Design Review 1:

Microgrid Team

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EE Senior Design/EE 41440

4 March 2021

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1 Introduction

In this design review, we will delve deeper into our microgrid system. We will go through each of the subsystems shown in Figure 1, explaining which parts we intend to use and how they are connected, as well as give descriptions of important components and their functions. Furthermore, we will outline the costs of each of the components we intend to purchase, proving that we will remain under budget for this project. Finally, we will address potential problems we foresee and what we can do to solve them.

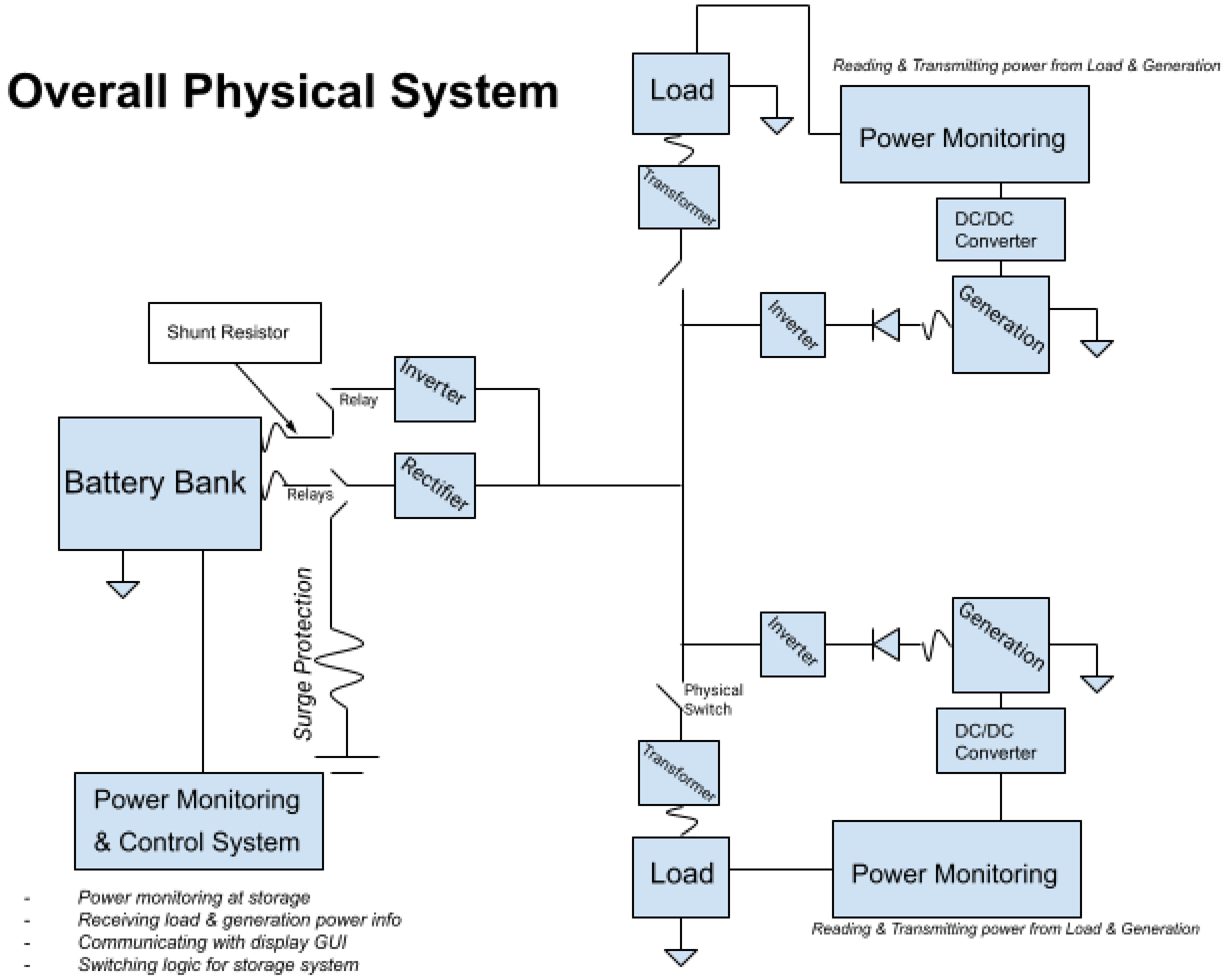


Figure 1. Overall Physical System Block Diagram

2 Generation Subsystem

Block Diagram

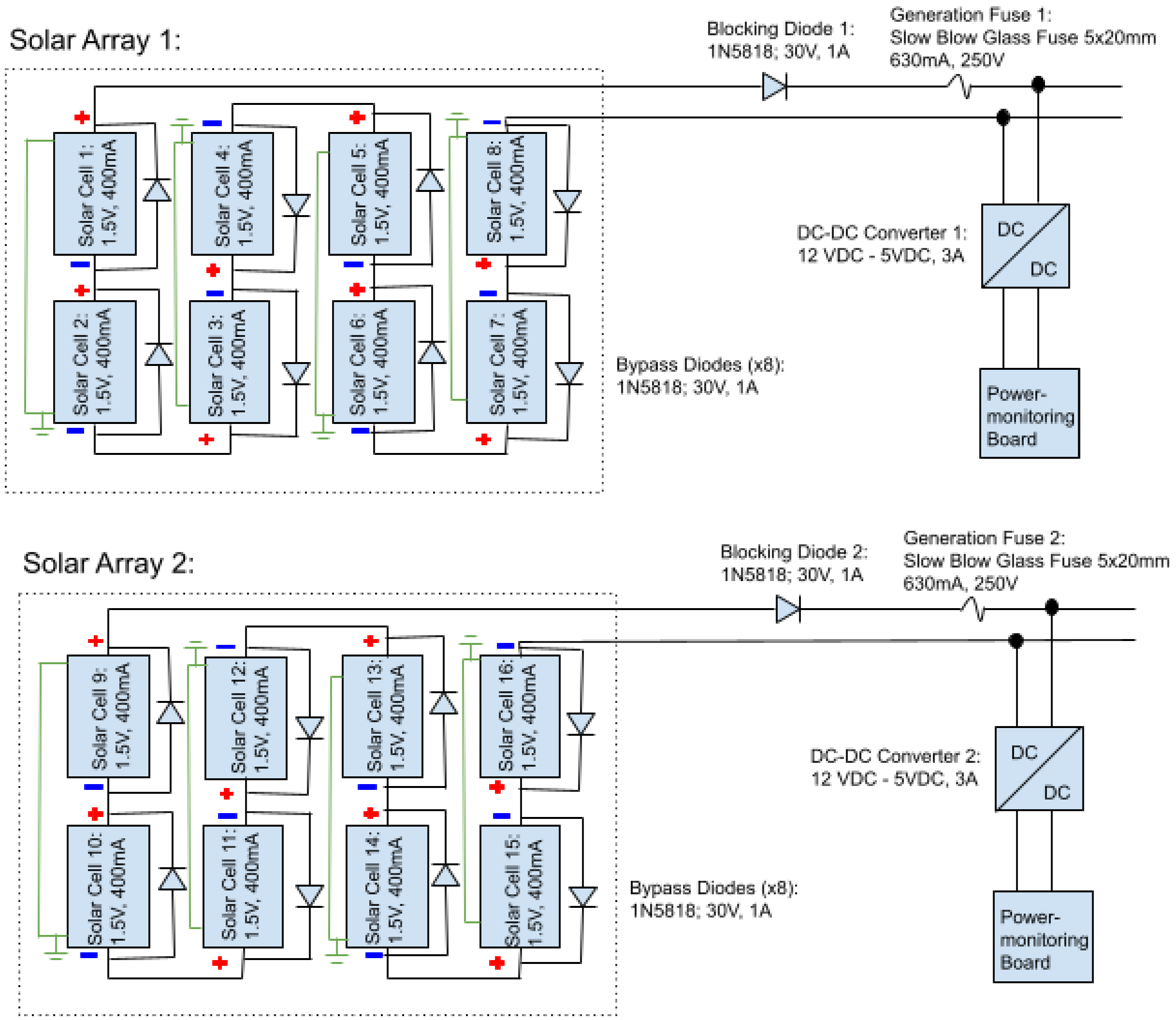


Figure 2. Generation Subsystem Block Diagram

Description and Function of Major Components

The major components of this subsystem include the solar panels (which are made up of the solar cells and the bypass diodes), the fuses, the blocking diodes, and the DC-DC converters.

Solar Cells: The solar cells take energy from the sun and convert it into electric energy. They will be the source of power for everything in the microgrid.

Bypass Diodes: The bypass diodes allow current to flow even when one of the solar cells is broken or shaded. They will allow the solar panels to produce more power in these conditions than if the bypass diodes were not present.

Fuses: The wires of the fuses will melt if the current is higher than they are rated. This breaks the circuit when the current is too high, which protects the microgrid's components.

Blocking Diodes: The blocking diodes block current from flowing from the batteries into the solar panels when the voltage at the solar panels is less than that of the batteries (for example, in the middle of the night when the panels are not generating any power). This protects the solar panels from becoming a motor, which would damage them.

DC-DC Converters: the DC-DC converters step down the voltage from 12V to 5V. This provides power to the power monitoring boards from the power generated by the solar panels.

