Final Report:

Microgrid Team

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1 Introduction

Problem

A fully sustainable energy microgrid relies on energy resources that are transient, not constant. This creates a disparity between when power is produced and when it is used. There is no issue when power is both generated and demanded; however, when power is not generated while it is demanded or is generated while it is not demanded, no energy is provided or energy is wasted. An adaptive intermediary system is necessary to mediate the use of energy in the system and respond as necessary to optimize power flow.

Proposed Solution

The intermediary system proposed is a smart energy monitoring and storage system that monitors the network of load and generation points, stores excess energy, and provides needed energy as demanded. This consists of a communal storage system, a control system, a monitoring system, and a display system. This also includes a model grid which demonstrates the solution via a generation system, distribution system, and variable power loads.

2 System Requirements

Project End Goals

Generation & Distribution: Generate & distribute power to each system using solar cells

Battery Storage: Store excess generated power and provide supplementary power when demanded

Control System: Charge, discharge, and disconnect the battery in response to system demand

Power Monitoring: Constantly track the power at the generations, loads, and battery storage

Display: Update and display the voltage, current, and power at the generations, loads, and battery storage

Demonstrated Features

The system demonstrates correct switching in response to all possible load and generation combinations. This includes a moderate-power, low-power, and off setting for a variable load, and on and off setting for a high-power load. Each combination of these loads results in a unique case for the control system to react in both the situation where the solar panels are generating power (simulating day time), and not generating power (simulating night time). The control system determines whether to discharge, charge, or disconnect the battery based on these inputs, and sends all data to a dashboard to be displayed.

3 Project Overview and Description

System Overview

The system consists of six main subsystems. These include the generation, distribution, battery storage, power monitoring, control system, and display subsystems. The project goals are accomplished through the implementation of these subsystems to model a real-life microgrid with an adaptive power monitoring, storage, and switching system.

