Impact of High PV Penetration on Distribution Systems

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Client: Alliant Energy
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Our Group

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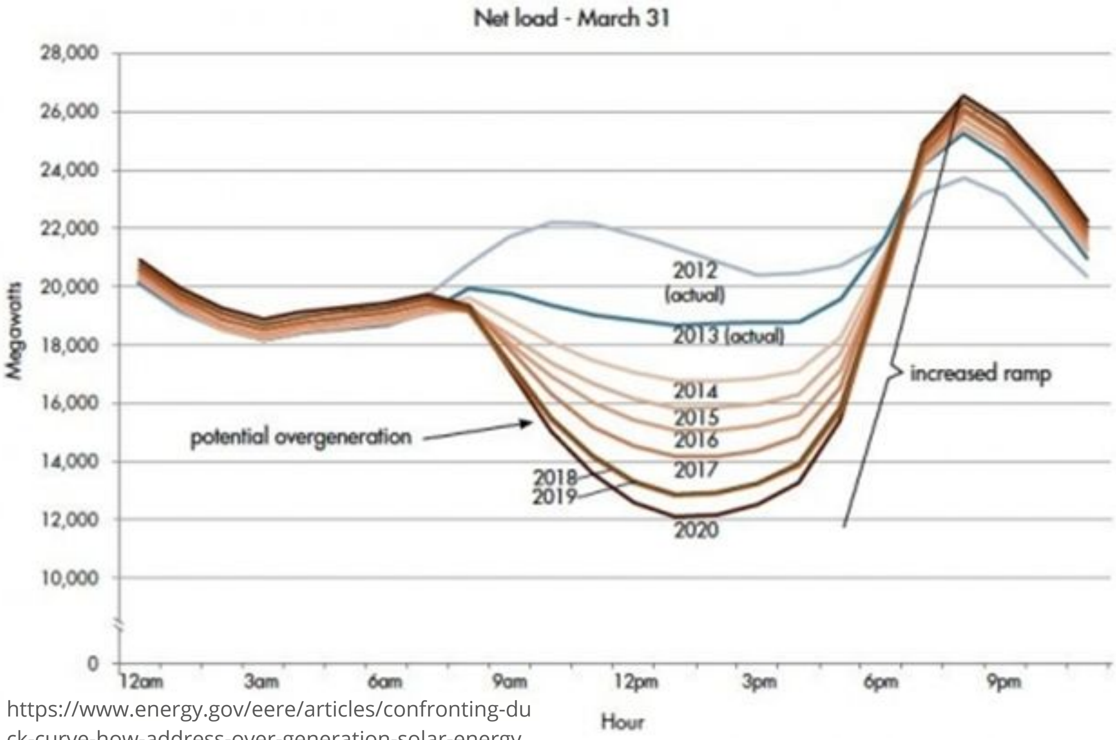
Problem Statement

- The Problem
  - Use of solar energy is increasing.
  - Variable nature of solar energy causes voltage problems.
  - Alliant Energy desires to add solar energy to their distribution systems.
- Our Solution
  - Simulate the Alliant Energy distribution system using GridLAB-D.
  - Add instances of high PV penetration to the system.
  - Note where voltage violations occur and make solutions.
  - Provide graphs explaining solutions and general guidelines for future implementations of solar energy.

Conceptual Sketch - The California Duck Curve



https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy

Functional Requirements

- Implement IEEE distribution systems in GridLAB-D.
- Add high PV penetration and make adjustments.
- Convert distribution system data in MATLAB to GridLAB-D's format.
- Implement an Alliant Energy distribution system in GridLAB-D.
- Add solar energy to Alliant's system, and find solutions to overvoltage and reverse power flow.

Constraints and Considerations

- Use of GridLAB-D
  - No user-interface.
  - Open source and not widely used.
- Need convincing, presentable data.
- Solar generation not consistent.
- Alliant Energy’s current infrastructure.
- Climate in Iowa.
- Profitability for Alliant Energy.