3 Distribution Subsystem

Block Diagram

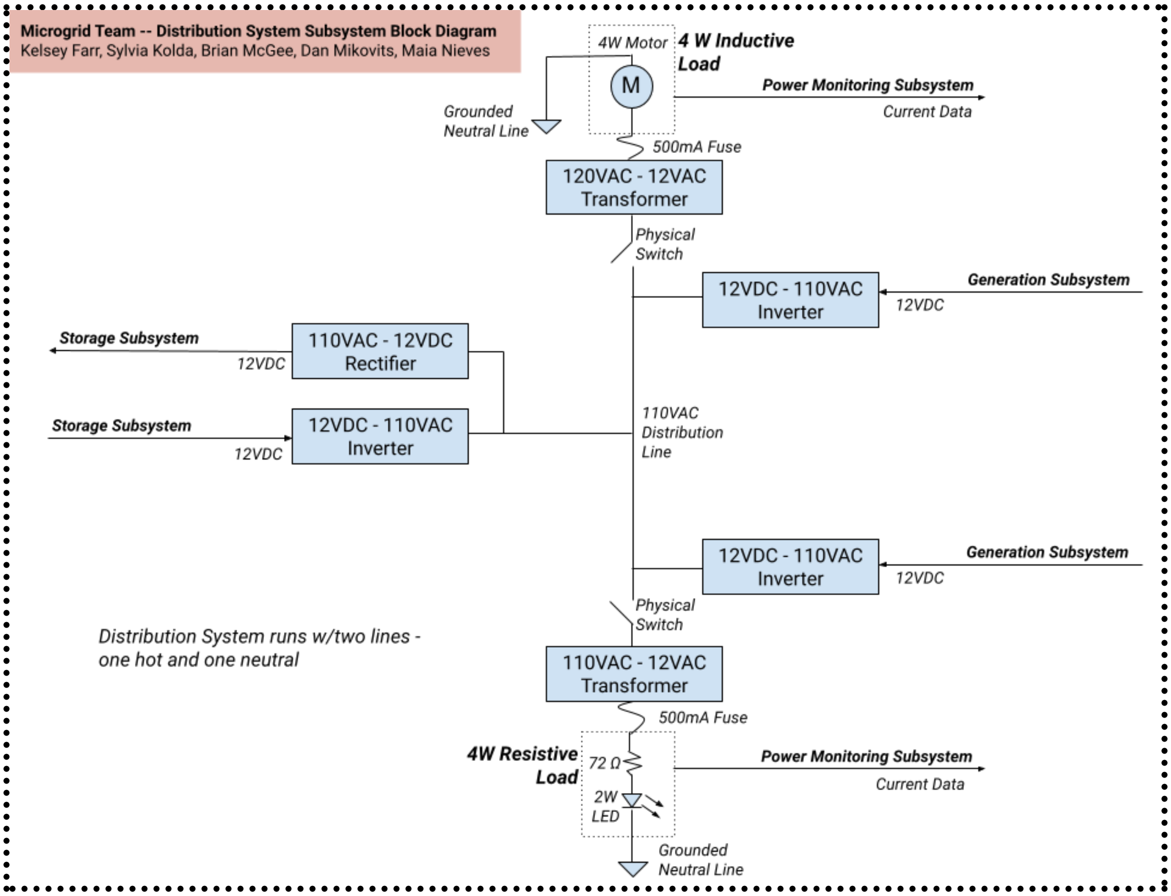


Figure 3. Distribution Subsystem Block Diagram

Description and Function of Major Components

System Summary

The distribution system models the transmission lines of a neighborhood and two loads, corresponding to two different building power demands. The system inverts 12VDC from the battery storage or one of the two generation modules up to 110VAC, which is then delivered to the loads. If the loads are disconnected or not consuming all of the generated power, it will be directed to the rectifier in order to charge the battery system. Both loads are modelled to consume 4W of real power, with the resistive load consisting of an LED and a resistor, whereas the inductive load consists of a 4W AC motor. The motor will most likely be loaded in order to consume real power and demonstrate that power is being delivered. The LED lighting up on the resistive load will serve the same demonstration role for the resistive load. Only one line is shown on the subsystem diagram, but in practice both a hot and a neutral line will be run through the entire system. The neutral line will be connected to earth ground at each of the loads.

Parts & Function

Wiring & Connectors: 12AWG, home-standard electrical line will be used for minimal line loss in the high-voltage portion of our distribution system. We will be using a breadboard standard 22AWG line with bare-wire connections for the lower voltage side of the system. Currently, our plan is to use crimp connectors for wiring connections (see questions section for further discussion).

Fuses: Both the inductive and resistive loads will have 630mA fuses, to protect them from currents greater than the expected ~400mA they will operate at.

Resistive Load: The resistive load's LED will be a two-pin, 20W halogen replacement, and a 72 Ω resistor will be in series with the LED for the load to consume 4W toal.

Inductive Load: The 4W AC motor will be loaded, possibly with a fan blade, to reach 4W of real power consumption. Additionally, this load introduces the possibility for PF Correction with the inclusion of a capacitor (see questions section for further discussion).

Switches: Physical switches will be included at each load to visually toggle the loads on and off. Internal resistance of the currently selected part is not given, so alternate options may be explored (see questions section for further discussion).

Inverters: Rated at 150W, the selected inverter will be included at each generation module and the storage system to invert the 12VDC up to the 110VAC it will be distributed at, for a total of three inverters.

Transformers: Rated at 25W, the selected transformers will step down the distribution voltage from 110VAC to approximately 12VAC at each load. Since 110VAC, not 120VAC, will be input into each transformer, they will be tested to determine exact turns ratio and output voltage. *Rectifier*: One rectifier will be included to correct the distribution voltage to the 12VDC required to charge the battery storage system.

