

Application - The team will be looking into solar energy at both the community and residential levels. The solutions for applying solar energy to an Alliant Energy system has to show the benefits/disadvantages at both levels for each recommendation.

2.4 Previous Work And Literature

For understanding the workings of distribution systems, the team will make use of the textbook *Distribution System Modeling and Analysis* by Kersting. At this level of research, this textbook will be able to supply the basis of the different aspects of distribution systems. A previous team has also done the same project, and their conclusions will be a good starting point for considering solutions to problems that occur from solar generation, as mentioned previously.

2.5 Proposed Design

There are two main components to this project. The first is designing the distribution feeder as it currently is using GridLab. The second component is analysing what happens to the system in different percentages of solar PV penetration are added to the system. The first component involves entering every node, distribution line, transformer, and any other parts of the distribution system into GridLab exactly as it appears today. The second component involves changing the loads at the nodes to account for different levels of solar penetration. We will be experimenting with both solar and residential solar generation, and seeing what happens with different levels of generation. Using the results we find from these experiments, we will attempt to implement guidelines or solutions to the problems that arise from the solar generation.

2.6 Technology Considerations

Before starting this project we had to decide what software to model the distribution system on. The two main options that were considered by the research assistants for this project were GridLab and OpenDDS. Both programs were open source and free, however, it was decided that GridLab would be easier to model the distribution system and was easier to use with MatLab.

2.7 Safety Considerations

There are very few safety concerns for this project. All of the project will be conducted using either the group's personal laptops or Iowa State's computers. This has no human safety issues. There is the possibility of getting viruses when downloading GridLab or MatLab but it is a very low risk and we will be taking precautions to prevent it.

2.8 Task Approach

The following chart is the process we follow when we receive a task from our advisor. We will follow this chart to come up with a design solution to any problems we come across during this project.

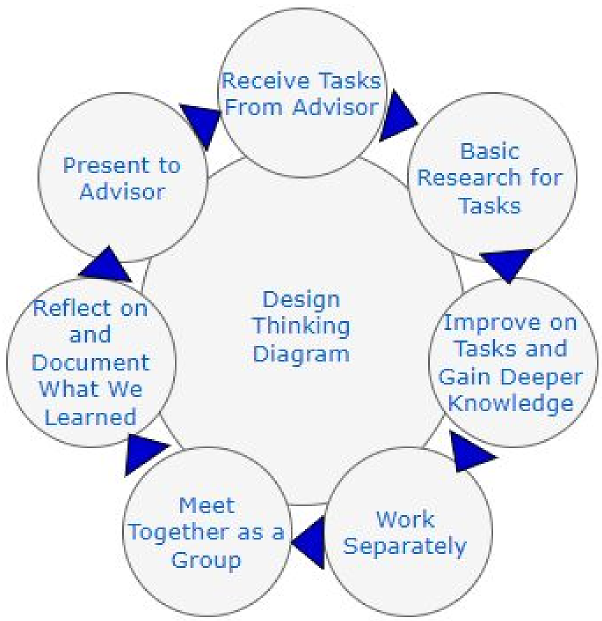

Figure 1: Task Approach

2.9 Possible Risks And Risk Management

One risk that we have to deal with is our lack of experience dealing with solar generation in a distribution system. We are learning about this topic as we go along but lack the practical experience associated with this. We also only have one member attending EE 455, which is the introduction to power distribution course, which means much of what we learn in out of a textbook. We have also never used GridLab previously which could slow down how fast we are able to implement the distribution system. It may also take time to come up with solutions to cases where voltage violations occur, as designing a solution to this is not something we have experience with.

2.10 Project Proposed Milestones and Evaluation Criteria

Our first project milestone is solving the IEEE 4 node system by hand. This is important so that we can understand when our GridLab simulation is having problems. We have the expected results from IEEE to check our work. Our second milestone will be to implement the distribution system in GridLab. We will test this by simulating the system and getting the actual values at all of the nodes.

2.11 Project Tracking Procedures

We will be using GitLab to keep track of our coding for the distribution system model. We will also be meeting as a group once or twice a week, as well as meeting with Professor Ajjarapu once a week.

2.12 Expected Results and Validation

The desired outcome of this project is to have a modeled distribution system in GridLab that we can use to simulate the effects of solar generation on the system. We also expect to come up with solutions that can solve problems from solar generation as outlined in section 2.1. We will know if our solutions work by implementing them into our test system and seeing if it works as we expect. We can also check if our solution is acceptable by making sure there are no voltage violations in the system. The voltage level will also be between 0.95 to 1.05 per unit, which is the ANSI standard.

2.13 Test Plan

All of our testing will be done using GridLab and MatLab. We will be making sure all voltages are within ANSI and IEEE standards. For each test we will first need to find the voltage profiles of all the loads in the system, as well as all transformer, line, and other values in the system.

Test Case 1: Distribution system is modeled correctly. If the system is modeled correctly the actual and simulation values should match.

Test Case 2: Proposed solution works. If the proposed solution works, then there shouldn't be any over voltage or opposite power flow in a system with high solar PV penetration. The voltage level will also be between 0.95 to 1.05 per unit, which is the ANSI standard. To do this we will first find the voltage profile of the loads with the addition of solar generation. Next, we will run a power flow solution on the system and check for voltage violations. If there are violations we will test a solution and if it fixes the voltage violations it is a success.