System Block Diagram

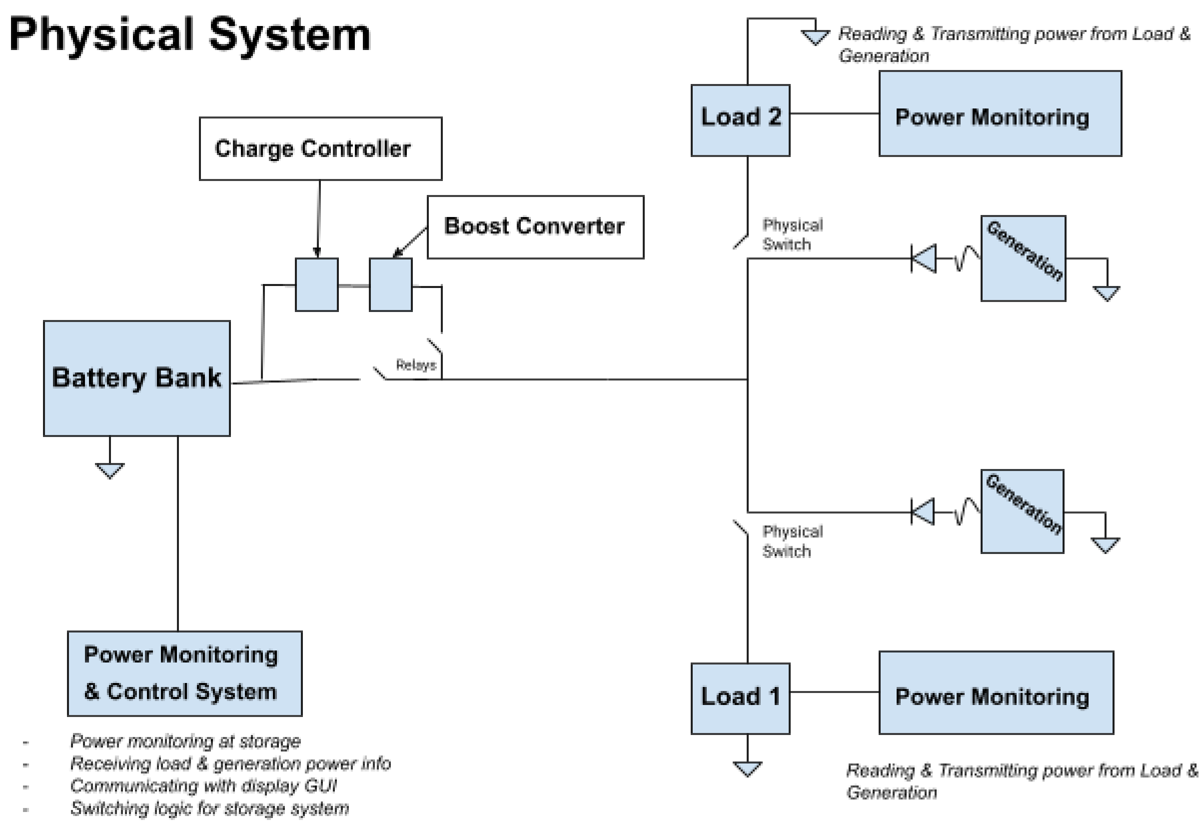

Figure 1. Full System Block Diagram

Description of Each Subsystem and Functionality

Generation

System Summary

The generation system consists of solar panels to generate power from the sun and provide it to the system, as well as diodes to optimize and fuses to protect the generation system. Additionally, a local storage is attached to the generation system in order to demonstrate the ability of the system to store excess energy in lab conditions.

Parts & Function

1.5V, 0.65W solar panels: The solar panels convert energy from the sun into electrical energy. Each generation has 8 panels connected in series in order to provide a max power of 5.2W to the system.

1N4004 diodes: Diodes are connected in parallel with each panel in order to act as bypass diodes. Bypass diodes allow the current to bypass a particular panel if it becomes shaded or broken and cannot maintain the same current as the rest of the panels. This ensures that one panel will not drastically decrease the power of the entire system.

630mA fuses: A fuse is connected in series with each of the generations in order to protect the panels from excess current, should some fault occur in our system.

Sun-simulating lamp: A full-spectrum lamp is used to simulate the sun in our system, since the weather can be unreliable. This ensures that both daytime and nighttime conditions can be demonstrated.

Local Storage System: In order to demonstrate the ability to save excess energy in the storage system, an analogous local storage system was implemented. This consists of 8 series connected 1.5 AA batteries in parallel with both the generation systems and storage systems. This system was implemented to produce enough energy to charge the battery as the solar panels could not produce their max power in a lab setting (when system was tested outside, the panels produced enough power to charge the battery on their own)

Distribution

System Summary

The DC distribution system was connected using 22 AWG wire and a power supply and multimeter were used to verify that power was being transferred between the variable load, both generation inputs, and the battery input/output. The power monitoring voltage divider was successfully implemented across the variable load, high power load, both generations, and the battery storage, allowing voltage data to be read into the two power monitoring boards and control board.

Parts & Function

22 AWG wire: Spools of red and black 22 AWG electrical wire were used to connect the loads, generations, and battery storage together and allow power transfer throughout the system.

T-Tap Connectors: These connectors were used to splice the electrical wire and allow each aspect of the system to be integrated into the complete network.

12V-5V Buck Converter: To power the control system board, a DC-DC converter was attached to the output of the battery, allowing for the system to provide power for the control board. The converter takes bare wire at the input and outputs through a mini USB port into the board's power supply.

Energy Storage

System Summary

The energy storage system consists of battery storage and a charging system which enable the system to work with the control system to store excess power and provide demanded power. The charging system consists of a boost converter and a charge controller. The boost converter converts the DC voltage of the system from 12V to 14V, the rated charging voltage, and passes the stepped up DC voltage into the charge controller which moderates the current into the battery.

Parts & Function

SP-1250 12V 5Ahr Battery: Functions as the energy storage for the system. The battery is connected to two lines. One line provides energy to the system as demanded. The other allows the excess energy to pass through the charging system and into the battery.

Boost Converter: Boosts the voltage up to 24V. Has been calibrated to step up a voltage of 12V to 14V to charge the battery.

