Off-Grid Photovoltaic Generator

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Abstract

The Off-grid Solar Generator project is a semi-remote photovoltaic power system with real time energy monitoring and control. The system is built for outdoor use and has the capacity to power or charge most modern electronic devices for extended periods of time. The power is readily available for use in the form of a standard US outlet. Data is transmitted over bluetooth from the solar system to a web server where it is manipulated into user friendly visuals. The data is then accessible via web interface from anywhere with an internet connection. This data consists of solar energy production, battery voltage level, and instantaneous power drawn by each load connected to the system. Moreover, the load power outlets can be individually controlled via remote interaction with the webserver. Additional prioritization can be given to one power outlet in order to optimize the power distribution.

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1. Introduction

1.1 Purpose

The daily lives of the general public have an increased dependence in electrical devices. This dependence causes the world to have a higher demand for electricity which can be seen in Figure 1 [2]. With an increase in global power demand comes an increase in global carbon emissions as seen in Figure 2 [6]. This influx of carbon causes an increase in the Earth's temperature, better known as global warming. In order to shift some of the power generation away from fossil fuels, a different source of energy must be harnessed.

Some of these recent electrical dependences include home projects such as smart gardens, heated/cooled dog houses, etc. which are typically on homeowner's property but away from the electrical grid. Current solutions such as fossil fuel generators, or extension cords have certain drawbacks including carbon footprint, control, and safety. The off-grid photovoltaic generator offers the ideal solution to these semi-remote home projects by delivering plenty capacity for these low power use cases as well as most modern-day electronics.

An additional inspiration for this project is its ability to act as a "starter kit" for those people intrigued by solar energy but intimidated by the overwhelming cost. While the average US home solar system (5kW) can cost anywhere from $25,000-$35,000 [7], our smaller system costs only around $600. While our system does not provide nearly as much power as a home system, it still allows the user to monitor and experience the capabilities of solar energy. In turn, we hope that this would inspire people to invest in full home solar systems.

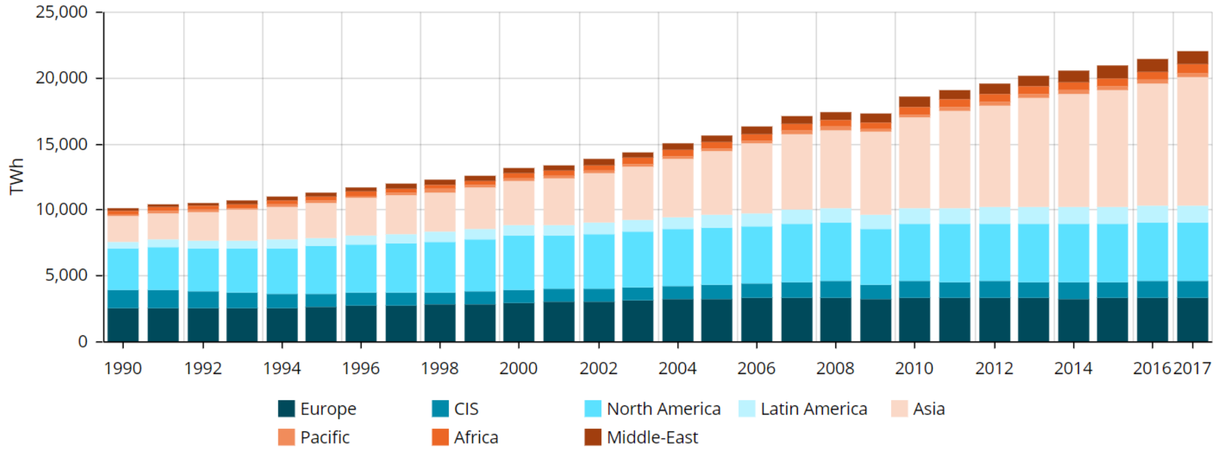

Figure 1. Global Power Demand 1990 - 2017

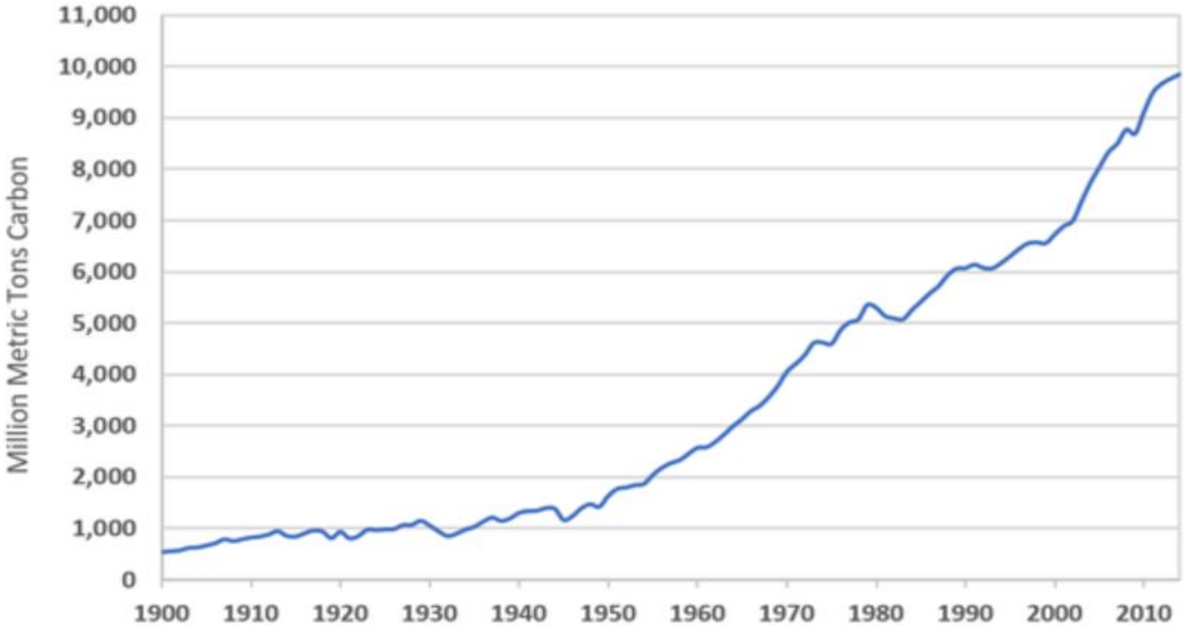

Figure 2. Global Carbon Emissions from Fossil Fuels 1900 - 2014

1.2 Functionality

In the initial design phase for this system, several high-level requirements were established to ensure the overall success of the project. These high-level requirements are as follows.

- The unit must provide a energy storage capacity of 250Wh on average per day and last 2 days without any additional charge from sunlight.
- The unit must transmit data depicting the solar energy production, charge of the battery and load power consumption 20 feet over Bluetooth to a web server where it will then be available to the user via internet connection.
- The user must be able to control the power being supplied to each outlet and add load preference in order to optimize the power being delivered.

In addition to these high-level requirements, we established a few more important functionalities to ensure the safe and successful operation of the system. These additional functionalities include semi-portability, rugged build for outdoor use, and self-standing, adjustable solar panels.