What Makes Project Important

- Solar and other renewables increasing.
- Iowa is predicted to have increase in solar.
  - Specific feeder
- Current infrastructure unprepared.
- Help utility prepare for increase in solar.

Potential Risks & Mitigation

- Learning Curve
  - GridLab Wiki
  - Test Feeders
- Data Entry Error
  - Avoid by common sense checking.
  - Check with actual values in beginning.
  - Converting data from Excel.
- No safety concerns
  - All work done in software.
  - Operating environments not a concern

Resource/Cost Estimate

- Using GridLab-D and MATLAB as our software.
- GridLab-D is open source.
- MatLab if free for students.
- No cost for Alliant Energy.

Semester 1 Schedule

Semester 1 - 8/29/2018 - 1/16/2019

Task	Task Title	Start	End	8/29	9/5	9/12	9/19	9/26	10/3	10/10
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	10/17							
4	Implement 4 Node System in GridLAB-D	9/26	10/17							

Task	Task Title	Start	End	10/17	10/24	10/31	11/7	11/14	11/28	12/5
5	Implement 13 Node System in GridLAB-D	10/17	11/7							
6	Summarize Research and Present Findings	11/7	11/14							
7	Write MATLAB code to convert data	11/14	1/16							
8	Prepare for next semester	12/5	1/16							

Gantt Chart for Semester 1

Semester 2 Schedule

Semester 2 - 1/16/2019 - 5/1/2019

Task	Task Title	Start	End	1/16	1/23	1/30	2/6	2/13	2/20	2/27
1	Implement IEEE 34 Node System in GridLAB-D	1/16	1/30							
2	Add Solar Energy to IEEE 34 Node System	1/23	2/6							
3	Build Alliant Energy Distribution System	1/30	2/20							
4	Add Solar Energy to Alliant Energy System	2/20	3/6							

Task	Task Title	Start	End	3/6	3/13	3/27	4/3	4/10	4/17	4/24
5	Document High PV Penetration Effects	3/6	3/13							
6	Adjust Alliant System and Document Solutions	3/13	4/3							
7	Analyze Solutions	4/3	4/24							
8	Compile and Present Solutions	4/24	5/1							

Project Milestones

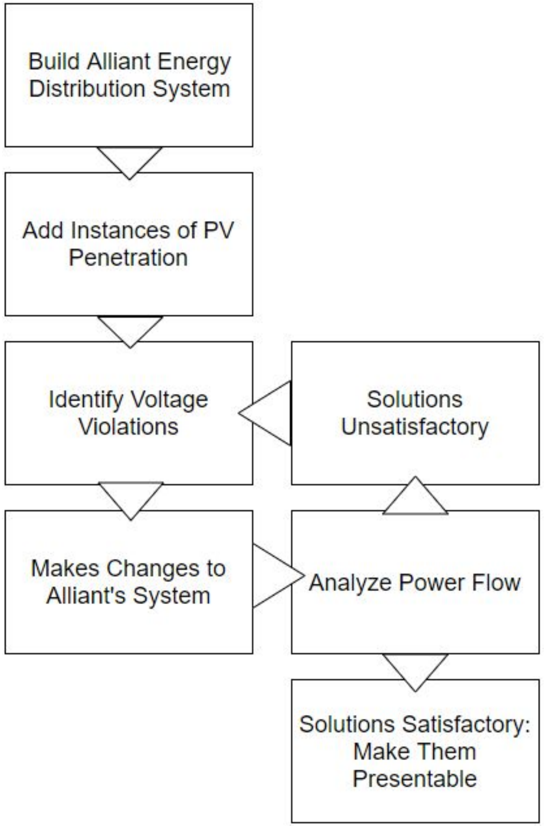
- Solving the IEEE 4 node system by hand.
- Implemented the IEEE 13 node test systems to get a better understanding of how voltage regulators and capacitors impact the system.
- Implement the Alliant Energy distribution system in GridLab, using a combination of our own code and spreadsheet data from Alliant.
- Add increasing amounts of solar generation to the system, analyze the results, and design solutions when problems occur.
- Present solutions to Alliant Energy.

