High-Level Design of a Distribution Microgrid

Design Document

Team Number: 11
Client: Alliant Energy
Advisor: James D. McCalley
Communications Engineer: Nicholas Stitzell
Power Engineer: Joseph Thurin
Power Engineer: Taylor Murphy
Research Engineer: Minoru Fernando
Data Engineer: Remo Panella
Team Email: ssdec18-11@iastate.edu
Team Website: https://sddec18-11.sd.ece.iastate.edu

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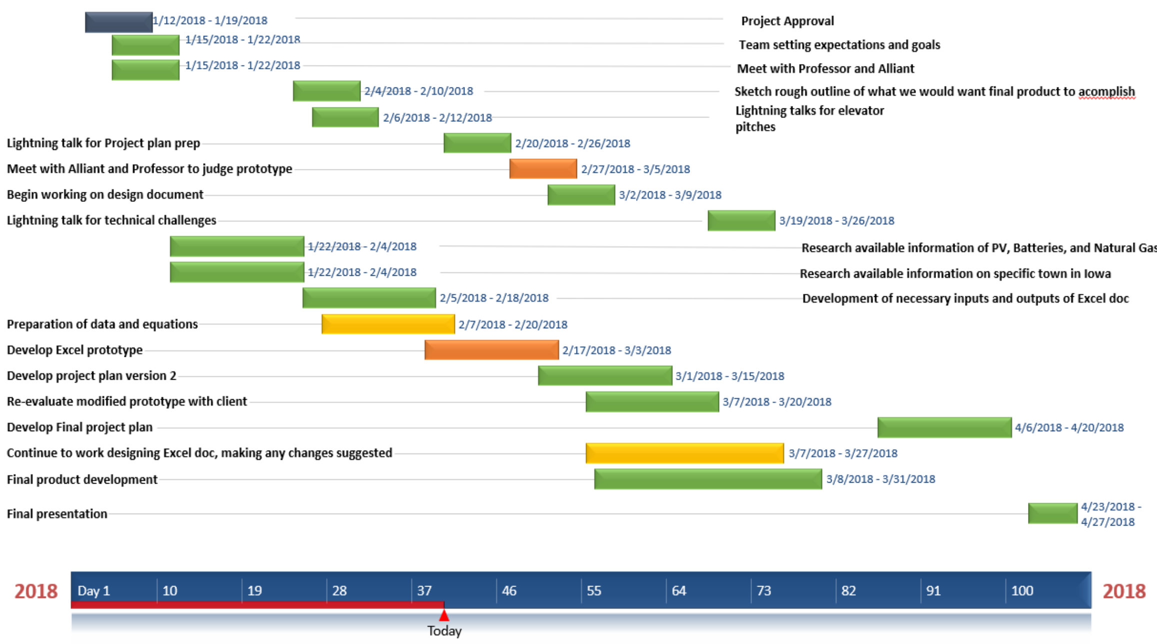


Figure 5: This is a Gantt chart showing our team’s project schedule through the first semester.

1 Introduction

1.1 Acknowledgement

Our design team has been in collaboration with Daran Lamos and Logan Heinan of Alliant Energy. Our team advisor, Professor James McCalley, has also been a vital resource in the direction of our design.

1.2 Problem and Project 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 Operational 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 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 <u>not</u> 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 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. Specifications and Analysis

2.1 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.

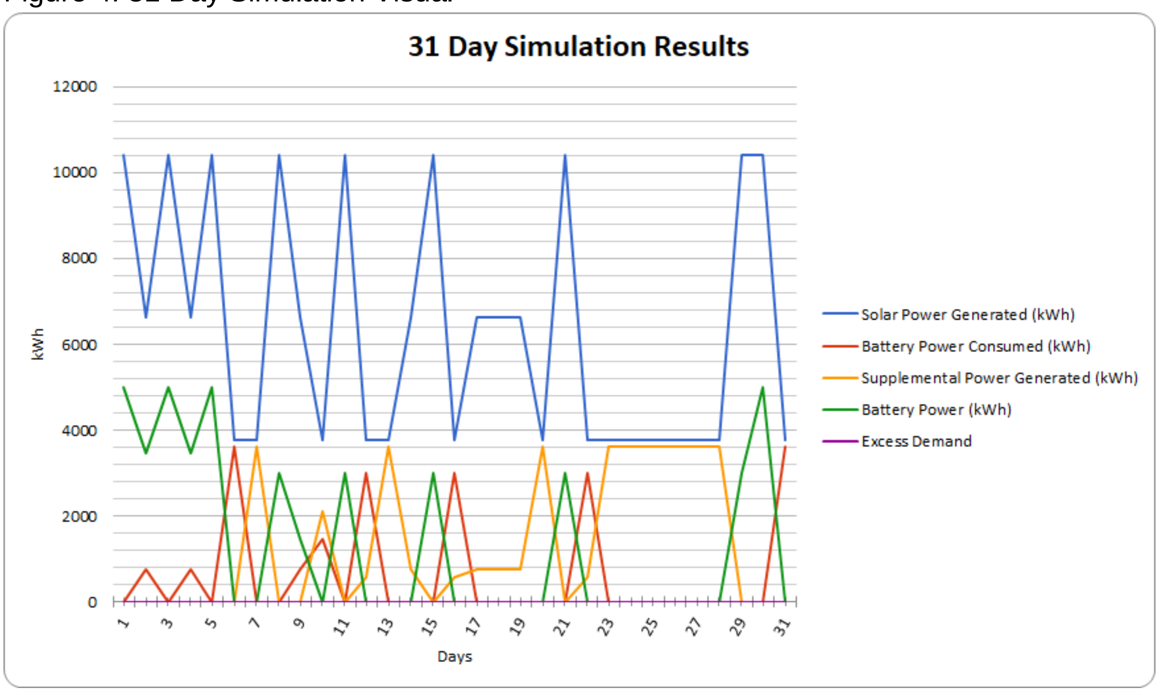
We are utilizing MATLAB as a means to build this simulation in excel. The end-product design will only require the user to input a few things to run the simulation, but we are piecing the extensive calculations and information for the simulation together manually. This is a very long process and not 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