1.3 Subsystem Overview

As shown in Figure 3 below, this system consists of six main sections. The Solar System/Battery section will consist of the photovoltaic array connected to a battery through a charge controller. The power will be fed out of the battery through a DC to AC Inverter to the Relays/Outlets section. The Relay/Outlets section will consist of two solid state relays controlling two outlets based on output from the microprocessor to implement the control and power optimization.

The Monitoring Circuit section will contain all necessary circuits for monitoring the battery voltage, solar production, and the power drawn from each load. It will then step down the readings to low enough levels for the microprocessor to handle. The Microprocessor will perform all the necessary calculations to convert the readings into voltage and current values then use the Bluetooth module to send the data to a raspberry pi which will host the web server.

User input data from the web server will then be sent back to the microprocessor where it will be used to control the loads and optimize the power output. The Raspberry Pi and Web/UI sections will work together to act as a server storing and then displaying the measured values and take in the user input then transmit that to the microprocessor.

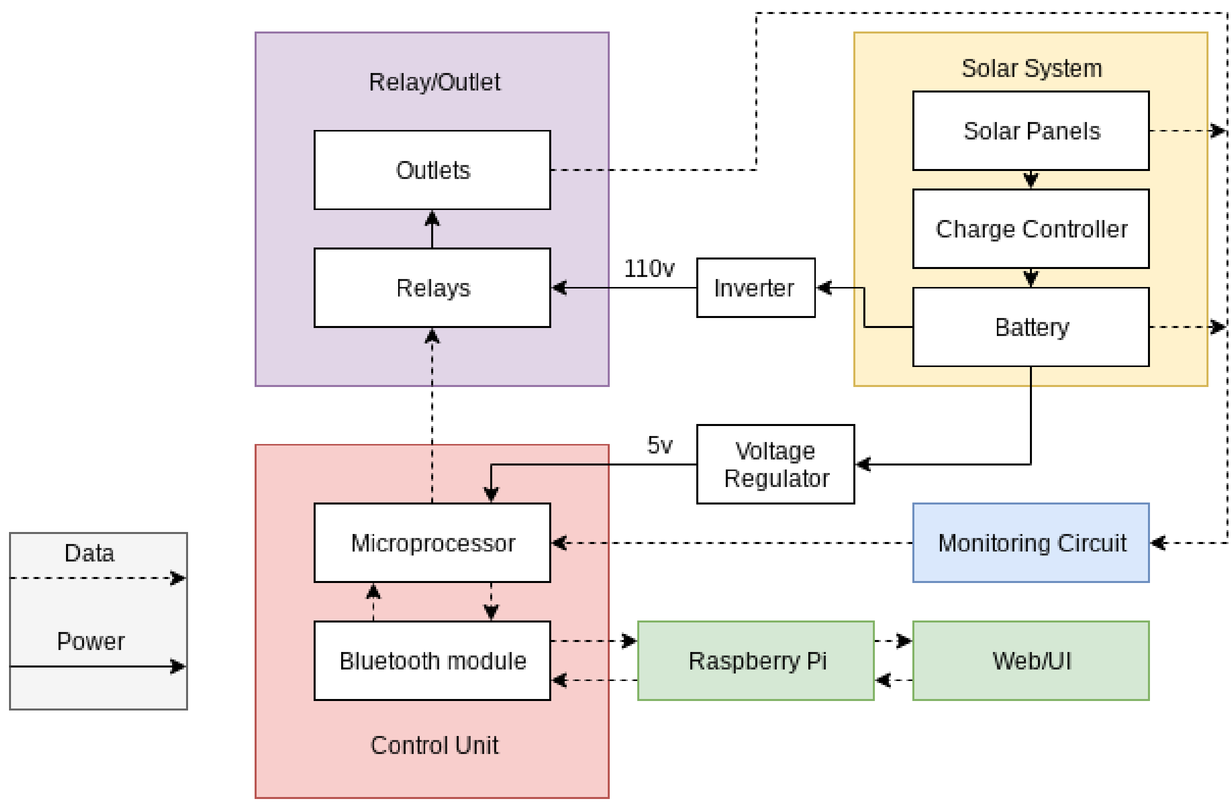

Figure 3: Off-Grid PV Generator Block Diagram

2. Design

2.1 Overview

This project consists of several different levels of design in order to function safely, efficiently, and reliably. The first of which was choosing/sizing the proper components to safely meet our energy goals. Designing, testing and perfecting the monitoring circuits was the next crucial component in order to provide accurate data to be used in the user interface. Ensuring smooth Bluetooth data transfer allows the gathering of data in a web server. Manipulating the data into readable graphs, charts and statistics allows the user to understand the current state of the power system and to make control decisions based on that understanding. Guaranteeing accessibility to the web server from anywhere with an internet connection allows the user to access the data remotely. Two-way communication between the solar system and the web server will then allow the user to choose which loads should be on/off and to add preference to their most important devices. Finally, the physical design must be considered as the project must be built to meet our requirements for semi-portability and outdoor use.

2.2 Physical Design

The overall physical design can be seen in Figure 4. A wooden frame was built around each solar panel with metal struts attached by bolt and chain to allow for self-standing and adjustable angles which can be seen in Appendix B, Figure 12. The main electronic components are housed in a rugged plastic container to protect against rain and snow. Inside the container is a wooden platform supporting the battery seen in Appendix B, Figure 16. A wooden shelf for the electronic components was placed above the battery and can be seen in Appendix B, Figure 11. Holes were cut in the sides of the enclosure to allow for the installation of 90° PVC elbows and an outdoor rated outlet which can be seen in Appendix B, Figures 13 and 14 respectively. The PVC elbows and outdoor outlet ensure proper ventilation and protection from water precipitation.

Figure 4. Off-Grid PV Generator Overall Physical Design

2.3 Power Subsystem

The power subsystem consists of the solar panels, battery, charge controller and inverter. The power circuit can be seen in Figure 5. This sketch also includes all the connection points for the monitoring and control system.

