High-Level Design of a Distribution Microgrid

Project Plan

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List of Definitions

Please include any definitions and/or acronyms the readers would like to know.
Microgrid: A small network of electrical consumers using a local supply that is usually attached to a larger grid, but with the ability to operate autonomously from the grid.
Distributed Generation: The generation of energy at or very near the location it is consumed.
kWh: kilo-watt hour, a unit of power.

1 Introductory Material

1.1 Acknowledgement

If a client, an organization, or an individual has contributed or will contribute significant assistance in the form of technical advice, equipment, financial aid, etc, an acknowledgement of this contribution shall be included in a separate section of the project plan.

1.2 Problem Statement

Alliant Energy has tasked our team with creating a spreadsheet that will calculate the amount of distributed energy needed to meet the kWh demands of a small town in Iowa. This town is miles from the grid and requires long transmission lines to provide power to the town, so it might be more cost effective to turn it into a microgrid.
We will be calculating the effectiveness of incorporating a combination of solar panel generation and battery storage into this town. Once this optimal combination of solar and battery is found, we will examine the effects of externalities such as latitude and longitude, average sunlight, and variable kWh demands on the efficiency of the microgrid.

1.3 Operating Environment

Our end product will be an excel spreadsheet that will have variable inputs and outputs which model a microgrid environment. This will be used in an office setting by Alliant Energy and shared with their clients.

1.4 Intended Users and Intended Uses

The end user of our product is Alliant Energy, specifically for their distribution team. They will be able to use this spreadsheet to estimate the efficiency of a microgrid and create bid sets off of. This will be shared with clients to demonstrate the economic value of a microgrid.

1.5 Assumptions and Limitations

Assumptions

- Our microgrid location is Nichols, Iowa
- The microgrid is to be designed with the intent of being completely self-sufficient
- We will be using Seraphim SRP-6MA solar panels
- We will be using Ideal Power SunDial Plus battery/inverters
- The reliability of the system will be tested for 31 day and 365 periods
- We will assume worst-case scenarios when making calculations
- Any load not supplied by the solar panels and batteries will be supplied by a natural gas turbine
- Our demand is based off of a load information gathered by Alliant Energy.

- We will be using the finished Nichols, Iowa microgrid design to test the effects of varying geological locations, average sunlight, variable kWh demands, and consumer growth.
- There will be no more than three consecutive days of low solar radiation.

Limitations

- We will not be factoring in mechanical failure rates of the equipment
- The effects of sunlight on the system is an estimate based off of past sunlight patterns and isn't entirely predictable
- The load growth on the system is estimated based off of past rates of growth in Nichols, Iowa
- Our current system's demand is based off of daily peak demands and isn't a comprehensive demand schedule

1.6 Expected End Product and Other Deliverables

On April 17th, Alliant Energy will be given the final prototype of the spring for a spreadsheet tool in excel that will allow them to manipulate inputs and outputs relating to their desired microgrid. This excel document will also be programmed to simulate a microgrid environment based on the inputs and outputs entered. We have an external simulation tool, MATLAB, that we will be using to build our simulation within excel. Alliant Energy will not be using this as a project deliverable since they don't desire a MATLAB license and the excel simulation is easy to understand for their clients. Alliant Energy will also be receiving an instruction manual for operating the excel file as an additional deliverable in the second semester of the project. By the end of the second semester, December 2018, Alliant Energy will be given the final design for the excel spreadsheet and simulation for their use in the Distribution Engineering department.

2 Proposed Approach and Statement of Work

2.1 Objective of the Task

The objective of the task is to have a spreadsheet which calculates an estimate of the quantity of solar panels and batteries needed to meet the requirements of a given system and simulates the environment of any microgrid.

