Designing a Community Microgrid

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HERE WITH YOU. HERE FOR YOU.

ELE 481 CAPSTONE DESIGN

PROGRESS REPORT #4

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National Grid

The University of Rhode Island

Project Summary

We are Blaine Baker, Harmony Smith and Javier Unceta, three Electrical Engineers from the University of Rhode Island. Our project is called *Designing a Community Microgrid.*

The main goal of this project has been to design a community microgrid in Rhode Island - project provided by National Grid. A community microgrid is an energy system specifically designed to meet some of the needs of a community; a system that operates as part of, or independent from, the larger utility infrastructure. The most important, and impressive, aspect of this community microgrid is that it is almost entirely self-sustainable. That is to say, it uses the energy that is generated by the renewable energy sources within the community and only has to use energy from the general electric grid when the alternative energy systems are unable to meet the power demand. A typical microgrid consists of the following components: Generation (solar, wind, thermal, hydro, etc.), energy storage, distribution capacity, and an energy management system (smart system).

The generation includes all the renewable energies that will provide the energy for the microgrid. This is essential considering the fact that community microgrids only use “green energies” (renewable energy sources).

Energy storage is also very important. There are various types of energy storage that can be used to store the energy provided by the renewable resources. One, familiar to most, is battery storage, where batteries are used to store electrical energy. Nowadays, battery storage is one of the weak points of “green energies”, so it is an important issue to take into account. Another method, not so commonly known, is the storage of hydrogen. The energetic potential stored in hydrogen, and the abundance of the element, is a powerful combination that can be used to increase the efficiency of a microgrid.

Distribution capacity refers to the amount of power that a community requires to operate. Depending on the size of the community, the microgrid needs to provide the required demand for power. This demand involves utilities, transmission lines, electrical machines and other components that have been to taken into account.

The energy management system (smart system) is a field in microgrids that involves all the electronic components and technology that provide a more efficient delivery of energy among the community. “Smart grid” generally refers to a class of technology that is currently being developed to bring the utility electricity delivery system into the 21st century using computer-based remote control and automation. These systems are made possible by two-way communication technology and computer processing that has been used for decades in other industries. Designing an accurate smart system will lead to faster delivery of energy, better security systems, and less energy loss.

The tasks that have been completed for this project are the following:

- Conceptual Design: What to anticipate it will look like
- Project Cost Estimate: Financial cost required for the design

- Create Technical Specifications: Product technical reviews
- Design and Configuration of the System: Using actual RI location for pilot
- Project Closeout: Review of conceptual design and cost estimates vs actual

The project was divided into two steps: Study → 1st Semester, and Implementation → 2nd Semester

Motivation for the Project

It is a fact that oil, gas and coal are energy resources that will someday disappear, some of them faster than others, but then, what will humans do? To understand the importance of renewable energies in our society, each person has to ask him/herself that question. "Green energies" are our future. We, the community microgrid design group, do not consider renewable energies important, but ESSENTIAL in our society. We are highly motivated to study this field of engineering and have really enjoyed developing this project with our best effort and our deepest commitment.

Renewable energies not only save money for countries but they also aid in avoiding harming the environment, which is also indispensable, bearing in mind the situation of the atmosphere and the greenhouse effect and the issue of climate change. This project is focused on the use of renewable energies and it would be a starting point for the development of renewable resources in our communities. We are proud to be part of this breakthrough and have worked hard to make it successful.

Nowadays, electrical systems are more complex and demand greater stability and reliability than ever before, and because of this, we have had to develop reliable and accurate systems so that they can be used in our daily lives. Technology has improved a lot in the past 20 years and we have to take advantage of it. Electronics have helped us in this field because it is the cornerstone of the smart system.

Another issue that has been taken into account is the fact that demand is increasing for cleaner power. People are beginning to use renewable energies in their houses such as photovoltaics (PVs), geothermal, and wind power. We have to encourage people to use these kinds of energies so as to avoid using oil and the other non-renewable resources. Here, the "Renewable Energy Growth Program" (by National Grid) will play an important role. The idea of this program is to give an economic benefit to customers that use solar energy (residential and non-residential customers). The more efficient microgrids are, the easier it will be to develop them in our cities - and we will all benefit from them. This benefit will be seen in cost savings. The amount of money that some countries could earn by using these energies is huge and much greater than the profit seen by the countries that have to import their energy from other locations.

And last but not least, there is a broad range of job opportunities that this field of engineering provides. This project is our first creditable encounter with the field of renewable energies and has given us a path to follow for our future. Taking into account that we are electrical engineers, it has been very important for us to make this project successful and we have been proud to have taken part in such an important development.

ABET Outcome C

After completing this project, we as a group have learned quite a bit about the impacts a project such as this has on a community. First and foremost, there are economic impacts that cannot be ignored when working on a project of this magnitude. But not only is the magnitude a major factor, but also the fact that mostly all types of renewable energy are still in the development phase which causes their prices to be very high. At the end of our report the costs are explained in further detail, but the total cost for the renewable energy sources alone is over 42 million dollars and the total cost of the smart grid devices is over 2 million dollars. For a microgrid as small as ours (involving only a small portion of Narragansett, RI), these numbers can seem outrageous and irrational. But keeping in mind that the renewable energy industry is still in its development stage, and the price of these technologies are expected to decrease in the future, can help to make the prices seem a bit less daunting. Also, the positive environmental impact that utilizing renewable energy sources will have on the carbon footprint of a community helps to make the high initial cost of these technologies seem a bit more rational.

Another impact that a project such as this has on a community is related to safety. There are many factors that weigh in in terms of safety, but the most obvious is the safety of the people of the community who are within the vicinity of these renewable energy sources. Fuel cells are a great example of a type of renewable energy source that have safety impacts on the surrounding community because the operation of fuel cells requires the use and storage of pure hydrogen and oxygen which are very combustible elements. Many people question the safety of fuel cells with the fear of explosions occurring due to the volatile nature of these elements. Another example of a renewable energy source that could have a significant safety impact would be the tidal generation system. The system itself is placed out in the ocean and needs to be in deep enough water that the powerful tides can have an effect on the system. Because of this, there are many safety concerns with boaters and fishermen in the area unknowingly coming into contact with the system. There are also safety considerations of the marine wildlife expressed by organizations like Save the Bay in Narragansett who are dedicated to preserving the natural habitat of the ocean's creatures. But with all this in mind, there have been measures taken to protect the safety of the community at risk. For example, durable hydrogen and oxygen storage tanks have been created to make the chance of explosions less likely, and also careful planning of the location of a tidal system would help to reduce the impacts it would have on the marine community.

Summary of the Technical Contributions Accomplished by the Team as a Whole

- Renewable energy research (Solar energy, wind energy, fuel cells, batteries and tidal energy) ***(Page 11)***
- Reviewed and studied possible clusters for the development of the microgrid ***(Page 14)***
- Learned about the current status of installed renewable energies in Rhode Island ***(Page 19)***
- Studied and learned about the power distribution system: Distribution lines, feeders, substations and devices
- Simulations using the *Homer Energy* software to test the reliability of our design ***(PR#3)***
- Used the SCADA system to study the distribution of the grid lines in Narragansett as well as the devices installed on it ***(Page 27)***
- Identified all the different devices on the grid around Narragansett: Capacitor Banks, Gang Load Breaks, Pole Top Reclosers, Load Disconnects, Motor Operated Load Breaks, Air Breaks, Fault Indicators and Regulators ***(Pages 23-24)***
- Studied different telecommunication systems: Radio Frequency (RF), Microwave, Satellite, Fiber Optics, Ethernet and Serial Communications. Among those, we selected and implemented in our design the following: RF and Satellite. These include the WiMAX radio system and the MSD Intrepid series backhaul system for the Radio Frequency technology. Satellite will be used to transfer the information to the Northborough National Grid data center
- Created innovative ways to control our smart grid by using a digital comparator that we designed
- Learned about grid automation technologies (smart grid). These include Pole Top Recloser control, Cap Bank Control, Switchgear Control and AMI systems ***(PR#3)***
- Included the automation of the Pole Top Reclosers (G&W Viper-S Recloser, S&C IntelliNode Control, SEL 651R Control) and Capacitor Banks (GE Capacitor Bank, SEL 734B Capacitor Control and Lindsey sensors) in the grid ***(Page 29)***
- Designed the telecommunication systems needed to communicate among intelligent devices on the grid ***(Page 36)***
- Designed an *Advanced Metering Infrastructure* system suitable for our microgrid. This system includes smart meters, backhaul systems and telecommunications (Radio Frequency) ***(Page 38)***
- Designed the haul followed by the communications to communicate between the base station and the control center including the location of the antennas ***(Page 37)***

Overall, we think that the contributions of the team and our accomplishments were very satisfying. We have learned about two important fields: Renewable energies and smart grid technology. Both are branches of electrical engineering that will be essential in the future and we believe that it is a field that will provide us with many opportunities. However, something that we were not able to implement is a real simulation of communication between WiMAX devices because of lack of time. That would have led to a really interesting hands-on experience. Nevertheless, we are more than satisfied with the outcomes of this project, and also with what we have learned.

My Individual Technical Contributions to date, By Javier Unceta

- Renewable energies research (Solar energy, wind energy, fuel cells, batteries and tidal energy) ***(Page 11)***
- Reviewed and studied possible clusters for the development of the microgrid ***(Page 14)***
- Technical specifications of the resources that we used (Photovoltaics, Wind Turbines, Fuel Cells, Tidal Energy, Hydrogen Tanks and Electrolyzers) including pricing and technical aspects ***(Page 11)***
- Diverse calculations:
  - Power demand in our cluster ***(Page 16)***
  - Sun power calculations, wind power calculations, average fuel cell power output calculations, hydrogen and water needed for the operation of the fuel cells) ***(Page 22)***
  - Cost calculations: price of the different resources to be installed and their installation, cost of the engineers involved on the project, cost of the project director, cost of the components and devices needed for the development of the smart grid, standby rate costs) ***(Page 47)***
- Skype conferences with the company Quionne (Huesca, Spain) to get information about fuel cells and wind turbines.
- Simulations of the operation of the microgrid by using the *Homer Energy* software ***(PR#2)***
- In-depth research on smart grid development. Characteristics, benefits, devices used, examples of smart grid implementations. ***(PR#3)***
- Research and development of the Cap Bank Controller system (GE Capacitor Bank, SEL 734B Capacitor Control and sensors), Pole Top Recloser Controllers (G&W Viper-S Recloser, S&C IntelliNode Control, SEL 651R Control) ***(Page 29)***
- Telecommunications:
  - RF: WiMAX Radio ***(Page 31)***
  - Fiber Optics: Telecom and Multicom Single Mode Fibers ***(PR#3)***
- Researched devices for the installation of the renewable resources ***(PR#3)***
- Researched smart meters for the communication among resources and buildings ***(Page 36)***
- Researched the devices needed to connect the different renewable resources to the grid: Fuses, switches and meters ***(PR#3)***
- Designed the comparator used for communication among renewable resources using Digital Electronics theory ***(Page 41)***
- Identified the devices on the grid and drew a map of the distribution lines around our area (Including feeders 17F3, 17F2 and 17F1, and also the Wakefield substation, the devices on the actual grid and the generation) ***(Page 27)***

- Identified the points of common coupling ***(Page 28)***
- Thought of other switches that could be installed on the points of common coupling instead of the manual gang load breaks that are installed on the actual grid ***(PR#3)***
- Researched backhaul systems (MSD Intrepid Series) as well as Meter collectors (*AMIS DC Data Concentrator*) ***(Page 32)***
- Research and development of the Advanced Metering Infrastructure system. Installation of such a system in our microgrid and its operation including all the devices involved ***(Page 38)***

As stated on the Team Contributions section, we were not able to implement a hands-on simulation of communication between WiMAX radios. I would also rather have made more accurate calculations in the energy side of the renewable energies. However, the time constraint and the workload were a hurdle. Nevertheless, I am very satisfied with the outcomes of the project and with what I have learned. Doing this project has been incredibly beneficial for me since, apart from learning a lot, we have worked alongside National Grid and we have had a real engineering project experience.

My Individual Technical Contributions to date, By Harmony Smith

- Researched electric grid ***(PR #1)***
    - Details about electric grid infrastructure and transmission of power
- Researched renewable energy sources ***(Page 11)***
    - Wind
        - Size, shape, power output, mechanism for operation, efficiency
    - Photovoltaics
        - Size, shape, power output, mechanism for operation, efficiency
    - Fuel Cells
        - Size, power output, types of fuel cells, mechanism for operation, efficiency
- Began looking into building scale model
    - Obtained small fuel cell from Intelligent Fuel Cell Car kit already owned
    - Looked into small wind turbines and solar calls (price, power output, etc.)
    - Conceptualized layout in a sketch
- Researched Rhode Island map ***(Page 14)***
    - Developed interactive map of clusters of critical infrastructure
        - Hospitals, police/fire, schools, nursing homes, etc.
    - Decided on location of microgrid based on most suitable cluster in RI
- Decided on final design of microgrid ***(Page 24)***
    - Decided on quantities of PVs, wind turbines, fuel cells, electrolyzers, and tidal system based on Paul Stasiuk's load information
    - Calculated area needed for development of our design
    - Researched actual location in Narragansett feasible for developing our design
- Researched operation of modes of communication ***(Page 29)***
    - Radio frequency, microwave, fiber optics, satellite

- Researched operation of smart grid devices ***(Page 29)***
    - Pole-top reclosers, gang load breaks, cap banks, motor operated load breaks, disconnects, air breaks, load disconnects, fault indicators, regulators
- Located all devices and created user-friendly map ***(Page 28)***
    - Excel spreadsheet outlining all devices within microgrid location with device type, pole number, street name, and feeder number
    - Map which outlines all distribution lines by feeder and all devices from spreadsheet
        - Three feeders are marked by different colors
        - Created symbols for all the different devices and made an easily readable legend outlining all the symbols
        - Placed symbols for associated devices in approximate location on map

Completing this project over the course of this year has been an amazing experience. I have learned an incredible amount about renewable energy sources, distributed generation, the electric grid in general, smart grids and smart grid technology, and most of all, microgrids. I am very pleased with the work this group has produced throughout this year and can't think of much that I would like to have improved. The only thing I wish we could have had the time to incorporate into this project would be a hands-on portion that involved building a scale model of the microgrid that we designed. I attempted to start such a model many times throughout the year but time and workload restrictions made it very difficult. But overall, I am very happy with the final product of this project and am very thankful to National Grid for giving us this opportunity.

My Individual Technical Contributions to date, By Blaine Baker

- Researched concepts of electric grid ***(PR #1)***
    - Details about electric grid infrastructure and transmission of power
    - Investigated smart grid technology
- Researched renewable energy sources ***(Page 11)***
    - Obtained information regarding size, power output, design for functionality, efficiency, and cost for construction and savings
        - Wind
        - Photovoltaics
        - Fuel Cells
- Developed multiple designs for the microgrid ***(Page 14)***
    - Looked at Rhode Island geography to see what resources we could utilize for renewable energies
    - Found newer renewable technology to help develop more designs
- Assisted in the construction of mini community microgrid model
    - Obtained small fuel cell from Intelligent Fuel Cell Car kit
    - Looked into small wind turbines and solar calls (price, power output, etc.)
- Researched microgrid components ***(Page 19)***
    - Discovered already existing renewable resources in Rhode Island
    - Components needed for a microgrid

- Researched telecommunication technology ***(Page 29)***
    - The different telecommunication technologies
    - Components needed for a system
    - Prices for each system to verify what is a more economical choice
    - Technical specifications of the communication systems
    - Smart metering
    - Pressure sensors for hydrogen storage tanks
- Calculations ***(Page 16)***
    - Hydrogen production based on size of electrolyzer
    - Elecrolyzer power consumption in order to produce large amounts of hydrogen
    - Power calculations for the specific resources that we were going to use
        - Tidal generation outputs
        - Fuel cell power outputs
        - Hydrogen and water needed when using our specific electrolyzers
    - Cost of components and the amount needed
    - Component specifications that are needed to ensure 99.999% reliability

There have been many aspects of this project that I have enjoyed and been able to learn about and excel in. Renewable energy sources, the electric distribution system, telecommunication systems (especially satellite communication), and more are all fields of electrical engineering that I have learned a tremendous amount about this year. I am very happy with the outcome of this project, but I do wish we could have done more hands-on research of telecommunication systems. I also started to create a scale model of our microgrid design and was disappointed that time constraints prevented us from completing that model. But as a whole, this project has been an amazing experience and I am very appreciative of National Grid for having given us this opportunity.