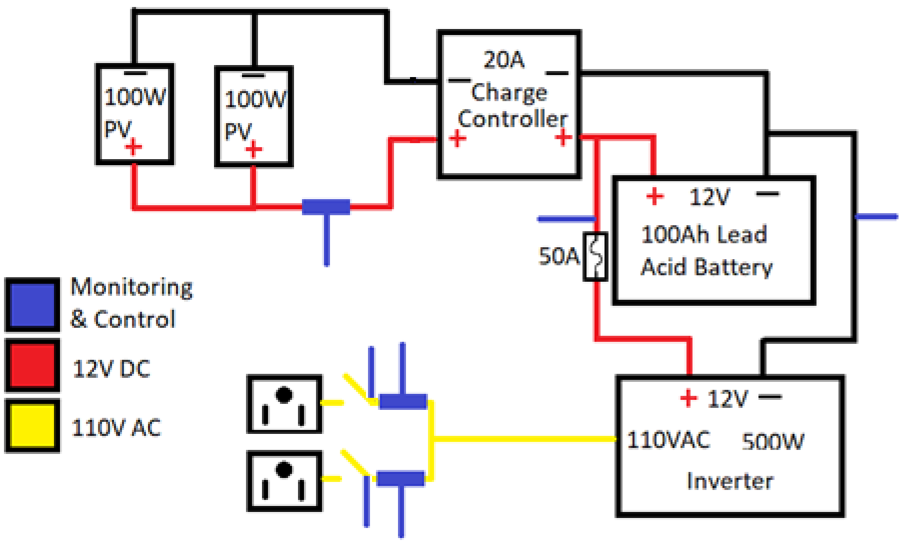

Figure 5. Solar System Circuit Diagram

2.4 Battery

The battery used for this project is 100Ah 12V Duracell deep-cycle flooded lead-acid group size 27DC. The first consideration in choosing this battery was that it needed to be deep-cycle. Deep-cycle batteries can discharge most of their capacity over a long period of time whereas typical vehicle batteries are built to discharge a small amount of their capacity in a short period of time [8]. The next decision was choosing flooded lead-acid instead of AGM or lithium-ion. Lead-acid proved to be the worst option because of maintenance, efficiency and weather concerns. However, it was the only option that could offer the required capacity within our budget. When choosing the capacity rating for the battery we took into consideration the battery and inverter efficiencies. Equation 1 was used to calculate a rating which would meet the requirements.

$$R = C / (hI * hB) \tag{1}$$

Where R is the calculated battery rating of 1176Wh ≈ 100Ah, C is the required capacity of 500Wh, hI is the inverter efficiency of 85% [9] and hB is the battery efficiency of 50% [10].

2.5 Solar Panels

The solar panels used for this project are two Renogy 100W monocrystalline panels. Monocrystalline panels are less efficient than Polycrystalline panels [12], however, they were in our budget. We chose to size the solar panels to provide enough power per day on average to fully charge the battery. Equation 2 was used to calculate the rating which would meet the requirements.

$$R = C / (H * hC) \tag{2}$$

Where R is the calculated solar panel rating of 199W, C is the required capacity to fill in one day which is 500Wh, H is the average hours of direct sunlight in Illinois which is 3.14 hours [13] and hC is the charge controller efficiency of 80% [14].

2.6 Charge Controller

The solar charge controller is an important part of the solar circuit as it takes the input from the solar panels and converts it into an optimized signal for charging the battery. It also ensures that the battery is not over charged or over discharged. For our project we chose to use a 20-amp PWM charge controller. There are two common types of charge controllers on the market which are pulse width modulation (PWM) and max power point tracking (MPPT). While MPPT technology is more efficient, it is also much more expensive. [15] We chose to use PWM as it is still very efficient and has a price tag well within our budget. A PWM charge controller takes the steady DC signal from the solar panels and converts it to a PWM signal for charging the battery. Other considerations we took into considering this charge controller were its LED display and 5V USB port. We used the display to check the voltage and current readings and the 5V port to power the PCB. When sizing the charge controller, we had to take into consideration the max current that would be produced by the panels. We used equation 3 to calculate a rating for the controller.

$$Imax = Isc * 2 \tag{3}$$

Where Imax is the max current of 11.5A and Isc is the rated panel short circuit circuit of 5.75A.

2.7 Inverter

The inverter is required to convert the 12 VDC battery voltage to 110 VAC ±2V for the load outlets. The inverter used in this project is rated for 500W continuous power and uses pure sine wave technology. The two types of inverters on the market are pure-sine and modified-sine. We chose to use pure-sine because of the high efficiency and ability to properly operate all electronic devices. Modified sine inverters are inefficient and do not work well with sensitive electronics. [16]

2.8 Relays/Outlets

An outdoor in-use outlet unit with two outlets is mounted on the side of the system's enclosure. We chose to use an outdoor in-use outlet in order that loads could continue to operate even in rain or snow. Each outlet is controlled by a solid-state relay which are both mounted on the shelf inside the enclosure. These relays are controlled by the microprocessor to allow the user to remotely turn on/off each individual outlet as well as add load preference in order to optimize power output.

2.9 Monitoring Circuit

The monitoring circuit consists of three different sensing circuits. One is the voltage sensing circuit which can be seen in Appendix B, Figure 17. The voltage sensing circuit consists of a simple voltage divider with filter capacitor. The purpose of this voltage divider is to scale down the battery voltage below 5V in order that the ADC pins on the microprocessor can process the data. We used a ratio of 2.2. Computation of this can be seen in equation 4 below. We used high valued resistors in order to minimize the power waste of the circuit. The results from the voltage monitoring circuit can be seen in Appendix B, Table 4.

$$\frac{R1}{R2} = \frac{220\ kOhm}{100\ kOhm} = 2.2 \tag{4}$$

The other two are the DC and AC current sensing circuits. The schematic for these two circuits can be seen in Appendix B, Figure 18. For the current sensing circuit, we used an ACS712 Hall effect IC. This sensor utilizes the Hall Effect which is the production of a potential difference across an electrical conductor when a magnetic field is applied in a direction perpendicular to that of the flow of current. [17] The only difference between the AC and DC sensing applications is the algorithm in the code. The DC algorithm simply takes samples over a period of time and finds the average. The AC algorithm takes rapid samples over a period. It then takes the max and min values to find the peak to peak current. Equation 5 is then used to calculate the RMS current.

$$Vrms = Vpp/(2*\sqrt{2}) \tag{5}$$

2.10 Microprocessor/Bluetooth

These modules are mounted on the PCB and make up the control unit. We used an ATmega328p [3] for our microprocessor for a variety of reasons. The first big reason was that it had 23 programmable I/O lines and has a six channel Analog to Digital Converter (ADC). We used the ADC module to convert the output of the monitoring circuit (0-5V) to digital values (0-1023) that we could perform calculations on [20]. The ATmega also had a serial UART, or Universal Asynchronous Receiver/Transmitter, module that we could use to communicate with other devices over serial. These features combined with very extensive documentation made this the ideal microprocessor for us.

For the Bluetooth module we chose to use an HC-05 master and slave module [4]. We chose this model primarily for its ease of use it uses the Serial Port Profile (SPP) protocol to send serial data. The SPP protocol we are using we ideal for this project because it allows for simple serial data to be sent to devices that are less than 100 meters away [11]. It also only requires 5V to operate and uses only two data lines one for transmitting and one for receiving making it good for this project [4].

Both modules were mounted directly to the PCB and shared a 5V and ground line. They are connected through a step-down circuit that converts the ATmegas 5V output to 3.3V so the Bluetooth module can properly read it.

2.11 Raspberry Pi/Web/User Interface

This component acts as the control hub for the entire project and consists of a Raspberry PI [5] that runs the control code. We chose to use the Raspberry Pi because it has built in Bluetooth and is very widely used so it has a lot of documentation. The main functions of this module are to request measurements from the ATmega and then display the data in a user-friendly format. It accomplishes this by requesting a measurement from the ATmega over Bluetooth then recording the data it receives back into the corresponding files every 30 seconds. While it does that there is also a simple web server that loads the data from the files and displays it in graphs for the user to read.