2.2 Functional Requirements

- Simulation of the environment including solar radiation, generation, and load
- Solar Panel generation and batteries must provide within 5% of the peak demand
- Hourly demand calculations
- Calculate the quantity of solar panels and batteries required to meet a user defined portion of the load (80%, 90%, 100%)

2.3 Constraints and Non-Functional Requirements

Constraints

- The final deliverable shall be in the form of an excel spreadsheet
- The only sources of power for the microgrid shall be solar panels and batteries
    - Supplemental generators are available for demand not met

Non-Functional Requirements

- Visual representations of load demand, generation, and battery supply
- Simulation able to run for at least a year of data
- Show all calculations and work in a separate tab
- Condense all important information together

2.4 Previous Work And Literature

http://www.outbackpower.com/applications/global/micro-grid
A basic design we might want to implement if we decide that a residential instead of utility system is preferred.

http://www.microgridinstitute.org/about-microgrids.html
Has good defintions of different types of systems under the microgrid image to determine what type of system we want.

https://en.wikipedia.org/wiki/Microgrid
Info under the Microgrid control section I think is most important, help us determine what sort of control systems we want in place for our system.

https://building-microgrid.lbl.gov/examples-microgrids
The examples on the left are very helpful. I haven't read thorugh them all yet but I will check them out tomorrow to see which fits our needs the closest.

https://building-microgrid.lbl.gov/about-microgrids

Images on the right just have a very basic idea of what we are trying to accomplish, good to visualize the components we need to address.

https://www.researchgate.net/profile/Alimul_Khan2/publication/271831897_A_Noble_Design_Of_DC_Micro_Grid_For_Rural_Area_In_Bangladesh/links/54d2f8c90cf2b0c6146c7296/A-Noble-Design-Of-DC-Micro-Grid-For-Rural-Area-In-Bangladesh.pdf
I believe the flow chart on page 7 will help us address the various components.

2.5 Proposed Design

A combination system of solar panel generation and battery storage. We will have solar generation providing most of the power and having backup battery storage along with supplemental generators when needed. The quantities of photovoltaic panels, batteries, and generators are determined based off of the simulation environment. The user is able to control the variables being input to create the simulation, and the simulation is used to calculate quantities and costs of the microgrid system which will be visualized in a table and diagrams.

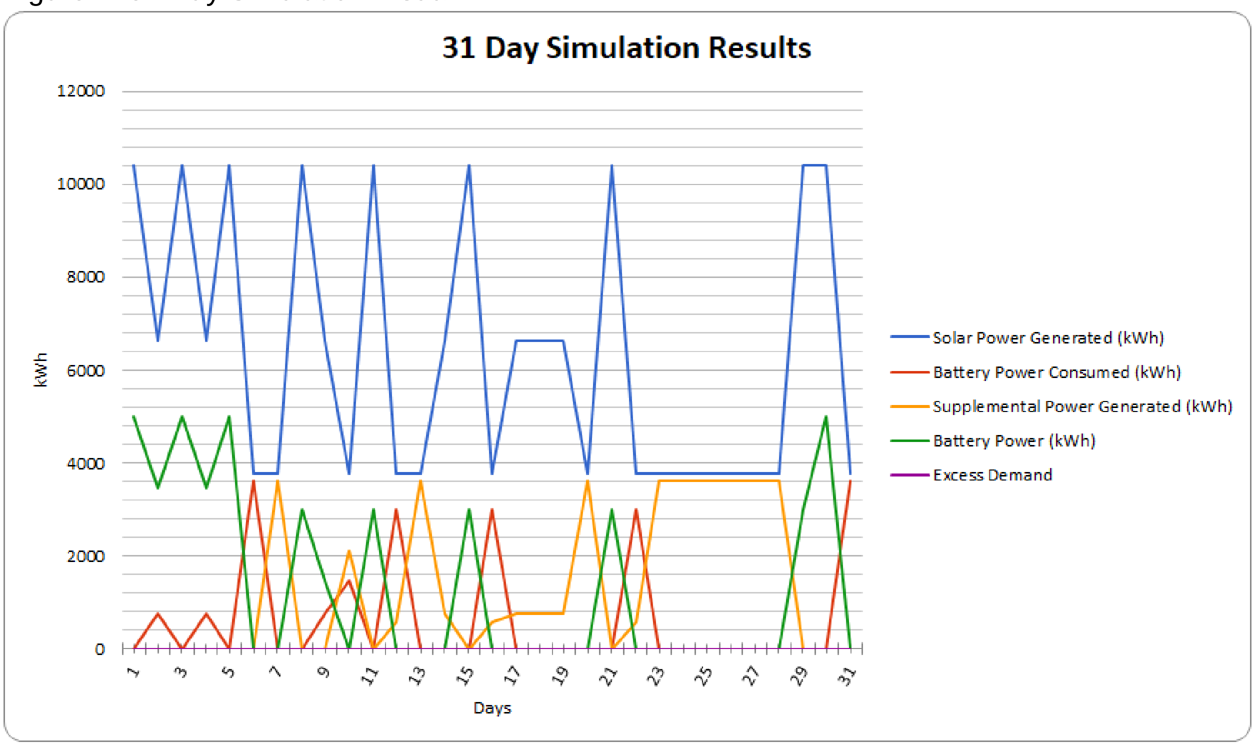
We are utilizing MATLAB as a means to build this simulation in excel. The end-product design will only require the user to input a few things to run the simulation, but we are piecing the extensive calculations and information for the simulation together manually. This is a very long process and not at all feasible for an end product. Therefore we will be simulating large numbers of data points automatically in MATLAB as opposed to constructing the whole simulation in excel off of manually generated variables. This will also give us a greater accuracy in the simulation design since we will be able to run the simulation hundreds of times more in MATLAB than excel.

