US Army Tactical Microgrid System Civilian Application

Design Document

ECE 445
2/23/2020

Team 49
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1 Introduction

1.2 Objective

The Tactical Microgrid System (TMS) of the US Army Corps of Engineers is a centralized power distribution system developed for seamless deployment in areas that have temporarily lost their means of producing electricity. It is currently deployed in multiple locations, however there exists no integration for this technology in a civilian environment. Our client, the US Army Corps of Engineers, wants us to adapt this project for civilian use.

The goal for our project will be to modify the current TMS deployed by the Army Corps of Engineers to allow for initial power generation with diesel engines and then seamlessly transition to using renewable sources of energy. During this semester we will be working with both Army Corps Engineers and 2 Seniors in the Agricultural Engineering Department. Due to the increased number of stakeholders and the compliance requirements of working with the military, we must follow the administrative guidelines of all involved parties. We will develop a functioning prototype of our design that will be demoed to our stakeholders, namely the US Army Corps of Engineers, the ECE Department, and the ABE Department.

1.2 Background

Across the globe there are still many places that do not have infrastructure in place to deliver sustainable energy to its citizens, or that the power grids in place were destroyed or damaged by natural disasters or outside influences. The current tactical microgrid utilized by the military is not practical or sustainable for civilian use, as it is large, expensive, and requires training to operate. The purpose of the diesel generators would be to provide immediate aid, and then over time use either renewable energy sources or connect to existing grids that would provide a more permanent energy solution. An example is that recent earthquakes in Puerto Rico have damaged its infrastructure, removing multiple areas' access to sustained power.

The prototype we will design this semester will be sent to Puerto Rico with a group of students over the summer. Research into the current power grid situation in the country of Puerto Rico has highlighted some major concerns the country is currently faced with. Approximately 70% of the energy generated in the country is located in the southern region of Puerto Rico, while about 70% of the required load is located in the northeast region.

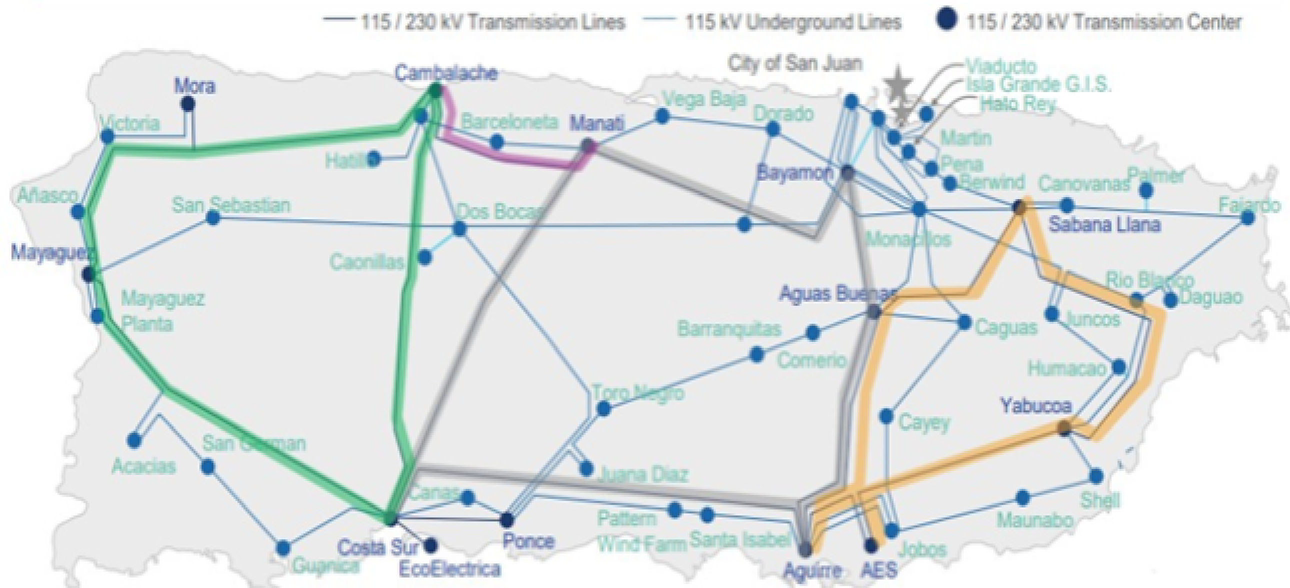


Figure 3: Puerto Rico Power Grid Coverage

From the map in figure 3, it is clear that there is a major gap in coverage located in the central regions of Puerto Rico. The mountainous terrain and heavy vegetation also make these areas susceptible to power outages. A successful project will directly impact the community that our first prototype will be deployed to, and showcase how it can be used to aid other communities across the globe.

