The University of Texas Rio Grande Valley

College of Engineering and Computer Science

Department of Electrical and Computer Engineering

Senior Design II

Report

Project: Maximum Power Point Tracking Energy System

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Technical Abstract

Renewable energy sources are commonly used in a variety of applications within the energy grid. In order to effectively harness energy from these sources, it is necessary to calculate the maximum power at any given time. This system implements the Maximum Power Point Tracking (MPPT) using the Perturb and Observe(P&O) method to modify the Pulse-width modulation (PWM) signal to increase the power of the Photovoltaic (PV) system. The system design consists of two Boost converters: one for the MPPT algorithm and the other for load regulation at the battery. The MPPT algorithm is applied to the PV system as the input. An AC/DC converter with a voltage regulator will charge the battery when necessary. Additionally, a mobile application was developed to display various sensor readings, such as current, voltage, temperature, irradiance and shutoff time. The hardware performance will be shown to the user through the data being displayed.

Non-Technical Abstract

Renewable energy sources like solar panels are commonly used in various applications throughout the energy grid. The use of renewable energy sources benefits most by obtaining the maximum power output from the source. The project aims to optimize the maximum power output from the solar panels and be able to charge and discharge a battery according to certain conditions. This method of extracting maximum power can increase the efficiency of photovoltaic (PV) systems without having to add moving parts that suffer wear and tear over time due to harsh weather conditions. Another advantage of this system is that the algorithm is stored in a microcontroller. So in the event where the microcontroller were to stop working or have a catastrophic failiure, the only part that would need to be changed out of the system would be the microcontroller. To make this project more user-friendly, a mobile application will show all of the data a user might need, such as temperature, current, voltage, among other sensor data.

1. Introduction

Energy management systems (EMS) have used a combination of different strategies and methods that can be used to improve efficiency, energy utilization, and the system overall. These systems are applicable in residential buildings, education buildings, offices, and industrial spaces. Additionally, they can possess the ability to have net-zero emissions in many cases, with the use of renewable energy systems, commonly referred to as RES. The use of smart buildings in the future must also compensate for weather conditions. Smart buildings should also provide adequate RESs and energy storage technologies to continue providing power when there is a low production of power taking place. The overall structure of the system consists of generation (preferably from RESs), energy storage, demand management, and communication of the entire system which all happens in the EMS.[1]

The energy management system takes effect in microgrids, or MGs. MGs integrate different sources of energy and loads while also being connected to the traditional utility grid, though they do not necessarily have to be connected. These MGs function the same way when using solar panels, wind turbines, other RESs, and energy storage; all of which will be used to fulfill the electrical loads of the system. Many designs have been made regarding the reduction of emissions in microgrids and the increase in the usage of RESs. This, along with a variety of configurations of RESs, helps determine the most optimal configuration for the system.[2]

Discrepancies that occur in EMSs consist of time-shifting, magnitude deviations and emerging inputs of RESs as well as the loads. A problem that also occurs is with reliable communications and measurements that come from the system. The resiliency of the power system is to ensure that it is able to withstand natural disasters like earthquakes and hurricanes are among other factors that may affect the power grid. Microgrids are being considered as the solution to have the resiliency for power systems. This is due to the ability to have renewable resources as the primary source energy.[3]

Many of the current systems are similar in the way of using RES as input sources, however there is a variety of configurations that we are eager to experiment with. There are many uses of converters when it comes to this area, with no consensus on the converter used. However, it is important to find which converter will be the most efficient. The use of an Arduino, a microcontroller, was determined to be adequate for this project as it will do most of the calculations and sensor readings from the system. A variety of sensors and chips within the system will be used to track various data points from different sections of the overall system and will provide us with the data. Our system will use a mobile application that will contain data from the variety of energy sources used to determine which source provides the most efficient power. The aim, as previously mentioned, is that the system will continue to function in a weatherproof container such that when issues arise from uncertain events such as changing climates or varying weather conditions, the system will continue to function seamlessly without damage to the physical hardware or the functionality of the whole system.