The diagrams are still in progress, so what is currently available are screenshots of the inputs tab and the 31 day simulation diagram. The inputs tab is used to either manually or automatically enter in daily environment variables to run through the simulation. Figure 3 below shows the first week of the full year simulation as well as the results of the first 10 hours of simulation in days one and two. Figure 4 is a one month chart of the solar generation, load, storage, and unsupplied demand.

Figure 3: Section of the simulation with highlighted inputs

SIMULATION PROTOTYPE V3				Legend	Inputs						
Initial Battery Storage	100%										
(When disconnected from grid)					Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
			Load Type Summer, Winter (1-2)		1	1	1	1	1	1	1
Daily Usage	7382	kWh	High, Med, Low, Zero Solar (1-4)		40	35	30	25	20	15	10
			Total Solar Power Gen. (kWh)		5846.40	11894.40	10080.00	8870.40	15120.00	10886.40	6451.20
Solar Panel Wattage	360	W	Supplemental Power Gen. (kWh)		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Number of Panels	5600		Excess Battery (kWh)		7322.07	8610.21	8986.69	8986.69	9673.22	8986.69	7018.36
Total Solar Generation Power	2.02	MW	Excess Demand (kWh)		0.00	0.00	0.00	0.00	0.00	0.00	0
			Excess Demand (%)		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Number of Batteries	350										
Single Battery Capacity	30	kWh									
Capacity of Battery Storage	10500	kWh									
Supplemental Generator Capacity	0	kWh									
DAY 1											
Hour	0	1	2	3	4	5	6	7	8	9	10
Load Type Summer, Winter (1,2)	228.84	214.08	206.70	206.70	214.08	236.22	250.99	273.13	302.66	324.81	339.57
High, Medium, Low, No Solar Hour (1,2,3,4)	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.3
Solar Power Generated (kWh)	0.0	0.0	0.0	0.0	0.0	0.0	100.8	100.8	201.6	403.2	604.8
Battery Power Consumed (kWh)	228.84	214.08	206.70	206.70	214.08	236.22	250.99	273.134	302.662	0	0
Supplemental Power Generated (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Excess Battery Power (kWh)	10271.16	10057.08	9850.38	9643.69	9429.61	9193.39	8942.40	8669.26	8366.60	8444.99	8710.22
Excess Demand (kWh)	0	0	0	0	0	0	0	0	0	0	0
Excess Demand (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DAY 2											
Hour	0	1	2	3	4	5	6	7	8	9	10
Load Type Summer, Winter (1,2)	228.84	214.08	206.70	206.70	214.08	236.22	250.99	273.13	302.66	324.81	339.57
High, Medium, Low, No Solar Hour (1,2,3,4)	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.6
Solar Power Generated (kWh)	0.0	0.0	0.0	0.0	0.0	0.0	201.6	403.2	604.8	806.4	1209.6
Battery Power Consumed (kWh)	228.84	214.08	206.70	206.70	214.08	236.22	250.99	0.00	0.00	0.00	0.00
Supplemental Power Generated (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Excess Battery Power (kWh)	7093.23	6879.15	6672.46	6465.76	6251.68	6015.46	5764.47	5894.54	6196.67	6678.27	7548.29
Excess Demand (kWh)	0	0	0	0	0	0	0	0	0	0	0

Figure 4: 31 Day Simulation Visual



2.6 Technology Considerations

The strengths of the current technology are that local solar generation and battery storage already exists on small and large scales. We will be able to use current examples of local generation and storage for our own design.
The downside is that the technology for solar generation is evolving rapidly and there are no perfect ways to store energy.