3. Verifications

3.1 Battery

The battery must be able to supply 250Wh on average per day without recharging for two days. In order to test this, we fully charged the battery and then made it discharge on a 200W load through the inverter. We then used a stopwatch to verify that the battery could supply more than 10.5V for 2.5 hours (+/-0.5 hours). The setup for this verification can be seen in Appendix B, Figure 15. The data for this verification can be seen in Appendix B, Figure 19. To calculate the capacity from the two trials we used equation 6 below.

$$C = 200W * t/60 \tag{6}$$

Where C is the calculated capacity which was 552Wh for trial 1 and 544Wh for trial 2 and t is the time until the battery reaches 10.5V in minutes.

3.2 Solar Panel

In order to test the solar panels, we used a protractor to measure the angle between the panel and the ground. We were able to change the angle by adjusting the two metal legs on each panel fixture. Once we angled the panel in the optimal sunlight setting, we measured the voltage across the two panel terminals with a multimeter. We then also used the multimeter to measure the current output of each panel. We then adjusted the panels to achieve their max and min angle and measured it with the protractor to ensure it is within the specification of 30-80 degrees.

3.3 Charge Controller

In order to know that the charge controller was working properly we hooked up the controller's terminals to a DC source and provided voltages ranging from 13-20V. We then hooked up the controller's output to an oscilloscope to capture the desired PWM signal as seen in Appendix B, Figure 6.

3.4 Inverter

The inverter was needed to convert the DC power into a pure sine AC waveform. In order to assure the inverter works properly we hooked up a DC source to the input terminals on the inverter and connected an oscilloscope to the output terminals of the inverter. We tested the inverter at both 10.5V and 16V input power. The oscilloscope captures can be viewed in Appendix B, Figure 7 and Figure 8 where you see a pure sine wave being generated by the inverter at 60Hz (+/-2Hz).

3.5 Relays

The relays must be capable of handling 110V (+/-10V) and up to 5A without failure. To ensure we can achieve this criterion, we hooked up an AC source to the input of the relays. We then activated the relays through the microcontroller and used a voltage meter to measure the voltage across the output relay terminals. In order to determine that our two terminals work independent of each other we checked to have 0 V across the off outlet and the proper voltage across the on outlet. We then switched the states of each outlet to ensure that the independence still holds. Appendix B, Figure 10 depicts our relay output.

3.6 Bluetooth

In order to test the Bluetooth module, we made the ATMega microcontroller start a program that would send over a predefined package of “abc123EFG456” to the Bluetooth module. The raspberry pi would then send a request signal to the Bluetooth module. Once received, the Bluetooth module would echo back the data for the raspberry pi to read the data. All this data transfer is over Bluetooth with a baud rate at 9600. We would then sweep the baud rates and confirm proper data transmission once the data is echoed. In order to assure that we can reliably transmit data under 20 feet, we tested data transmission at different distances between Bluetooth module and raspberry pi.

3.7 Monitoring Circuit

In order to verify that the monitoring circuits were working properly, we used a standard multimeter to read the DC voltage and current at the specified measuring points. The measuring points are parallel with the battery and in line with the solar panels. We then compared the values to the monitoring circuit measured values. Data from the voltage monitoring circuit can be seen in Appendix B, Table 4. As the voltage increases, the difference between the measured and actual voltage remains steady. This shows how reliable the voltage circuit can be.

For the AC current measurements, we used an outlet meter in series with each load to verify the current. We swept through different loads in order to obtain different amperages and compare the sensing circuit results with the meter results. The data can be seen in Appendix B, Table 5. As the AC current increases, the accuracy decreases. We believe this may be due to the way that the sensor samples the current. As mentioned in the design section, the IC takes samples for AC measurement. This form of measuring is susceptible to noise. We expect that the noise is higher at higher amperage and believe this explains the trend in the data.

The DC current data can be found in Appendix B, Table 6. As the current increases, the accuracy increases. We believe this is due to the fact that we used the highest current rating possible for the Current sensor IC. If we wish to have accurate readings for low amperage then we would use a lower rated IC.

3.8 Raspberry Pi/Web/User Interface

In order to test the Raspberry Pi we made the ATmega microcontroller run a program that sent the predefined string ¨abc123EFG456¨ to the Raspberry Pi once every six seconds. We then recorded the time it took between Bluetooth packets, the data can be seen in Appendix B, Table 7. The second verification we needed to test was the ability for the user to independently control the outlets and toggle them on or off. To test this verification, we turned on the ATmega and connected it to the relays that controlled the outlets we then plugged a light into both outlets to make sure they we both powered off. We then sent the command to toggle the first outlet and checked to make sure the light came on. Then we sent the command to toggle the outlet again and verified that the light had gone out. We repeated the same steps for the second outlet to verify that both outlets could be independently controlled.

4. Cost and Schedule

4.1 Labor

$$3\ people\ x\ \frac{\$33}{hour}\ x\ \frac{10\ hours}{week}\ x\ \frac{14\ weeks}{semester}\ x2.5 = \$34{,}650 \tag{7}$$

4.2 Parts

Table 1. Bill of Materials

System	Part	Vendor	Cost	Quantity	Total
PV System	Panels	Amazon	$115	2	$230
	Battery	Sam's Club	$100	1	$100
	Charge Controller	Amazon	$20	1	$20
	Inverter	Amazon	$80	1	$80
Monitoring and Control	Current Sensor	DigiKey	$5	3	$15
	Resistors	ECE Shop	$1	5	$5
	Capacitor	ECE Shop	$1	5	$5
	Relays	Amazon	$5	2	$10
	ATMEGA328P	MicroChip	$2	1	$2
	Bluetooth Module	Amazon	$9	1	$9
	Raspberry Pi	Adafruit	$35	1	$35
				Total:	$511

4.3 Grand Total

$$\$511 + \$34{,}650 = \$35{,}161 \tag{8}$$

4.4 Schedule

Table 2. Schedule

Week	Member	Objective
10/8	Robert	Have all power circuit parts ordered and delivered
	Jack	Have Microprocessor ordered and delivered
	Ruben	Have Bluetooth module ordered and delivered
10/15	Robert	Have voltage sensing schematic complete
	Jack	Have ADC ports setup on microprocessor with accurate readings
	Ruben	Have Current sensing schematic complete
10/22	Robert	Confirm setup location
	Jack	Solar panel and Charge controller connected to battery with full functionality
	Ruben	Have PCB gerber file ready for first round of orders
10/29	Robert	Find and buy battery
	Jack	Have solar panel legs built
	Ruben	Find interior insulation for battery and electronic circuitry
11/5	Robert	Find and order waterproof container
	Jack	Mount all accessory components to fixture
	Ruben	Solder PCB board
11/12	Robert	Have user interface functional
	Jack	Have web interface functional
	Ruben	Have bluetooth communication between module and Raspberry Pi
11/19	Robert	Finish debugging and troubleshooting power analysis
	Jack	Finish debugging user/web interface
	Ruben	Finish building container with holes for outlets and have circuitry installed

4. Conclusion

4.1 Accomplishments

Our design was able to meet all of the requirements and was able to provide consistent data with accuracy within our tolerance. The PV system was able to supply 250Wh per day all while allowing the user to have real time data on the performance of the system. The user was also able to successfully control the two individual outlets and turn them on/off remotely.