1.3 Physical Design

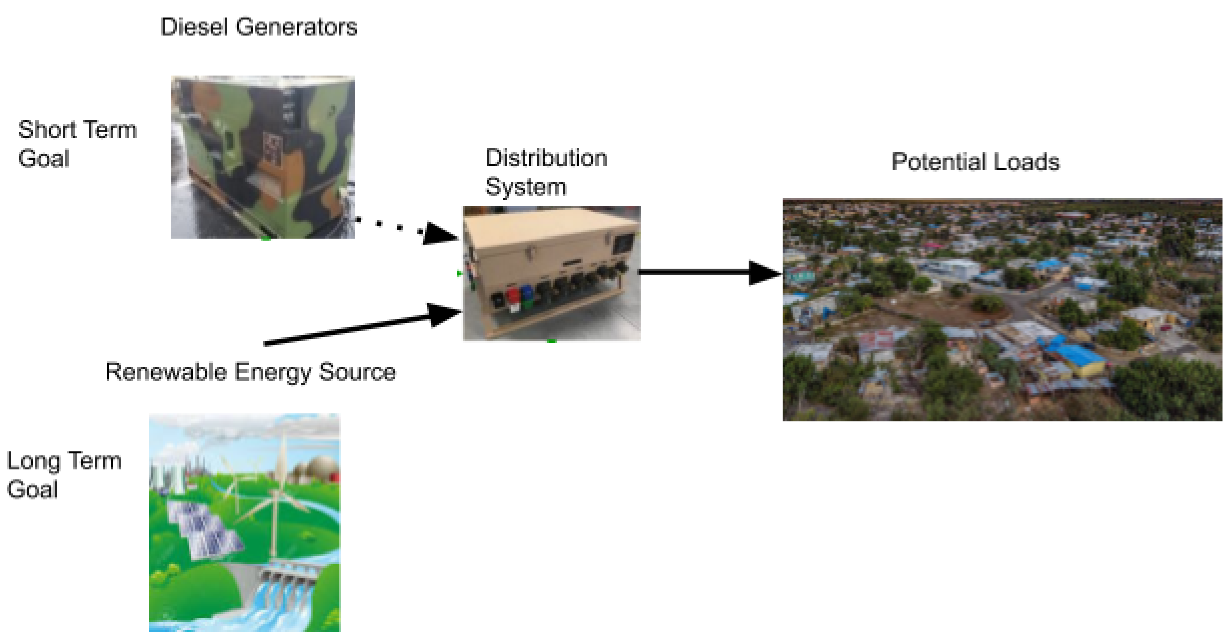


Figure 2: High Level Idea for the Physical Layout

1.4 High Level Requirements

1.4.1 Microgrid System High Level Requirements

- We must design a modular microgrid system following the USACE's TMS-DDS Protocol
- Our project must be able to adapt its power output to match the power grid of Puerto Rico
- We must modify existing microcontroller code for diesel generators to work for other power sources, such as solar panels or hydroelectric power
- The operation of the microgrid should be simple enough to require minimal training to run and maintain; simple enough that a civilian with little to no education could setup and control the microgrid

1.4.2 Cycling Status Display High Level Requirements

- Presents distribution box performance in a way that can be easily understood by the user, and in language options of English and Spanish
- The system does not interrupt the communication between the distribution box and the microgrid microcontroller
- The display unit is localized to only display the data of the distribution box that the device is connected to

