Project Proposal

US Army Tactical Microgrid System
Civilian Energy Storage

ECE 445
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1 Introduction

1.1 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 is to develop the battery management system for the microgrid. The significance of the battery management system is to allow for sustainability. Diesel generators are to be used to power the microgrid initially, and provide long-term backup. Solar energy will be the main source of power for the microgrid, and the energy storage system is essential to make sure the efficiency of the microgrid is kept high, regardless of the power demand of the loads.

We will be providing analysis to the US Army Corps of Engineers about the physical design of the energy storage system for the microgrid. That includes providing the type of batteries that will need to be used, as well as how many will be required. We will also be developing a PCB design for the battery management system that will be in charge of making sure the power drawn from the batteries will keep the microgrid running efficiently.

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 the power grids in place are destroyed by natural disasters. The current tactical microgrid utilized by the military is not practical for civilian use and it is not sustainable. There is currently no energy storage capability on the design of the Tactical Microgrid system. The location that the design of the microgrid will first be tested is in Guayabota, Puerto Rico. The city currently has access to the commercial power grid infrastructure available, however; the grid is being run at near max capacity. Earthquakes that have struck the area in recent months are the reason the city is turning towards a microgrid solution. There is a water pumping system in the city of Guayabota that is our goal to power using our microgrid design.

The city of Guayabota also has a solar farm that is available for use. The US Army Corps of Engineers wants the ability to incorporate renewable energy sources to the tactical microgrid design, and in order to efficiently use this solar energy that is in the city the microgrid needs this energy storage system. The city also does not have any supply of batteries available from the solar farm for use on the microgrid. The local population of Guayabota is approximately 3000 people, and it is located in a rural, mountainous region. According to a survey by the United States Geological Survey agency, the groundwater that must be pumped to the surface for drinking is approximately 56.5 ft below the surface [5]. This will be critical when calculating the amount of energy required for the daily energy consumption of the water pumping system in Guayabota.

1.3 Physical Design

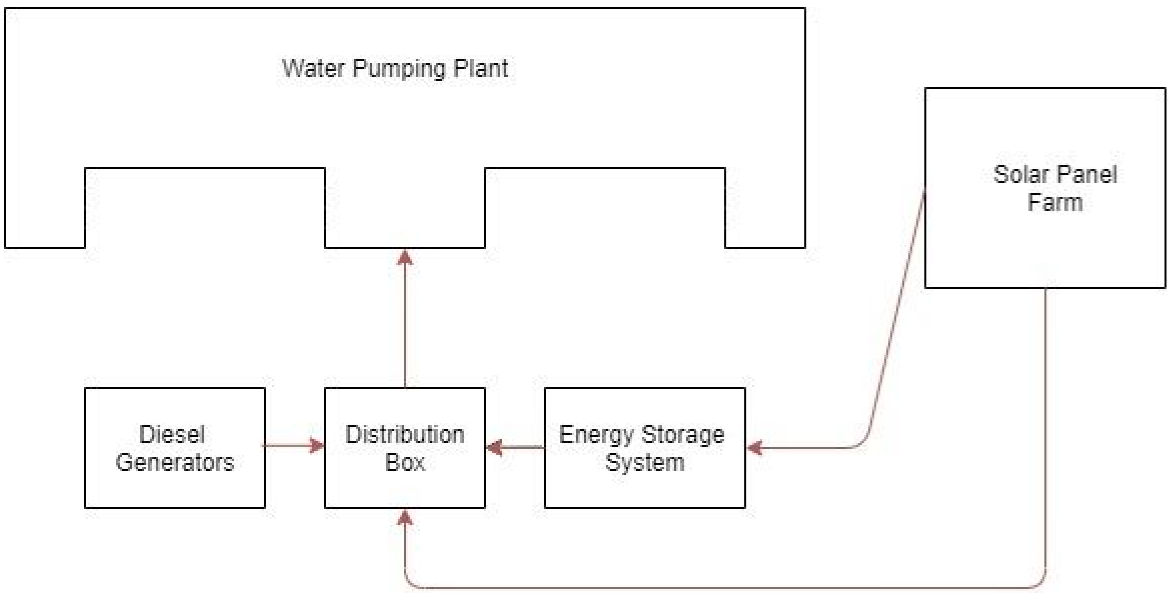

Figure 1: Layout of the microgrid architecture for the Guayabota water pumping system.