4.2 Uncertainties

As seen in Appendix A, Table 3, we were able to achieve most of our requirements except for proper display of the AC current during the project demonstration. We were achieving accurate readings prior to this demonstration which leads us to believe that the severe cold present during the demonstration could have caused the current sensor IC to not work properly. Could not properly map the battery level due to the max voltage the battery being capable to provide varies with its current state, i.e. charging, supplying, idle.

4.3 Future Work

For future works we plan on finding a solution to displaying the battery levels. In order to achieve this, we must know what the ranges of voltages for the battery is for each possible battery state. We also plan on reinforcing the physical design and possibly upgrade the container and outlets to IPX3.

4.4 Ethical Considerations

Because we are using a deep cycle lead-acid battery in our project, we will refer to IEEE 931-2007 “IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems” [18] when installing and working with the battery. In addition, we will include standard operating procedures for the battery in our final report. We will also add a fuse and insulated disconnect switch to the battery for safety.

The project is intended to be used outdoors so we will need to take special care to make sure the housing is element proof and can protect the internal components. We will accomplish this by making sure the housing is waterproof up to IPX2. [19]

The overall project will follow the following IEEE Code of Ethics [1].

All of the electrical components, minus the solar panels, will be stored in a weather proof container that will have all the dangers of high power batteries insulated. We provide quantitative claims with ranges due to the variability of our idea, but plan on building and testing all the components before finalizing product claims. The project is not sponsored so we will not be accepting any bribery. The reason for pursuing our idea is for society to have the knowledge and access to renewable energy. Every member of our group has successfully completed the lab safety module and all offer experience in fields required to successfully implement this idea. Our team consists of diverse members with different backgrounds and experience who offer a unique point of view for all aspects of our project. The safety of everyone is always a concern for our group and we plan on creating our idea properly and following all suggested guidelines. Our team is motivated to achieve our goals and understand that knowledge share and skills development is required by all of us to successfully build our idea.

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Appendix A - Requirement and Verification Table

Table 3. Requirements and Verifications

Requirement	Verification	Success (Y or N)
Microprocessor/Bluetooth: 1. Verify that data packets are sent correctly 2. Correct Baud rate 3. 20 feet data transmission	1. First we connect the bluetooth module to the ATmega microcontroller and power them both on. We then start a program on the ATmega to listen for a call from the Raspberry Pi and echo back the data that was sent. On the Raspberry Pi, using serial communication over bluetooth, we send the command to echo back the data that was sent to the ATmega. Then we send the string "abc123EFG456" to the ATmega and verify that the data sent back was identical to the data sent 2. We power on both the ATmega and Raspberry Pi and connect them via bluetooth. Then we set the ATmega to echo mode so it will send back the string it was sent. We set the baud rate on both to 9600 and sent the string "abc123EFG456" and verify you get back the same string without data loss. Then repeat the previous steps for 2400, 4800, 9600, 14400, 19200, 38400, 57600, and 115200 baud rates and verify the data is correctly transmitted. 3. Run the code to start the bluetooth module and have it start transmitting data. Use a bluetooth signal meter app to test the signal strength of the bluetooth module at different distances up to 20 feet and record results.	1. Y 2. Y 3. Y
Battery: 1. Must supply 250 Wh on average per day for 2 days	1. We leave the battery charging until max capacity and then connect a 200W load and see that it lasts for 2.5 hours +- .5 hours.	1. Y
Solar Panels: 1. Must supply 13-20 V and 4.5-5.75 A in direct sunlight 2. Must be self standing	1. Set panel at optimal sunlight settings and measure voltage and current using a multimeter 2. Set up panel at lowest possible angle and measure with a protractor to ensure a 30	1. Y 2. Y

and adjustable between 30-80 degrees from the ground	degree maximum. Then set up panel at largest possible angle and verify a minimum of 80 degrees.	
Charge Controller: 1. Must take 13-20V input and convert to PWM signal with amplitude ranging from 12V to 16V	1. Hook up DC source to positive and negative PV terminals on charge controller then hook up oscilloscope to battery terminals on charge controller to obtaining a PWM output with amplitude of 15 V+/-1 V	1. Y
Inverter: 1. Must provide 110VAC(+/-10 V) 60 HZ(+/-2 Hz) sine wave output with inputs ranging from 10 - 16 VDC 2. Must provide 110 VAC(+/-10 V) 60 Hz(+/-2 Hz) sine wave output with loads ranging from 0W to 400W	1. Hook up DC source to DC terminals on inverter and hook up oscilloscope to the AC output of inverter. We then change DC alter our DC source from 10-16 V and verify the waveform is 60 Hz sinusoid at 110 V(+/-10 V RMS) 2. We plug an outlet meter into Inverter outlet and verify 110 V(+/-10 VRMS) and 60 Hz (+-2 Hz). We then plug a power strip with a 400W load into outlet meter and verify 110 V(+/-10 VRMS) and 60 Hz(+/-2 Hz)	1. Y
Relays/Outlets: 1. Relays must be able to handle up to 110 V(+/-10 V) and up to 5 A without failure 2. Relays must be independently controlled	1. Hook up known AC source to the input of the relay and set up relay control pin for the selected outlet to high on the microcontroller. Using a voltage meter we measure the voltage across the chosen outlet and compare with known value 2. We set up the relay pin to high for one outlet and the other to low and use a multimeter to ensure one outlet does not influence the other	1. Y
Monitoring Circuit: 1. Voltage readings are within 0.5 V of actual value and are stepped down to within 0-5 V for microprocessor 2. AC current readings are within 0.2 A of actual value 3. DC current readings are within 0.5 A of actual value	1. We use a multimeter or outlet meter to measure both voltage and current of the different measurement locations and compare the values with the computed values from our monitoring system	1. Y 2. N 3. Y
Raspberry Pi/ Web UI: 1. Must be able to receive and display the data from	1. Send known data from the microcontroller over bluetooth and check the validity of the received data against the know values to	1. Y 2. Y

the microcontroller in real time at least once every 6 seconds(+/-1 second) without loss of data or precision 2. User can turn on and off the different outlets independently and remotely	confirm proper transmission. We must also time the data transmission to endure it receives data every 6 seconds 2. We use a multimeter to verify the voltage across the chosen outlet is low then high once the activation command is sent.	

Appendix B - Schematics and Results

Table 4. Voltage Reading Comparison

Actual(V)	Measured(V)	Difference(V)	Percent Difference(%)
12.24	12.33	0.09	0.74
12.20	12.28	0.08	0.66
12.17	12.22	0.05	0.41
12.14	12.19	0.05	0.41

Table 5. DC Current Comparison

Actual(A)	Measured(A)	Difference(A)	Percent Difference(%)
0.34	0.41	0.07	20.5
0.67	0.75	0.08	11.9
1.21	1.36	0.15	12.4
5.67	6.03	0.36	6.3

Table 6. AC Current Comparison

Actual(A)	Measured(A)	Difference(A)	Percent Difference(%)
0	0.1206	0.1206	
0.229	0.2332	0.0042	1.8
0.5	0.5224	0.0224	4.5
1.67	1.48	0.19	11.3