One major technology consideration to take into account is our use of excel. Excel is a great tool for laying out information in a user friendly way, which is why our team and Alliant chose this as our deliverable. However, our team needs to be able to run extensive simulations to create the microgrid and we have our limitations in excel, the biggest being that our team isn't able to code in the language that excel runs on. This is why we will be using MATLAB to build the simulation in excel. MATLAB is a tool designed for large quantities of data points and we are well acquainted with this tool.

2.7 Safety Considerations

No safety concerns to consider.

2.8 Task Approach

Describe any possible methods and/or solutions for approaching the project at hand. You may want to include diagrams such as flowcharts to, block diagrams, or other types to visualize these concepts.

2.9 Possible Risks And Risk Management

Possible risks include,

- Using less efficient solar and battery systems than are available. The goal of our project is to demonstrate the modern feasibility of a microgrid, so we need to be using the most modern equipment available in the industry.
- Confusion with representing information in an intuitive spreadsheet. Because there is so much information and data within the excel sheet, it will need thorough organization. Alliant will be using this spreadsheet to show to clients, so it needs to be understandable to someone outside of the Electrical Engineering field.
- Accuracy of future load growth and PV and battery quantities to supply the load
    - The growth of a town can only be estimated based on past trends and would affect the growth of the microgrid
    - The ratio between the quantity of PV and batteries is dependant on the weather of the microgrid location.

        - For example, a location with less solar radiation will require more batteries to supply the load than a location with more solar radiation.

2.10 Project Proposed Milestones and Evaluation Criteria

- Initial combination of solar and battery capable of supplying enough power
- Simulating the microgrid for one week, one month, one year
- Implementing supplemental generation and 100%, 90%, and 80% power supply
- Future changes to system to keep up with increasing kWh demand
- Use the simulation to model the environment of Nichols, Iowa and prove that the design is capable of supplying enough power to the load.
- Applying cost and life cycle analysis to the designed system

2.11 Project Tracking Procedures

We will be using this project plan and our internal google folder to track the overall progress of our project. Depending on the progress of our project, we will be able to complete specific milestones, and update the project plan if any new problems arise. Since our final product is an Excel document and simulation, we will have multiple iterations of our design. After doing research and building an outline of our system we will, begin working with the client to develop a basic simulation. Depending on the clients needs, they will request changes and updates to the design. We plan to have three prototype iterations and will repeat the process with the client until they are satisfied with our final simulation document.

2.12 Expected Results and Validation

The desired outcome of our project is a satisfied project advisor and client (Alliant Energy). There are several other metrics in which we can analyze the success of our project;

We will evaluate the effectiveness of our project on a high level by testing our spreadsheet with many different scenarios for microgrids.

2.13 Test Plan

Once the final Excel prototype is completed, we we will begin testing by entering a sweep of all the variable inputs in the simulation. After each input, the simulation will automatically determine the excess demand needed by our system. Running a sweep of inputs will allow us to determine the minimum amount of materials needed without going over a 5% excess demand. Depending on how the client works with their customers, they may allow for a larger amount of excess demand. Running the same sweep as before will allow us to easily determine the new material amounts. In addition to changing the inputs, we will be able to change the load demands for all possible scenarios using our pre-made profiles. An implementation issue we will run into is that we haven't received the necessary load data for an entire year from the client. This is due to the client implementing the data collection system in the same month we began our design. As the year progresses, we will be given more and more data to enter into the simulation. Until we receive all of the data, we will design our own estimated load profiles based on data we were able to obtain through resources online.

Tests:
Testing that enough power is supplying the demand

- Run the simulation with many combinations of microgrid environments, simulated in both excel and MATLAB
- The power generated by solar generation should be capable of supplying 80%, 90%, or 100% of the load, depending on the input variable from the user
    - To test that the solar generation is capable of supplying the load, the excess demand should never exceed 5% of the total demand.