From doing literature review and looking at possible patents regarding our project area, there are no existing patents relating to any design parts of the project. There is research primarily being done on how to improve these EMSs and MGs from various configurations of energy sources. Due to the scale of the project, most parts are interchangeable. This will allow the patent in this area to be used in a project that covers hospitals, aircraft carriers, schools, or any other possible applications. Overall, the project has a wide range of applications, making it feasible and easy to use. Building on the previous statement, its flexibility and feasibility will allow itself to improve in different ways depending on its application. A variety of configurations, converters, and controllers can be used to accomplish the same purpose, which is to provide reliable, clean, and efficient power to consumers.

2. Design Objectives and Realistic Design Constraints

2.1 Design Objectives

Marketing Objectives

1. The system must be easy to install and provide maintenance, offering a seamless user experience.
    a. The system will be integrated and easily accessible to workers who will be able to troubleshoot and resolve any problems related to the various aspects of the project.
2. The system must be seamlessly adaptable to existing solar arrays for an effortless integration process.
    a. The components required for the system should be easily configurable with existing solar arrays.
3. The system should achieve maximum power output from the panel, optimizing performance.
    a. The implementation of the MPPT algorithm is crucial in ensuring the maximum power point, resulting in increased output from the panel.
4. The system should work seamlessly together.
    a. The different components of the project, from the hardware to software, should ensure a seamless and efficient system.

5. The system should provide a safe and secure user experience in ideal operating conditions.
    a. The different components of the project, from the hardware to software, should work in ideal normal conditions ensuring a reliable and safe system.
6. The system should provide a secure and reliable user experience in non-ideal conditions.
    a. To ensure the system is protected and safe to use, appropriate measures such as implementing a weatherproof enclosure are used in this system.
7. The system should have a user-friendly mobile application that connects with the system.
    a. The mobile application will display essential information such as system status, temperature, voltage, current, irradiance, and shut-off time to provide users with system monitoring.

Engineering Objectives

1. The system should be highly efficient.
    a. The converters should operate with maximum efficiency, meeting or exceeding the specifications for the project.
2. The system should monitor data with accuracy.
    a. The sensors integrated into the system must be reliable in reading the data with accuracy. This will enable the control to make adjustments based on data received, ensuring optimal performance of the system.
3. The system should be easily replicated, with minimal modification required to integrate it with different solar panels.

   a. The hardware components and software can remain largely unchanged simplifying the replication process.
4. The system should be scalable and allow it to be used with various DC sources.
   a. The system's scalability is enhanced by utilization of the Maximum Power Point Tracking(MPPT) algorithm which is not limited to solar panels. It can be used with a variety of DC sources including wind turbines making it versatile and adaptable to different renewable energy systems.
5. The system should be easily accessible for maintenance.
   a. The system will be easily accessible to both consumers and technicians in case of maintenance. The system should be compact to allow for easy storage and transportation of the system.
6. The system should be cost efficient without compromising its functionality.
   a. With a budget of approximately $600, However, with the expected energy savings that may occur from the implementation of this system, the consumer will be saving money from this system.
7. The system should be user-friendly and easy to comprehend.
   a. The primary function is to obtain the Maximum Power Point from the solar panel based on the conditions present. The system is designed to require little to no maintenance that will be required from the consumer side.

8. The system should be able to withstand weather conditions.
    a. The system should be equipped with a weatherproof enclosure to protect its hardware components from harsh weather conditions. This will also ensure that the software components of the system remain intact and the system continues to function efficiently.

2.2 Realistic Design Constraints

The project consists of multiple components with requirements that must be met to ensure it is successful. An essential feature of the system is the integration with the various sensors placed at different points to monitor its performance. The boost converter, which includes the MPPT controller, is a crucial part of the system and the input parameters must meet specific values to achieve optimal performance. The other boost converter at the battery side will be used as the form of load regulation so that the load is satisfied. This means that the converter will be discharging. The AC/DC converter with the voltage regulator will be used as the form of charging the battery. This will occur when the battery is not connected to the rest of the system for safety reasons.