2 Design - Power Grid

2.1.1 Overall Block Diagram

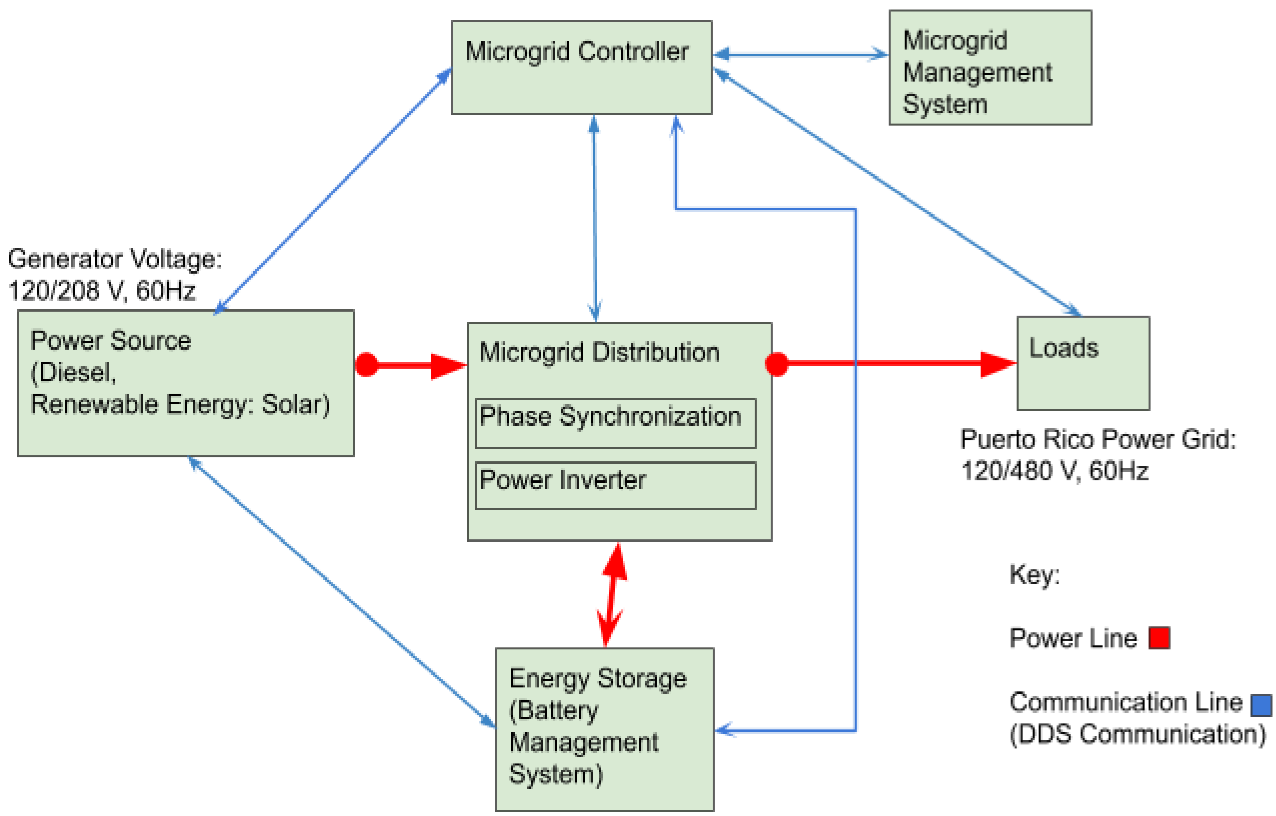


Figure 3: High Level Block Diagram

2.2 Functional Overview

Due to the large scope of the project that we are working with the ABE department, and engineers at the US Army Construction Engineering Research Laboratory, we are narrowing our focus. An essential subsystem required for the operation of the microgrid is a phase synchronization circuit, also known as a phase locked loop. The power grid in Puerto Rico requires that the AC voltage is set to 60 Hz. The purpose of the phase locked loop would be to monitor that AC voltage in the distribution system of the microgrid, and ensure that the output frequency from the distribution system is held at 60 Hz. We have included the requirements for each system of the microgrid project as a whole, however; our main focus on the project will be developing our own phase locked loop.

2.2.1: Power Source:

Responsible for delivering power to the microgrid. The types of power sources will be diesel generators for short term use to get electricity up and running in the area, and as an emergency backup. The long term, sustainable option will be to use a renewable energy source. The application would determine the best renewable energy source to use, and for our focus on deploying the microgrid in an interior location, away from the coast of Puerto Rico the renewable energy source we will utilize is solar energy.

Requirement	Verification
1. Capable of providing 180kW input power 2. Input power sources provide 120V Single-Phase, 208V Three-Phase power at 60Hz	The generators we will be working with have relays that provide detailed information about the electrical performance.

The USACE has said that initially 3 generators will be used. 2 are 100 KW modified CAT diesel generators, and the third is a 60 KW modified Cummins diesel generator. The USACE already has these generators, and they have modified them to fit current military applications. We will have to modify these in some way to fit civilian applications. The few requirements that come to mind based on our initial meeting with the USACE is that these generators must be modified so that they can be easily re-integrated into the microgrid when necessary. The end goal is to use renewable energy as the source for the microgrid, and solar was chosen to be the initial focus for this project. We have to keep in mind that these microgrids will be deployed in affected areas where transportation of equipment can be difficult or even impossible by ground. This is why wind power has been excluded because the size of wind turbines make it difficult to transport, as well as reliant on where it is deployed.

2.2.2: Microgrid Distribution:

The distribution system converts the energy produced by the power sources so that the proper amount of power is transferred based on the loads connected to the microgrid. The distribution will also be able to add or take power from the energy storage unit depending on the energy requirements of the microgrid at a given point in time. We plan on integrating our custom PCB in this module.

Requirement	Verification

1. Must be able to handle the integration of different power sources at different times	1. Use of the Army Corps of Engineerings Deployable Metering and Monitoring System a. System will also us to record high power measurements for the distribution system

The diesel generators are rated to deliver up to 800 Amps of power, so the distribution system has to be able to tolerate that level of current. Transformers will be required to bring the level of voltage down to civilian use, so 120-240 Volts. Converters will also be needed to convert the electricity from the source to DC in case civilian applications call for it. The distribution system will need to operate at all times, so a separate back-up power source will be needed in case the primary power source fails. This will most likely be a back-up battery that is charged by the primary power source. Since the microgrid will be placed in locations that are impacted by weather, this system must be robust and able to tolerate harsh weather conditions. The distribution system will need to communicate the state of the loads with the microgrid controller, so hardware will need to be installed as well with the ability to quickly let the controller know the state of the loads.