Future changes to system to keep up with increasing kWh demand

- With the inputs tab, the user will have the ability to change the rate of population growth that the microsystem supplies. This will automatically increase the simulated load and can be tested to show that the generation can keep up with the changing demand for a finite amount of time. Without any change in the design, there will be an increase in excess demand with an increasing kWh demand.
- In order to continue supplying enough power to meet the demand, there will be an output quantity of solar panels and batteries needed to meet the projected increase in demand. This is testable by adding the amount of solar panels and batteries needed to meet the demand and re-running the simulation with this new quantity of generation.

Use the simulation to model the environment of Nichols, Iowa and prove that the design is capable of supplying enough power to the load.

- Similar to testing the previous milestones of power supply, the load profiles from Nichols will be used to demonstrate the effectiveness of our spreadsheet at creating a microgrid design.
- The load data from Nichols, Iowa will be entered into the spreadsheet and ran through the simulation
- The resulting outputs will be displayed as quantities and charts to show that the demand from the load is met by the microgrid design

3 Project Timeline, Estimated Resources, and Challenges

3.1 Project Timeline

The below Gantt chart is a visual representation of our project timeline based on the objectives from the class, our client, our advisor, and our team. We've listed the primary objectives below and gave them each a designated window that we expect to have them finished by. This is an accurate representation of the flow of our project..

Spring 2018

	January	February	March	April
Design system with combination of solar and battery to meet demand data collected by Alliant Energy.				
Develop excel simulation tool prototype to model the microgrid environment and supply visual and quantifiable information for the design.				
Develop Matlab tool for assisting in microgrid simulation and calculations to improve accuracy of excel tool.				
100%, 90%, and 80% power supply calculations from solar generation.				
Finalize simulation and microgrid design, project plans, design documents, weekly plans, and website.				

Fall 2018

	August	September	October	November	December
Incorporate summer load profile data into calculations					

100%, 90%, and 80% power supply calculations for updated data					
Improve MATLAB simulation for assisting in design and calculations					
Future changes to system to keep up with increasing kWh demand					
Improve simulation to be able to simulate microgrid environment of any kind					
Finalize cost/quantity estimations and microgrid design					

As the above Gantt charts demonstrates, the bulk of the design portion of the project will be completed during the first semester. The second semester will be for finalization of the design, simulations, and financial calculations based on the remaining load data Alliant Energy will be collecting for the remainder of 2018. Considerations for the future of the system including up-keep and growth will also be made during this semester.

One of our primary constraints for objectives is that not all load data for Nichols, IA will be available until the end of the summer. Thus, our simulations prior to to the availability of this data will be based on reasonable estimates based on average monthly load trends.

Another considerable constraint will be in the financial aspect of the project. Since our final design may be dependent on results of simulations, which are also constrained by a lack of data until the fall, our financial estimations cannot be finalized until the last couple months of the project. Finally, we will be fine tuning our design to be capable of accurately representing any possible environment.

3.2 Feasibility Assessment

A realistic end-product will be an excel spreadsheet that estimates the efficiency of a solar and battery microgrid for a variable load system. It will be challenging to make an all-encompassing spreadsheet, so we will base our calculations off of our microgrid design for

Nichols, Iowa and extrapolate this information to other potential locations in the second semester. We only have load data from Nichols for half of a year, so we will be simulating the second half of the year to design the spreadsheet. This will be feasible as we will be using similar load profiles from other towns to estimate the hourly load at any given time of year. This will not be 100% accurate, as it is a future projection. It will not be feasible to use this design as an exact estimate for costs seeing that accurate cost projections aren't available without a full-year load profile from Nichols, Iowa. The initial cost of photovoltaic and battery technology also changes frequently enough to make a long term cost projection likely obsolete. The estimated rate of return from solar generation, as well as the cost of electricity, change often enough to make a financial estimation un-feasible for our senior design team with only one year of reliable data.