Details of Results and Discussion

In this section we will make a summary of the entire project. However, a further explanation will be made in the last part of Advanced Metering Infrastructure since we did not include an in-depth study in the last report.

We started our project by collecting data of renewable energies in the state of Rhode Island. This was our beginning point. We studied each location in Rhode Island that used renewable energies (focusing on wind and solar energies). We studied each resource's location, power supply, reliability and owner. This gave us a broad and accurate idea of how renewable energies are distributed in Rhode Island.

The summary of resources that we studied is the following:

Row Label	Biogas	Solar	Wind	Total general
Block Island			1	1
East Providence		1		1
Jamestown		3		3
Johnston	1			1
Newport		1		1
North Kingstown			1	1
North Scituate		1		1
Portsmouth		1		1
Portsmouth			1	1
Providence		1	1	2
Rocky Hill School		1		1
Wakefield		1		1
Warwick			1	1
West Kingstown		1		1
Total general	**1**	**11**	**5**	**17**

Figure 1: Installed renewables in Rhode Island

Location	Adress	Developer, owner
Providence	Fields Point, Providence RI	Goldwind USA
Block Island	In the see of Block Island (3 miles south-east)	Deepwaterwind
Portsmouth	Portsmouth High School	Wind Energy Development LLC
North Kingstown	Ten Rod Road, North Kingstown RI	Wind Energy Development LLC
New England	Warwick Route 95, RI	New England Tech
East Providence	Forbes Strees, East Providence RI	CME Energy and Hecate Energy
Cranston	269 Melrose Street in Providence, RI	NF
Johnston Landfil	Resource Recovery Complex, Johnston, RI	DCO Energy
Rocky Hill School	Rocky Hill School East Greenwich, RI	Newport Renewables, (Family is owner)
Jamestown Residence PV	Residence in Jameston, RI	Newport Renewables, (Family is owner)
Wakefield Residence PV	Residence in Wakefield, RI	Newport Renewables, (Farm is owner)
Jamestown Community Farm	Jamestown Community Farm, RI	Newport Renewables (Family is owner)
Jamestown Kent Residence	170 Walcott Ave. Jamestown, RI	Island Solar, (Family is owner)
Farm in West Kinstown (PVs)	Farm in West Kingstonw, Rhode Island	Newport Solar, (Farm is owner)
Portsmouth Rooftop PVs	Potsmouth Residence in West Kingstown, RI	Newport Solar, (Family is owner)
Newport Residence PVs	Newport Residence, RI	Newport Solar (Family is owner)
North Scituate PVs	North Scituate Residence, RI	Newport Solar (Family is owner)

Figure 2: Details of installed renewables in Rhode Island

Components needed for a microgrid

1) Various distributed generation technologies

- Photovoltaic arrays
- Wind turbines
- Combined heat and power units
- Fuel cells
- Geothermal, etc.

2) <u>Means of energy distribution</u>

- Wires
- Transformers: Depending on the power supply, different transformers have to be taken into account. US electricity system → 120 V and 60 Hz frequency
- Pipes: Used to deliver the steam so as to move the turbines
- Telephone Poles: Support system for wires

3) <u>Microgrid energy consumption and storage</u>

- Automation → Smart grid (smart meters, relays, sensors, battery management, pole top reclosers)
- Batteries
- Flywheels
- Physical materials
- Hydrogen Cisterns

Microgrids are designed to be able to operate detached from the grid in "island mode".

A **Small Microgrid** has:

- *Energy Efficiency Programs*: Ensures that all cost-effective energy efficiency measures are installed so as to reduce energy consumption.
- *Combined Heat and Power production* (CHP): The simultaneous production of useful thermal energy and electricity
- *Connection to the main grid (PCC):* The microgrid connects to the local utility at a Point of Common Coupling (PCC) where it can buy and sell electricity, as well as safely disconnect from the grid and operate independently in island mode.
- *Retirement home:* It will serve as a center of refuge for the community during emergencies.

A **Bigger Microgrid**, such as our community microgrid may have:

- *Energy storage*: Uses batteries, flywheels and physical materials such as hot water, ice and hydrogen to store energy. In our case, hydrogen was the best option for energy storage
- *Intelligent Energy Management and Demand Response*: Also known as "smart grid". Intelligent technology is used to monitor and control electricity consumption in real time. The system itself will be "smart" enough to analyze the electricity demand of the community and the supply from the renewable sources and have the ability to connect to the larger electric grid when the demand is higher than the supply
- *Combined Heat and Power production* (CHP). In our case, we did not include CHP due to environmental constraints
- *Connection to the main grid (PCC)*

- *Renewable Distributed Generation:* Renewable energy sited at, or close, to where its energy is consumed. Including solar photovoltaics, fuel cells, solar thermal, wind, hydro, geothermal and biomass. This will be the main source of energy of our microgrid. The main renewable energies used will produce energy for our community here
- *Critical Infrastructure:* Buildings within the community such as hospitals, police and fire departments, schools, retirement homes, etc., that require power when there is a shortage from the electric grid. The microgrid will allow these critical infrastructure to still have power when the electric grid is experiencing a black/brown out by operating in island-mode
- *Housing within the community:* Neighborhoods of energy-users that contribute to the energy demand of the community

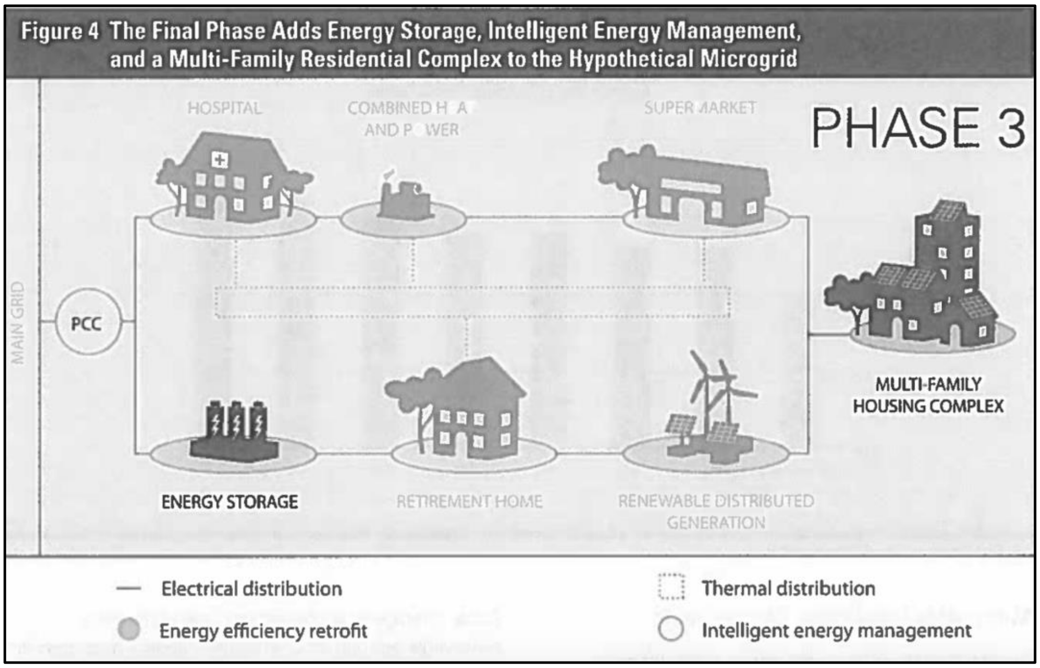


Figure 3: Outline of microgrid

Our Microgrid

1) <u>Site Location</u>

The first step after doing research was to decide in which area of Rhode Island we were going to develop our microgrid. To do this we had to gather all the data of the critical infrastructure within Rhode Island.

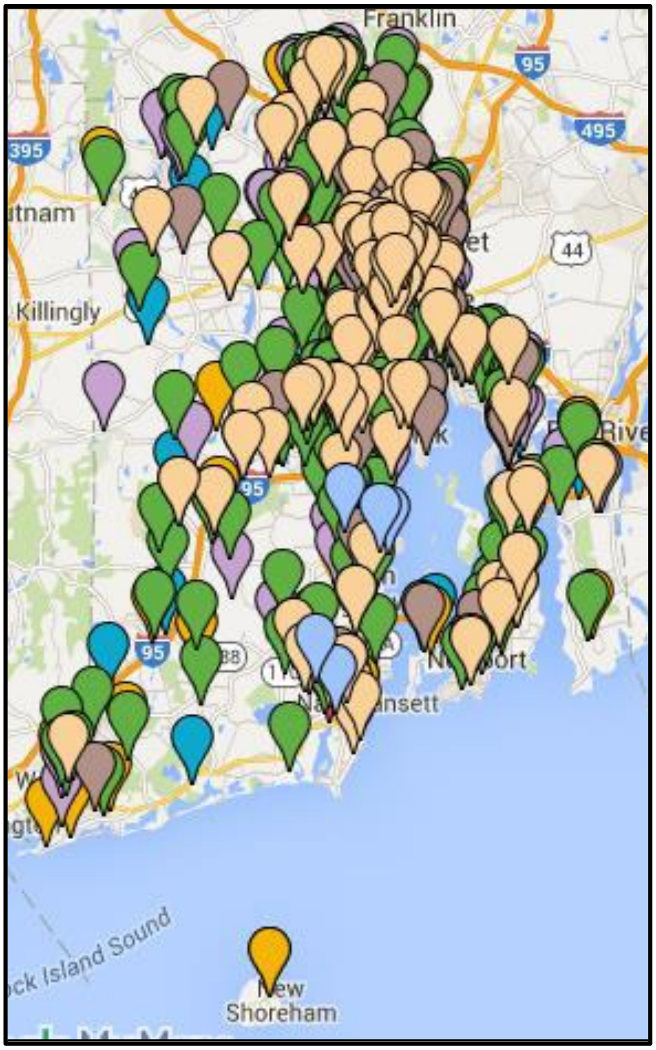


Figure 4: Critical infrastructure in Rhode Island

The area that we thought would be the best was located in Narragansett. It was a suitable choice due to the amount of critical infrastructure that it contained. This critical infrastructure includes the following:

- South County Hospital
- Monsignor Clarke Middle School
- Narragansett Pier Middle School
- Narragansett High School
- Narragansett Elementary School
- Narragansett Police & Fire Departments
- Pier Market Place
- Approximately 300 homes in the area
- Salt Pond Plaza

We thought that this included enough infrastructure to develop our microgrid since it included a hospital, high schools, police & fire departments, a neighborhood and a shopping center.

Hence, we decided to develop our microgrid in this area. The location of the critical infrastructure within our area is shown below.

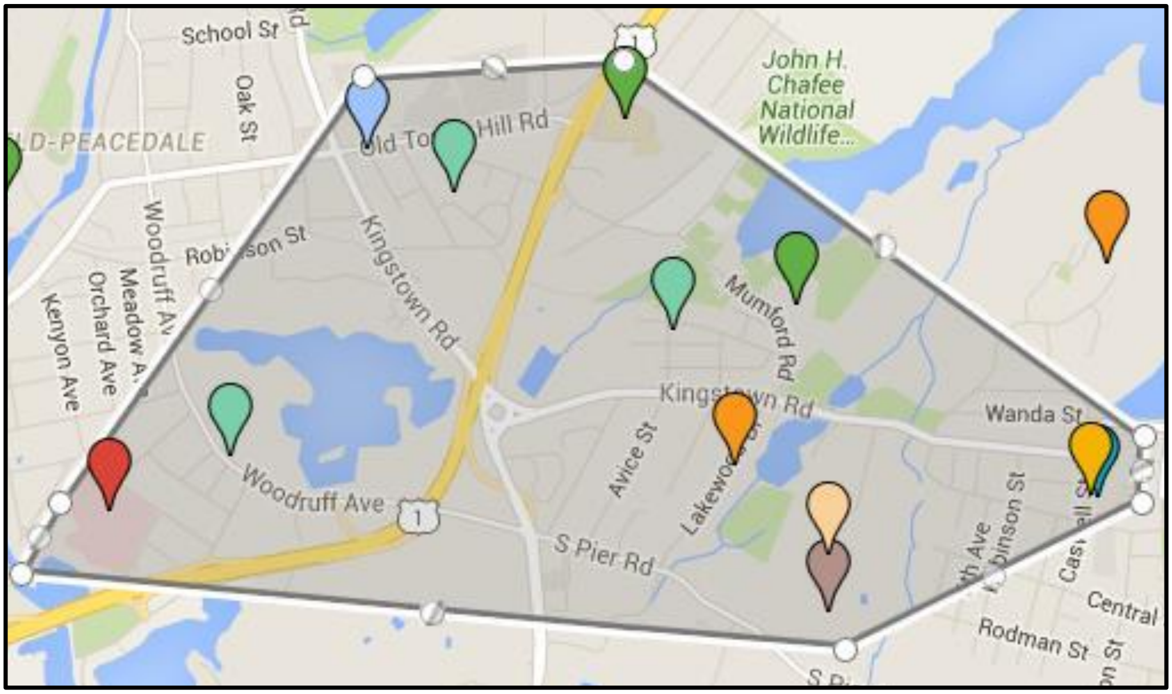


Figure 5: Location of cluster in Narragansett

2) <u>Power Demand</u>

Once we decided our cluster location, we needed to know the load that we would have to cover. We got the information about the different loads in our cluster from Paul Stasiuk, the Lead Program Manager at National Grid. He gave us the average load of each building, including houses. The information he gave us is the following:

- South County Hospital: 1,412 kW
- Monsignor Clarke Middle School: 91 kW
- Narragansett Pier Middle School: 186 kW
- Narragansett High School: 312 kW
- Narragansett Elementary School: 216 kW
- Narragansett Police & Fire Departments: 77 kW
- Pier Market Place: 1,132 kW (includes shops, restaurants, cinema, hotel, offices, condo units)
- 300 homes in area: 750 kW
- Salt Pond Plaza: 1,647 kW (includes all commercial customers in the plaza).