1.4 High Level Requirements

- The battery management system keeps the microgrid operational when the solar panels are not outputting maximum power.
- The batteries are not being overcharged or undercharged when balancing the input power and the load power requirements.
- The energy storage system is cost effective and adds sustainability

2 Design

2.1 Block Diagram

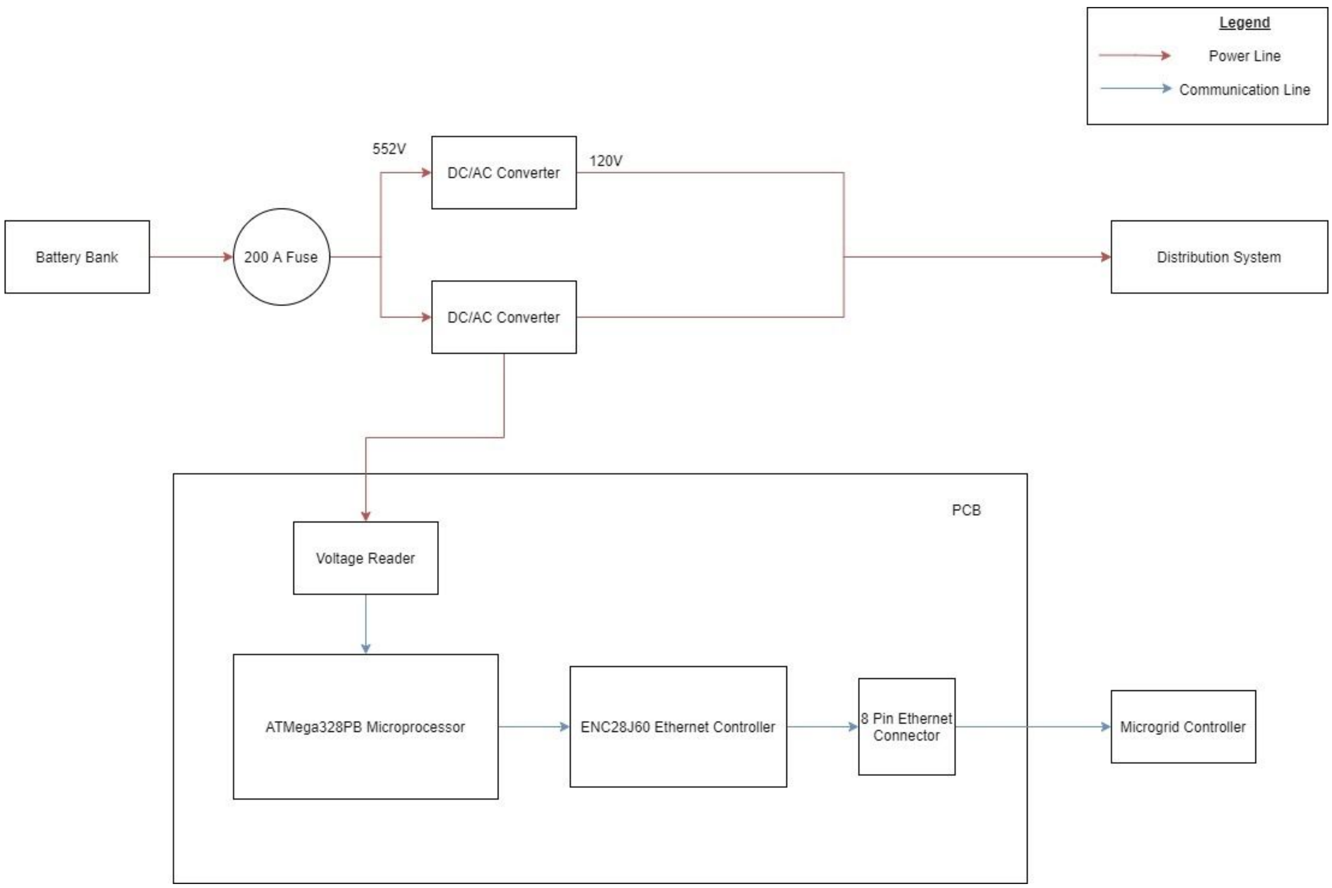

Figure 2: Block Diagram

2.2 Functional Overview

2.2.1: Battery Bank

The batteries will be charged when the input power generators, whether it is solar energy or diesel generators, are providing the necessary power to meet all of the load requirements. When the load requirements are not being met, that is when the batteries will have to be used. In order to solve for the energy consumption there are several assumptions that must be made. First, the National Environmental Education Foundation estimates that Puerto Rico residents require 62 gallons of water per day [6]. Next, one acre-foot of water is equivalent to 325,851 gallons of water. Finally, the energy consumption to pump one acre-foot of water one foot is

1.71 kWh, operating at 60% efficiency [7]. Combining information with the depth of groundwater and the population of Guayabota, the energy consumption result is shown in Equation 1.

$$\frac{62\ gal/person\text{-}day * 3000\ people}{325851\ gal} * 1.71 kWh * 56.5ft = 55.15\ kWh/day$$

Equation 1: Equation to solve estimated energy consumption of a water pumping plant.

The size of the battery bank is dependent on many factors. The first factor is that we will assume that the batteries will have enough storage to power the water pumping station for a single day. The reason for this choice is that the solar panel farm will be the long term solution for power, but the batteries will have to work at night, and if there is a prolonged period of bad weather or lack of sun for the solar panels, the diesel generators are there for backup. The next factor is the type of battery that is used for the battery bank. The options that are available are Lithium Ion batteries or lead acid batteries. Lead acid batteries are a proven technology that cost less, but have a shorter lifespan. Lithium Ion batteries are more efficient