4 Battery Storage Subsystem

Block Diagram

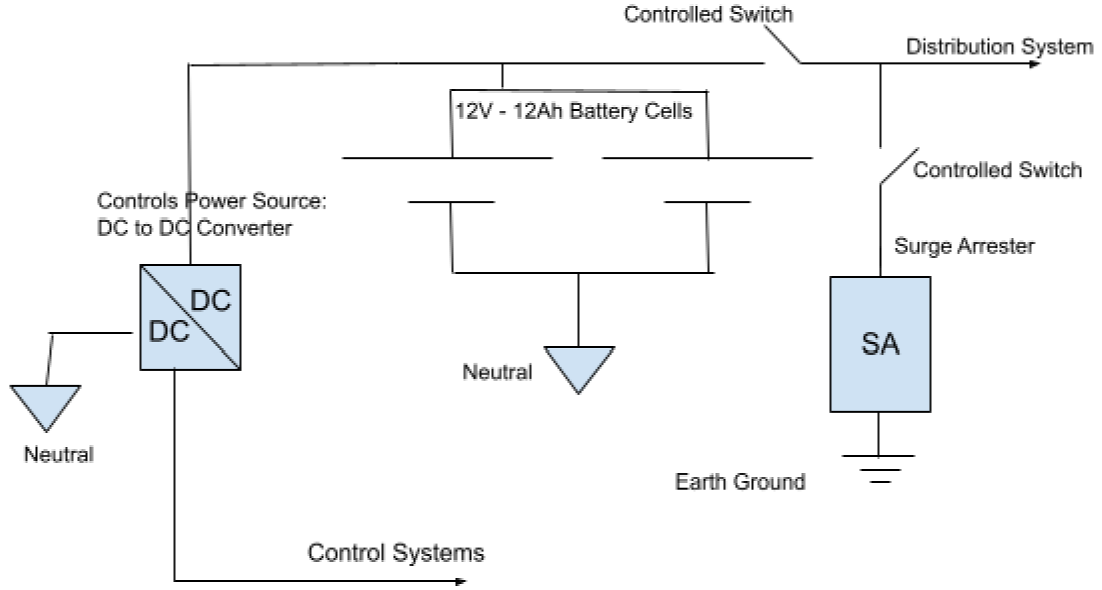


Figure 4. Battery Storage Subsystem Block Diagram

Description and Function of Major Components

This system contains the energy storage portion of the microgrid. It both saves excess energy produced by the solar generation and provides needed energy to the loads when solar energy cannot. The main parts of this system are the battery array, DC to DC converter, controlled switch, surge arrester, neutral line, and the main power line.

Battery Array: The array contains two 12V, 12Ah rechargeable lead-acid batteries in parallel. Based on our load profiling, these batteries would be able to hold up to 4 days worth of power without charge.

DC to DC Converter: This converter powers the control system as it steps 12V down to 5V

Controlled Switch: The two switches are coordinated in such a way that, unlike the diagram depicts, one will be open while the other is closed. The line to the battery is closed in all situations except when the current charging the batteries is of a higher magnitude than the batteries can handle. In this situation, the battery is cut out and the surge arrester is cut in to ground the excess current.

Neutral & Power Lines: Our distribution is a two wire system and includes the main power and neutral lines that connect to the storage as shown

5 Control System Subsystem

Block Diagram

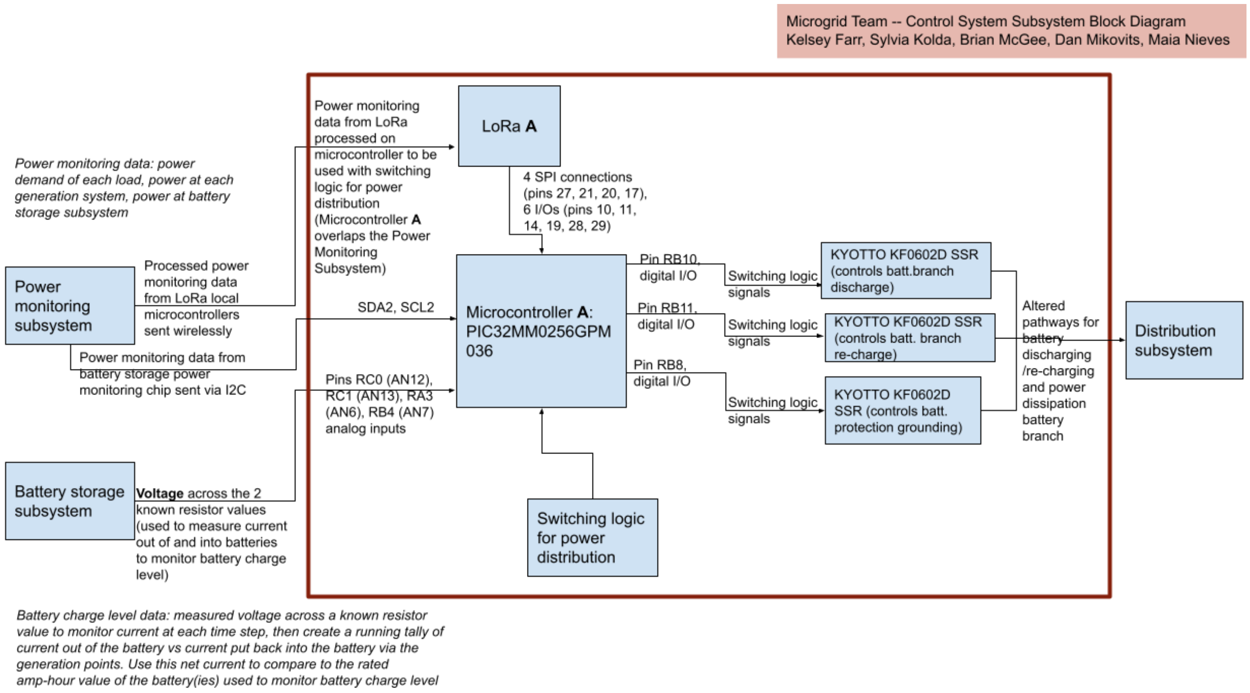


Figure 5. Control System Subsystem Block Diagram

Description and Function of Major Components

System Summary

The Control System Subsystem performs logic operations using information from the power monitoring data and opens or closes each of the SSR switches depending on the power and loading conditions of the microgrid.