2.2.3: Microgrid Loads:

This block will be the devices that are connected and powered on by the microgrid. The types of devices connected would vary widely depending on the application of the grid and the location that the grid is being deployed to. For our project, the focus will be loads that are plugged into the microgrid must meet the single-phase and three-phase requirements for the country of Puerto Rico. The single-phase grid requirements in Puerto Rico are the same as the United States, the challenge will be with three-phase power because the two standards are different.

Requirement	Verification
1. Single Phase: 120V, 60Hz 2. Three-Phase: 480V, 60Hz	1. Use of the Army Corps of Engineerings Deployable Metering and Monitoring System

The loads this microgrid will serve can wildy vary. We know the microgrid will serve civilian applications, so initially we can assume that the distribution system should be able to output 120-240 Volts to the loads.

2.2.4: Energy Storage:

One of the USACE's objectives is that the microgrid should be sustainable; this means that a method of energy storage and an inverter are required when the primary renewable energy sources are not producing enough power to fulfil the loads' demands. Stationary batteries for renewable energy storage are not something new, but further research will be needed to figure what type of batteries are best suited for our design.

Requirement	Verification
1. Capable of providing back power to the grid	1. If this goal is reached, the microgrid controller and deployable metering system will give us an indication of how it is functioning

We will need to communicate with the microgrid controller so that it knows when to turn on and start delivering power to the loads via the distribution system. It will need to be capable of being charged by the primary power sources. Our clients at CERL have recognized this block as a stretch goal.

2.2.5: Microgrid Controller:

The microgrid controller is in charge of communicating with all other subsystems so that the state of the microgrid can be monitored and adjustments can be made accordingly. The controller utilizes a DDS communication method to monitor all devices connected to the microgrid, a protocol written and designed by the USACE. The DDS communication protocol acts is an Internet-Of-Things application capable of letting the user know what devices are connected, as well as the profile of the device connected and having control over how it operates. The protocol is highly modular, compatible individual components like generators and loads can be attached and removed with minimal effort. The equipment we select for our project must follow this DDS Protocol.

Requirement	Verification
1. Shows all devices connected to the microgrid 2. Connected devices are recognized	1. The information from the microcontroller will be fed back to a remote computer

and have the proper profile that fits the device's description 3. Users can control the devices that the controller recognizes.	a. We must be able to monitor the entire system from this computer

The controller is the brain of the microgrid; it has to always be on and therefore will need a back-up power source in case primary power fails. This most likely could be coming from energy storage. Since the USACE would like this microgrid to be scalable, the controller needs to be able to be reprogrammed easily to account for new loads or changes in power generation (more/less diesel generators, integration of renewable energy sources). The testing of our microgrid controller must be compliant with IEEE standard 2030.8. IEEE 2030.8 has a set of testing procedures that microgrid controllers must pass for verification, quantification of performance, and how it compares to minimum requirements. [4]

2.2.6: Microgrid Management System:

The management system for the microgrid controller will be to give us a way to analyze the performance of the microgrid remotely. Also, the system is used by the US Army Corps of Engineers currently to implement cybersecurity measures to protect the microgrid systems from being hacked.

Since cybersecurity is one of the USACE's concerns, this system will need to be robust enough so that it can withstand cyber attacks from threats since it will be hosted on a remote network, separate from the microgrid network. This system is for monitoring purposes only, so there should be no communication back to the grid from this system. On the flip side, the connection between this network and the microgrid network must be robust enough to tolerate physical harm. While this portion is a necessary component for the microgrid's application, we will likely have little to no responsibility on this portion of the design.

2.3 Risk Analysis

The block that will prove to be the most difficult to get correct will be the microgrid controller. Being able to control how energy is being stored, distributed, and drawn from the energy source will be the key to the successful operation of the microgrid. The controller will have the greatest responsibility, as it will be constantly monitoring the loads that are connected to the grid, which will determine how power will be distributed to each of the loads efficiently. The controller will also be responsible for determining how much energy the microgrid is capable of storing depending on what power sources are being used at the time, whether it is the diesel generators or a clean energy source, and how much power is required to power all connected loads. The efficiency and safe operation of the microgrid will hinge on the success of the controller being able to actively read in the data that it is fed and respond accordingly to ensure power is being utilized properly.

2.4 Tolerance Analysis

The demands from the loads dictate how much power needs to be produced and distributed throughout the microgrid. Load demands change throughout the day, and it will be up to the microgrid to communicate the requirement to the power sources. The diesel generators have a fixed output, while renewable energy sources such as solar have variable power generation. All of these sources must have an output at a frequency of 60 Hz because that is the frequency at which civilian loads operate in Puerto Rico. This means that we may potentially have multiple phase locking circuits installed to ensure that electricity of different frequencies is not injected into the microgrid.