5A 6V/12V Lead Acid Charge Controller: Moderates the current into the battery to safely charge the battery

Power Monitoring

System Summary

Voltage dividers were designed and set up at each generation point, at the battery, and at the variable load to scale down the microcontroller input to 1/100 of the actual voltage while providing the recommended input impedance to the microcontroller. The values sampled are the voltage at the node above a shunt resistor and the node which is both the base of the shunt resistor and the top of the block being sampled. These samples provided the current through the block as well as the voltage across the block. Using analog-in pins, values are read-in at the load, generation, and battery storage blocks using analog input scanning. These values are then converted and sent via UART transmit to the control board for processing. Each UART data package includes an ASCII start character unique to the data being sent (i.e. a '+' indicates the following messages will be the voltages across the battery storage system) and allows the control board to decode the voltage data.

The power monitoring board across the high-power load and generation 2 simultaneously reads in 4 analog inputs (two for load and two for generation), and sends the data via UART to the control board. The board across the variable load and generation 1 functions similarly, but includes an extra analog pin to monitor the voltage across the generation's blocking diode. This extra information allows the control system to determine whether the panels are detecting daytime or nighttime-level voltages. Two analog inputs are included on the control board to monitor the voltage across the battery storage system.

Parts & Function

Voltage Dividers: Step down the voltage at the sampled nodes to the level of the microcontroller. Consists of a sum resistors that add to 250 kΩ and a sum of resistors that add to 2.5 kohms. The voltage sample is read from the top of the 2.5 kohm sum of resistors.

Power Monitoring Board: The boards contain a PIC32MM0256GPM036 microcontroller which uses 4 analog voltage pins to read in power data from the load and generation points . The boards then send the raw data to the main control board via UART transmit.

Main Control Board: The main control board uses 2 analog voltage pins to monitor the storage system power characteristics and receives and processes the power data from the load and generation points. (see control system for process and control functionality of this board)

Control System

System Summary

The Control System Subsystem performs logic operations using information from power monitoring data. This power monitoring data is both read in locally via analog-in for the battery storage subsystem and received via UART for all load and generation points. The Control Microcontroller determines which point in the system the power monitoring data is coming from by interpreting the unique ASCII start characters sent by the Power Monitoring microcontroller boards. The Control System then sets digital output pins LOW or HIGH to, respectively, open or close each of the solid state relay (SSR) switches, depending on the loading conditions of the microgrid.

Parts & Function

The major components of this subsystem include the microcontroller and 2 SSRs.

Control Microcontroller (PIC32MM0256GPM036): This microcontroller is responsible for receiving power monitoring data, both from the analog-in pins associated with the battery storage subsystem and via serial communication from the other two Power Monitoring microcontrollers associated with each Load/Generation point. The Control Microcontroller sends the voltage, current, and power information to the Display subsystem, then uses the voltage readings at the generation points to perform logic to send control signals to the SSRs.

Solid State Relays (KYOTTO KF0602D): Each SSR is controlled by the Control Microcontroller 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 complete disconnect of the battery from the distribution lines. The opening and closing of the SSR switches depends on the voltage across the generation points and the blocking diode at one generation point. Each SSR input is connected to a digital output pin on the Control Microcontroller that is set high when the SSR should close and low when the SSR should open. Each SSR output is wired to the distribution circuit such that it acts as a switch controlled by the microcontroller to either charge the battery, discharge the battery, or disconnect the battery from the circuit.

Display

System Summary

The display system receives all the power monitoring data from the Control Subsystem via UART to continuously present the updated values on a MATLAB GUI. The data being read in consists of two voltages from all points of interest, including both load and generation points and the battery. One voltage is that of the specific subsystem point, while the other is from the other side of a shunt resistor of known resistance, so that the current and power values can be calculated. There are unique identifier characters before each of the Load 1, Generation 1, Load 2, Generation 2 and Battery Storage data, so that if/else statements can parse through the packages and separate them into their respective fields. Then, the data can be scaled and assigned to the GUI. The GUI has two buttons, connect and receive, that allow the values to be filled out in the table.