Parts & Function

The major components of this subsystem include the microcontroller, a LoRa module, and 3 solid state relays (SSRs).

Microcontroller **A** (PIC32MM0256GPM036): This microcontroller is responsible for receiving power monitoring data, both from the power monitoring chip (I2C) associated with the battery storage bank and wirelessly from the other two microcontroller/LoRa modules associated with each Load/Generation point. There is a LoRa module attached to this microcontroller for receiving data. This chip then uses this information and performs logic to send control signals to the SSRs. The microcontroller also samples voltage across known-value shunt resistors on both battery branches (power in and out) and performs a running tally logic of battery amp-hours in and out to indicate the charge level of the battery. This is the same microcontroller **A** used for a portion of the Power Monitoring Subsystem. The number and type of pins needed to perform all communication and other functions was carefully assessed, and the required functionality is possible with the microcontroller chosen. A pin mapping table with notes can be found in Table A1. These pin mappings are in addition to chip power and grounding.

LoRa module (**A**): The LoRa module (**A**) in the Control System Subsystem receives power monitoring data sent wirelessly from LoRa modules **B** and **C**, which are located adjacent to each load/generation site and are part of the Power Monitoring Subsystem. LoRa (**A**) is attached to the microcontroller (**A**) via SPI and 6 digital I/O pins, 3 of which are interrupt-capable, in addition to chip power and grounding.

Solid State Relays (KYOTTO KF0602D): Each SSR will be controlled by microcontroller **A** and will open or close parts of the distribution circuit to control battery storage discharge to the loads, battery storage charging from generation points, or power dissipation via a large resistor to ground in the case of a sudden power surge that the battery bank would not be able to handle. The opening and closing of the SSR switches depends on power monitoring data giving power demand of the loads and power generation of the generation subsystem, as well as battery storage charge level. Each SSR is connected to microcontroller **A** on the input side, to ground and an output pin that is set high when the SSR is to close the switch and low when the SSR is to open the switch, and wired to the distribution circuit such that it acts as a switch controlled by the microcontroller.

Outline for Control System Switching Logic

- Case 1: No generation is occurring (night time) and the battery is sufficiently charged to meet power demand
    - Battery alone supplying power to the loads
        - *Battery outflow switch CLOSED, battery inflow switch OPEN*
- Case 2: Generation is able to supply as much OR more power than the load(s) is(are) demanding
    - Extra power goes to charging battery
        - Generation ON and power flowing to loads AND battery
        - *Battery outflow switch OPEN, battery inflow switch CLOSED*
- Case 3: Generation alone is NOT able to meet the demand of the load, battery is sufficiently charged
    - Generation power supply is supplemented with power from the battery
        - Battery AND generation
        - *Battery outflow switch CLOSED, battery inflow switch OPEN*
- Case 4: Generation alone is NOT able to meet the demand of the load, battery is INsufficiently charged
    - Crisis mode → what do we do in this case?
        - *Battery outflow switch CLOSED, battery inflow switch OPEN*

6 Power Monitoring Subsystem

Block Diagram

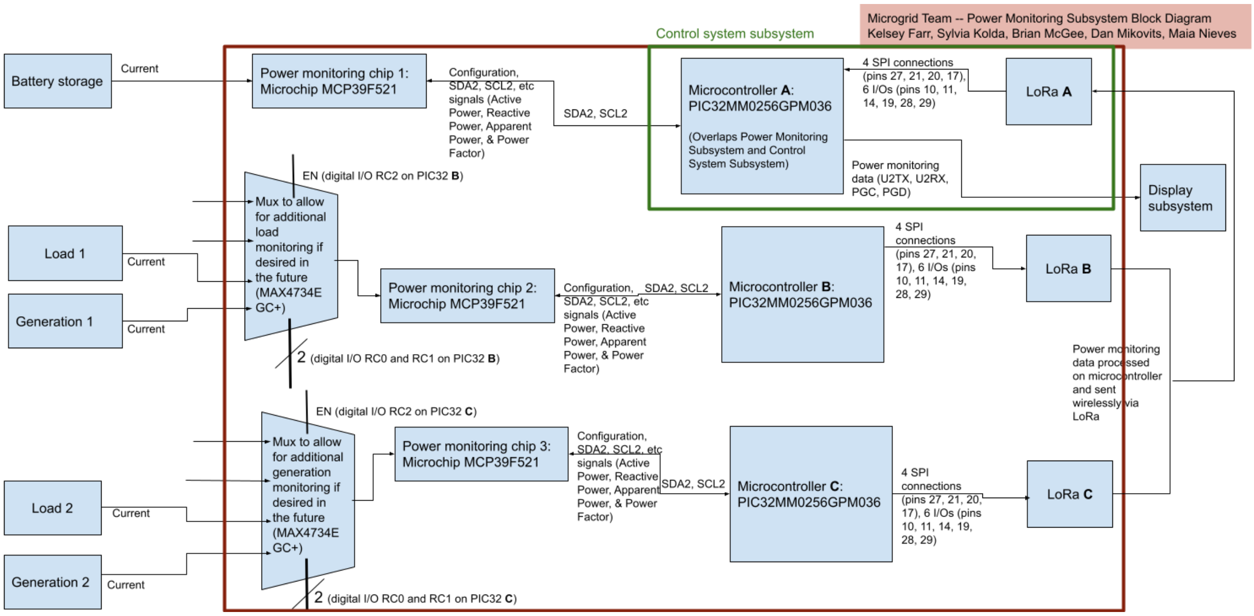


Figure 6. Power Monitoring Subsystem Block Diagram

Description and Function of Major Components

The major components of this subsystem include 3 power monitoring chips, microcontrollers **B** and **C**, LoRa modules **B** and **C**, and 2 multiplexers.