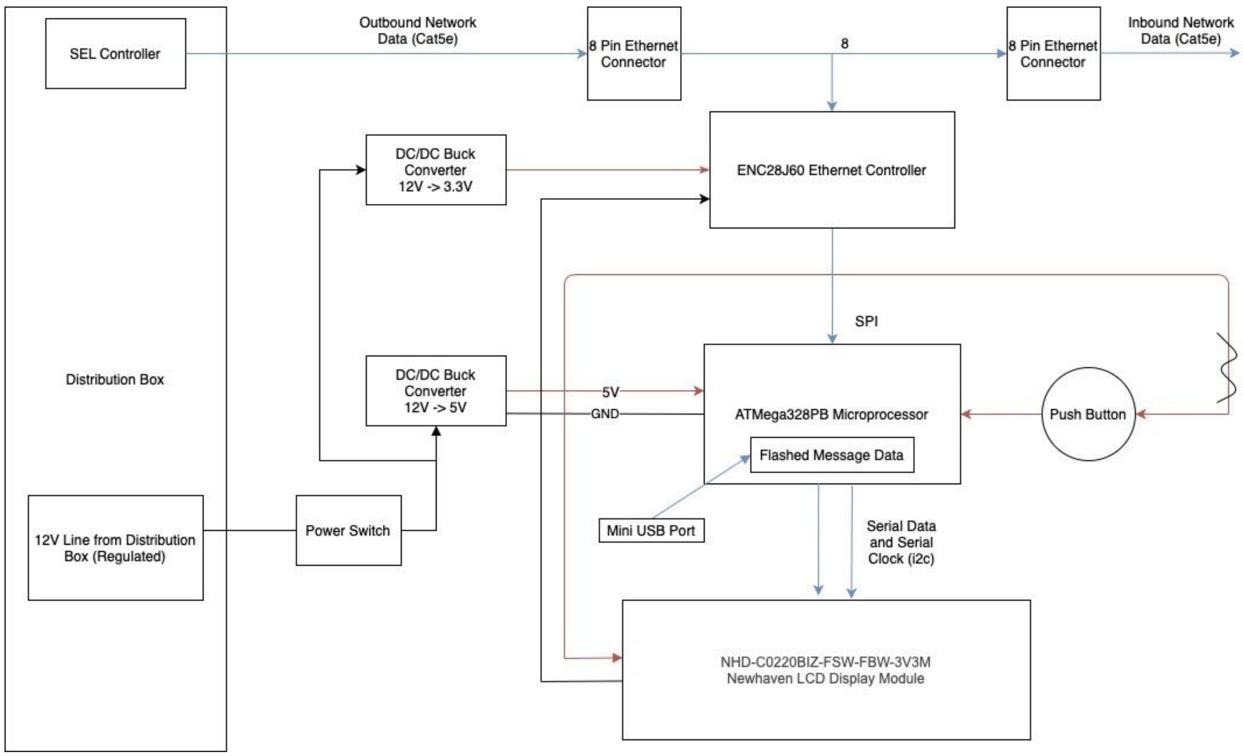
2.5 Physical Design

The advantage of the tactical microgrid system that we are implementing is the fact that it is not limited with a single point of failure. If a certain generator for the grid goes down, the other generators connected to the grid will pick up the slack based on the loads being driven.

Figure 6: Physical Layout of a Tactical Microgrid Application [1]

3 Design - Cycling Status Display

3.1 Block Diagram



3.2 Functional Overview

The main project of adjusting the distribution box does not present any opportunities to insert a PCB, so we are creating a separate component to fulfill this requirement. The CSD is a network tap that listens to the data packets sent from the Distribution Box to the DDS Microcontroller, interprets the data, and then displays it in a cycling format, where the Push Button advances to the next message. The purpose of this display is to show rudimentary data about the status of the machine, the main display unit (SEL) can be difficult to use for an untrained technician, so this display will provide an alternative way to display the most essential data, as well as in different languages.

The reason we chose this approach is to avoid interfering with the already existing components; the communication protocol being used has been designed by industry engineers, and it would be impractical to get in contact with them to modify the protocol for our class project. The data is sent through unencrypted UDP packets, so a network tap is able to be developed independently and to be easily attached or removed, depending on the operator's needs. The design is simple to allow us time to work on the distribution box design as well.

3.2.1 Power Source:

The Distribution box is fed 24V DC to provide power to the hardware within the distribution box. This is internally stepped down to 12V as well. We would use the 12V line for the DC power required to power our circuit and display. The microcontroller and display require 5V and the ethernet controller requires 3.3V. To step down the voltage to the required levels, we would install 2 buck converters, one for each voltage level.