Parts & Function

It was decided to use MATLAB because it has all the capabilities for meeting our needs, including having the ability to read data from a COM port, process the data and continuously update it for displaying purposes, all within a GUI function.

The MATLAB code involves functions to establish a serial connection to the UART pins of the microcontroller, if/else statements to separate the data packages into their specific fields, and then functions to scale the data and calculate the power and current values from the voltages that are read in. The data processing functions are in a constant while loop, so that the GUI handles are updated every 0.2 seconds.

Final Board Design

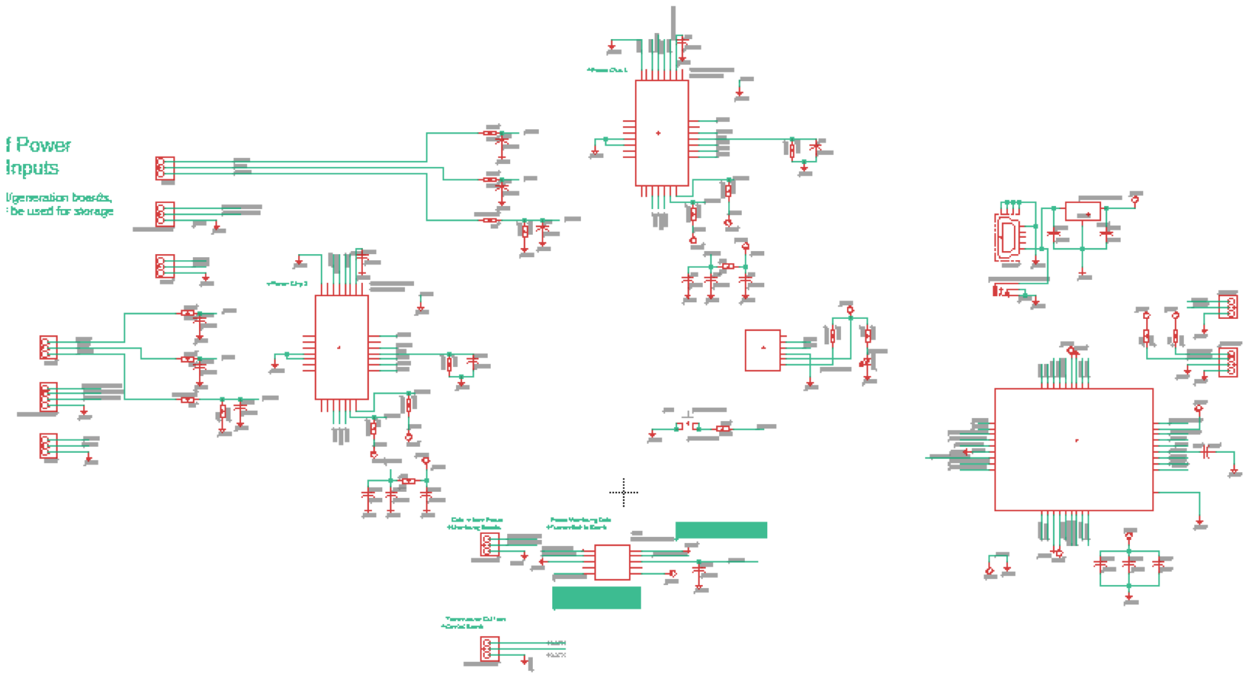

Figure 2. Board Schematic

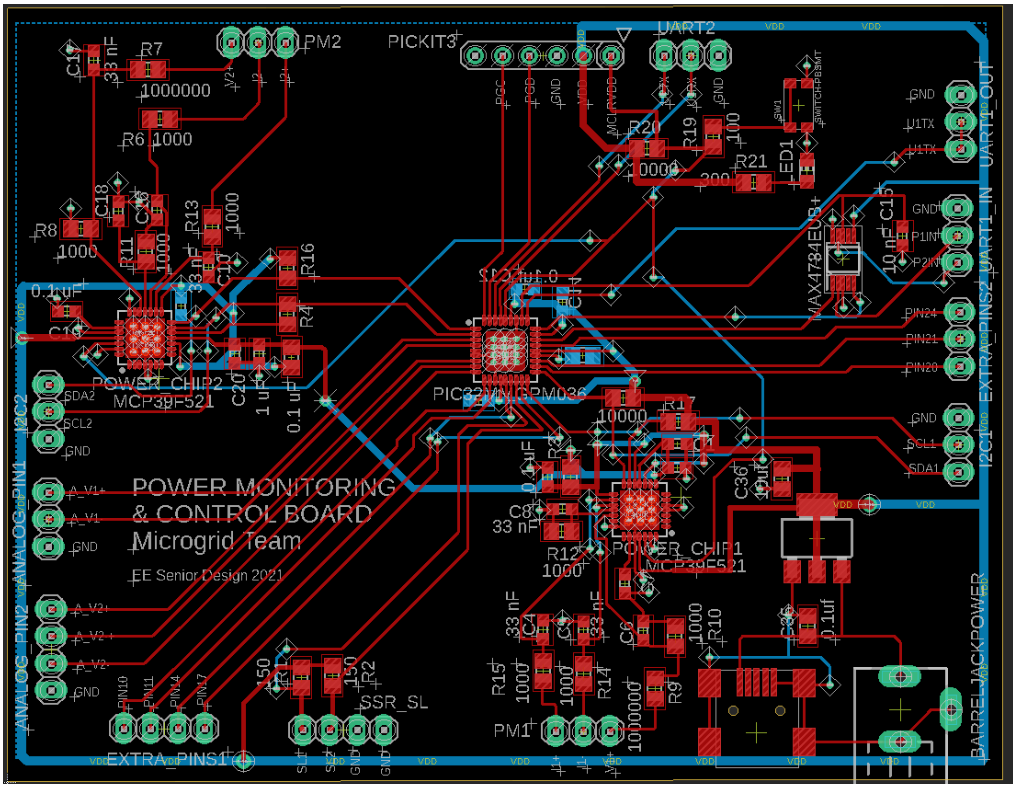

Figure 3. Routed Eagle Board

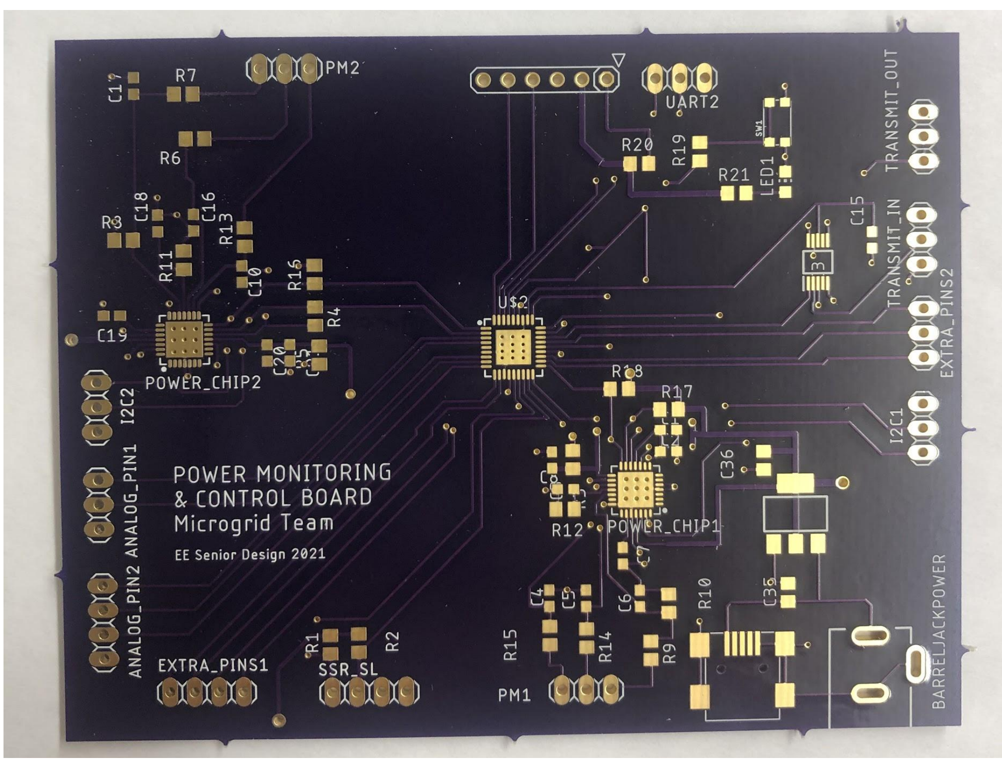

Figure 4. Printed PCB

Bill of Materials

This project had a budget of $500. The total cost of the project stayed under budget, only totaling $426.68. The breakdown for these costs can be seen in Figure 5.

System	Part	Cost per unit	Number of units Needed for Total Project	Shipping and Tax	Total Cost	Notes	
Battery	1A Fuse	$0.21	3		$0.63		
Battery	Charge Controller	$13.99	1	$0.98	$14.97		
Battery	Boost Converter	$8.39	1	$0.59	$8.98		