Total Area Demand: 5,823 kW or 5.823 MW **(this does not include all commercial buildings, condos and restaurants).**

With that information, we decided that our cluster would include: South County Hospital, Monsignor Clarke Middle School, Narragansett High School, Narragansett Pier Middle School, Narragansett Elementary School, the Narragansett Police & Fire Departments, and 300 houses. We did not include all the commercial buildings, condos, restaurants and both Pier Market Place and Salt Pond Plaza because, otherwise, the load would be very high and we would have to use a lot of resources. Therefore, we decided to develop our project in that location, but just taking into account the selected buildings**. The maximum average demand that we got from selecting those buildings is: 3.044 MW.** (We used a higher load of 3.4 MW during peak moments during the day to make it more realistic)

This demand varies between the winter and summer months because of heating, air conditioning and other factors. To get a graph of the daily power demand in our cluster we used the information provided by Paul combined with power demand information on the ISO New England website. We used the Rhode Island daily power demand as a model for our cluster so that we could design an average daily power demand. We also used the Hybrid Optimization of Multiple Energy Resources (HOMER) computer program to design a load that we could compare with the resources that we would use in our cluster. The power demand that we got for summer and winter are the following:

Demand Power (Summer)	Hour	Power (MW)
	0:00	1.7
	1:00	1.6
	2:00	1.5
	3:00	1.3
	4:00	1.4
	5:00	1.5
	6:00	2.1
	7:00	2.2
	8:00	2.3
	9:00	2.5
	10:00	2.7
	11:00	2.8
	12:00	2.9
	13:00	3.1
	14:00	3.2
	15:00	3.4
	16:00	3.4
	17:00	3.4
	18:00	3.1
	19:00	2.5
	20:00	2.1
	21:00	2
	22:00	1.8
	23:00	1.7

Demand Power (Winter)	Hour	Power (MW)
	0:00	1.2
	1:00	1.1
	2:00	0.9
	3:00	0.8
	4:00	0.8
	5:00	1.1
	6:00	1.5
	7:00	1.8
	8:00	1.9
	9:00	2.1
	10:00	2.3
	11:00	2.5
	12:00	2.6
	13:00	2.8
	14:00	2.9
	15:00	3
	16:00	3
	17:00	2.9
	18:00	2.8
	19:00	2.3
	20:00	1.8
	21:00	1.7
	22:00	1.4
	23:00	1.3

Figure 6: Power demand for summer vs winter

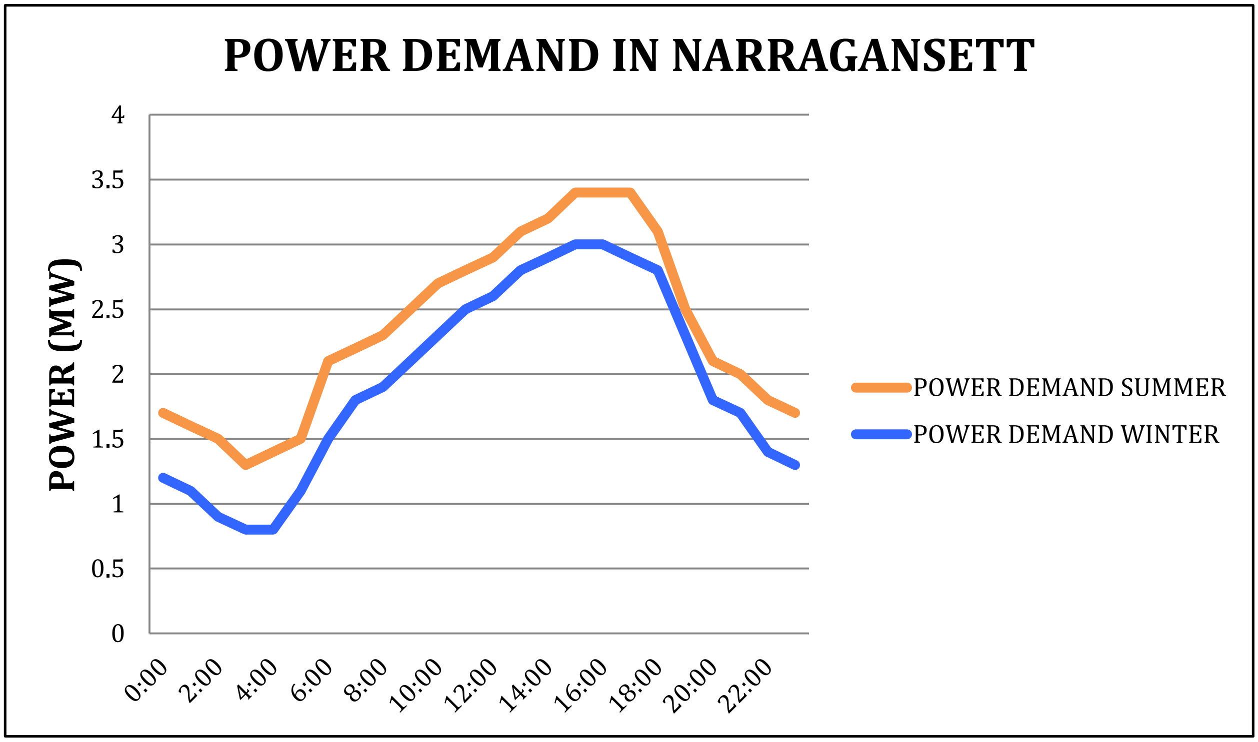


Figure 7: Power demand curves in Narragansett

With this knowledge of the power demand in our community, we have created a design for our microgrid that is capable of providing enough power to cover the load every hour. That is to say, we need the power supply to be higher than the demand each hour.

We will use the following resources in our microgrid design:

- Wind Turbines
- Photovoltaic Panels
- Fuel Cells
- Tidal Generation

We have to make a difference between the resources that we will be using. These resources are grouped into controllable and non-controllable power. Controllable power includes batteries and fuel cells. It is called controllable because we can get a constant power output and these resources do not depend on the weather. On the other hand, non-controllable power includes wind power, sun power, and tidal power. This is called non-controllable power because we cannot predict the exact power that we will be able to get each hour of the day due to changes in wind, sunlight, and the tides, respectively. These resources are, thus, dependent on the weather. (Due to this, all of the calculations involved in our design are approximate to give us an idea of the distribution of these kinds of power generation).

3) <u>Renewable Energies in Rhode Island</u>

Before designing the renewable energy system to implement, we studied the different renewable energies located in Rhode Island so as to know whether we could take advantage of some or not.

Highlighted in the below spreadsheet are locations where photovoltaics are already installed which are located near our cluster. However, only one is within the boundaries of our location: 67 Lakewood Drive. Combined, these resources could provide to us a capacity of 111 kW, but the only one which is within our cluster has a capacity of only 4.75 kW, therefore, we did not take it into account.

Address	Town	State	ZIP Code	Capacity (kW)	Feeder Numb	Interconnect Date
250 Tower Hill Rd	North Kingstown	RI	2852 -	2	56-30F2	8/15/02
58 King Phillip Drive	North Kingstown	RI	02582-	2.9	56-46F2	3/23/11
38 Spring Rd	North Kingstown	RI	02852-	3	56-46F2	6/1/05
22 Conch Rd Apt B	Narragansett	RI	02882-	3.3	56-17F1	7/26/06
22 Conch Rd	Narragansett	RI	02882-	4	56-17F1	10/27/05
61 Southwest Dr	Narragansett	RI	02882-	4	56-17F1	3/2/06
111 West Bay Drive	Narragansett	RI	02882-	4	56-42F1	10/5/10
36 Ridge Dr	Narragansett	RI	02882-	5	56-42F1	1/18/11
102 South Bay Dr	Narragansett	RI	2882 -	5.3	56-42F1	11/9/04
41 Conanicut Rd	Narragansett	RI	02882-	5.32	56-42F1	6/9/08
19 West Bay Dr	Narragansett	RI	02882-	5.7	56-42F1	9/16/06
50 Belver Ave	North Kingstown	RI	02852-	405		9/9/11
338-343 COMPASS CIR	NORTH KINGSTOWN	RI	02852	2000	56-46F4	10/16/2013
65 ALL-AMERICAN WAY	NORTH KINGSTOWN	RI	02852	335	56-46F4	
40 PAT CIR	NORTH KINGSTOWN	RI	02852	2	56-46F2	7/16/2012
574 CAMP AVE	NORTH KINGSTOWN	RI	02852	500	56-83F2	
614 CAMP AVE	NORTH KINGSTOWN	RI	02852	500	56-83F2	
594 CAMP AVE	NORTH KINGSTOWN	RI	02852	500	56-83F2	
424 HATCHERY RD	NORTH KINGSTOWN	RI	02852	20	56-30F2	4/2/2012
870 OCEAN RD	NARRAGANSETT	RI	02882	10	56-17F2	3/30/2012
6 RIVER DR	NARRAGANSETT	RI	02882	3.66	56-42F1	7/20/2012
6000 POST RD	NORTH KINGSTOWN	RI	02852	500	56-46F3	
1720 DAVISVILLE RD	NORTH KINGSTOWN	RI	02852	0	56-83F2	
424 HATCHERY RD	NORTH KINGSTOWN	RI	02852	23	56-30F2	8/2/2013
97 SHORE RD	NARRAGANSETT	RI	02882	4	56-17F1	6/14/2013
686 HAMILTON-ALLENTON RD	NORTH KINGSTOWN	RI	02852	9	56-88F3	11/13/2014
95 CRIPE ST	NORTH KINGSTOWN	RI	02852	10	56-83F2	5/7/2015
252 EARLE DR	NORTH KINGSTOWN	RI	02852	2.5	56-88F5	10/1/2014
50 BURBANK AVE	NARRAGANSETT	RI	02882	5	56-42F1	10/17/2014
7 MIDWAY RD	NARRAGANSETT	RI	02882	3	56-17F1	10/30/2014
135 ALLENTON RD	NORTH KINGSTOWN	RI	02852	5	56-88F1	7/8/2015
28 LANDS-END DR	NORTH KINGSTOWN	RI	02852	12.5	56-46F4	2/9/2015
200 BRIARBROOK DR	NORTH KINGSTOWN	RI	02852	4.5	56-46F2	3/5/2015
90 MORNINGSIDE DR	NORTH KINGSTOWN	RI	02852	3	56-46F4	3/25/2015
84 MORNINGSIDE DR	NORTH KINGSTOWN	RI	02852	1.5	56-46F4	3/31/2015

67 LAKEWOOD DR	NARRAGANSETT	RI	02882	4.75	56-17F2	6/29/2015
65 ALL-AMERICAN WAY	NORTH KINGSTOWN	RI	02852	300	56-46F4	9/16/2014
0 GATE RD	NORTH KINGSTOWN	RI	02852	260	56-83F2	
1720 DAVISVILLE RD	NORTH KINGSTOWN	RI	02852	495	56-83F2	10/2/2015
200 FRENCHTOWN RD	NORTH KINGSTOWN	RI	02852	3060	56-46F3	
129 ALLENTON RD	NORTH KINGSTOWN	RI	02852	6.5	56-88F1	
110 GATE RD	NORTH KINGSTOWN	RI	02852	120	56-46F4	
991 SHERMANTOWN RD	NORTH KINGSTOWN	RI	02874	6	56-88F3	
20 SHORT RD	NORTH KINGSTOWN	RI	02852	10	56-46F4	
38 OLD-PINE RD	NARRAGANSETT	RI	02882	6	56-42F1	10/6/2015
28 MANOR DR	NARRAGANSETT	RI	02882	3.8	56-17F1	
221 SUNNYBROOK-FARM RD	NARRAGANSETT	RI	02882	7.6	56-17F2	
25 LAKE RD	NARRAGANSETT	RI	02882	3.8	56-42F1	
50 WOOD AVE	NARRAGANSETT	RI	02882	4.5	56-42F1	10/29/2015
60 CANONCHET WAY	NARRAGANSETT	RI	02882	10	56-17F3	
0 DAVISVILLE RD	NORTH KINGSTOWN	RI	02852	140	56-83F2	
53 BIRCHWOOD DR	NARRAGANSETT	RI	02882	3.8	56-88F3	
43 FRANCES AVE	NARRAGANSETT	RI	02882	2.365	56-17F2	
15 CALEF AVE	NARRAGANSETT	RI	02882	2.5	56-17F2	

Figure 8: Installed renewables in Narragansett

4) Our Design

We studied and researched many different kinds of renewable energies to use in our design. These include:

- Solar Panels
- Wind Turbines
- Cogeneration
- Biogas
- Batteries
- Fuel Cells
- Geothermal energy
- Tidal energy

Since we wanted to design a microgrid that was as close to 100% clean as possible, we decided not to include cogeneration, biogas, geothermal and batteries in our design. When batteries are thrown away they cause damage to the environment due to their components.

Thus, we focused on the following: Solar Panels, Wind Turbines, Fuel Cells and Tidal Energy

We did a lot of research and gathered a lot of information. This information is summarized in the next figure.

Resources	Kind of Resource	Model	Max Power(KW)	Price($)
	PV	Kyocera KD100GX-LPB	0.1	130
	PV	Kyocera KD240XGX-LPB	0.24	525
	PV	Kyocera KD140GX-LFBS	0.14	277
	PV	LG LG305N1C-B3	0.305	375
	PV	LG LG300N1C-B3	0.3	428
	PV	LG LG270S1K-B3	0.27	335
	PV	LG LG275S1C-B3	0.275	316
	PV	SolarWorld SW285	0.285	310
	PV	SolarWorld SW250	0.25	215
	PV	SolarWorld SW315	0.315	356
	PV	SolarWorld SW270	0.27	284
	Wind Turbine	GE2	2000	2,000,000
	Wind Turbine	Vesta1.65	1650	2,300,000
	Wind Turbine	Clipper1.5	1500	1,900,000
	Fuel Cell	FC Velocity-HD6	150	400,000
	Fuel Cell	Fcgen-1300	10.5	30,000
	Fuel Cell	1MW Ballard	1,000	2,000,000

Figure 9: Technical details of renewables for our design

Electrolyzers	HYDROGENICS				
Type	H2 Production (kg/24h)	Dimensions (m)	Voltage (VAC)	Weight (tons)	Price ($)
Hystat 10	8.6 to 21.5	9.12 x 2.4 x 2.895	3x400	14.5	50,700
Hystat 15	13 to 32	9.12 x 2.4 x 2.895	3x400	14.5	80,800
Hystat 30	26 to 65	9.12 x 2.4 x 2.895	3x400	14	90,800
Hystat 45	39 to 97	12.19 x 2.437 x 2.895	3x400	15.5	100,800
Hystat 60	52 to 130	12.19 x 2.437 x 2.895	3x400	15.5	125,800
Outdoor Electrolyzer	1080	12.19 x 2.437 x 2.895	3x450	16	1,300,000

Figure 10: Technical details of electrolyzer for our design

The renewable resources that we decided to use are the following:

- Solar Panels: *LG LG305N1C-B3*
- Wind Turbines: *GE2*
- Fuel Cells: *1MW Ballard*
- Outdoor Electrolyzer: *Hydrogenics*

Once we had decided on the renewable energies that we wanted to use, we had to do some technical calculations so as to get the average power supply that these resources could produce. These calculations include:

- Average power output of Wind Turbines in the area of Narragansett
- Average power output of solar panels in the area of Narragansett
- Average power output of the fuel cells taking into account all of the losses and efficiency
- Average output of the tidal system depending on the tide

All these required calculations were developed in the Progress Report 2 (PR#2, from page 15 to 26).

According to the calculations that we gathered of sun power and wind power, we got the following graphs:

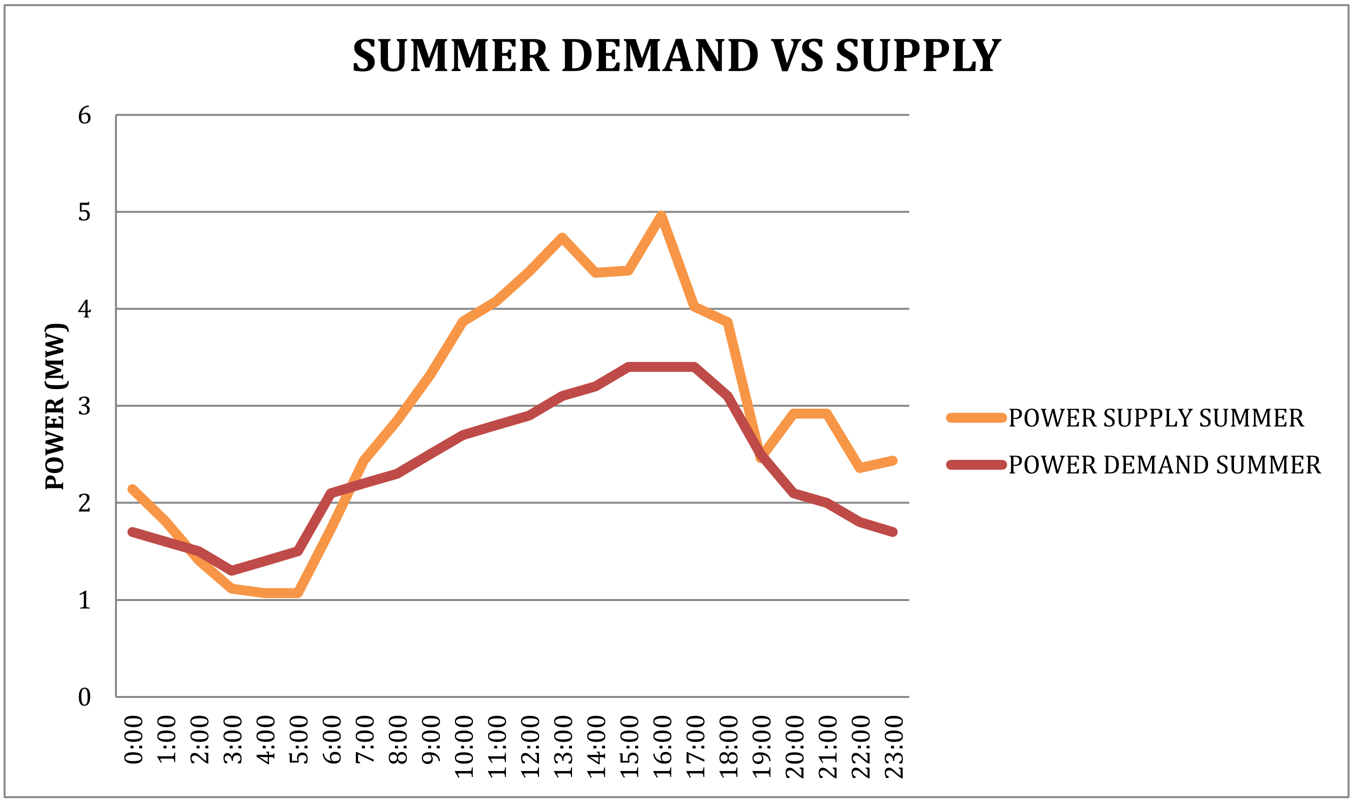


Figure 11: Demand vs supply in summer

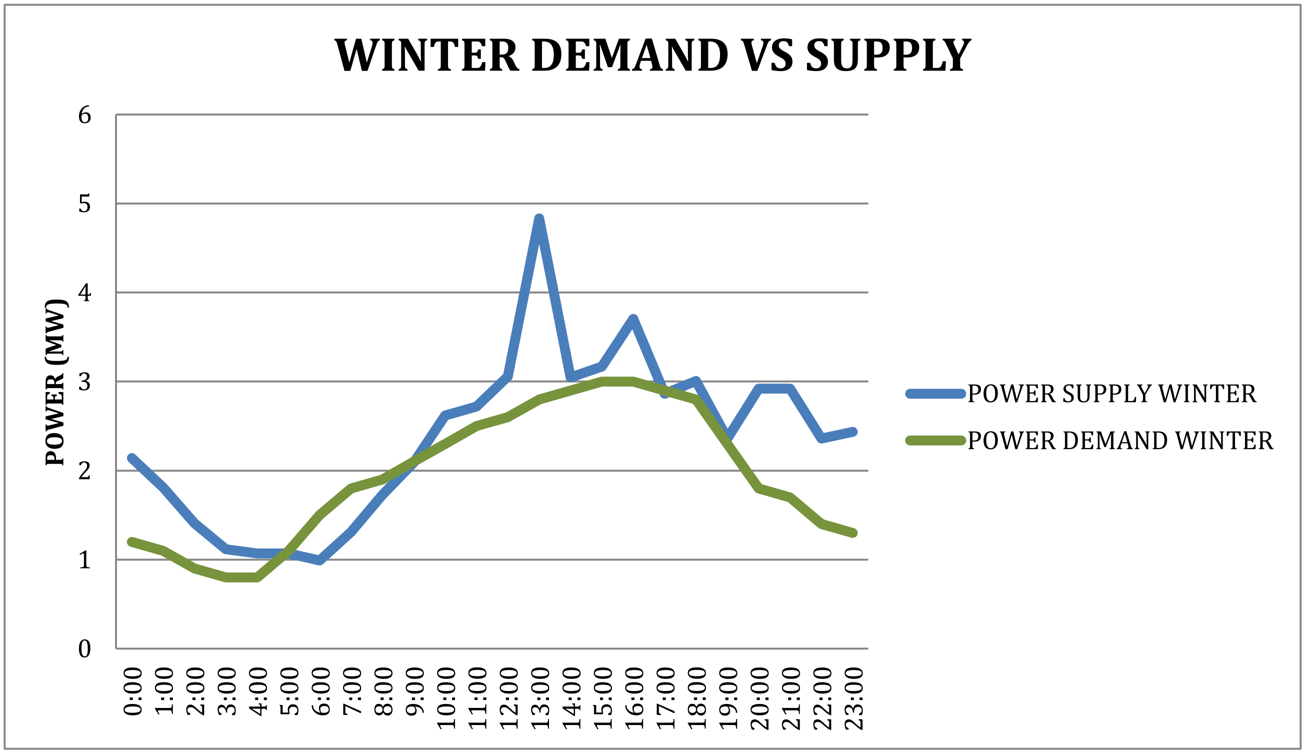


Figure 12: Supply vs demand in winter

These graphs were calculated taking into account using three wind turbines and the PVs that we decided to use. We can see that for most of the time, the power demand is lower than the power supply, which is what we are looking for. However, we need to make sure that we can use controllable power to power our microgrid during the times when there is not enough power. However, these graphs are not reliable because wind and sun are non-controllable power. That is to say, some days we will not be able to get that same amount of power by using PVs and wind turbines. In fact, these calculations were made to get an idea of the average power that we could get in our clusters by using wind turbines and PVs. Therefore, we will use other resources apart from these to make sure that we can meet the demand at all times. These resources are fuel cells and a tidal system. The worst-case scenario is when it is cloudy and there is no wind blowing, which means that the cluster does not get any power from the PVs and wind turbines. Thus, we have to make sure that the demand is covered during those times (we also consider connecting to the grid in the case that all of our systems are not capable of meeting the demand). According to the calculations that we made, we decided that we had to include eight fuel cells and eight outdoor electrolyzers in our cluster, as well as an 800 kW tidal system, to cover the load.

Due to the high expense of using eight fuel cells and electrolyzers, we have decided that it would be better to rely on six fuel cells and six electrolyzers and utilize the electric grid in the event of a worst-case scenario. It is cheaper to use the electric grid in those cases (which will rarely happen) than including more resources in our design. Furthermore, the advantage of tidal is that it is almost constant power and such a big tidal system will be very beneficial for us. This tidal system will be primarily used to power the six electrolyzers.

We will include the following resources in our cluster:

- 3 Wind Turbines (2 MW GE)
- 1,675 PVs distributed on the rooftop of each building, following this organization:
    - 5 on each house (300 houses gives us 1500 PVs)
    - 40 on the Narragansett High School
    - 30 on the Narragansett Elementary School
    - 50 on the South County Hospital
    - 30 on the Narragansett Police & Fire departments
    - 25 on the Monsignor Clarke Middle School
- 6 Outdoor Electrolyzers
- 8-1000 m^3 Hydrogen Tanks
- 6 Fuel Cells (1 MW Ballard)
- 1 Tidal system of 800 kW (theoretical)

Then, our system will operate following this pattern:

- Wind turbines and PVs will be producing as much power as the weather conditions allow
- Tidal will be running every hour and every day producing power that will mainly fluctuate between 500 and 800 kW
- Electrolyzers will also be running every hour of every day storing hydrogen in tanks
- If the load is not met, we have an array of 6 Fuel Cells that will provide a peak of 2.4 MW
- In the worst case scenario the microgrid will be able to connect to the grid by using the point of common coupling

The distribution of the resources in our cluster will be the following:

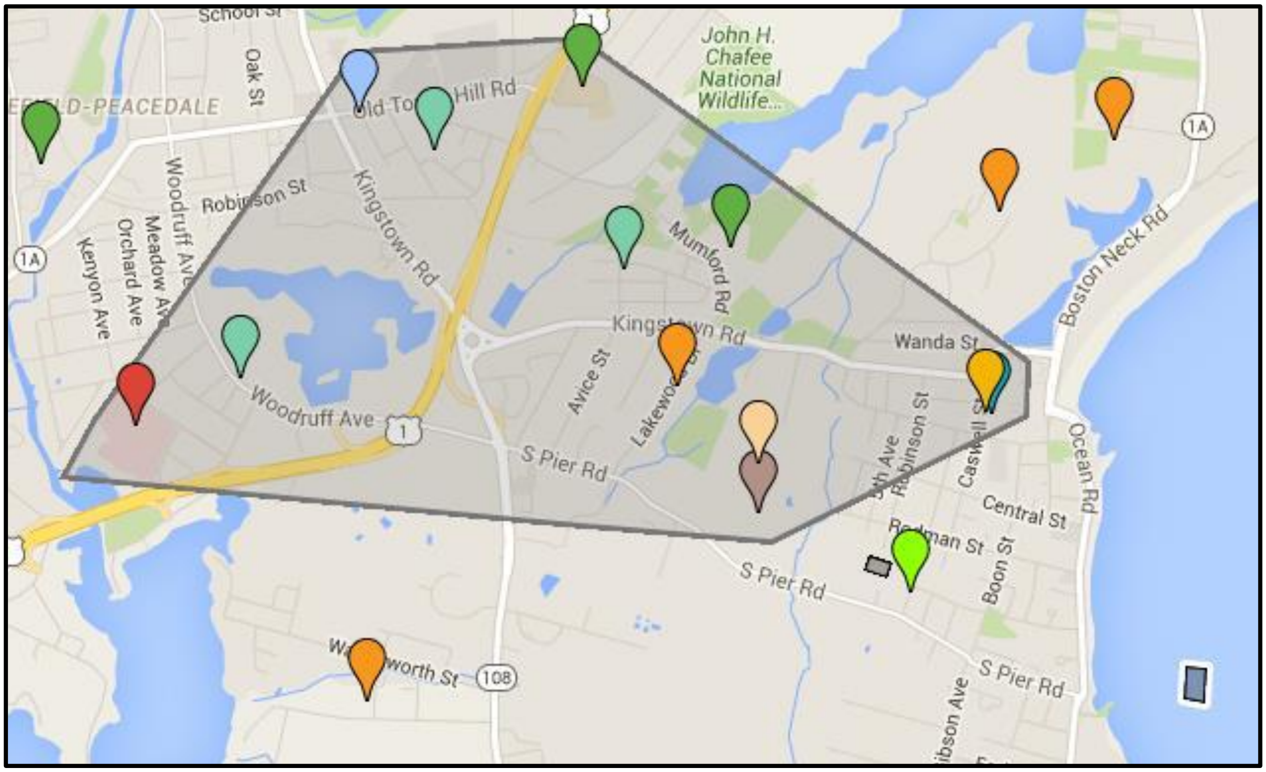


Figure 13: Location of renewables within cluster

As seen in Figure 13 above, there are two locations for the components of our microgrid. In the lower right hand corner of the figure, there are two small rectangles which mark the locations on land (for the fuel cells, electrolyzers, and wind turbines), and in the ocean (for the tidal system). The area for the tidal system is approximate due to the fact that there is little information about the system including the size. In addition to this, it is unknown where, in the ocean, it is acceptable to build these systems.

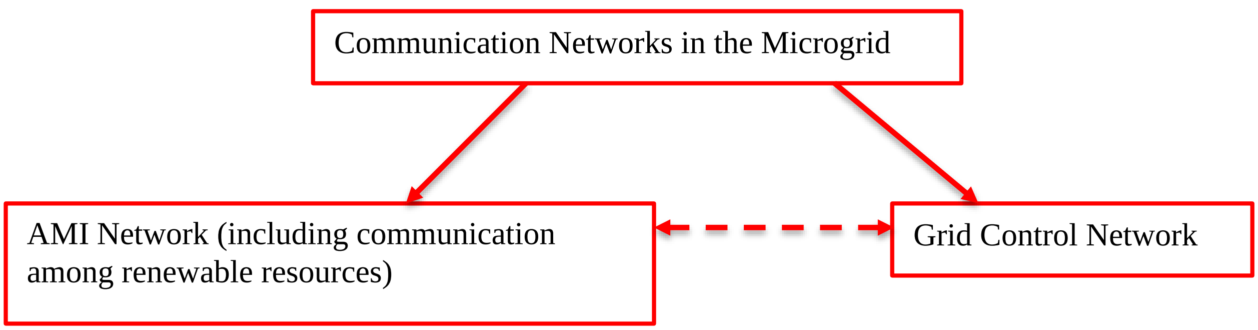
The area for the fuel cells, electrolyzers, and wind turbines is a bit more exact. The location is at 0 Tern Rd., which is currently for sale by the state of Rhode Island. The actual plot of land that is for sale is 2.10 acres, but to meet the requirements of our design, all that we would need is roughly 1.38 acres. The electrolyzers have dimensions of 40x8x9.5 ft (LxWxH) and the fuel cells have dimensions of 29.5x7.9x9.5 ft (LxWxH). Assuming that there is a 30 ft clearance between neighboring fuel cells and electrolyzers and a 50 ft clearance on the outside edges, the total area will be roughly 60,000 ft^2. Additionally, the wind turbines are 308.4 ft tall to the hub with blades that are 186.7 ft long, so there will be a clearance between the tops of both the fuel cells and electrolyzers and the lowest tip of the blades of 112.2 ft. This difference in height, and with a negligible size of the base compared to the fuel cells and electrolyzers, means that the wind turbines can be placed nearly anywhere in this plot of land.

Using the land that is actually currently for sale by the state, this location is optimal for our purposes because it is close to our cluster location and is also fairly close to the ocean so as to minimize the distance between the electrolyzers and the tidal system.

5) Smart grid and Telecommunications

Smart grid: A smart grid is an electrical grid which includes a variety of energy measurement technologies including smart meters, smart appliances, renewable energy resources, and energy efficiency resources. Electronic power conditioning and control of the production and distribution of electricity are important aspects of the smart grid.

A difference has to be made in the smart grid that we developed:



Before starting the design of our smartgrid, we had to study the actual status of the grid around the area where we wanted to develop our microgrid.

Using the SCADA technology and doing some field assessments, we drew a map including the distribution lines and the devices pertaining to the grid. The outline of the current status of the grid is the following:

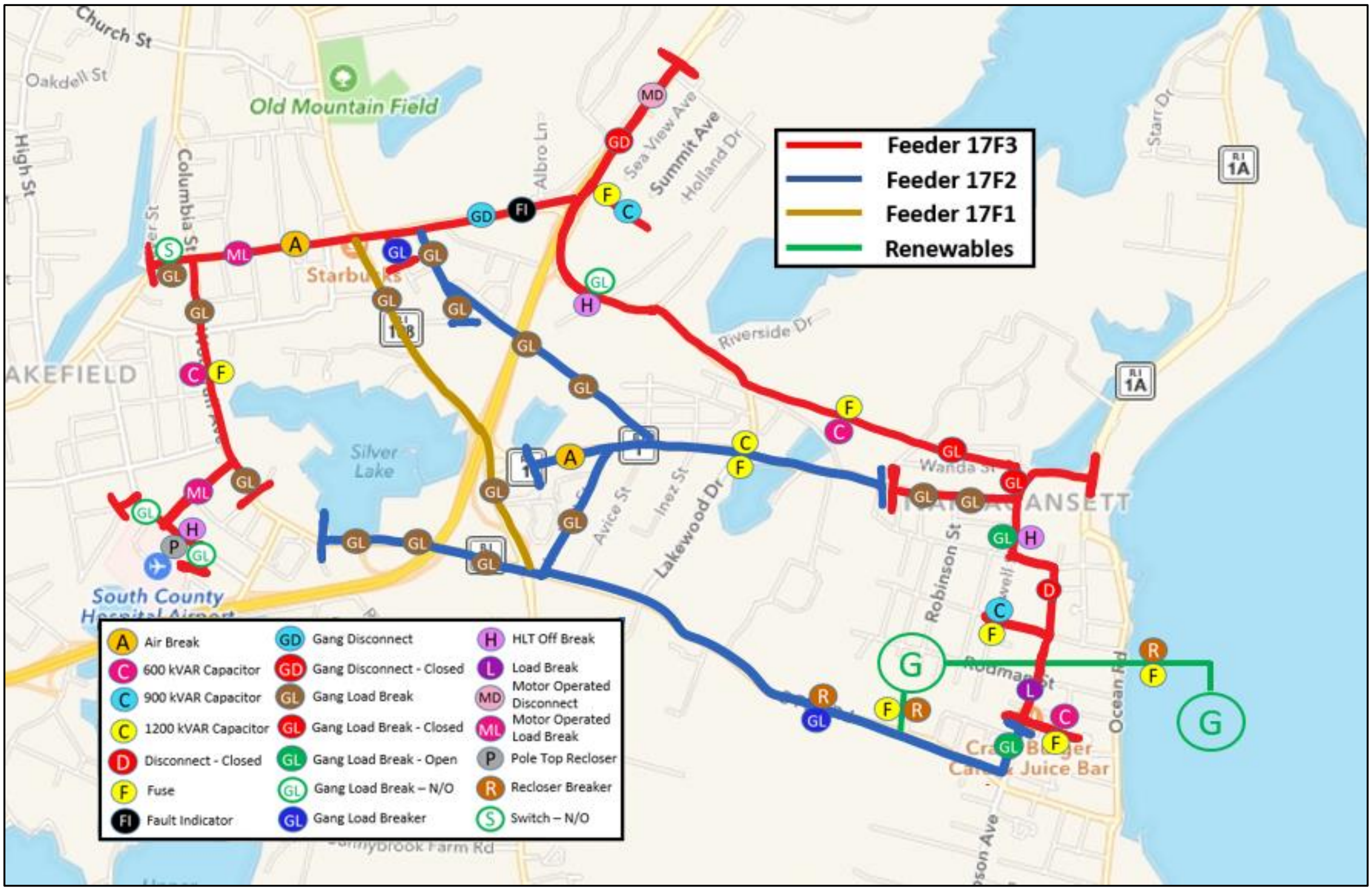


Figure 14: Distribution lines and devices within cluster

Our microgrid needs to operate in island mode, that is to say, being independent from the grid. Hence, we had to identify the points of common coupling. These points are the connections of the surrounding feeders to the grid.