Requirement	Verification
1. Provide a steady source of 5V power to the Microcontroller and LCD Display 2. Provide a steady source of 3.3V power to the Ethernet Controller	1. Microprocessor and Display Module components are able to be powered, current is constant and does not draw more than 1 A 2. Ethernet Controller is able to be powered, current is constant, and does not draw more than 500 mA

3.2.2 Ethernet Connectors:

These components are very straightforward, they are female connectors for CAT5e ethernet cables and expose the pins for each wire.

Requirement	Verification
1. Is able to connect an ethernet cable to our design 2. Does not affect the quality of the connection it is listening to	1. Connection to the ethernet cable is secure and reliably transmits data to the microcontroller with effective 100% accuracy and no delay. 2. Output data is 100% accurate to the input data with no delay

3.2.3 Ethernet Controller:

This component interprets the data received from an ethernet cable, and then transmits it to the microcontroller via a SPI data line. The outbound data is infrequent, so we will not have to worry about the input buffer overflowing.

Requirement	Verification

1. Is able to interpret ethernet data messages and transmit data through a SPI interface to the microcontroller 2. The receive buffer does not fully fill up	1. Microcontroller successfully receives the data packets, and is able to process them in code 2. The ERXRDPT Register (forbidden receive buffer pointer) does not equal the ERXST Register (next write location)

3.2.4 Microprocessor:

The microprocessor is responsible for many aspects. It interprets the data received from the Ethernet controller, it processes that data into a readable text format, and then transmits it to the LCD Panel. The Microprocessor must also store multiple messages, and cycle to the next message every time the push button is pressed.

We will put english and spanish messages on the programmable flash memory (32KB max), and then use the received network packet to determine which message should be displayed and relevant numbers in that packet (voltage or current). The microcontroller will have to keep an internal state of all messages, and overwrite old message data with the most recent data upon receiving a new message.

Requirement	Verification
1. Is able to interpret ethernet packet data from the Ethernet Controller 2. Is able to flash message data onto the on-board memory via USB from a computer, and also able output that data 3. Is able to register the push button event and switch the message that is being displayed 4. Is able to output message data through i2c to the display module 5. Must be able to process network packet data faster than it is being received 6. Must be able to track the state of multiple messages 7. Must be able to track the time the button was last pressed, and turn the LCD display to idle after not receiving a press for 10 seconds	1. We are able to display network data on a GPIO during tests (e.g. voltage of a prespecified output) 2. We are able to output onto a GPIO the bits that make up a specified character in a predetermined place in memory, and memory does not overflow 3. Builds on requirement two, upon pressing the push button switches the GPIO output to another specified character in a predetermined place in memory 4. Display module properly displays the output message. Verification will be visually. 5. The receive buffer does not overflow, we will have an overflow warning GPIO in the microcontroller code 6. Switching between messages does not cause previous message data to be lost, message data persist in

	memory for at least 5 minutes, or until overwritten 7. Output on a GPIO will be high after pressing the button, and low after not pressing the button for 10 seconds

3.2.5 LCD Display Module

The display module is a 16x2 character screen with preset message formats for displaying characters. The i2C connection to the microcontroller writes data to certain buffers, which are then displayed upon an activation signal.

The component already supports numerous alpha-numeric characters, including spanish. We will aim to have support for english and spanish, in testing we will display english but for demonstration we will use spanish mode. These modes will be pre-programmed, and not configurable in production.

Requirement	Verification
1. Displays i2c messages received from the microcontroller 2. Powers off display upon receiving an idle signal from the microcontroller	1. Message is displayed at the correct locations on the screen with < 10ms latency 2. Display is powered off upon receiving the message.