3.3 Personnel Effort Requirements

Milestone	Nick	Joe	Taylor	Remo	Minoru

System combination of solar and battery	Understand and communicate the process/outcome with client and advisor through weekly status reports and other course material	Use the specs from the client and Minoru to design an efficient generation and storage system for Nichols, IA	Use the specs from the client and Minoru to design an efficient generation and storage system for Nichols, IA	Model the equations used and the inputs/outputs in an excel spreadsheet to send to the client	Research to fill any information gaps and to find efficient solutions
Implementing a supplemental generation system	Understand and communicate the process/outcome with client and advisor through weekly status reports and other course material	Use the specs from the client and Minoru to design an efficient supplemental generation system	Use the specs from the client and Minoru to design an efficient supplemental generation system	Model the supplemental generations effect on the microgrid through excel	Identify possible supplemental generation solutions. (ex: diesel vs natural gas)
Power Supply Calculations	Understand and communicate the process/outcome with client and advisor through weekly status reports and other course material	Use a combination of solar, battery, and supplemental generation to meet the different levels of power supply	Use a combination of solar, battery, and supplemental generation to meet the different levels of power supply	Model the power supply as a variable input based on the amount of power supply being delivered by the microgrid	Find economical differences between different levels of power supply

Durations of distributed generation	Understand and communicate the process/outcome with client and advisor through weekly status reports and other course material			Find out how long the system will be operable under normal and extreme conditions in the system location	Find out how long the system will be operable under normal and extreme conditions in the system location
Future changes with increasing demand	Understand and communicate the process/outcome with client and advisor through weekly status reports and other course material	Come up with solutions to combat the increasing demand on the microgrid system	Come up with solutions to combat the increasing demand on the microgrid system	Model future estimates for inputs/output in excel	Look at the possible constraints to growth with our current design
Use Nichols, IA as a basis for design	Understand and communicate the process/outcome with client and advisor through weekly status reports and other course material	Design the microgrid system to meet the kWh requirements sent from client	Design the microgrid system to meet the kWh requirements sent from client	Distinguish in the excel chart the microgrid design for Nichols vs any other systems	Find any externalities on the system coming from Nichols, IA and its surrounding environment

Model all milestones in excel	Create a test plan for all milestones in our design. Reflect this test plan in the final Project Plan document.			Work with Nick to ensure that the excel spreadsheet accurately represents our microgrid design in an intuitive way for the client to handle.	

3.4 Other Resource Requirements

All necessary resources on data and technology specifications for the Nichols system is provided by Alliant.

3.5 Financial Requirements

There is no financial cost for our design as we have full access to all the materials we need to design the microgrid. We also will be delivering the final design electronically and without any physical properties. Testing of our design will also be conducted using simulations which have no associated costs.

4 Closure Materials

4.1 Standards

The following sets of standards were applied throughout the life cycle of our project. Each set of standards are developed and approved by IEEE.

1. “IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems.” *IEEE Standards Association,* http://standards.ieee.org/findstds/standard/1547.4-2011.html

   This standard is about power distribution, and it describes the good practices for the design and operation of distributed island systems. Considering that the purpose of our project is to design a distribution microgrid, this set of standards is directly applicable to our project.

2. “IEEE Guide for Array and Battery Sizing in Stand-Alone Photovoltaic (PV) Systems.” *IEEE Standards Association.* http://standards.ieee.org/findstds/standard/1562-2007.html

   This standard is about PV solar panels, and about the appropriate sizing/capacity of PV arrays and their associated storage systems (batteries). Since the solar panels of our system would be insufficient to always meet the demand, some sort of battery storage is required. This is an important set of standards in dictating how large our storage capacity should be in relation to the number of solar panels used.

3. “AEIII Storage Batteries.” *IEEE Standards Association.* http://standards.ieee.org/findstds/standard/36-1928.html

   This standard is about storage batteries, and the related standards and accepted usage of lead-acid and nickel-iron alkaline type batteries. This standard was relevant in determining which type of batteries would be ideal for our system.

4.2 Conclusion

Ultimately, we will be providing a spreadsheet that allows Alliant Energy to see the costs/benefits of creating a microsystem in Nichols, IA. The spreadsheet may also be used for other similar systems, but Alliant is addressing Nichols because it is a far distance from interconnection and has promise of being a candidate for a microgrid.