The location of the points of common coupling in our grid is shown in the figure below:

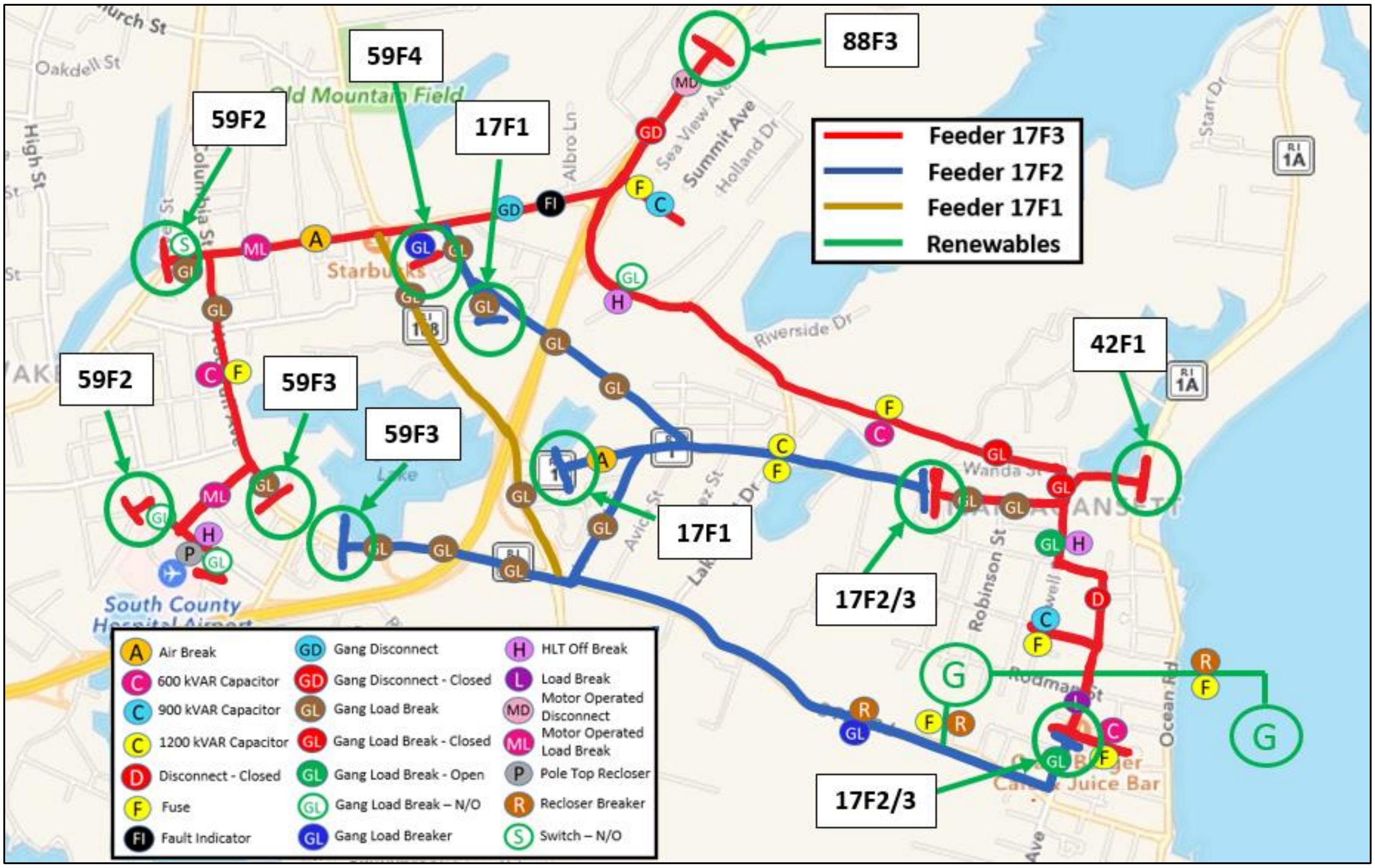


Figure 15: Locations of points of common coupling

These points will be automated (explained below) and will usually be open so as to isolate the community from the grid.

Grid Control Network

This network is focused on the automation of the devices in charge of delivering power to customers and the telecommunications used to achieve an efficient operation of the automated system.

In the automation design of the grid we focused on the following devices:

- Pole top reclosers: Will open or close the circuit depending on the demand. Using the Recloser Control, these devices will be intelligent enough to identify faults and self-heal
- Capacitor Banks: Will correct the power factor of the grid, and will also be controlled by a Cap Bank Control System

In addition to this, we decided to focus on researching the following means of telecommunication for our smart grid:

- *Satellite:* Will be used to send all the data from the grid to the National Grid center at Melrose Street in Providence and also in Northborough, MA, and for the tidal system to communicate with the base station
- *Radio Frequency*: Will be implemented by utilizing WiMAX radio. WiMAX will be the device that will be installed on each pole and will communicate among the different radios located on different poles. This information will be gathered by a modem located at our base station
- *Fiber Optics*: A great option for communication between devices, but too expensive for our needs

The main automation and communications of our grid will be focused on the following:

- Smart communication among reclosers located at our points of common coupling. As stated before, these points of common coupling are the following: Wakefield Substation and feeders 59F2, 59F3, 17F1, 88F3, 59F4, 42F1, 17F2 and 17F3.
- Smart communication among the cap banks pertaining to our microgrid. These include:
    - Cap Bank located on Pole 34, Feeder 17F2. Pertaining to the connection of Narragansett High School and Narragansett Elementary School
    - Cap Bank located on Pole 3, Feeder 17F3. Pertaining to the connection of Monsignor Clarke Middle School
    - Cap Bank located on Pole 8, Feeder 17F3. Pertaining to the connection of South County Hospital
    - Cap Bank located on Pole 10, Feeder 17F3. Central St.
    - Cap Bank located on Pole 10, Feeder 17F3. Congdon St.
    - Cap Bank located on Pole 10, Feeder 17F3. Wanda St.
- Smart communication among the different renewable resources

This system will be based on AMI (Advanced Metering Infrastructure) systems. We need smart meters installed on all the buildings within our microgrid as well as on each renewable. By doing this, we will be able to get information of the power demand and supply and, therefore, we will be able to control which resources turn on and off. More about this is explained later in the report.

1) <u>Recloser Control</u>

This system is explained in more depth in Progress Report 3 (PR#3, from 16 page to 21)

The reclosers that we will automate are the following:

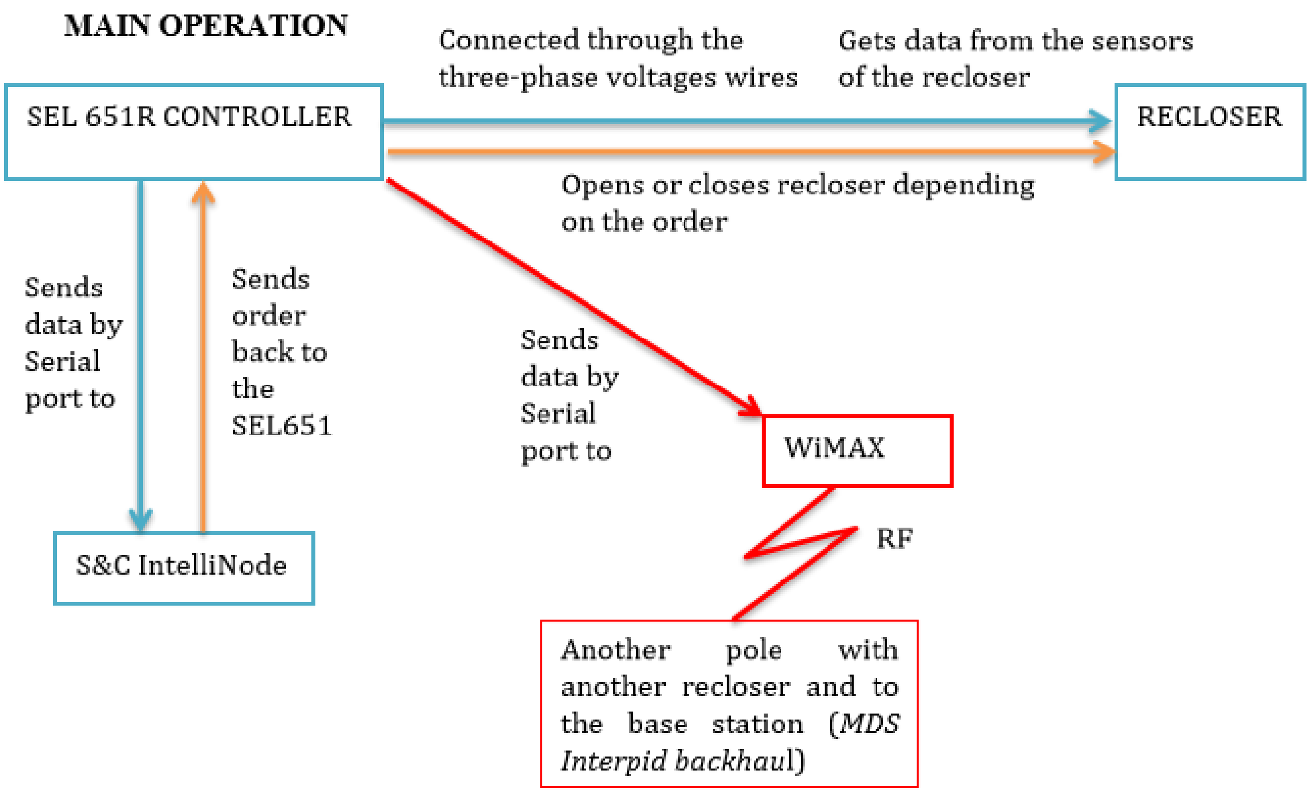
- Points of common coupling: Wakefield Substation and feeders 59F2, 59F3, 17F1, 88F3, 59F4, 42F1, 17F2 and 17F3

- Reclosers located on: P16 S Pier Road, P23 in South County Hospital, P6 in Caswell Road, P159 Narragansett Ave
-

The system contains the following devices:

- Recloser Controller. *SEL 651R Control*
- *IntelliNode Control*
- *G&W Viper-S Reclosers*
- *WiMAX Radio*

Outline of its operation:



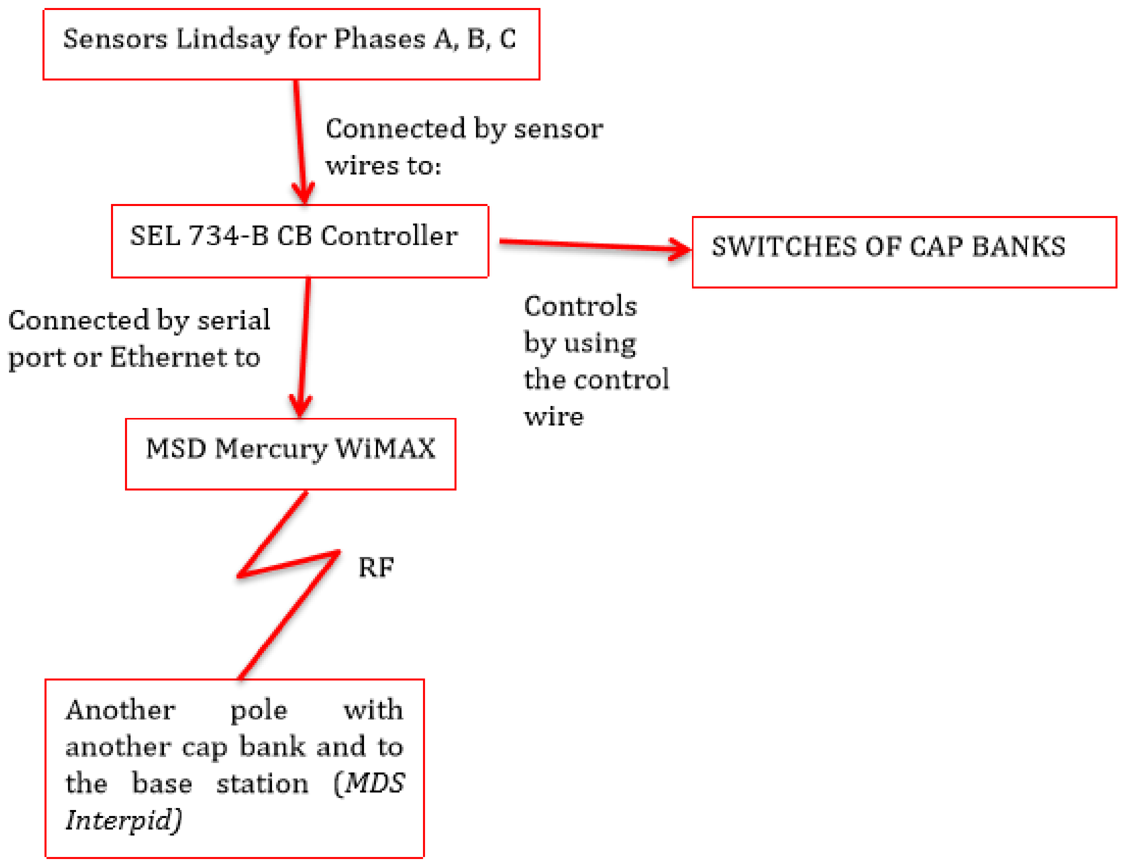
2) Cap Bank Control

This system is also explained in more depth in Progress Report 3 (PR#3, from page 22 to 25)

The system contains the following devices:

- Cap Bank Controller. *SEL 734 CBC*
- *Capacitor Bank*
- *WiMAX Radio*
- *Lindsey 1Φ Sensors*

Outline of its operation:



3) <u>Communications</u>

As explained before, we will use two kinds of telecommunications for our smart grid. These are radio frequency and satellite:

Radio frequency will be the main means of communication between the grid devices. This system will also provide the main connection between smart meters, renewable energies and the control center in Northborough.

The system uses the following devices:

- WiMAX Radio: The product line provides a global licensed and unlicensed solution designed to facilitate high throughput wireless networking requirements. The WiMAX supports Ethernet, serial, USB and Wi-Fi connectivity, and offers extended range and aggregate throughput of up to 30 Mbps.

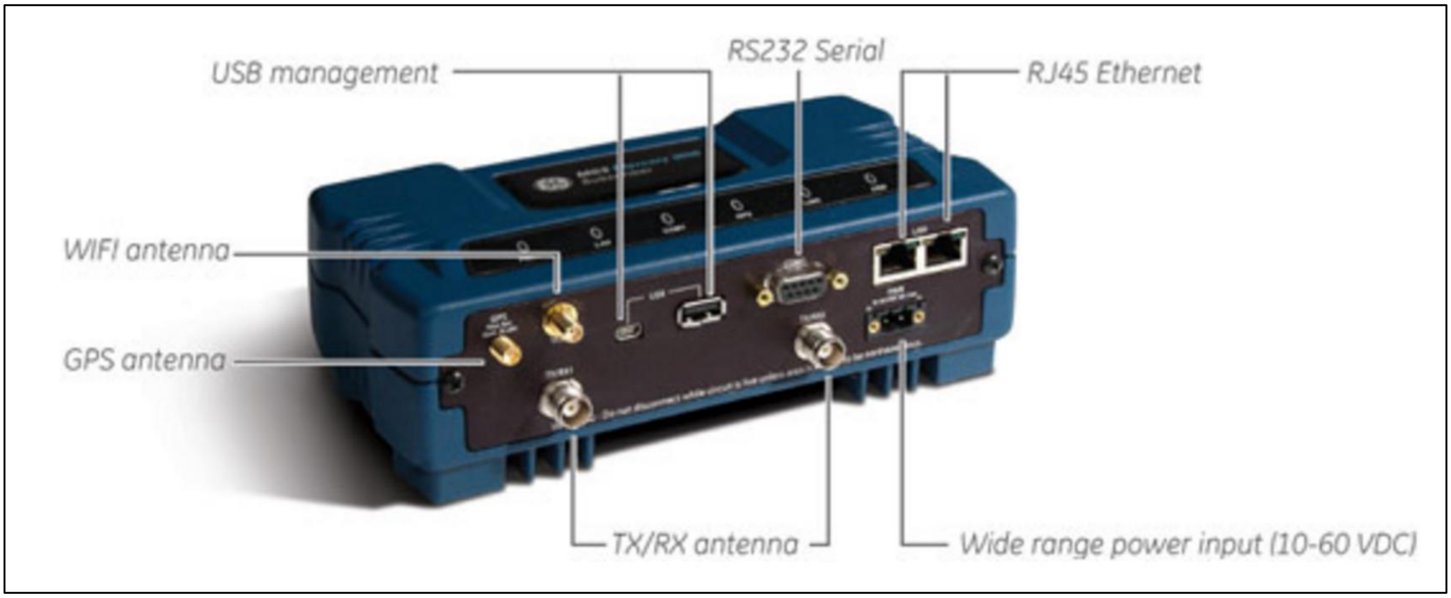


Figure 16: Components of WiMAX radio

This device will be installed on each of our devices (pole top reclosers and capacitor banks). It will communicate among the different devices and will send the data to the *MSD Intrepid* backhaul system located on our base station.