Table 7. Transmission Times

Trial number	Time between transmissions (Seconds)
1	6.4

2	5.9
3	6.2
4	6.1
5	6.4
6	5.8
7	6.3
8	5.9
9	6.1
10	6.3

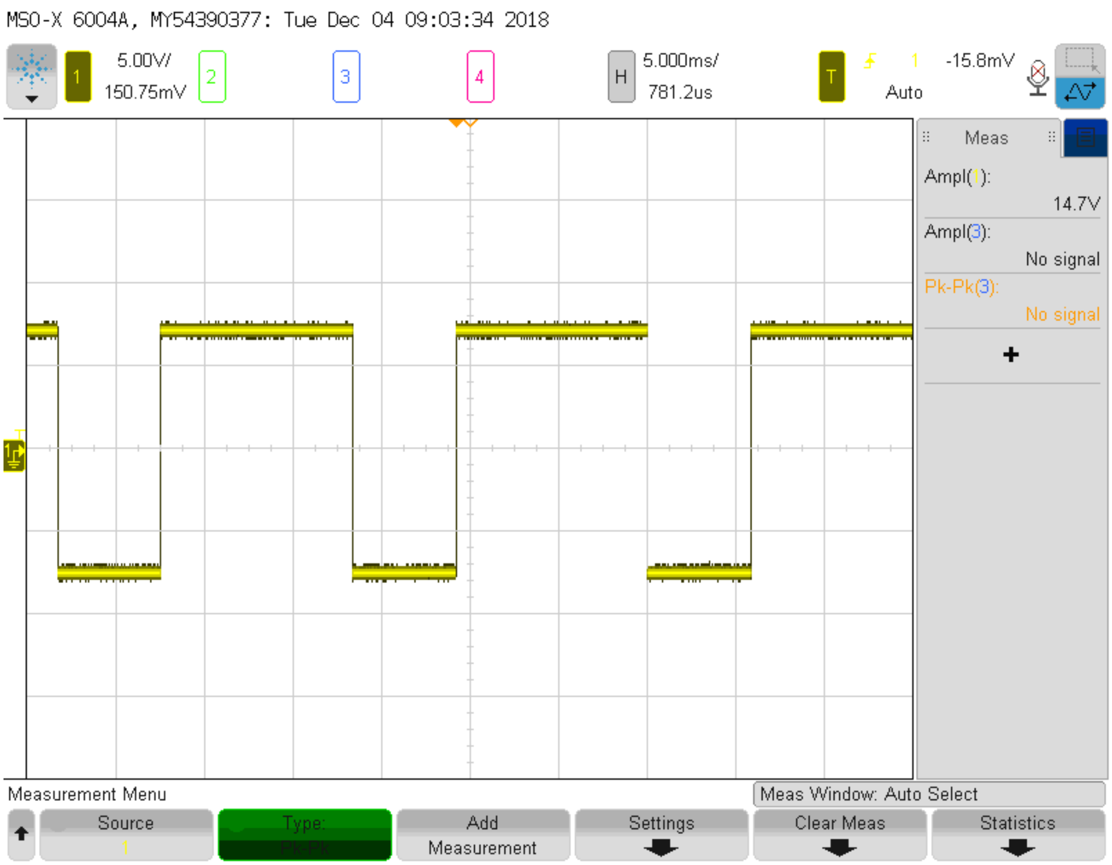

Figure 6. Controller Battery Terminals with 19 VDC at PV terminals

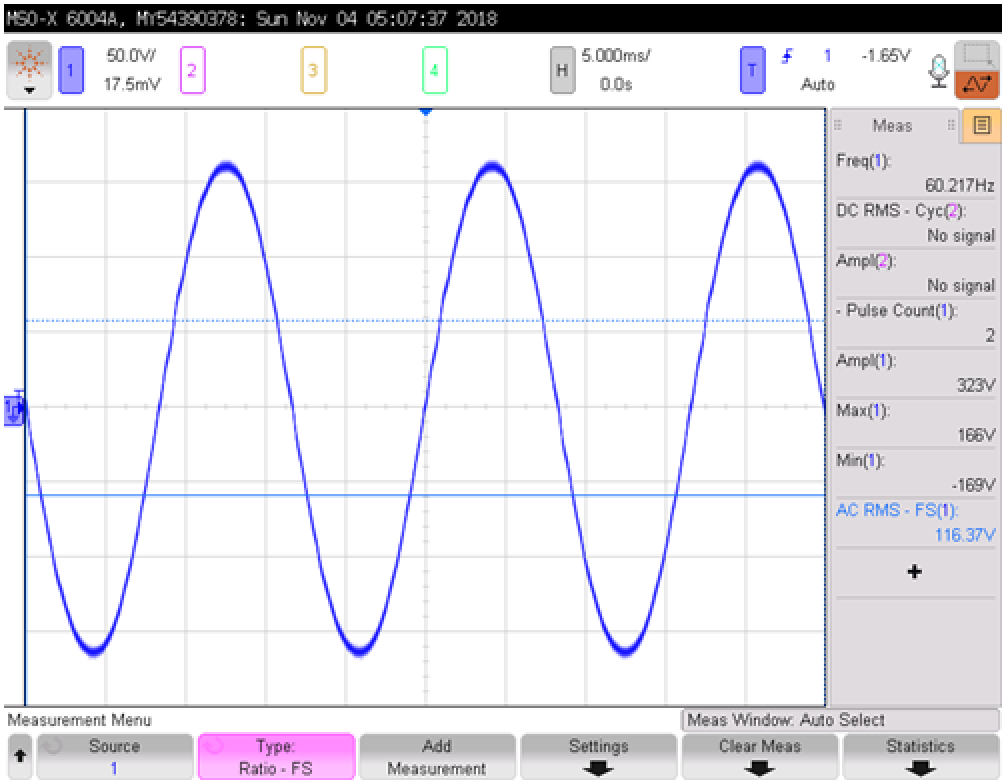

Figure 7. Inverter output with 10.5 VDC Input

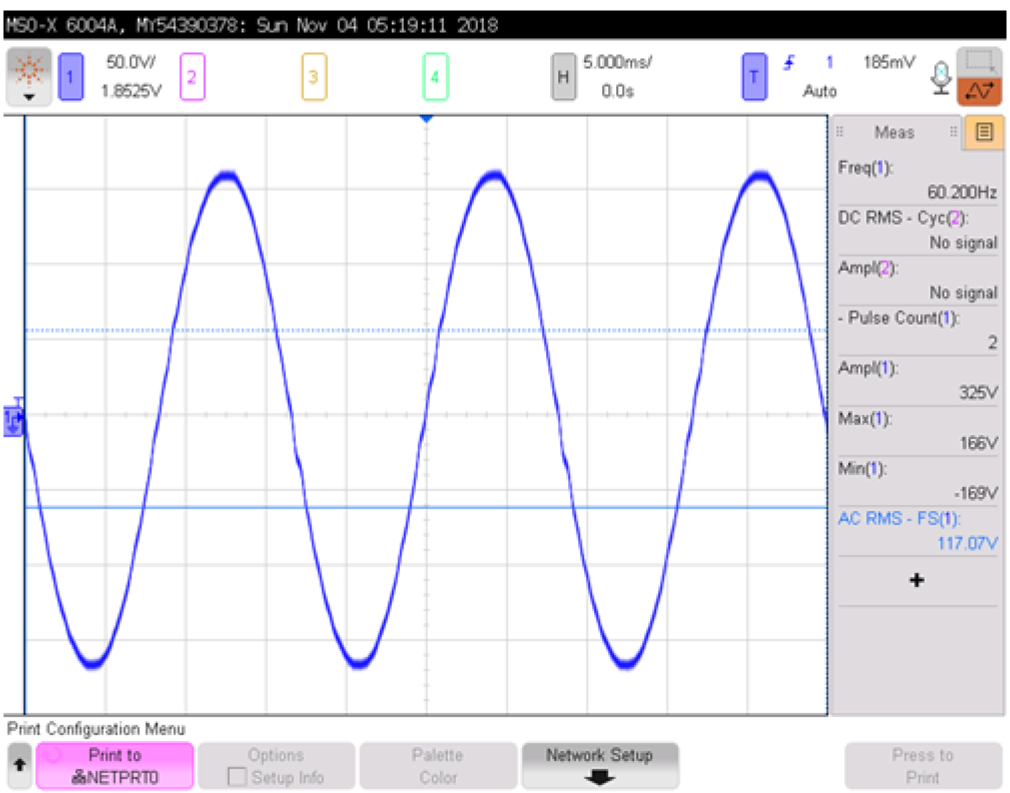