Table 2.1 Input Specification for Energy System

Converters	Voltage	Current	Power
MPPT Boost Converter	Varies Max: 17.8V	Varies Max: 2.86A	Varies Max: 50W
17.8V Boost Converter	12.4V	Varies on the Load	Max: 50W
AC-DC Converter w/ Voltage Regulator	12Vac 24Vac	2A	50W

Table 2.1 outlines the input specifications at each converter in the system. The MPPT Boost Converter will use the solar panel as its input source with the input varying due to outdoor conditions. The maximum voltage and current output that the panel is able to output is shown in the table with a maximum output power of 50W. In the event that the output from the panel is insufficient to meet the load, the battery side will provide additional power. Shown in Table 2.1 is also the input voltages for the battery side boost converter which are the maximum values that there can be. It is also important to note that the voltage shown is reading when the battery is under a load. Lastly, the AC/DC Converter with voltage regulator input specifications are shown. It is also worth noting that the 12V(AC) and 24V(AC) are coming from a transformer.

Table 2.2 Output Specification for System

	Voltage	Current	Power
MPPT Boost Converter	Varies Max: 19.3V	Varies Max: 2.59	Varies Max: 50W
20V Boost Converter	20V	2.5A	50W
AC-DC Converter w/ Voltage Regulator	13.5V	1.25A	13W

Table 2.2 outlines the output specifications at each converter in the system. The MPPT Boost Converter will output approximately 19.3V when the input is at its maximum. However, this varies based on the input due to the outdoor conditions. In the event that the output from the panel is insufficient to meet the load, the battery side will provide additional power. Shown in Table 2.2 is also the input voltages for the boost converter on the battery side which are the maximum values that there can be. It is also important to note that the voltage that was read occurred when the battery is under a load. Lastly, the AC/DC Converter with voltage regulator input specifications are shown, it is also worth noting that the 12V(AC) and 24V(AC) are coming from a transformer.

Table 2.3 Engineering and Marketing Requirements

Requirements		
Marketing	Engineering	Justification
1,3	Power converters should have at least 90% efficiency	Based on existing converter design and established technologies, most converters are able to achieve at least 90% efficiency
1,3	Converters should be to sustain the applied voltage and current(power) at various points	With the proper selection of the different components such as transistors among other components, the converter is able to apply our input power and not affect our system
1,2	The monitoring of data from various points should remain accurate through the use of the system and ensure all desired data is collected	The sensors that will be used have shown to be highly accurate and are also able to measure the voltage and current for which the system will operate in
2, 3	Real-time data from the various sensors should be shown on the mobile application	Based on established technologies that exist, showing real-time data on the mobile application is possible.
1,2,3	Maximum power should be extracted from the DC source using MPPT	Established methods and technologies have shown that it is a possibility to implement this into DC applications, such as PV systems
1,3	System should be stable throughout	System stability will be provided through established techniques for which system stability is achievable

3. Gantt Chart – Project Timeline

3.1 Original Gantt Chart

The Gantt Chart provides the project schedules by showing the past, current, and future activities. They also provide the status of activities and their expected date of completion. This Gantt Chart was a preliminary schedule at the beginning of the semester, in which we planned on designing a bidirectional converter which would charge and discharge the battery as needed. Our new Gantt Chart with the new objectives are described in Section 3.2. The original Gantt Chart was developed on January 17, 2023, as follows:

Table 3.1 Gantt Chart Beginning of SD II

	Senior Deisgn II																				
	Project Title: Maximum Power Point Tracking Energy System																				
					Jan			Feb				Mar				Apr				May
	Task Name	Start	Finish	Duration	1/17	1/23	1/30	2/6	2/13	2/20	2/27	3/6	3/13	3/20	3/27	4/3	4/10	4/17	4/24	5/1
1.1	Research Solutions to Problems	1/17	1/27	13D																
2.1	EAGLE CAD Simulations and PCB Layout	1/30	2/10	14D																
2.2	Testing of Boost Converter(PCB)	2/6	2/20	4D																
3.1	Controller Coding and Testing	2/13	4/21	35D																
3.2	Bidirectional Testing	2/20	4/28	25D																
3.3	Integration of Sub-System	3/6	4/28	37D																
4.1	Mobile App Development	3/20	4/21	24D																
4.2	Data Collection	3/20	4/21	24D																
5.1	System Integration	4/3	5/3	21D																