and last longer, but have a higher cost. Given the remote location that the microgrid will be sent to we will use Lithium Ion batteries for our application. Finally, the battery voltage multiplied by the discharge rate represents the 50% depth of discharge, so a factor of two must be included to make sure the battery bank's energy storage will not be used up in a single day.

$$\frac{2 * kWh}{Battery\ Voltage * Battery\ Discharge\ Rate} * 1000 = \#\ of\ Batteries$$

$$\frac{2 * 55.15 kWh}{12V * 100AH} * 1000 = 92\ Batteries$$

Equation 2: Calculation for the size of the battery bank.

Since the distribution boxes that the USACE wants to use are rated for 200 A, the battery bank should be set up with 2 rows in parallel, with each row having 46 batteries in parallel. This limits the amount of current that can be discharged at once to 200 A, matching the rating of the distribution boxes. The power output of the battery bank is calculated below in equation 3.

$$Battery\ Discharge\ Rate * \#\ of\ rows\ in\ parallel = current\ output$$
$$100\ AH * 2 = 200\ AH$$

$$Battery\ Voltage * \#\ of\ batteries\ in\ series = voltage\ output$$
$$12\ V * 46 = 552\ V$$

$$current\ output * voltage\ output = power\ output$$
$$200\ AH * 552\ V = 110.4\ kWh$$

Equation 3: Battery bank power output calculation

2.2.2: Power Conversion

Solar panels produce DC electricity, however the microgrid needs to transmit AC electricity because that is what the water plant runs on. This means that DC/AC converters will be needed. Based on the calculations in 2.2.1 (Battery Storage) and the fact that the civilian microgrid distribution boxes are rated for 200 A, we know that our power converters need to be rated for 110.4 KWh and 200 A. The battery bank will output to one bus, which we can call the battery bus. This battery bus will be connected to a 200 A rated fuse and a switch. After the switch there will be two power converters. The reason there would be two power converters is in case the primary power converter is damaged for whatever reason. If this happens, the switch will then direct power flow through the secondary power converter. This extra precaution is necessary in order to ensure that the battery bank can always discharge to the microgrid.