It will also be installed on the different antennas that gather the AMI information. However, this will be explained in the next part of the report (AMI System).

- MSD Intrepid Series: The Intrepid Series is a cost effective, scalable, reliable and hardened backhaul solution that operates in the 2.3-2.4 and 4.8-6.0 GHz bands. In telecommunications networks, the backhaul portion of the network is comprised of the intermediate links between the core network, or backbone network and the small subnetworks at the edge of the entire hierarchical network. This device, will gather all the information transferred by the WiMAX radio and will be, then, sent to the control center.

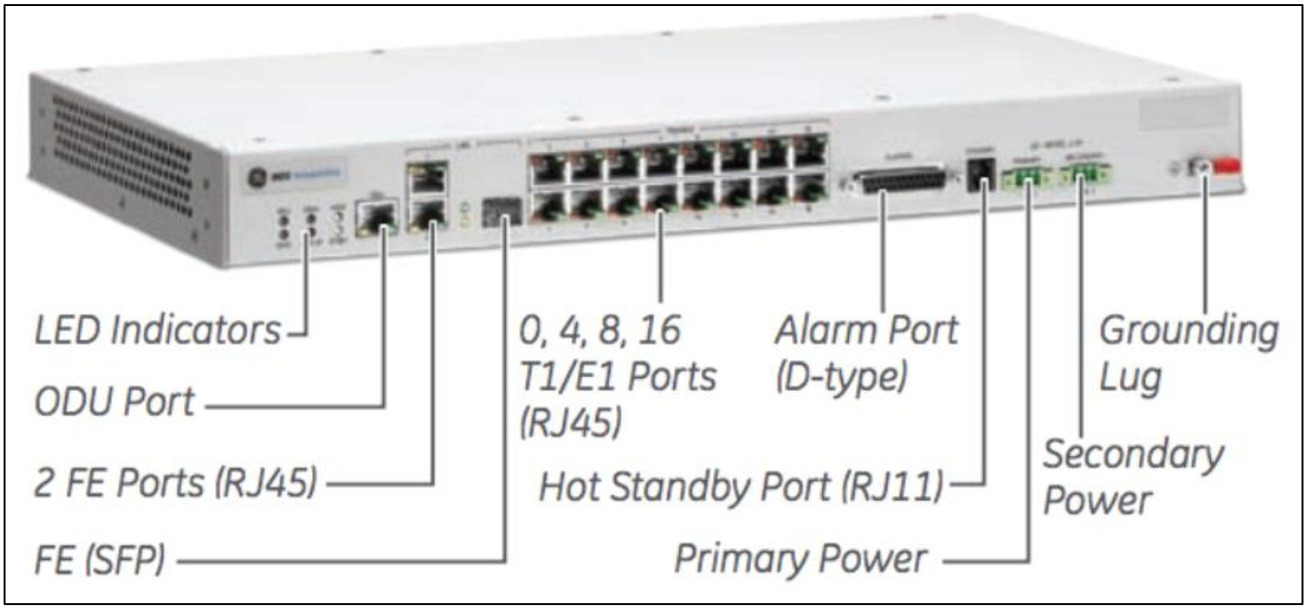


Figure 17: Intrepid indoor unit

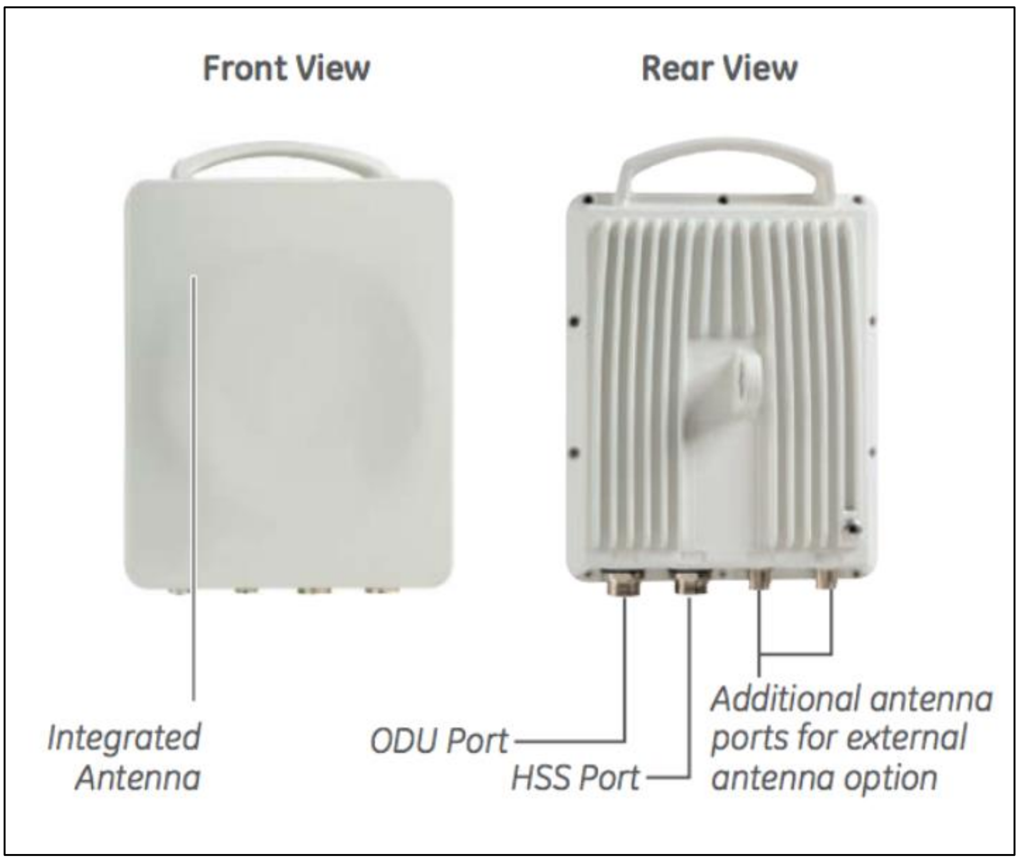


Figure 18: Intrepid outdoor unit

Out of all the communication systems that are available to use, including satellite into our communication system design was appealing for a few reasons. The satellite's main application will be to receive and transmit critical data over long distances wirelessly. Although using fiber seems like a more logical approach to transmit and receive data, using satellite will ensure that even during "blackout" conditions, the system will still be able to communicate with different control centers. Satellite communication still plays a strong role in day-to-day life, however latency issues have been the cause of satellite not being used in "real time" dependent systems such as automation programs like SCADA. ViaSat is one of few leading companies in satellite communication service providers and offers a high performing system, called M2M Terminal FT2225, which has applications for SCADA networks, power distribution and transmission monitoring, and even smart grid communications. Other reasons for choosing this system fall into the categories of its physical and operating durability, friendly interface agnostics, hearty cyber security system, and real time monitoring with no delays.

Figure 19: ViaSat terminal

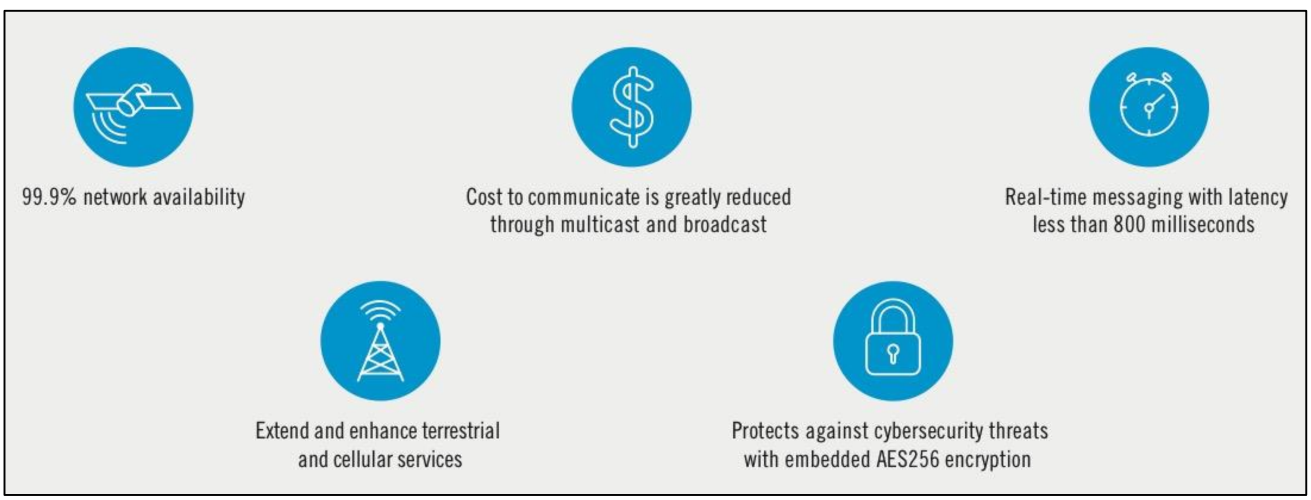


Figure 20: Benefits of using ViaSat system

Outline of its operation:

High Performance M2M Terminal FT2225

SPECIFICATIONS

GENERAL

Antenna Polarization	RHCP & LHCP, software configurable
Frequency Band	
» TX	1626.5 to 1675.0 MHz
» RX	1518.0 to 1559.0 MHz
Transmission Security	
» Link Encryption	AES-256
GNSS	GPS + GLONASS

EXTERNAL INTERFACES

Power	10 to 32 VDC, via multi-pin connector Short circuit and surge protection
Bluetooth	4.0
Wi-Fi	IEEE 802.11 B/G, 2.4 GHz
Ethernet and Serial	» Ethernet and USB 2.0 » Via multi-pin connector
GNSS	L1 frequency

MECHANICAL

Size (L x W x H)	178 x 130 x 42 mm
Weight	<1 kg

ENVIRONMENTAL

Temperature	
» Operational	-40° to +71° C
» Transport	-40° to +85° C
» Storage	-40° to +85° C
Solar Radiation	1120 W/m² p per IEC-60068-2-5
Relative Humidity	Up to 100% condensing at 45° C, per IEC 60068-2-30

ENVIRONMENTAL (CONTINUED)

Ingress Protection	IP 66 dust and spray proof in all directions
Wind	Wind speeds up to 200 km/hr
Air Pressure Transport	4500 m AMSL
Vibration	
» Operational	Random vibration of 1.05 g rms in each of three mutually perpendicular axes
› 5 to 20 Hz Vibration	0.02 g² /Hz
› 20 to 150 Hz Vibration	-3 dB/octave
» Survival	Transportation vibe per IEC 60068-2-64
› Frequency	5 to 200 Hz
› ASD	1.0 m²/s3
Shock	
» Operational	IEC 60068-2-64, 50 m/s², 11 ms
» Survival	Transportation shock per IEC 60068-2-29, A = 180 m/s², t = 6 mS

REGULATORY APPROVALS

CE	Per R&TTE Directive 1999/5/EC, Low Voltage Directive 2006/95/EC
FCC	Title 47 Section 15, Title 47 Section 25
RCM	AS/NZS CISPR 22:2009 Safety IEC/EN/AS/NZS 60950-1, IEC/EN/AS/NZS 60950-22
RoHS	Per European Union Council Directive 2011/65/EU
REACH	Per European Union Council Directive 1907/2006/EC
WEEE	Per European Union Council Directive 2012/19/EU

Figure 21: M2M Terminal FT 2225 data sheet

4) The Grid Network

5) <u>Control Center and Base Station</u>

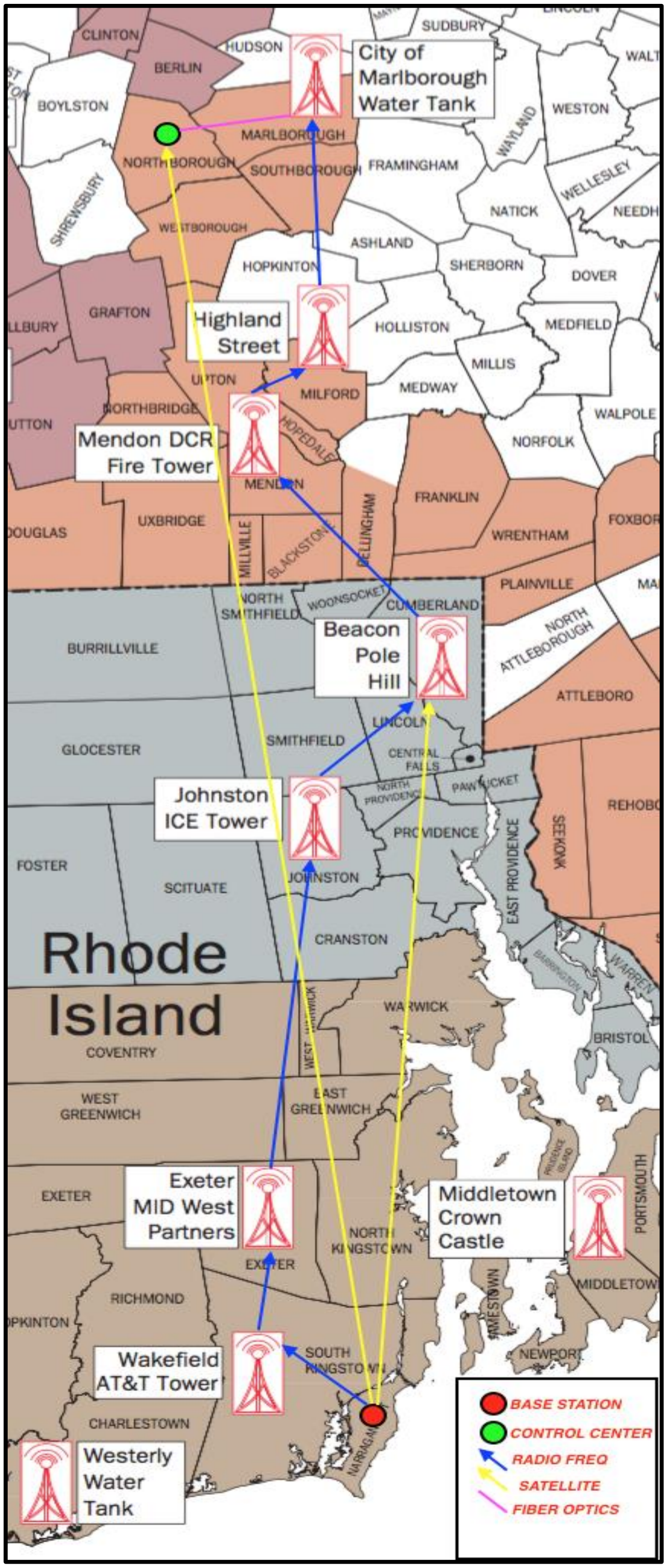


Figure 22: Communication scheme

Our control center is the National Grid Northborough Control Center. All of the information gathered by the smart grid will be transmitted to Northborough. Since Northborough is far from our microgrid, we will transmit all of the information from the base station to the nearest tower, which will send the information to the next tower and so on until the information arrives to Northborough. The nearest antenna to the base station is the AT&T antenna located in Wakefield. This antenna will transfer the information to MID West Partners antenna in Exeter. After that, the information will be transferred to the ICE Tower in Johnston, which will send the information to Lincoln. From Lincoln, the information will be sent to the Mendon DCR Fire Tower, then Highland Street and, finally, to the City of Marlborough antenna. This communications chain will operate using radio frequency; that is to say, we will use WiMAX to send the information from the base station to the AT&T Tower. We will also be able to send the data directly to Northborough and Lincoln by using satellite in case a backup is needed.