3.2 Revised Gantt Chart

The revised Gantt Chart is as follows:

Table 3.2 Revised Gantt Chart SD II

	Senior Design II																				
	Project Title: Maximum Power Point Tracking Energy System																				
					Jan			Feb				Mar				Apr				May
	Task Name	Start	Finish	Duration	1/17	1/23	1/30	2/6	2/13	2/20	2/27	3/6	3/13	3/20	3/27	4/3	4/10	4/17	4/24	5/1
1.1	Research Solutions to Problems	1/17	1/27	13D																
2.1	EasyEDA PCB Layout and LTSpice Simulations	1/30	2/10	14D																
2.2	PCB Soldering of Converters	2/6	2/20	4D																
3.1	Controller Coding and Testing	2/13	4/21	35D																
3.2	Integration of Sub-System	3/6	4/28	37D																
4.1	Mobile App Development	3/20	4/21	24D																
4.2	Data Collection	3/20	4/21	24D																
5.1	System Integration	4/3	5/3	21D																

One of the reasons for the timeline adjustment is because the decision was made to focus more on the mobile application than the previous semester. Additionally, as mentioned in section 3.1, the objectives had to be adjusted due to issues that rose from hardware. The changes to the objectives came in the form of designing another boost converter for the battery side which would allow for load regulation. Another converter that was designed was an AC/DC converter with a voltage regulator which was used to charge the battery when necessary.

4. Project Design Process

4.1 System Design and Block Diagram

The system designed will be an energy system that will find the maximum power point from the use of the MPPT algorithm along with a battery which will be used for load regulation. An AC/DC converter will also be used as has been mentioned previously in the form of charging the battery. The system will be designed to work with DC loads and will have the flexibility to work with other various DC loads. Overall, the system will be designed to provide an efficient and reliable source of energy with the ability to adapt to different loads and weather conditions. The use of various sensors and algorithms will ensure that the system operates at its maximum efficiency and provides consistent energy output. In this chapter, the overall system will be discussed.