Functional Decomposition

- Distribution feeder with integrated solar
- Actual System
  - Alliant Data
- Integrated Solar
  - Residential & Community
  - Level of penetration

Detailed Design

- Use Alliant data to correctly model.
  - Use MATLAB to move data from Synergi/Excel to GridLab.
- Add solar to system.
  - Both residential and community.
  - Different levels of penetration.
- Design solutions to problems.
  - Amount system can handle.
  - Use voltage regulators, capacitor banks, & smart inverters.
  - Individual solutions.
  - Guidelines.



Software Platform - GridLab-D

- Open Source
- Object Based
- No User interface
- Power Distribution System Simulation and Analysis
- Works well with MatLab

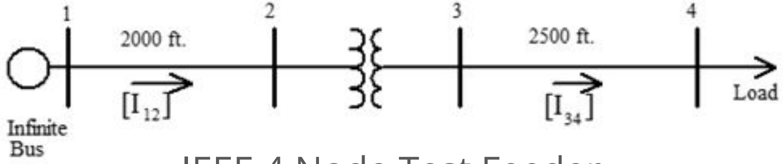
```
object load {
     name load4;
     phases "ABCN";
     voltage_A +2400;
     voltage_B -1200-2078.46j;
     voltage_C -1200+2078.46j;
     constant_power_A +1800029.41+871719.07j;
     constant_power_B +1800029.41+871719.07j;
     constant_power_C +1800029.41+871719.07j;
     nominal_voltage 2400;
```

Test Plan

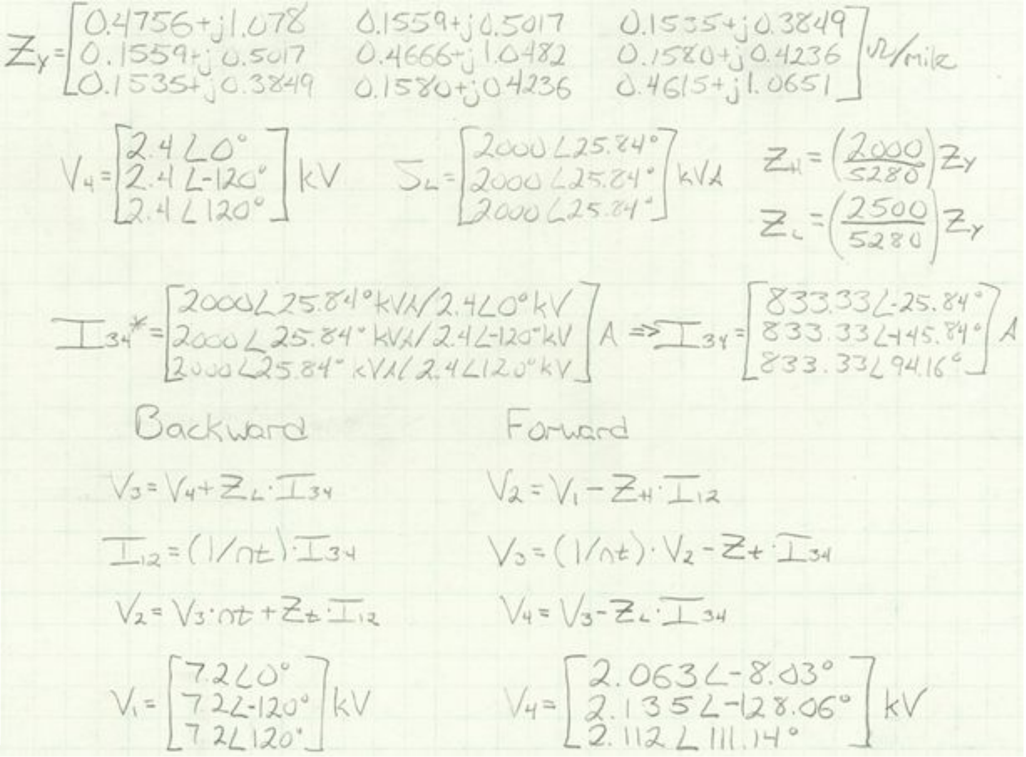
- Run power flow of Alliant system in GridLab.
- Test if distribution system is correctly modeled.
  - Compare with actual values provided by Alliant Energy.
- Test system with added instances of PV penetration.
  - Voltage within standards (0.95 and 1.05 per unit).
- Create and test solutions.
  - Create solution if voltage not within standards.
  - Test if solution returns voltage to within acceptable standards.
  - Compare potential solutions to find the one which is optimal.