Battery, Distribution	I-Type Battery Clip Holders	$5.36	1	$0.38	$5.74	Pack of 5	
Control	SSR	$8.95	3	$1.89	$28.74		
Control	10W 10ohm resistors for SSR output	$6.99	1	$0.49	$7.48	Pack of 10	
Control	Buck Converter	$10.99	1	$0.77	$11.76		
Distribution	630mA Fuse	$0.24	5		$1.20		
Distribution	12AWG Wire	$9.99	1		$9.99		
Distribution	12VDC-110VAC Inverter	$17.95	1		$17.95	Not being used, but unreturnable	
Distribution	110VAC-12VAC Transformer	$15.99	1		$15.99	Not being used, but unreturnable	
Distribution	120VAC-12VDC Rectifier	$15.48	1		$15.48	Not being used, but unreturnable	
Distribution	Buck Converter	$10.99	1		$10.99	Not being used, but unreturnable	
General	Wire T-Taps	$10.99	1	$7.19	$18.18		
General	2-Prong Outlets	$2.98	1		$2.98	Not being used, but unreturnable	
General	2-Prong Plugs	$6.80	1		$6.80	Not being used, but unreturnable	
General	Fuse Holders	$4.49	1		$4.49	Pack of 5	
General	PCB	$55.00	1		$55.00		
General	0.1ohm 2W resistors	$6.08	1	$0.43	$6.51	Pack of 15	
General	USB Hub	$6.98	1	$0.49	$7.47		
Generation	Solar Cells	$14.99	4	$4.20	$64.16	Pack of 4	
Generation	630mA Fuses	$0.24	4		$0.96		
LoRa	Module	$13.44	3		$40.32	Not being used, but unreturnable	
LoRa	915MHz Antenna	$4.64	3		$13.92	Not being used, but unreturnable	
LoRa	PCB antenna edge mount (5pc)	$6.99	1		$6.99	Not being used, but unreturnable	
LoRa	Protyping LoRa adapter board	$3.00	2	$3.15	$9.15	Not being used, but unreturnable	
Power Monitoring	Multiplexers (MCT4734EUB+)	$2.71	6	$7.99	$24.25		
Power Monitoring (prototyping)	PCB adapter board	$6.00	1	$9.60	$15.60		

Figure 5. Bill of Materials for Entire Project

4 System Integration

Model and Function

Together, the system allows for responsive switching and power monitoring across the entire network. The power monitoring boards simulate embedded systems reading in data at different buildings on a local distribution network, and the generations represent solar panels present in a community. The variable load models a home that demands more power during peak-hours, but less power off-peak. The 1.5W DC fan represents a business building that consumes more power at a more constant rate. The distribution system is the network of power lines throughout the neighborhood, and the two power monitoring boards transmit their data back to a central hub: the control board. The battery storage system and control board are modeled as a community center or other central point in the neighborhood where a power monitoring dashboard is present to show the consumption of each load on the network and react to an increase or decrease in power demand by switching the battery in or out of the system. This switching is based on the voltages read in across each system on the network.