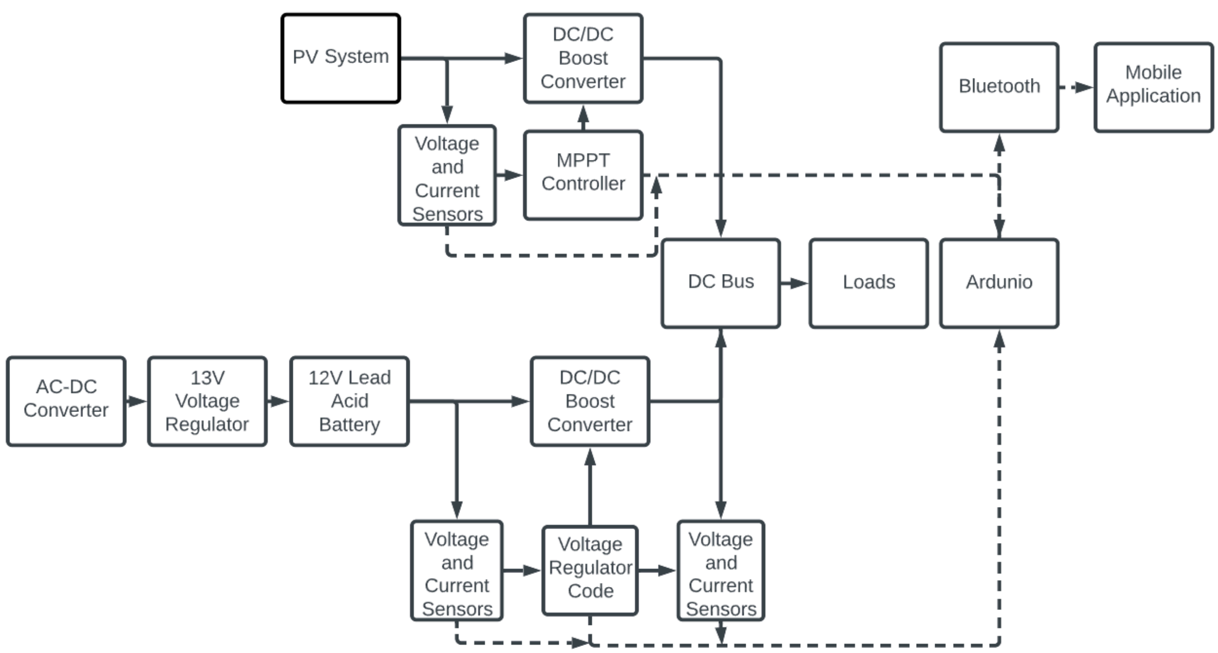

Figure 4.1 Level 1 Block Diagram of the Energy System

Figure 4.1 shows the Level 1 design of the project and how everything is interacting. As shown, we have a solar panel that is connected with voltage and current sensors which are used in our MPPT controller that is connected to a boost converter. On the battery side, we have another boost converter in which we are using a similar setup with voltage and current sensor used for the controller. The output of these converters are at a DC Bus in which are connected to the loads being used. Another section of the system is the AC/DC Converter with the voltage regulator used as the charger for the battery. Also shown is the Arduino where our controller code is located and where the Bluetooth module is connected to which will be able to send the data being from the system to the mobile application. The system components will be described in Section 4.2.

4.2 System Block Diagram Description

- PV System

  The PV System will get the energy from the sun from which we will then obtain the voltage and current sensor readings of the PV system. This will be used to obtain the readings for the MPPT Controller to use.

- DC/DC Boost Converter

  The DC/DC Boost Converter will be used as the medium for the MPPT algorithm. The boost converter is designed to step up the voltage from its maximum power point.

- Sensors for Boost Converter

  The input sensors for the Boost converter will also be used from the PV system. This means that the output sensor readings from the PV system will be used for the input sensors of the Boost Converter. Sensors at the output of the Boost converter will also be used to calculate efficiency. Sensors for this project include analog temperature sensors, voltage sensors, and current sensors.

- Boost Converter at the Solar Panel Controller

  The Boost converter at the solar panel controller consists of the MPPT Algorithm. The Boost Converter Controller will be required to reach the maximum power point from the MPPT Algorithm.

  - MPPT Algorithm

    MPPT or Maximum Power Point Tracking is an algorithm that is implemented in PV systems to adjust the impedance seen by the solar array to keep the PV system operating at the maximum power point under the varying outdoor conditions. This algorithm will be using the input sensors such as voltage and current of the PV system to determine the maximum power point, resulting in the PWM signal being changed according to the conditions.

  - P&O Method

    The method that is used in the algorithm is referred to as the Perturb and Observe method which is an MPPT algorithm that allows us to perturb the operating voltage to ensure that the maximum power point is reached.

- Battery

  The battery is used as our energy storage component of the project. The battery will be charged by the use of an AC/DC converter using a 13V voltage regulator. The battery chosen is a 12V Rechargeable SLA AGM Battery.

- Boost Converter at the Battery Controller

  The boost converter at the battery controller consists of a 24V regulator, this is done to primarily satisfy the load when the solar panel is not able to. To maintain the 24V, the duty cycle will be changed for the 24V regulation.

- Sensors for the Boost Converter at the Battery

  The input sensors for the Boost Converter at the battery are used for data collection as values will be used for the controller. This means that the input sensor readings from the battery will be used with the output sensors of the boost converter to be used in the controller.

- AC/DC Converter with Voltage Regulator

  This part of the system is the charger for our battery. We are using an AC/DC converter and a voltage regulator which consists of a full-wave rectifier, filter & bleeder resistor, and voltage regulator. The voltage regulator is set to put out 13V to charge the battery with an approximate 1.25A short circuit current output.