3 Project Timeline, Estimated Resources, and Challenges

3.1 Project Timeline

Task	Task Title	Start	End	8/29	9/5	9/12	9/19	9/26	10/3	10/10	10/17
1	Study Distribution Systems and Solar Power	8/29	9/5								
2	Solve 4 Node Distribution System by Hand	9/5	9/26								
3	Integrate Voltage Regulator in 4 Node System	9/26	10/24								
4	Implement 4 Node System in GridLab	9/26	10/24								
Task	**Task Title**	**Start**	**End**	**10/24**	**10/31**	**11/7**	**11/14**	**11/21**	**11/28**	**12/5**	**12/12**
5	Implement 13 Node System in GridLab	10/24	11/7								

Figure 2: Semester 1 Gantt Chart

The basis of the project for the first semester will be research into distribution systems while getting an idea of how high PV penetration impacts a distribution system. Figure 2 shows the general schedule of the tasks for the first semester. The team studied concepts pertaining to distribution systems, and solved some relevant examples including the power flow of IEEE's 4 node test system. After becoming comfortable with how distribution systems work, the team will implement distribution systems using GridLab, starting with the original 4 node system. To show how far the team has come in their understanding of distribution systems, a presentation will be given to the advisor. The team will then move on to working on more complex distribution systems in GridLab. This will start with solving the power flow for the IEEE's 13 node system in GridLab, which will introduce the team to working with voltage regulators and capacitors in a distribution system. After understanding fully how different setups with capacitors and voltage regulators affects a distribution system, the team will construct IEEE's 34 node system in GridLab. With this system, the team will begin integrating solar power, and study its effects on distribution systems. Once the team has an understanding of solar energy's effect on a distribution system, work will begin constructing Alliant Energy's real-life distribution system in GridLab to end the first semester.

For the second semester, the team will be working with Alliant Energy to simulate one of their distribution systems. Once the system is modeled in GridLab, the team will begin adding solar power at different parts of the system. This work will be labor intensive, as all of the code will be in notepad files. The team will adjust variables like substation positions, voltage regulator and capacitor placements, and voltage levels. At this time, we have not been able to meet with Alliant Energy, and are not sure of what the timeline will look like.

3.2 Feasibility Assessment

For the first part of the project, the team will be doing research on solar power and distribution systems, and getting comfortable with understanding distribution systems in using GridLab. During this time there will not be many challenges as the team is solving problems that already have solutions, and will receive guidance from the team's advisor. When the team begins research into how high PV penetration impacts the distribution systems, there will be more challenges. The team will have to have become adept at understanding all that effects distribution systems, and separate outlying factors from how the excess solar energy is affecting the system. In finding methods to avert the impact of high PV penetration, the team will be trying to fix problems that have been difficult for the world's engineers to find an answer to. The known solutions to handling the excess energy, however, will help make the work more manageable by being able to apply them to our own distribution systems.

There are some specific problems we may run into regarding Alliant's distribution system. The first challenge will be converting Alliant's distribution system from Synergy to GridLab.

Synergy is a high-end power system software that is outside of the team's price range. Data will have to be received in Synergy's format, and then converted into the text format of GridLab. To do this the team will have to write code to remodel all of the data without error. This is because there will be thousands of lines of GridLab format code, which will have to be broken into different notepad files, as text files can only hold 10,000 lines. Once the system is modeled in GridLab, the team will have to go through those thousands of lines to make adjustments to the distribution system, which will be challenging for a four-person team.

3.3 Personnel Effort Requirements

The table below shows all of the tasks that need to be completed in order to do the project. We will be spending most of our time using GridLab working on the Alliant Energy distribution feeder.

Task	Description	Time(hours)
General Research	Research duck curve, parts of transmission line, per unit calculations, and residential and community solar generation.	20
4 Node System	Solve by hand IEEE 4 node system with and without voltage regulator, shunt capacitor, and in per unit.	60
Learn GridLab	Using GridLab, solve IEEE 4 node system, IEEE 13 node system, and IEEE 34 node system.	100
Implement Distribution Feeder in GridLab	Using GridLab, model Alliant Energy distribution feeder.	80
Research High Solar Penetration	Using distribution feeder modeled in GridLab, research what happens when high amounts of solar PV generation is added to the system. Research for both residential and community solar cases.	100

Identify Solutions	Based on the research on high solar penetration in the distribution system, identify guidelines or solutions to prevent problems that occur with high solar penetration	100
Prepare Presentations	Throughout the class we will be preparing presentations for Professor Ajjarapu	30

Table: Primary Tasks

3.4 Other Resource Requirements

As of now, there are not many resources required for the project. All of the team member's are in possession of the textbook *Distribution System Modeling and Analysis* by Kersting, which is relevant to the distribution systems we will be working with. The work will primarily be done in using the software GridLab, OpenDDS, and MATLAB.

3.5 Financial Requirements

This project uses a number of open source software programs to model the system. All of the programs we are using are free of charge or covered by using a student license. We are using GridLab, OpenDDS, and MATLAB for this project.

4 Closure Materials

4.1 Conclusion

In this project, we have done the voltage and current calculations by hand for the IEEE 4 node system in order to understand basic principles of power flow. On this basis, our team is going to assess the impact of high penetration solar power generation on distribution feeders and the power supply to consumers. High penetration solar power energy can cause problems such as reverse power flow and over-voltage in the distribution process. Our mission is to simulate an Alliant energy system and determine how to avoid problems caused by high PV penetration. In examining the impact on distribution systems, we can find solutions for those potential problems. We will use open source GridLab software to simulate the effectiveness of integrating high PV penetration impacts into the distribution systems, and to determine the most appropriate method in transmission when solar energy is applied to distribution systems. From various attempts and mistakes, we will find the most reliable way to supply energy.