Our base station will be located where our renewable resources are since we have plenty of space to fit all the devices. Hence, our Base Station will be comprised of the following:

- 6 Outdoor Electrolyzers
- 8 Hydrogen Tanks
- 6 Fuel Cells
- 3 Wind Turbines
- Radio Frequency antenna including the MSD Intrepid
- A Satellite dish

And as mentioned earlier, the location of our base station will be the following:

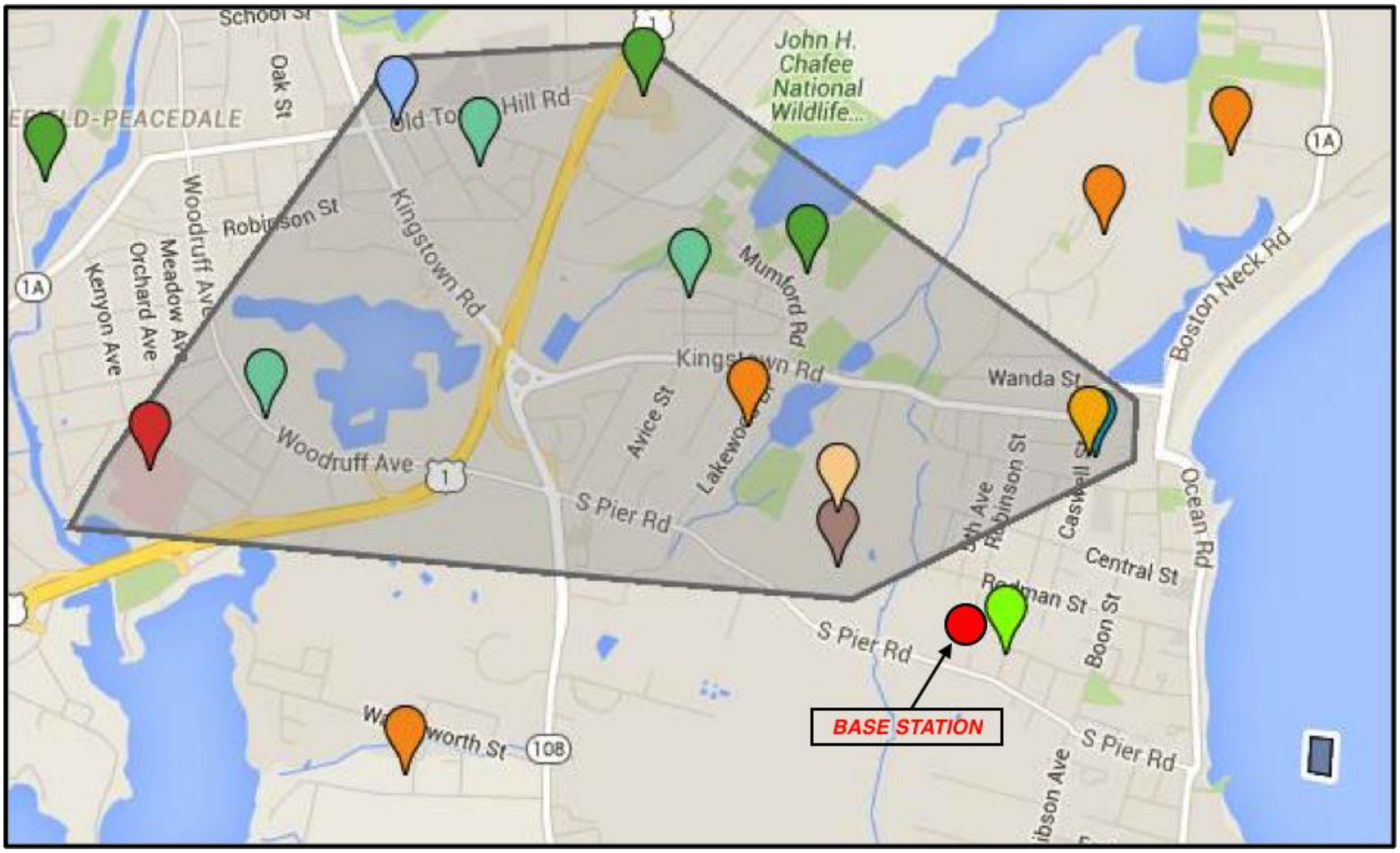


Figure 23: Location of base station

AMI Network (AMI)

AMI: Advanced metering infrastructure (AMI) is an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers.

This system will include smart meters in the following locations:

- Each building of the microgrid. This will allow us to monitor the demand of each building on a real-time basis. These will be installed on the following buildings:
    - 300 smart meters, one for each house
    - 1 smart meter for the South County Hospital
    - 2 smart meters for the Narragansett Police & Fire buildings
    - 1 smart meter for the Monsignor Clarke Middle School
    - 1 smart meter for the Narragansett High School
    - 1 smart meter for the Narragansett Pier Middle School
    - 1 smart meter for the Narragansett Elementary School
- Renewable energies. This will allow us to monitor the power that is being produced on a real-time basis. These will be installed on the following resources:
    - 6 smart meters, one for each fuel cell
    - 3 smart meters, one for each wind turbine
    - 1 smart meter for the tidal system
    - 307 smart meters, one for each building of the microgrid. In this case, these meters will only measure the power produced by the solar panels.
- Primary Metering Cluster. This cluster will be the main connection to National Grid and will have a bidirectional smart meter. (This will be explained further).

These meters will send all the gathered information by radio frequency to a meter data collector located on an antenna. The smart meters that we decided to use have an RF antenna embedded in the system. The meter data collector will send the information to the base station by radio frequency too, by using a WiMAX radio.

A rough outline of the smart grid Advanced Metering Infrastructure (AMI) private wireless network utilizing MDS Mercury 3650s is the following:

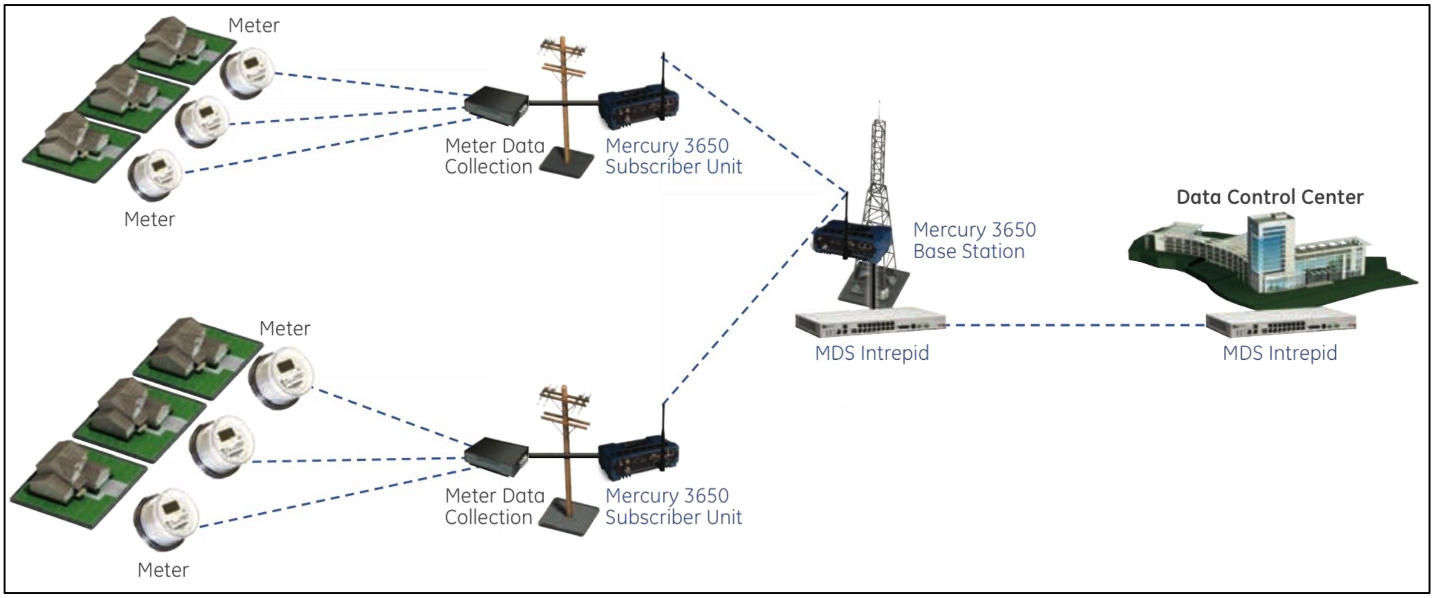


Figure 24: Smart grid private wireless network system

We will need the following devices for the design of the AMI System:

- *Smart meters*: These will collect the information of the power demand and the power supplied by the renewable resources
- *WiMAX Radios*: These will be the same model as used for the grid network. Their main purpose is to transfer all the information via radio frequency to the meter data collectors
- *Meter Data Collectors (Routers):* These devices will collect the data from the smart meters and will transfer it to the WiMAX radio. Both devices, the data collector and the WiMAX radio will be located on the same pole
- *Backhaul*: The MSD Intrepid will be used as the backhaul. It will gather all the information transmitted by the WiMAX radio. This information will be, then, transferred to the control center. This device will be located on the antenna of the base station.

As we explained in the last report, this network will be separated from the grid network and there will be no interferences among radio frequency signals.

The smart meter and meter data collector that we will include in the design are the following:

- Smart Meter: *GE I-210+c Smart Meter*

Figure 25: Smart meter GE I-219+c

- Meter Data Collector: *AMIS DC Data Concentrator*

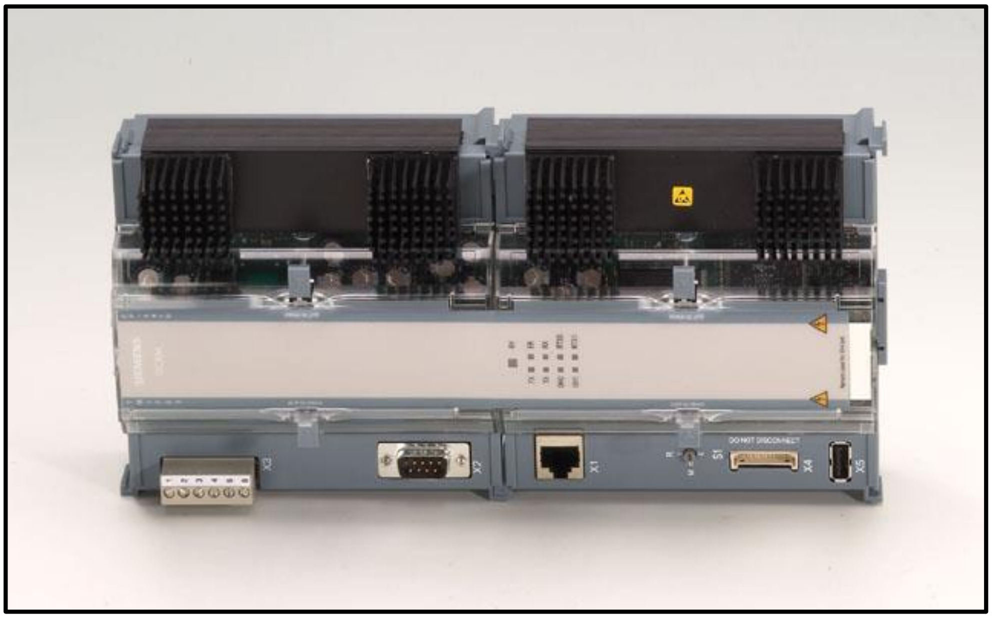
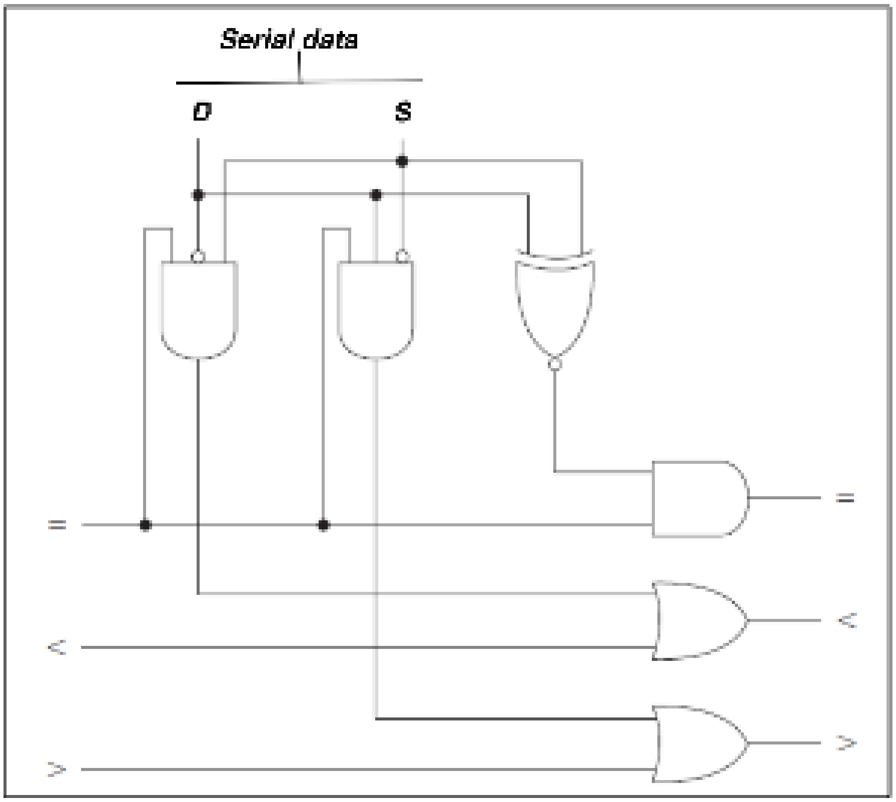


Figure 26: AMIS DC Data Concentrator

1) <u>Connection Among Renewable Resources</u>

The AMI system will provide real-time information of the power demand on each building pertaining to the microgrid as well as the power supplied by the renewable resources. This will be achieved by installing smart meters in the buildings and in the renewable resources.

The device that will also be essential for the operation of the AMI system is the digital comparator that we designed. This comparator will get the data by the serial port on the WiMAX radio. It will compare the total power demand and the total power supply in the microgrid and, according to that, it will turn on/off the generator to which it is connected by sending a digital signal that opens or closes the switch. Photovoltaics and the tidal system will be producing power all the time, so these devices will only be installed on the fuel cells and the wind turbines. The comparator design is the following:



- Node ‘=’: Connected to 5VDC
- Node ‘>’: Connected to GND
- Node ‘<’: Connected to GND
- *‘D’*: Power Demand
- *‘S’*: Power Supply

Figure 27: Comparator design

This device will receive the power demand and power supply as bits from the WiMAX serial port. It will compare the numbers and send logic ‘1’ if the demand is larger than the power supply. That signal will be connected to the relays on each resource, opening the switch and adding more capacity to the system to increase the power supply.

These devices will be connected on the fuel cells and also on each of the three wind turbines. The wind turbines will be connected in order, so that each of them is connected when needed. The same process will be followed for the fuel cells.

2) <u>Antenna Distribution</u>

These antennas will be in charge of gathering all the smart meter information from the different buildings of the microgrid.