Power monitoring chip (**1**) (MCP39F521): Reads in current and assesses data from battery storage subsystem to send to microcontroller **A** (I2C) to be used in Control System logic

Power monitoring chip (**2**) (MCP39F521): Reads in current and assesses data from load/generation subsystem point 1 to send to microcontroller **B** (I2C) to be sent via LoRa **B** to microcontroller **A** and subsequently used in Control System logic

Power monitoring chip (**3**) (MCP39F521): Reads in current and assesses data from load/generation subsystem point 2 to send to microcontroller C (I2C) to be sent via LoRa **C** to microcontroller **A** and subsequently used in Control System logic

Microcontroller **B** (PIC32MM0256GPM036): Receives data from power monitoring chip (**2**) and transmits it to the main control system (Microcontroller **A**) via LoRa **B.**

Microcontroller **C** (PIC32MM0256GPM036): Receives data from power monitoring chip (**3**) and transmits it to the main control system (Microcontroller **A**) via LoRa **C.**

LoRa module (**B**): Enables transmission of data originating from Load 1 and Generation 1 over long distances.

LoRa module (**C**): Enables transmission of data originating from Load 2 and Generation 2 over long distances.

Multiplexers (MAX4734EGC+): In the case of each load/generation point, this data will first pass through this 4x1 multiplexor. The select lines and enables for each of the two 4x1 muxes will be controlled by digital I/O pins on the microcontroller (Pin RC2 will be used as the enable for the muxes, and pins RC0 and RC1 will be used as select lines for the generation mux and load mux.), and will determine whether the load or generation data is read in. Our initial design involved one mux selecting between loads and the other selecting between generations, but to more accurately model a real-life grid, the selections were rearranged since the load/generation pairs are together in terms of proximity.

7 Display Subsystem

Block Diagram

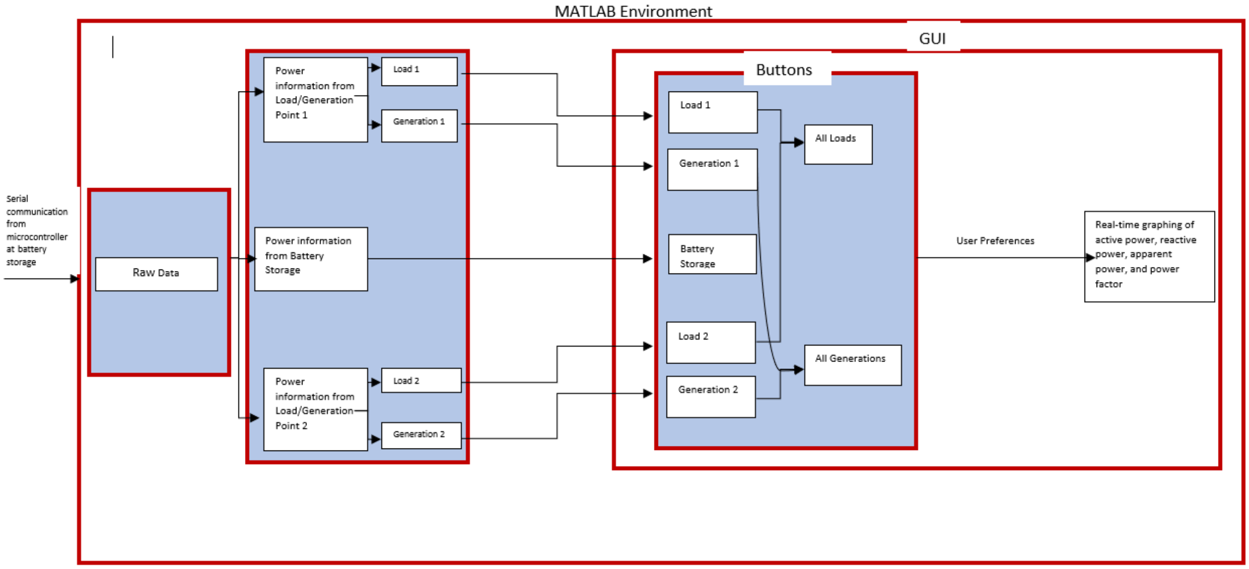


Figure 7. Display Subsystem Block Diagram

Description and Function of Major Components

There are four main categories of the display subsystem: Enabling serial communication, Data processing and formatting, real-time graphing and gui design. The steps on how to achieve this are described below.

<u>Outline for MATLAB Code for Serial Port Data Analysis</u>

1. Create a serial port object using the built in `serialport` function

    - The function has two input values, the specified communication port and the baud rate
    - For instance, creating an object would look like `s = serialport(‘COM1’, 9600);`
    - Dot notation is used to configure and display the property values i.e `s.BaudRate`, `s.Port` etc.
    - The serial port object and the instrument communication settings must be identical for reading data.

2. Configure other serial port communication settings.

    - `Parity`, `DataBits`, `StopBits` and `Terminator` will depend on the format that data will be transmitted from the PIC microcontroller.