Figure 8. Inverter output with 16 VDC Input

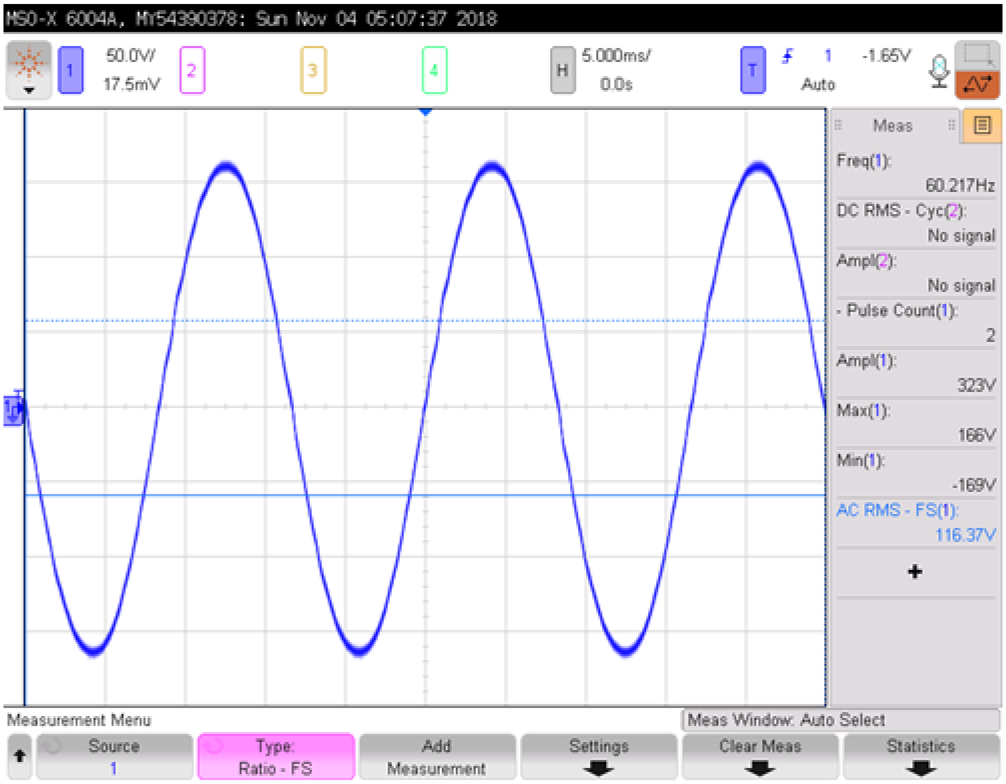

Figure 9. Inverter Output without Relay

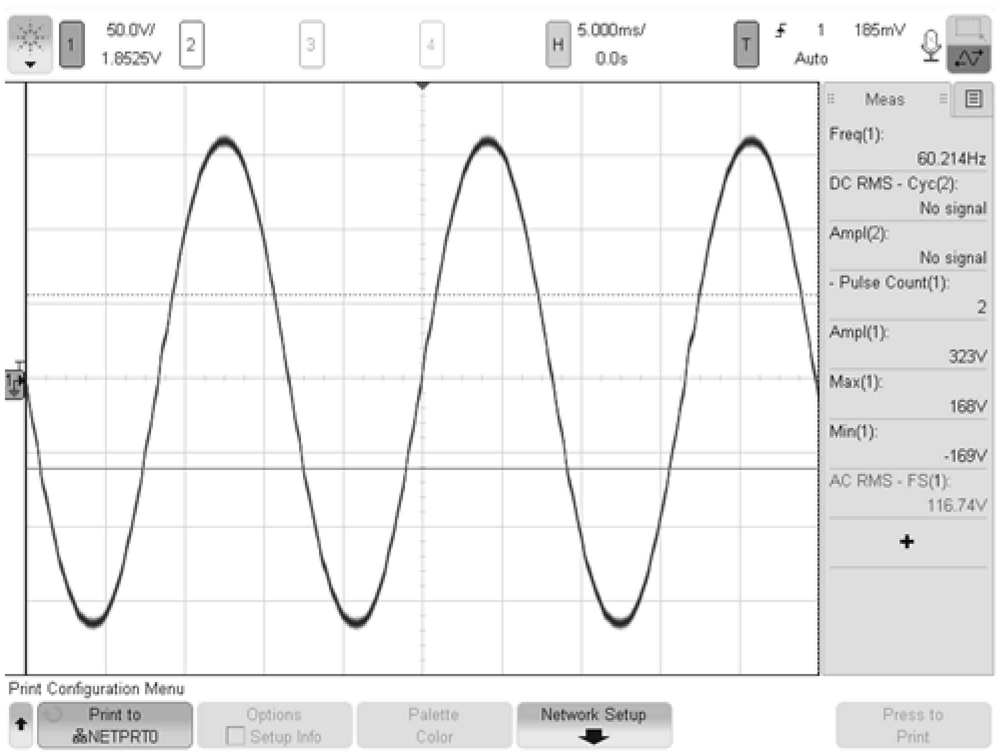

Figure 10. Inverter Output through Relay

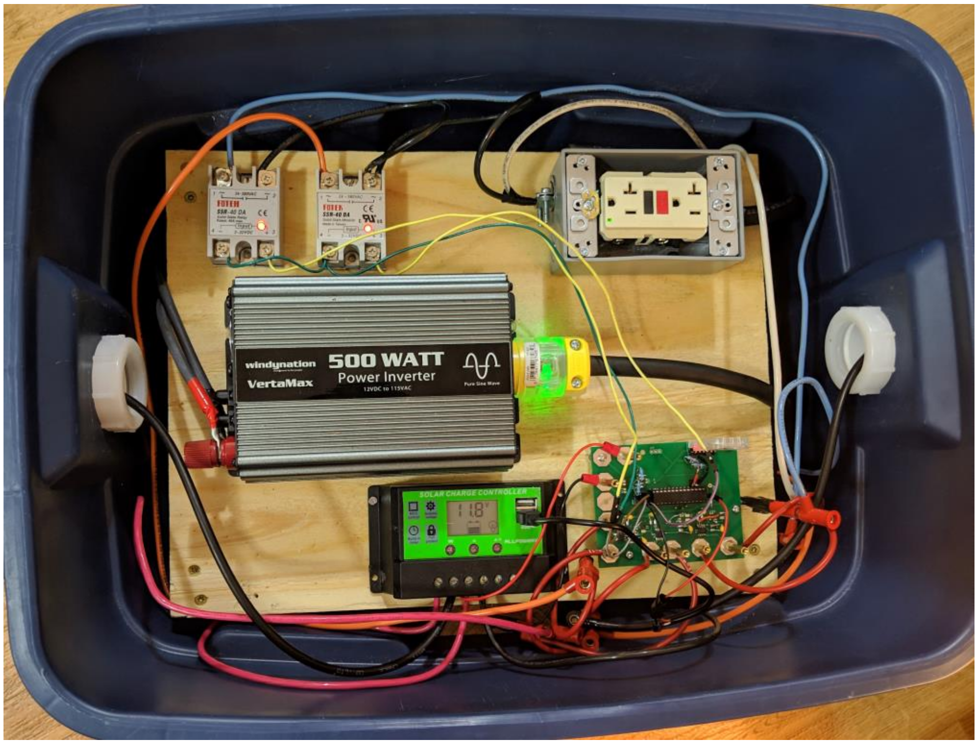

Figure 11. Wood Shelf with Mounted Electrical Components

Figure 12. Solar Panel Frame with Metal Struts

Figure 13. 90 Degree PVC Elbows for Solar Panel Wire Inlets