The locations of the antennas can be seen in the figure below:

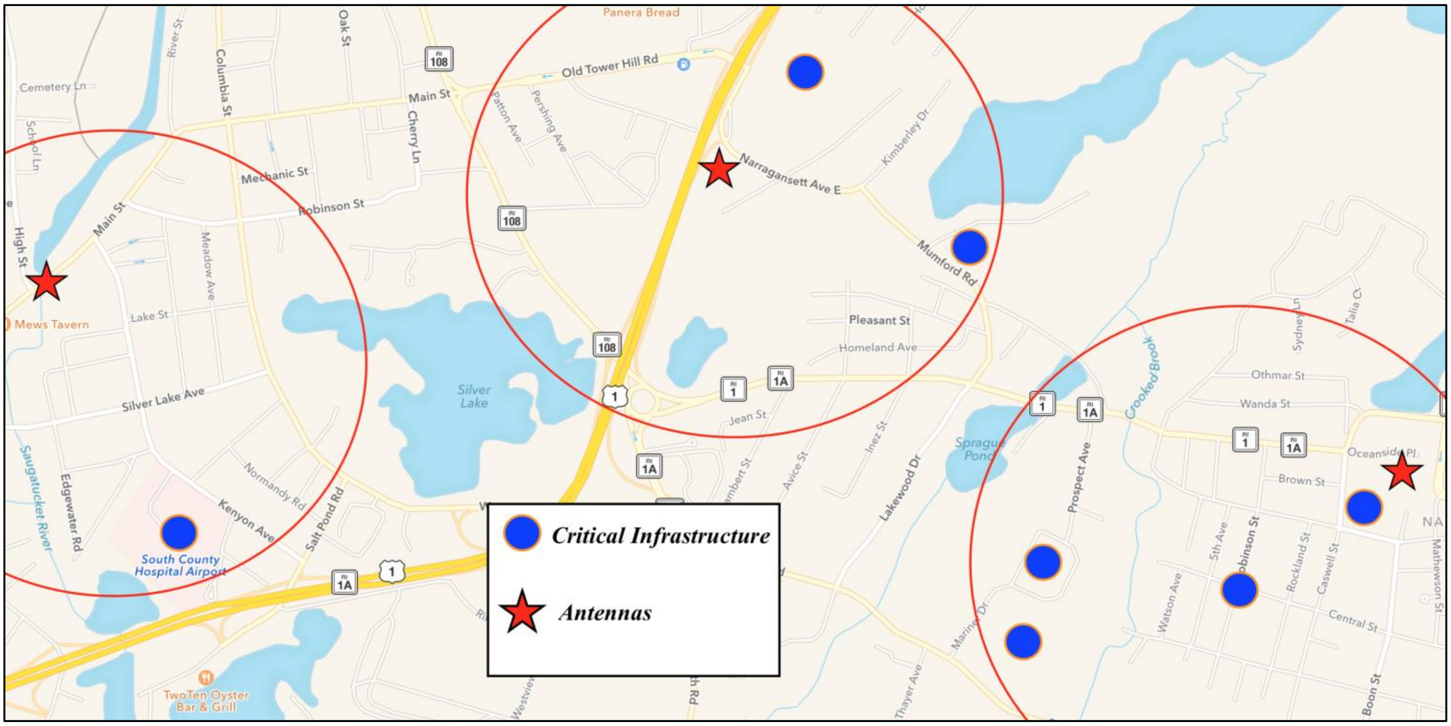


Figure 28: Location of antennas

In the case of the antenna located on the left, we will use the AT&T Wakefield tower that is already built in that area. This antenna will gather the data from the South County Hospital. The antenna located in the middle, will take care of the Monsignor Clarke School and the Narragansett Elementary School. The antenna located on the right side of the figure will collect the data from the meters located on the houses, Narragansett Police & Fire, the Narragansett Pier Middle School and Narragansett High School.

By using three antennas we will make sure that all the information is gathered. These antennas will have the *AMIS DC Data Concentrator*, which will be in charge of gathering the information from the meters. Furthermore, the antennas will be equipped with a WiMAX radio so that the information from each antenna can be sent to the base station.

3) <u>Primary Metering Cluster</u>

This cluster will be the main connection to National Grid and will have a bidirectional smart meter. It will provide information to both the microgrid and National Grid about the excess or lack of power in the microgrid. This means that, in the worst-case scenario, if there is not enough power to cover the demand in the microgrid, we will be able to purchase power from National Grid. However, if we produce more power than needed, National Grid will pay us for that power. Hence, we need to monitor that power supply/demand by installing a bidirectional smart meter.

This smart meter will be located at the point of common coupling located at *South County Hospital (Point 59F2)*. The location of this point is shown in the figure below:

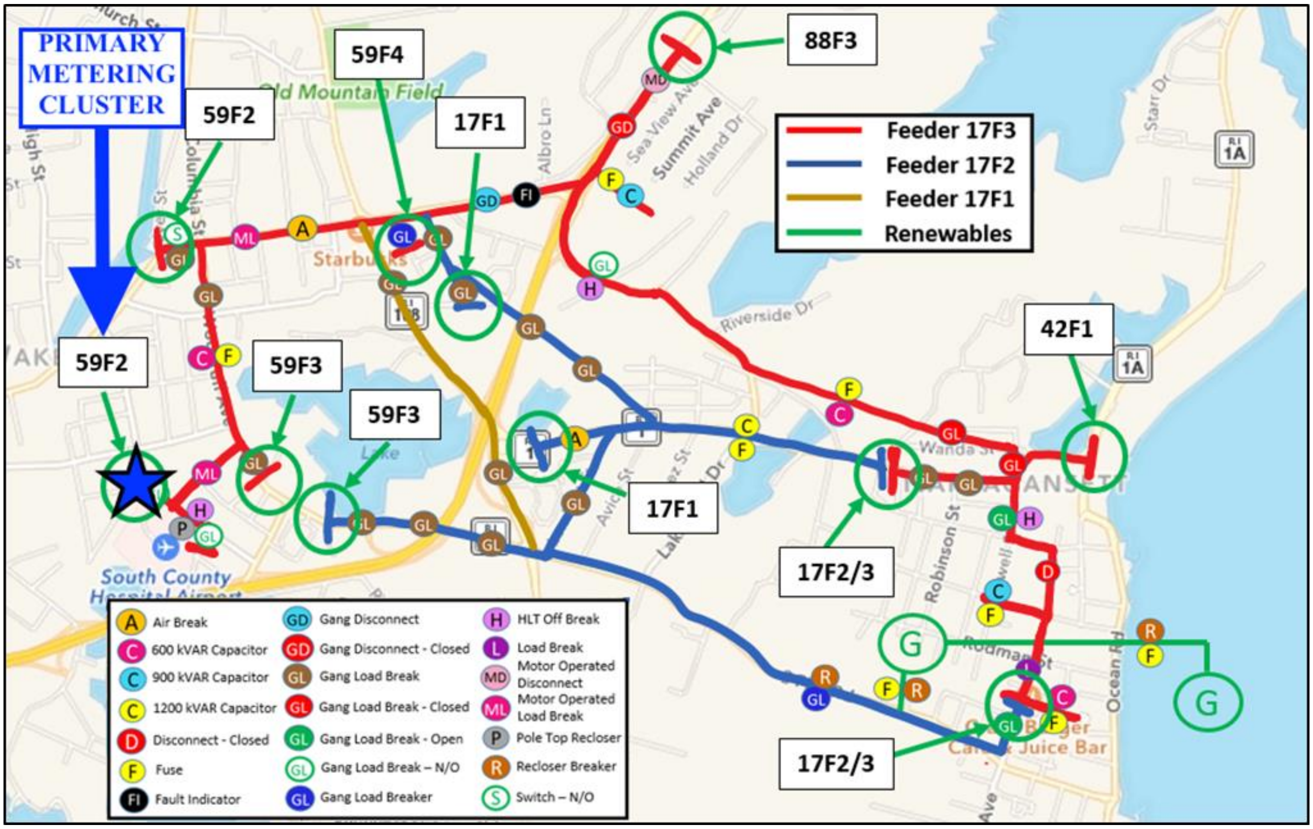
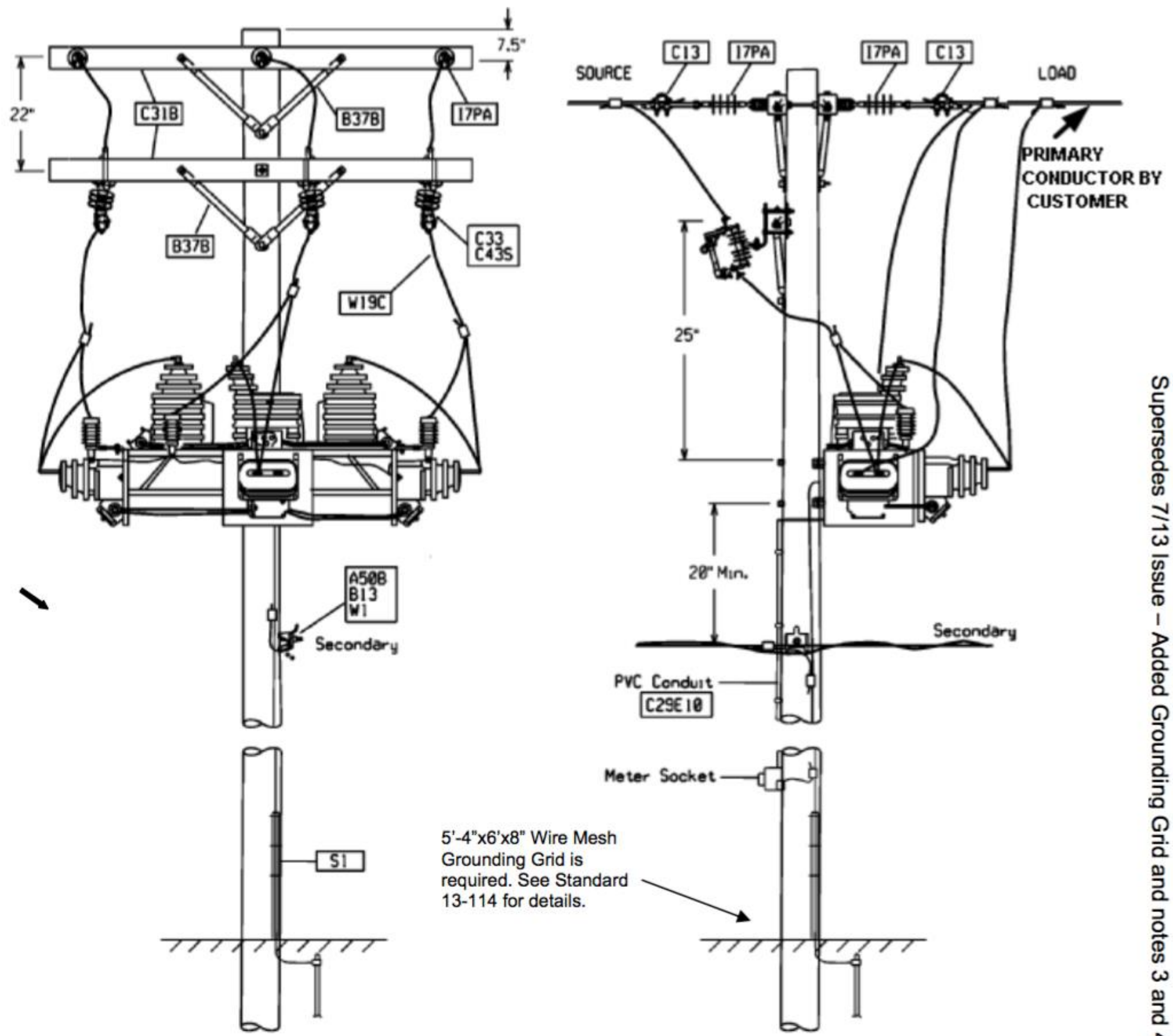


Figure 29: Location of primary metering cluster

We won't include this in the final price, since National Grid will pay it.

The combination of the renewable energies with the grid network and the AMI network will ensure an efficient operation of the microgrid.

The schematic of the primary metering system is shown below:



Supersedes 7/13 Issue – Added Grounding Grid and notes 3 and 4.

NOTES:

1. Metering equipment shall be specified by Meter Engineering.
2. Meter socket height is to be no less than 3 feet and no more than 6 feet from ground to center of meter unless otherwise specified by Meter Engineering.
3. A ground grid shall be installed directly beneath the meter socket (See standards 13-113 and 13-114).
4. For all installations including Distributed Generation, The SOURCE or LINE primary taps are connected to the Utility. The LOAD primary taps are connected to the Customer.

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Figure 30: Primary metering system

A diagram of our entire microgrid and smart grid system can be seen below.

Costs

For the calculation of the cost estimates, we gathered information of the costs of the whole project. To develop the spreadsheet we used the following costs:

- Cost of purchasing the renewable energies
- Cost of installation of the renewable energies
- Cost of purchasing the smart grid devices
- Cost of installation of the smart grid devices
- Cost of engineer salaries
- Cost of capstone director salary

In the spreadsheet we will compare the monthly charge of purchasing electricity from National Grid and the monthly charge of producing power for the microgrid (including the price per kW of the renewable energies).

In the calculations of purchasing electricity from National Grid we used the C-06 standby rate which is the cost National Grid charges to stay connected to the grid even if not buying electricity from them (when the microgrid is in island mode). This rate includes the following charges:

- Customer charge (per meter): $10/month
- Price of electricity: $0.083/kWh
    - Distribution Charge: $0.03763/month
    - Renewable Energy Distribution Charge: $0.00233/kWh
    - RE Growth Charge: $0.26/kWh
    - Transmission Charge: $0.02072/month
    - Transmission Charge (Credit): $0.00201/kWh
    - LIHEAP Charge: $0.73/month
    - Energy Efficiency Programs: $0.01107/kWh

Generation Cost	**Size (in KW)**	**Install & Commission**	**Cost per KW**	**Purchase Cost**	**Total cost**
			(in dollars/cents)		
Photovoltaics	369	$369,000	2.38	$510,875	$879,875
Wind Turbines	1,980	$1,782,000	3.93	$6,000,000	$7,782,000
Fuel Cells	2,400	$3,120,000	6.30	$12,000,000	$15,120,000
Tidal	500	$700,000	17.40	$8,000,000	$8,700,000
Hydrogen Tanks	-	-	-	$1,800,000	$1,800,000
Electrolyzers	-	-	-	$7,800,000.00	$7,800,000.00
Totals	5,249	$5,971,000	8.02	**$36,110,875**	**$42,081,875**

SMARTGRID DEVICES			
Device	**Number of units**	**Price per unit ($)**	**Total Price ($)**
G&W Viper-S Recloser	15	22500	337500
SEL 651R Controller	15	5750	86250
SEL 734B Controller	3	1600	4800
SEC1075 Backup Battery	21	18	378
Lindsey 1Φ Sensor	9	190	1710
WiMAX	22	1400	30800
MDS Interpid Series	4	1555	6220
Solectria PVInverter-7600TL	307	2369	727283
MidNite Stop Switch(Wind Turbine)	3	74	222
Eaton's line disconnects (UL 98)	306	68	20808
ViaSat M2M Terminal FT2225	2	1000	2000
Engineering Salary	6	104000	624000
Capstone Director Salary	1	208000	208000
Smart Meters GE I-210+c	616	274	168784
Meter Data Concentrator AMIS DC	4	2000	8000
TOTAL PRICE			$2,226,755

Peak Demand (kW)	3,400			
Stand by demand charge per month		$10		
Cost for service (avg demand in kWh)	2,140	**$0.0833**		
	Total Hours	**Days in Month**	**Total Hours/Mo**	**kWh Cost/Mo**
Monthly energy charge	24	30	720	**$128,302**
Stand by rate				$3,070
Total cost to buy from National Grid per month				**$131,372**
kWh cost from microgrid each month				$5,772
Generation cost (depreciation value)				$175,341
Total cost to run microgrid per month				**$181,113**

From the above spreadsheets, it can be seen that the total cost of the renewable energies themselves is $42,081,875, and the total cost of all of the smart grid devices is $2,226,755. Based on that and the data we have of the standby rates and National Grid charges, we were able to calculate the monthly charge to buy electricity from National Grid without using the microgrid at all and the monthly cost to run the microgrid at its full capacity. The monthly cost to buy electricity from National Grid is $131,372 and the monthly cost to run the microgrid at its full capacity is $181,113. Doing these calculations shows explicitly the difference in costs to buy from National Grid or run our microgrid, which, at first glance, seems like a dramatic difference. But taking into account that these calculations do not include any state or government incentives for the renewables, and also the positive environmental impact that utilizing renewable technologies would have on the community, this difference in price could be both reduced and/or a more widely accepted and viable alternative to buying electricity from the electric company.

Project Continuation

This year, we were able to cover pretty much all bases of what we wanted to complete for this project. We were able to put together a complete, albeit theoretical, community microgrid that includes calculated quantities of renewable energy sources to cover a specific load demand, and an intelligent communication system that allows the microgrid to analyze the demand vs supply and make any appropriate changes, all at a cost that is reasonable for the stage of development that this technology is currently in. Because of this, future progress of this specific project is not necessary.

Of course, future projects involving these renewable energy and smart grid fields of electrical engineering would be highly recommended to include in the list of options to choose from. This industry is going to grow exponentially over the next couple years and it is going to be very important to have more engineers who are knowledgeable in these fields. We would definitely recommend that National Grid consider continuing to be involved with capstone in this way as it would not only benefit students by being able to get valuable experience in this field, but also benefit National Grid by providing training to the future generations of engineers at little to no cost.

We all feel very lucky to have had the opportunity to work on this project this year, and to have worked with National Grid, and we hope that future capstone designers can have the opportunity to have a similar experience.

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  - Fred Paine

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