- `Getpinstatus` reads the serial pin status and returns s struct giving information on whether the pin is clear to send or receive data.
- Since the display system will only be reading and not writing data, the `configureTerminator` function can be configured appropriately.

3. Read data from microcontroller

    - Depending on how the data is processed on the microcontroller, the functions `read` and `readline` will be used.
    - `Readline(s)` reads ASCII data until the first occurrence of the terminator from the serial port connection and returns data as a string without the terminator
    - `Read(s, count, datatype)` reads the number of values specified by count in the form specified by datatype from the serial port connection s. for all numerical datatype types, data is a row vector of double values. For the text type datatype uses 'char' or 'string'

4. Do necessary data manipulation

    - Depending on how the data is received, there may be necessary formatting to be done so that it is arranged in a readable, desirable way.
    - For instance, if we decide to calculate the percentage of current coming from generation vs storage, here is where the calculations and functions will be done.

5. Create callback functions to continuously read data for plotting.

    - The following are properties associated with callbacks:

Property or Function	**Purpose**
NumBytesAvailable	Number of bytes available to read
BytesAvailableFcn	Bytes available callback function
BytesAvailableFcnCount	Number of bytes of data to trigger callback
BytesAvailableFcnMode	Bytes available callback trigger mode
configureCallback	Set serial port callback function and trigger

    - The `IsContinuous` function is also important for continuously acquiring data. It takes a Boolean input and is necessary for a continuous stream of data until explicitly stopped. It is specified through dot notation of the serial object (`s.IsContinuous = True`).

6. After successfully acquiring the data comes the GUI creation and real-time data presentation.

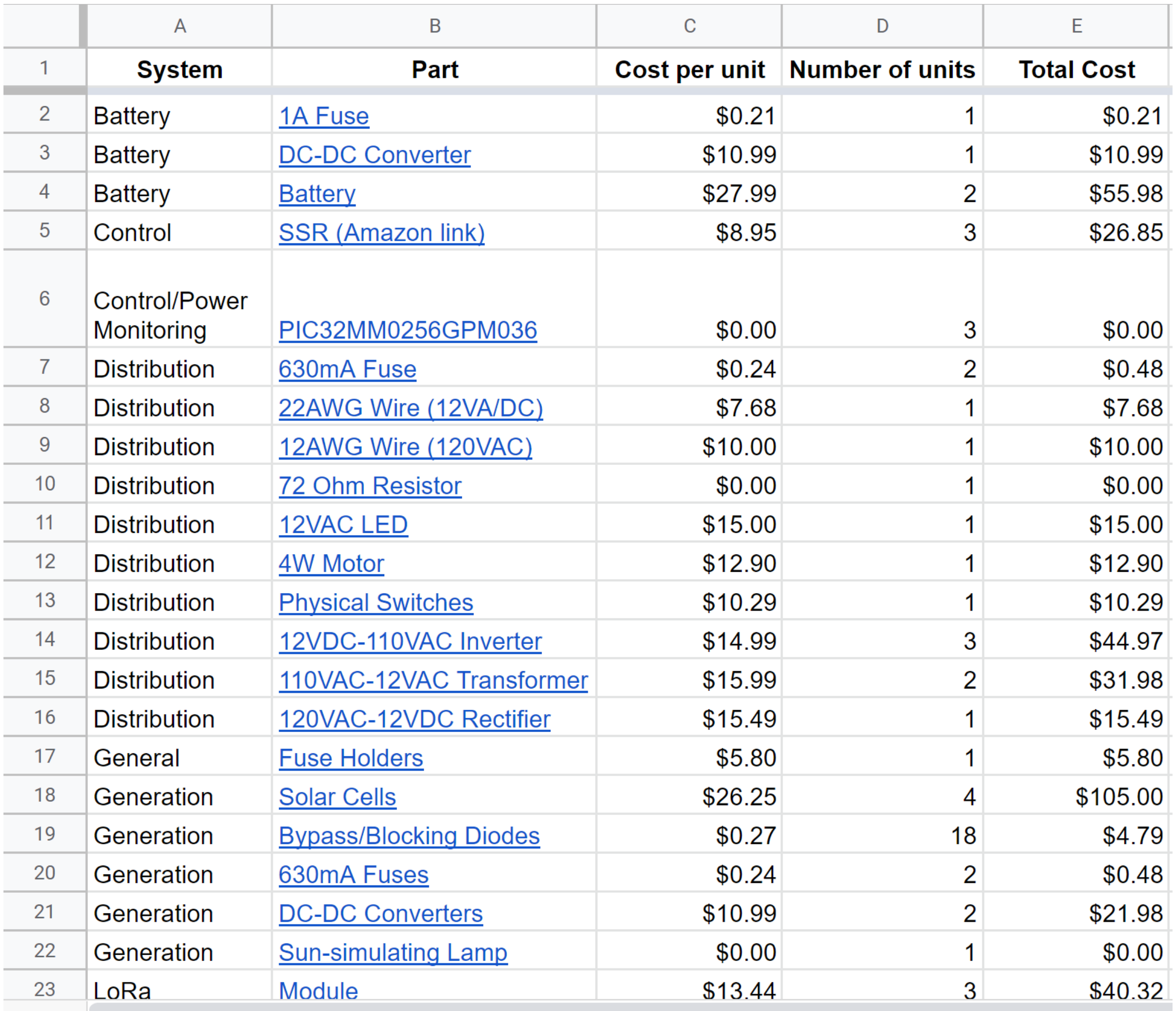
    - Using guide, and the callbacks, handles and events for different user actions, the information at each monitored system can be presented in real-time.