The model includes a “local storage system” which serves as a means of proving the ability of the system to safely charge the battery within a laboratory setting. This is physically just another battery pack that can be switched into the system to provide excess energy which is captured by the battery. It is analogous to a local storage system seen in solar home implementations which serves as an energy storage system for that singular home. The system implemented does not serve this purpose but rather serves the purpose of providing excess energy when the solar panels are not producing at their rated values; when the system is implemented indoors. When the system was implemented outdoors, in direct sunlight, the panels produced their rated power and were able to drive both loads and charge the battery with no additional energy required from the analogous local storage system.

Switching Data

Ideally, the decision to open/close the SSRs and hence charge, discharge, or disconnect the battery storage subsystem from the larger system would be based on the *power data of the loads*. However, the behavior of the SSRs is actually based on voltage readings at the generation points and across a blocking diode at one of the generation points. Because the analog-in voltage readings of the microcontrollers have a high tolerance of fluctuation in reading accuracy, reading the voltages at two separate points (across a known-value shunt resistor) to calculate current proved to have limitations in accuracy and consistency of readings. A related problem that the group encountered was that at some times, both voltage readings (at either side of the shunt resistor) would be read in as identical due to inaccuracy of the analog-in readings. In this case, the group had to write an algorithm to adjust the voltage readings to be as accurate as possible so the current calculation across the resistor would not end up being zero. This introduced difficulties and inaccuracies in current and power readings. However, the group was able to obtain fairly stable and accurate single voltage measurements for the voltage readings across each generation/load/battery point in the system.

The voltage readings used as thresholds for switching the SSRs are based on if the battery is currently connected to the system and if it needs to be to meet system power demand. At night, the battery is always on, as there is no power coming from the solar cells at the generation points. During the day, the battery is only switched on if the 1.5W motor is switched into the system (with or without a combination of the moderate- and low-power load), as the solar cells provide enough power to the moderate- and low- power load without requiring supplemental power from the battery. The voltage readings at the generation points are used to make these determinations in the “day” cases (i.e. when the solar cells are supplying power to the system), and the voltage reading across the blocking diode is used to determine if it is “night” (i.e. whether or not the solar cells are supplying power to the system).

The limitations of accuracy of the analog-in voltage readings could be remedied in the future if a voltage follower op amp circuit is used to stabilize the voltage by providing higher input impedance. Also, the reference voltage scaling could be increased on the analog values to create a larger difference in the voltages read into the microcontroller.

5 Conclusions

This project successfully demonstrates a microgrid through implementation of multiple subsystems, namely the generation, distribution, battery storage, power monitoring, control system, and display subsystems.

While the project meets all of the requirements, there is still room for improvements in the future, as is always the case. Four such improvements have been identified for this project. The first improvement would be using the designated power chips on the PCB boards for power monitoring, as opposed to the analog pins which are currently being used. This would allow voltage readings to be less variable and consequently more accurate.

The second improvement would be to use wireless communication to communicate power data from the load and generation points to the main control board. This would remove the PCB's location restrictions that are currently present and also clean up the system a bit by removing some of its many wires.

Third, the breadboards on which the system currently resides could be switched to a through-hole, soldered set of boards. This would be a bit more neat and also help lessen the possibility of a connection coming loose from the breadboards as they are currently set up.

Finally, a much larger improvement to the system would be to implement an AC system with power factor correction. This is quite a task, as using AC for distribution instead of DC would introduce some problems with phase matching that are difficult to solve within the $500 budget. However, implementing this improvement would allow the system to more accurately represent a real-life microgrid.

Overall though, the project does an excellent job of demonstrating a real-life microgrid. It models the multiple subsystems of a real-life microgrid and accounts for multiple real-life scenarios, such as providing power in both the daytime and nighttime and adjusting for higher and lower power consumption by the homeowners. This project also displays valuable information from the system, which allows the homeowner to track the system and react accordingly. As evidenced by this, this project is a valuable tool for any community hoping to implement a microgrid and make it more energy-efficient.