IEEE 4 Node System By Hand

- Solved the first iteration of the power flow for IEEE's 4 node test system by hand using the backward-forward sweep method.
- Calculated further iterations of the power flow using MATLAB.

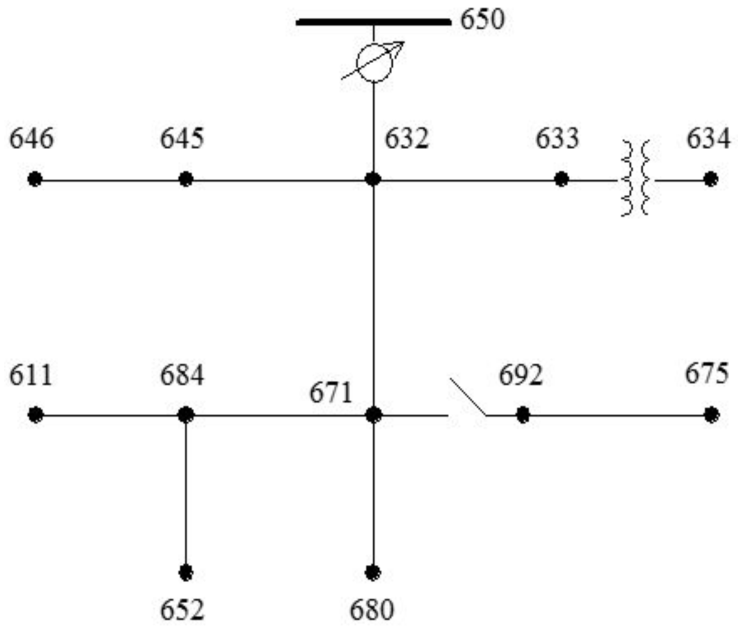


IEEE 4 Node Test Feeder

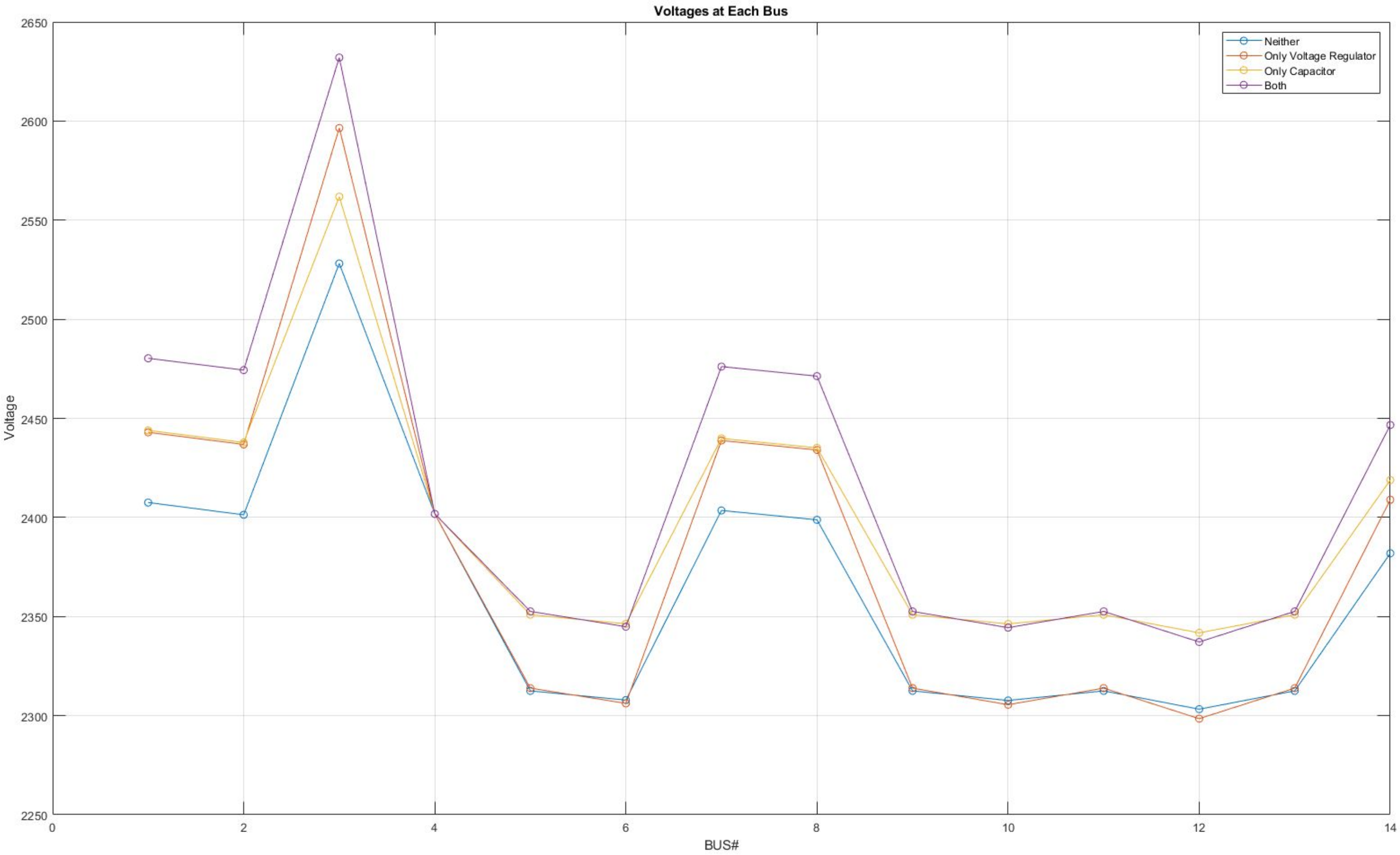


IEEE 13 Node System in GridLAB-D

- Modeled the 13 node system in GridLab.
- Learned how to work with capacitors, voltage regulators, and split loads.
- Ran power flow using Newton-Raphson method.
- Simulated with both the voltage regulator and capacitor
- Removed one of each, and then both to see the effects.



IEEE 13 Node Test Feeder


Voltages at Each Bus
Neither
Only Voltage Regulator
Only Capacitor
Both
Voltage
BUS#
2650
2600
2550
2500
2450
2400
2350
2300
2250
0
2
4
6
8
10
12
14

Converting Distribution System Data in MATLAB

- Receive system data from Alliant Energy.
- Read spreadsheet data in MATLAB.
- Write code in MATLAB to convert data into GridLAB-D's format.
    - GridLAB-D is object-based (nodes, voltage regulator configurations, etc.)
    - Need to create format for each object.
    - Each component can be defined based on its values.

Current Project Status

- Completed
    - Background research on distribution systems and solar energy.
    - Power flow for IEEE 4 node test system solved by hand.
    - IEEE 4 node test system implemented in GridLAB-D.
    - IEEE 13 node test system analyzed using GridLAB-D.
- In Progress
    - Write MATLAB code to convert distribution system data into GridLAB-D's format.
- Near Future
    - Implement IEEE 34 node test system in GridLAB-D.
    - Study effects and find solutions to problems in adding high PV penetration to the IEEE 34 node test system.
    - Build Alliant Energy distribution system.

Plan for Next Semester

Build Alliant Energy's system

- Implement IEEE's 34 node system in GridLab-D.
- Add instances of high PV penetration to IEEE's 34 node test system.
  - Find solutions to any voltage violations.
- Build Alliant Energy's distribution system in GridLAB-D.
  - Verify the system is correct with Alliant Energy.
- Add solar energy to Alliant Energy' system.
  - Find solutions to any voltage violations.
  - Present findings to Alliant Energy.