2.2 Design Analysis

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.

3 Testing and Implementation

3.1 Interface Specifications

For testing the different systems we design for Nichols, we will be creating a simulation program to test different levels of solar radiation generation and load profiles for many different scenarios. We will be designing the program to simulate year-round profiles, as well as low, medium, and high solar environments. This simulation will be used in the final design that outputs quantities and visuals for the microgrid system.

The user will be able to manually or automatically enter load information into the spreadsheet, which will then be simulated by the design.

3.2 Hardware and software

For testing our system, we will be using Excel to simulate a real-world profile of a day's load, and solar generation. This software will be using hourly load profiles, as well as high, medium, and low solar generation throughout the day. After the load and solar generation is manually or automatically entered in, the program will track the solar power generated, battery power consumed, and supplemental power generated throughout each hour during the day. MATLAB will also be used, not in the final product deliverable however, to assist in creating an accurate simulation environment within excel. Using MATLAB will allow our design to be tested quickly with many variable environments.

Our project will have no physical hardware being that it is a software tool to estimate the specifications of a microgrid system.

3.3 Functional Testing

In the simulation Excel document, we will be tracking the system to see the amount of solar generation, and then the needed battery and supplemental generation power needed. Because we are given the city's usage in kWh, we will be tracking all variables with kWh. After simulating the system with different profiles, we will be accepting the system based on the excess demand. Accepted designs will have an excess demand within 5% of the demand. The design will be functionally tested by using data from Nichols, Iowa to test the simulation and calculate a quantity of equipment. The quantities and subsequent load data will be represented as calculations and visual representation.

3.4 Non-Functional Testing

In addition to testing the performance of the system under normal conditions, we will be testing the system under intense profiles of high load, and low solar generation. In terms of usability, if the system can supply enough power to minimize the excess demand within 5%, the system will be compatible with Nichols. The design will be non-functionally tested by assessing the output information in the form of visual charts. The simulation will output the amount of power generated, variable by the user, and compared to the demand. This will be visually represented and clearly seen by the user after simulation.

3.5 Process

Be begin testing by loading the kWh demand information into the microgrid design. The simulation then generates a year of low, medium, and high solar radiation days. We then reverse engineer the design by manually controlling the quantity of solar panels and batteries used to supply to load. By the end of the project this will be done automatically. We then continue to change the quantities of solar panels and batteries through trial and error to get within 5% of the peak demand in the winter supplied with power. Our simulation then prints the hourly outputs of the system for a full year and plots the excess demand (demand not met). If the excess demand is within 5%, it is successfully designed.

3.6 Results

After load information was input into the microgrid design from Nichols, we repeatedly ran the simulation with many different combinations of solar panels and batteries. In each trial, the excess demand increased as solar radiation decreased. This causes the system to require an increase in solar panels. In the case of three consecutive days of low solar radiation being common, we had to increase the quantity of batteries.

4 Closing Material

4.1 Conclusion

Our goal for this project is to provide Alliant Energy with a functional spreadsheet which will model and simulate a microgrid system with any given demand and environmental conditions. Our plan of action, or solution, for this design is to approach it with a test-fail approach. Because weather conditions are so unpredictable, we will be designing this system with the worst case scenarios in mind. When a system is connected to the grid, it has backup power readily available. However, an isolated microgrid doesn't have backup grid connection. We must be confident that our design is reliable and efficient. Our simulation will be able to demonstrate the responsiveness of a microgrid to weather and demand conditions.

After testing our design by incorporating the load data and demand from Nichols, we found that the number 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.

4.2 References

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]"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.

[6]"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.

[7]"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.

[8]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.