The power converters themselves will be DC/AC converters. The parameters of the converter will be that the input voltage is 552 V, the output voltage will be 120 V, and output load is 120 kWh.

2.2.3: Control System

The control system is needed to instruct the battery bank on when to charge/discharge. It needs to not only monitor the charging levels of the battery bank, but the load demands on the microgrid as well. This means that it will need to be able to receive information from the microcontroller. This means that a network tap to the microgrid's microcontroller will likely be necessary.

2.2.4: Voltage Reader

The voltage reader will be necessary to read the output of the battery bank after the power is transferred through the DC/AC converters. This information will be used by the microcontroller to determine the charge level of the battery bank, since the voltage will slowly drop as the batteries are discharged. This measurement will give an indication to the battery management system that the batteries are in need of recharging, or if they have become fully charged and all of the energy can be used to power the water pumping system.

2.2.5: Ethernet Controller

Information in the Tactical Microgrid System is transferred to the main microcontroller via ethernet. To ensure proper utilization of the batteries in the energy storage system, we will have to communicate with the microgrid controller. The ethernet controller will read the data from the battery management microprocessor about the current state of the battery bank. This will then be sent to the microgrid so that it can redirect power from the solar panel farm, or activate the backup diesel generators in order to meet the load requirements at any given time of operation.

2.2.6: Microprocessor

This will be the main component of the battery management system. The responsibility of the microprocessor is to read the information about the battery bank, and translate this information so that the data can be transmitted to the microgrid controller. The microprocessor will be responsible for making sure the battery bank is not being overcharged or undercharged by power generated from the solar panels. The microprocessor will also give an indication when the charge of the battery bank becomes depleted.

2.3 Risk Analysis

The microprocessor's ability to manage the power drawn from the battery storage system will be the most significant factor of success. In the event that the batteries are undercharged, this will lead to the water pumping plant being left without power. No power would severely harm the water supply for the people of Guayabota that depend on the plant for clean water. If the batteries were to be overcharged that would cause the microgrid to operate inefficiently. In extreme circumstances, it could lead to the batteries exploding. The majority of rural cities in Puerto Rico have struggled to maintain their power grid infrastructure, so it will be key to utilizing the energy storage system in tandem with the solar farm setup in the city of Guayabota. Without the microcontroller to control how the batteries are being used, the city will continue to struggle having consistent power performance.

3 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. Another safety concern that must be taken into account is that the end user of this product will be someone who receives minimal training to run and maintain the microgrid after the initial setup. This means that we must provide clear instructions on how to operate the microgrid, and also place safety measures to block any extreme hazards that should not be approached during operation.

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 as well. 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.

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] United States Geological Survey, "Groundwater levels for Puerto Rico," *National Water Information System: Web Interface*, April 3, 2020. Available:

https://nwis.waterdata.usgs.gov/pr/nwis/gwlevels/?site_no=180548065513700&agency_cd=USGS& [Accessed: 3- Apr- 2020].

[6] S. Blount, “Home Water Use in the United States,” National Environmental Education Foundation, 2020. Available: https://www.neefusa.org/weather-and-climate/weather/home-water-use-united-states#Puerto%20Rico [Accessed: 3- Apr- 2020].

[7] B. Peacock, “Energy and Cost Required to Lift or Pressurize Water,” University of California Tulare County, Pub. IG6-96. Available: http://cetulare.ucanr.edu/files/82040.pdf [Accessed 3- Apr- 2020].