Figure 14. Outdoor In-use Outlet

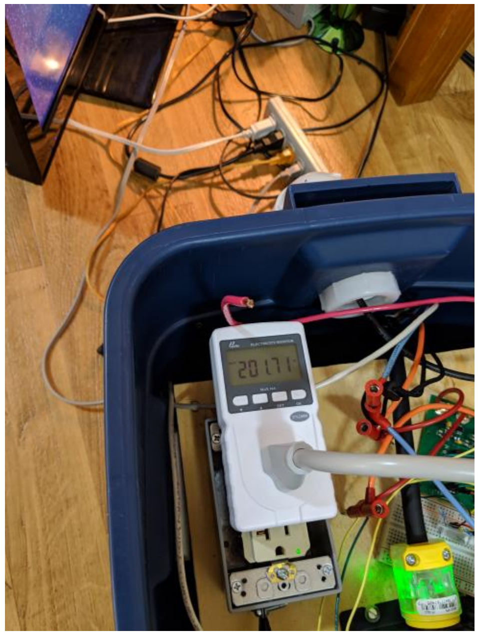

Figure 15. 200 W Battery Capacity Verification Setup

Figure 16. Wooden Battery Support

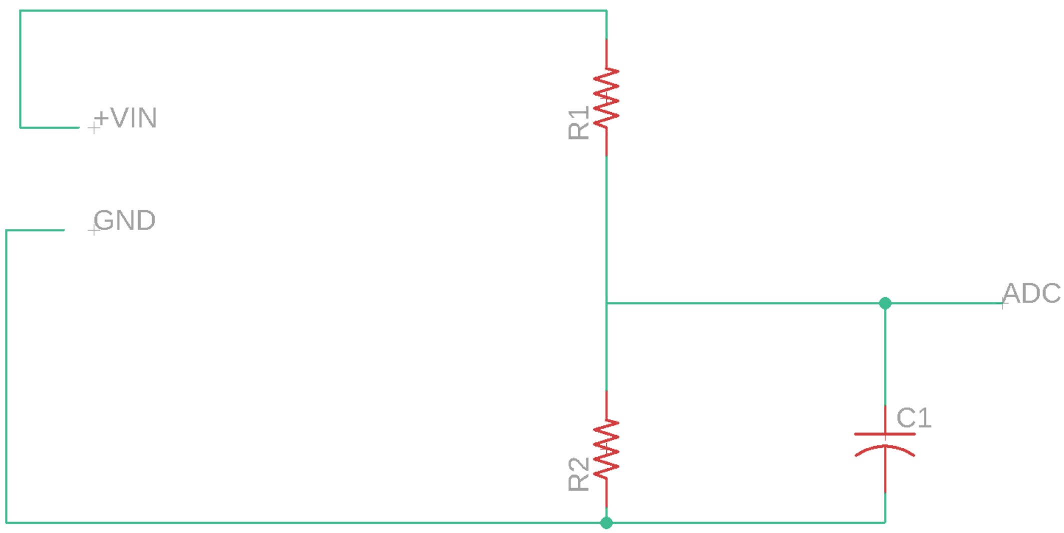

Figure 17. Voltage Sensor Circuit Schematic

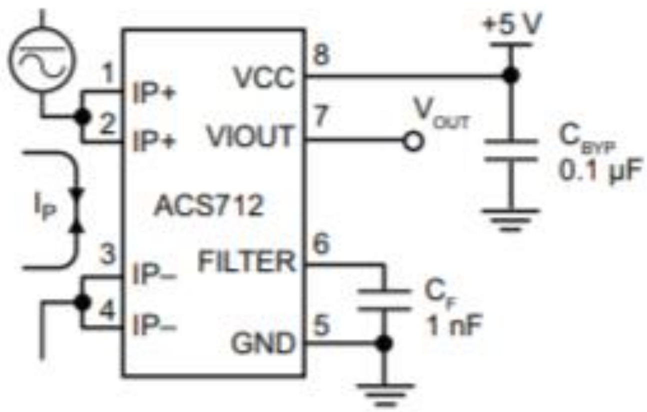

Figure 18. Current Sensor Schematic

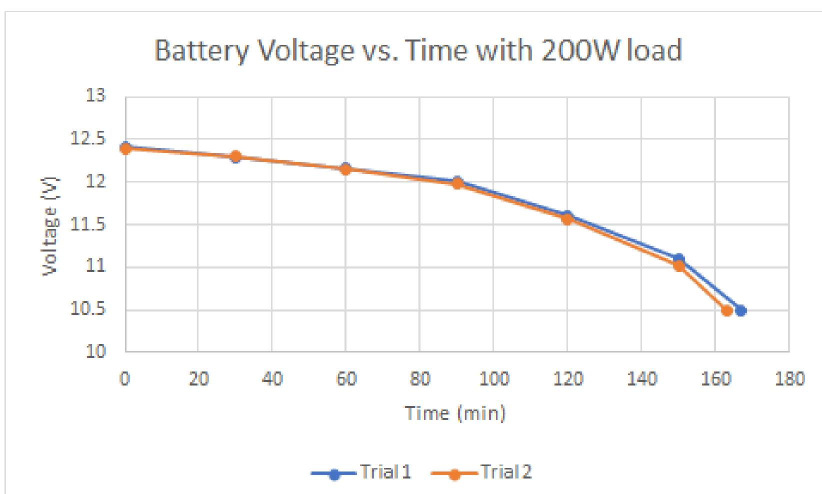

Figure 19. Battery Capacity Data