After testing our design by incorporating the load data and demand from Nichols, we found that the quantity of solar panels and batteries are highly dependant on the amount of consecutive days with low solar radiation. We have been able to design the microgrid system to provide the load within 5% of peak winter demand when there are less than three consecutive days with low solar radiation. It is rare that there will be four or more days with low solar radiation, but still possible. Therefore our design assumes that there will not be four consecutive days of low solar radiation and generation for the sake of an accurate design at the end of the semester with the load data we currently have. This also reflects the assumption that Alliant makes when estimating solar radiation. When the second semester begins, we will have summer load data to include and by the end of the year, almost a full year of data. The data that is collected will allow us to more accurately quantify the number of solar panels and batteries needed because the solar radiation variability in the summer and fall are different than the winter and spring.

4.3 References

[1]A. Haque Khan and A. Rahman, "A Noble Design Of DC Micro Grid For Rural Area In Bangladesh", 2015. [Online]. Available: https://www.researchgate.net/profile/Alimul_Khan2/publication/271831897_A_Noble_Design_Of_DC_Micro_Grid_For_Rural_Area_In_Bangladesh/links/54d2f8c90cf2b0c6146c7296/A-Noble-Design-Of-DC-Micro-Grid-For-Rural-Area-In-Bangladesh.pdf. [Accessed: 01- Mar- 2018].

This Research paper provided us with information regarding the design of a system with similar requirements to ours. It specifically helped us conceptualize when we should be switching from battery to supplemental generation and how the demand of the location will be met. It also provided us with information related to estimating the growth of the system depending on the locations needs.

[2]"About Microgrids | Building Microgrid", *Building-microgrid.lbl.gov*, 2018. [Online]. Available: https://building-microgrid.lbl.gov/about-microgrids. [Accessed: 01- Mar- 2018].

This website provided us with information regarding how the system will be disconnected from the grid and how we will have to account for the load of the town. It also gave us information distinguishing various types of loads and how important they are to the Microgrid system.

[3]"About Microgrids", *Microgrid Institute*, 2018. [Online]. Available: http://www.microgridinstitute.org/about-microgrids.html. [Accessed: 01- Mar- 2018].

This website allowed us to explore different types of systems for various different uses. It also defined many terms that will be useful in describing our system. It also explained certain economic factors that will give us a strategy for creating the most economically efficient system.

[4]C. Bravo, "Outback Power Inc. - Global Micro-Grid", *Outbackpower.com*, 2018. [Online]. Available: http://www.outbackpower.com/applications/global/micro-grid. [Accessed: 01- Mar- 2018].

This source detailed a basic design of a Microgrid. It allowed us to define the components we will need to create a self-sufficient system that will meet the demands of our location.

[5]Metelitsa, Colleen. “U.S. Microgrids 2017: Market Drivers, Analysis and Forecast.” *U.S. Microgrids 2017: Market Drivers, Analysis and Forecast* | *Greentech Media*, Nov. 2017

[6]"Solar Panels in Nichols, IA: Solar Companies, Cost, and Installation | Decision Data", *Decisiondata.org*, 2018. [Online]. Available: https://decisiondata.org/solar-by-city/nichols-ia/. [Accessed: 01- Mar- 2018].

This website provided us with solar data for Nichols, Iowa that we will use to size our system. This information along with the demand profile of the town will allow us to create the most efficient system.

[7]"Find How Many Solar Panels You'll Need – In 8 Easy Steps", *Coastal Solar*, 2018. [Online]. Available: https://coastalsolar.com/many-solar-panels-will-need/. [Accessed: 01- Mar- 2018].

This website detailed some of the calculations necessary to size the system according to demand and solar data. It also briefly explained the cost analysis in determining if the system is economically viable for our location.

[8]"Solar Maps | Geospatial Data Science | NREL", *Nrel.gov*, 2018. [Online]. Available: https://www.nrel.gov/gis/solar.html. [Accessed: 01- Mar- 2018].

This source provided us with solar irradiance data for the United States. This will be used later in our design when we expand it to various locations instead of just Nichols, Iowa.

[9]B. Capehart, "Microturbines | WBDG Whole Building Design Guide", *Wbdg.org*, 2018. [Online]. Available: https://www.wbdg.org/resources/microturbines. [Accessed: 01- Mar- 2018].

This website explained the purpose and uses of microturbines. This allowed us to understand how we can use microturbines as supplemental generation for our system. If we don't produce enough solar power, and we don't have any stored in our batteries, then we can activate the microturbines to meet the necessary demand until we can begin producing solar energy again.