7. GUI Design

- There are a few possible options for how we plan to design the display system.
- As mentioned before, the display system will be receiving information from the generation subsystem, battery storage subsystem and load subsystem.
- This can be represented on the display system by having a pop-up menu giving the user the choice of which subsystem to view. On clicking the desired choice, the relevant data will be shown.
- A possible option would be to also display real-time graphing of the data, with the possibility of showing multiple plots on the same figure for energy references.

8 Finances

Figure 8 below shows the estimated costs of each of this project's needed components. The total estimated cost is $421.19, which is within our budget.



	A	B	C	D	E
1	**System**	**Part**	**Cost per unit**	**Number of units**	**Total Cost**
2	Battery	1A Fuse	$0.21	1	$0.21
3	Battery	DC-DC Converter	$10.99	1	$10.99
4	Battery	Battery	$27.99	2	$55.98
5	Control	SSR (Amazon link)	$8.95	3	$26.85
6	Control/Power Monitoring	PIC32MM0256GPM036	$0.00	3	$0.00
7	Distribution	630mA Fuse	$0.24	2	$0.48
8	Distribution	22AWG Wire (12VA/DC)	$7.68	1	$7.68
9	Distribution	12AWG Wire (120VAC)	$10.00	1	$10.00
10	Distribution	72 Ohm Resistor	$0.00	1	$0.00
11	Distribution	12VAC LED	$15.00	1	$15.00
12	Distribution	4W Motor	$12.90	1	$12.90
13	Distribution	Physical Switches	$10.29	1	$10.29
14	Distribution	12VDC-110VAC Inverter	$14.99	3	$44.97
15	Distribution	110VAC-12VAC Transformer	$15.99	2	$31.98
16	Distribution	120VAC-12VDC Rectifier	$15.49	1	$15.49
17	General	Fuse Holders	$5.80	1	$5.80
18	Generation	Solar Cells	$26.25	4	$105.00
19	Generation	Bypass/Blocking Diodes	$0.27	18	$4.79
20	Generation	630mA Fuses	$0.24	2	$0.48
21	Generation	DC-DC Converters	$10.99	2	$21.98
22	Generation	Sun-simulating Lamp	$0.00	1	$0.00
23	LoRa	Module	$13.44	3	$40.32

Figure 8. Project's Components' Estimated Costs

9 Problems, Questions, and Action Plans

Distribution Subsystem

- The ramifications of adding a PF-correction capacitor to the inductive load still needs to be explored, including sizing the capacitor and determining how it would be introduced into the circuit.
- The team has little to no experience completing the physical wiring for a system like this, so a way to practice connecting wires will be devised and practiced before attempting to wire up the actual system.
- The internal resistance of the physical switches is currently undetermined, so they will have to be tested once the part is ordered or alternate parts will have to be explored to make sure the switches are not consuming a non-negligible amount of the system's power.

10 Conclusions

After looking closely into each of the subsystems of our project, we have a better understanding of how our microgrid will fit together. We understand the specific components that we will need to purchase to carry out this project as well as how much they each cost. Although we will inevitably have some problems in the future, we have anticipated them as much as possible and have planned accordingly. Having these new insights into our project will allow us to successfully move on to constructing our microgrid.

11 Appendix

Table A1. Pin Mapping for Microcontroller **A** and Notes

Function	Communication Type	# of Pins Needed	**Configuration 1:** Pin #s on PIC32MM
Power Monitoring and Battery Charge Monitoring at Battery Storage	I2C, analog sampling	**2** for I2C comm from Power Monitoring Chip + **4** (one sampling point on each end of 2 separate resistors) = 6 total	*SDA2*
			1
			SCL2
			2
			Analog IN
			3
			4
			8
			9
Receiving Load and	LoRa	**6 I/O and 4 for SPI =**	*Digital I/O*

Generation Power Information		**10 total**	10
			11
			14
			19
			28
			29
			SPI - SCLK3
			27
			SPI - MOSI3
			21
			SPI - MISO3
			17
			SPI - SLCT
			20
GUI Communication	Serial	**4 serial comm pins**	*PGC*
			36
			PGD
			35
			U2TX
			34
			U2RX
			33
Switching/SSR Control Signals	Digital output	**3 I/O**	*Digital I/O*
			18
			24
			25
Benefits of/notes on this configuration choice			Digital I/O pins open: 5, 7, 15, 16, 18
			Analog IN pins open: 7

General Notes	The PIC32MM has a 2.0V to 3.6V operating range, with typical operating voltage (I believe) of 3.3V.
	When measuring the analog voltage across the shunt resistors (for the analog sampling at the battery storage subsystem), we need to ensure that the measured voltage will be within an acceptable range so as to not damage the microchip
	SPI (SCLK3, MOSI3, MISO3, SPI SLCT) and serial (U2TX, U2RX, PGC, PGD) setup is consistent with the setup of last semester's microchip
	If we end up only using one shunt resistor (i.e. if the discharge and charging port for the

	battery is the same connection point), we only need 2 analog pins, and the additional two in use right now could be used as remappable pins, analog inputs, or OSC2/CLKO (pin 8) *if needed*