3.3 Risk Analysis

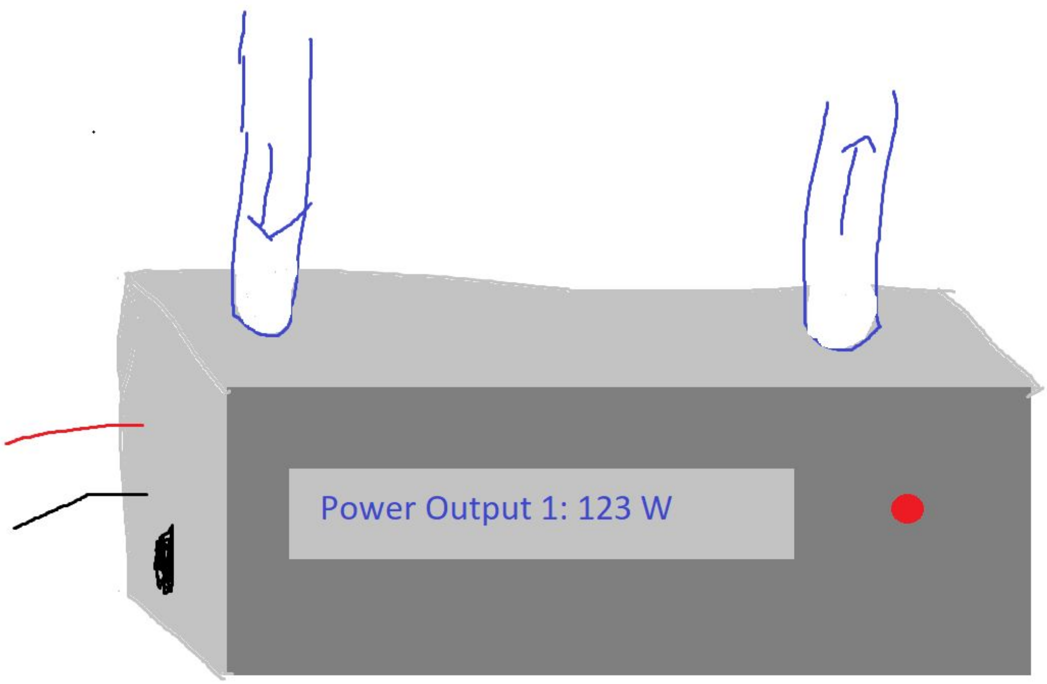
Due to the passive nature of this component, there are few points of risk. The highest priority concern would be a disconnect on the ethernet connection, which would cause the outbound messages to not be sent to their destination, causing a critical error in the function of the overall microgrid. Another source of risk would be the current draw of our component, since we are drawing from the internal power supply of the distribution box (and not the generator) there is a possibility that our power draw would cause the other components to not have enough power. We will carefully monitor the current draw of our component, and do additional research about the available power inside of the box, however if this is an issue we can also draw from the generator output itself. We do not anticipate our power draw to be significant.

3.4 Tolerance Analysis

Due to our component not driving any critical features of the distribution box, there is considerable amount of tolerance in our design. From the user's perspective, we can have up to 1 second latency between reading the messages and displaying them, as changes in the microgrid are slow, and the user must also take their own time to process the information. We will aim for a latency that is significantly less.

Other parts of the design have less tolerance, the ethernet tap listener must be as fast as possible to ensure the original operability of the distribution box. We also have leniency with how we choose to display the message, we can display it in multiple formats, but we can also simply create documentation with translations, making this feature optional.

3.5 Physical Design



Our physical design will essentially be a box with all of the components inside. There will be an in and out port for the ethernet connection, a button on the outside to cycle through the display, and two wires for 12v and ground. The box can be attached to the distribution box in numerous ways, we will most likely use velcro or an adhesive. There is also a female mini USB port for accessing the microprocessor's flash memory.

4 Cost and Schedule

4.1 Cost Analysis

Labor: We will assume that our contacts in the USACE will not be receiving wages for this project.
5 Students * 10 hours/week * 10 weeks * 50$/hour = $25,000

Power Grid Equipment: Much of the equipment we will use for prototyping is already owned by the USACE, or it will be custom made by the USACE. The cost of the microgrid as a whole would cost an estimated $320,000 [7]. The microgrid we are developing will be at a smaller scale than the current tactical microgrid system, so our price will not get as high as performed by the NREL study. These values are estimates at this point, and due to the scale of the project and the custom equipment used by the Army Corps of Engineers the exact breakdown has been difficult to research.

Item	Quantity	Price
60kW TQG Generator	3	$118,500
Distribution Box	1	$90,000
SEL Microgrid Controller	1	$10,000
Battery Management System	1	$9,360
Phase Synchronization PCB	3	$100
	Total (Equipment + Labor)	$252,960

Cycling Status Display Equipment: All of this equipment is very cheap and easily obtainable through online retailers. We will most likely make the casing through the machine shop. We plan on buying spare parts with the leftover budget.

Item	Quantity	Price
ATMega Microprocessor	2	$3
Ethernet Connectors	4	$4
Female USB Port	2	$2

Ethernet Controller	2	$3
Push Button	2	$2
LCD Display Module	2	$12
Power Switch	2	$2
DC/DC Buck Converters	4	$3
	Total (Equipment)	$31

4.2 Project Schedule

The roles of the team are broken as follows:

- Sahil Morrow will focus on the hardware design of the power grid systems.
- Matthew Weberski will assist Sahil in hardware design and on the hardware necessary for hardware/software interfacing.
- Patrick Yang will have his focus on implementing the necessary software for this project.