- DC Bus

  The constant DC Bus is used as a point of reference for where the output voltages from boost converters from the solar panel and battery come together.

- Load

  The load is simply any desired load that is selected. Due to our system being primarily DC, the loads used will be primarily DC loads; these include a small fan, DC light, as well as a USB charger panel.

- Arduino

    The Arduino was the microcontroller that was chosen for our project. This is a common controller used for projects and is easy to use and customizable with our system.

- Bluetooth

    A bluetooth module is used to communicate the data from the solar panel and battery to output to the mobile application.

- Mobile Application

    The mobile application used to show the data in a user friendly application which will show the user the values that are being obtained.

4.3 Calculations/Schematics and Simulations

The design of both the boost converters used similar calculations in determining the component values as well as duty cycle for determining the ideal duty cycle.

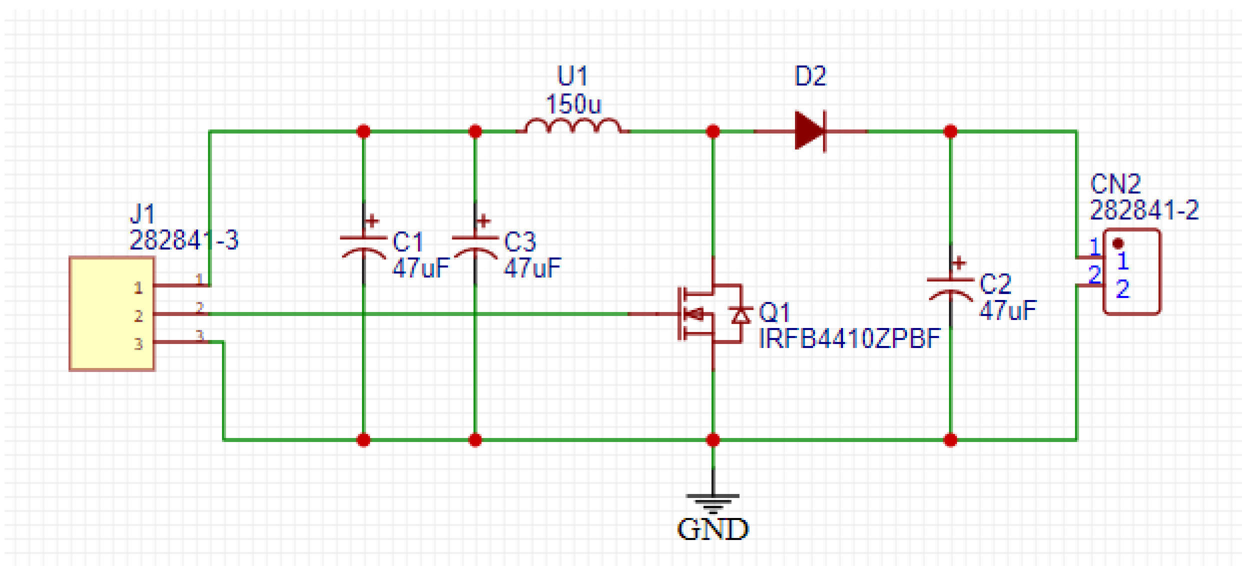

Figure 4.2 Boost Converter Schematic

Figure 4.2 shows the schematic for a boost converter which will be a varying input that will be coming from the solar array. The design was made using a 17.8V input and 2.86A which is the maximum output from the PV systems. As previously mentioned, the boost converter allows us to step up the voltage of the system along with the MPPT algorithm implemented in order to achieve the maximum power point.

The same boost converter schematic will be used for the converter at the battery part to discharge from the battery. The converter will vary slightly in terms of the values of the various components in the boost converter shown in Figure 4.3.