Feb 24 - March 1:

- [Class] 2/27 Design Document Final Submission
- First trip to the CERL Facility, we were introduced to our primary USACE contact, the available equipment, and our project success criteria
- [Design] Selection and Research of Parts

March 2 - March 8:

- [Design] Selection and Research of Parts
- [Design] Connection of Modules

March 9 - March 15:

- [Class] 3/12 Early Bird PCBway Order
- [Class] 3/13 Soldering Assignment
- [Design] Propose Design to USACE
- [Design] Iterate on Feedback from USACE

March 16 - March 22:

- Spring Break

March 23 - March 29:

- [Class] 3/26 First Round PCBway Order
- [Design] PCB
- [Design] Propose design to USACE (2)

- [Prototyping] Begin

March 30 - April 5:
- [Class] 3/30 Individual Progress Reports
- [Prototyping] Module, Power Supply
- [Prototyping] Module, Power Distribution
- [Prototyping] Module, Controller and Interface

April 6 - April 12:
- [Class] 4/6 Final Round PCBway Order
- [Prototyping] Loads
- [Prototyping] PCB integration
- [Design] Final PCB Design

April 13 - April 19:
- Final Prototyping and Testing

April 20 - April 26:
- [Class] Mock Demo
- Presentation Preparation

April 27 - May 3rd:
- [Class] Demonstrations
- Presentation Preparation
- Documentation

May 4th - May 10th:
- [Class] Presentations
- [Class] 5/6 Final Paper, 5/7 Lab Notebook Due

5 Ethics and Safety

The high power levels of our microgrid can lead to serious safety concerns if care is not taken. Each individual diesel generator that we will be utilizing will output power as high as 60kW, with a current limit of 800A. Extreme caution will have to be taken to ensure that the generators, and the grid as well, is operated in as safe of conditions as possible. Our project is designed for deployment in Puerto Rico; we will use information received from our client to design our system to suited for that environment, but we will also analyze how our system will perform in other environments.

Using diesel generators also leads to another safety risk for the individuals around them during operation. The diesel generators will give off toxic fumes, mostly in the form of carbon monoxide, so it will be essential to make sure that the area that has these generators are sufficiently ventilated to lessen the risk of breathing in the toxic gas. Also the diesel fuel is highly flammable, which will be that this fire hazard must be monitored to ensure the fuel is not unintentionally ignited.

The renewable energy source that is used to take over for diesel generators to make the microgrid more sustainable will also bring up safety hazards. The type of renewable energy source used will be based on the environment that the microgrid will be deployed in, but all of the renewable energy sources will be capable of high and extremely dangerous levels of voltage and current that can electrocute an operator.

An ethical issue that our project will face is the pollution caused by running diesel generators. We have an understanding that diesel engines in this capacity are not sustainable in areas with minimal power grid infrastructure in place, which is why renewable energy sources must be capable for our microgrid so that the diesel energy source will serve the purpose of being a back-up power supply in case of emergency. This is in accordance to the IEEE code of ethics, #1, "...to disclose factors that might endanger the public or the environment." [2].

Another ethical issue that our project will face will be that we must have detailed documentation for safe operation of the microgrid. The assumption that we are under is that the individuals using the microgrid long term will not be an experienced technician. According to the IEEE code of ethics, #5, we are responsible "to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies…" [2]. This means that we must have clear instructions on how to initially train and operate the microgrid once the system has been deployed, as well as make sure the end user is clear about the purpose of each component and how to safely operate the equipment. Our project partners from the ABE department will be in charge of drafting a safety manual.

6 References:

[1] D. Herring. Presentation. "Tactical Microgrid Standard (TMS)." OMG Technical Meeting, Reston, VA, Mar. 19, 2019. Available: https://d2vkrkwbbxbylk.cloudfront.net/sites/default/files/tms-omg-mars-20190319-release-v2_sm.pdf

[2] ieee.org, "IEEE Code of Ethics", 2016. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 13- Feb- 2020].

[3] IEEE Standard for the Specification of Microgrid Controllers," in IEEE Std 2030.7-2017 , vol., no., pp.1-43, 23 April 2018

[4] IEEE Standard for the Testing of Microgrid Controllers," in IEEE Std 2030.8-2018 , vol., no., pp.1-42, 24 Aug. 2018

[5] Puerto Rico Electric Power Authority. Presentation. “2019 Fiscal Plan for the Puerto Rico Electric Power Authority.” Financial Oversight and Management Board. Jun. 27, 2019

[6] J. Goebel, “Energy Metering in Remote Sites,” *The Military Engineer,* vol. 111, no. 720. March 2019. Available: https://samenews.org/energy-metering-in-remote-sites/

[7] J. Giraldez, F. Flores-Espino, S. MacAlpine, P. Asmus, *Phase I Microgrid Cost Study: Data and Collection and Analysis of Microgrid Costs in the United States.* Golden, CA: National Renewable Energy Laboratory, 2018

[8] E. Csanyi, “Preparing to synchronize a generator to the grid,” *Electrical Engineering Portal*, Mar. 27th, 2013. [Online]. Available: https://electrical-engineering-portal.com/preparing-to-synchronize-a-generator-to-the-grid