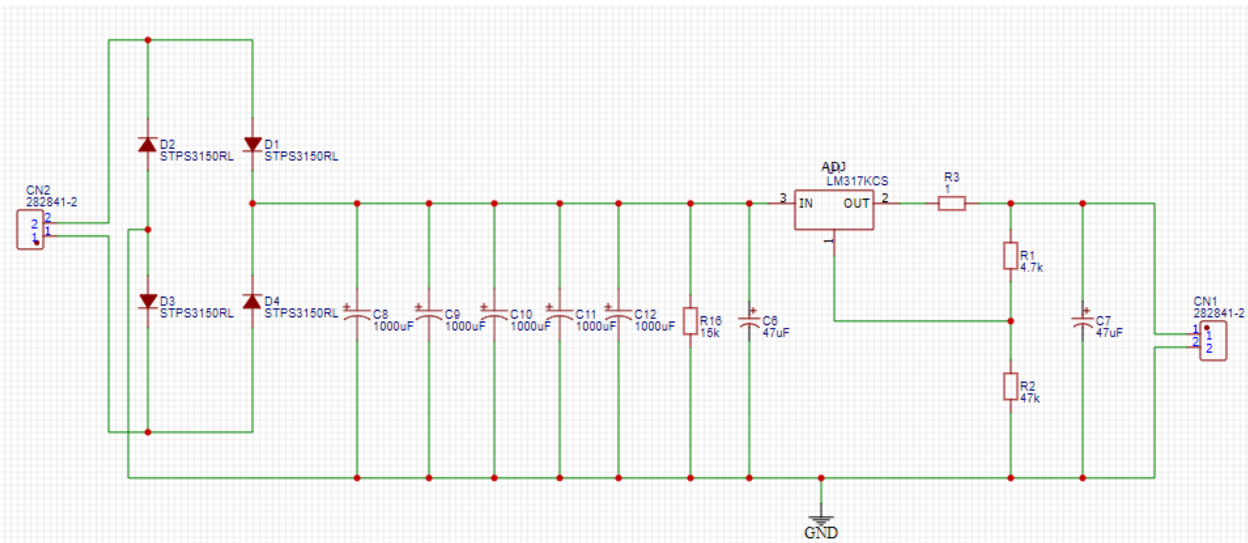

Figure 4.3 AC/DC Converter with Voltage Regulator Schematic

Figure 4.3 shows the AC/DC Converter with a voltage regulator that will be used to charge the battery. The charging component of the project is crucial in order for the user to not have to replace that battery when it dies.

4.3.1 Boost Converter Calculations

The boost converter design along with the calculations was made to design our desired output based on input values. The formulas used for the boost converter include duty cycle, inductor, and capacitor values. The duty cycle formula is as follows:

$$D = 1 - \frac{Vin}{Vout}$$

Duty cycle is the ratio of the time in which the pulse wave is high over the period. For the boost converter, the duty cycle is calculated as shown with Vin being the input voltage and the Vout as the output voltage. For the inductor, the calculation for this is also done using the following formula:

$$L = \frac{Vin * (Vout - Vin)}{\Delta iL * fs * Vout}$$

For this calculation, we use the ΔiL as the estimated inductor ripple current which is usually 20% to 40% of the average load current. fs is the switching frequency of the converter as the same variable used in the duty cycle calculation is used here. The capacitor value is also calculated for which the formula is as follows:

$$C = \frac{D}{Ro * fs * \frac{\Delta Vout}{Vout}}$$

For this calculation, the $\Delta Vout$ is the output ripple and Ro is the output load resistance along with the other variables being the same as the other formulas. At the end of the design and calculations, we obtained our values for the duty cycle, inductor, and capacitor values. For the duty cycle, we obtained a 26% duty cycle. The inductor value was calculated to be 126uH, but an inductor of 130 uH was chosen to get a fixed inductor. The capacitor was calculated to be 37uF. These values will be used in the boost converter which will be connected to the MPPT algorithm.

4.3.2 Boost Converter at Solar Panel Simulations

Once the design and calculations were developed, we proceeded with the simulations on Simulink in which we were able to obtain and use a variety of different inputs such as the temperature and the irradiance. These components of the Simulink will determine the output from the simulation. The values for these will determine the output from the simulation.

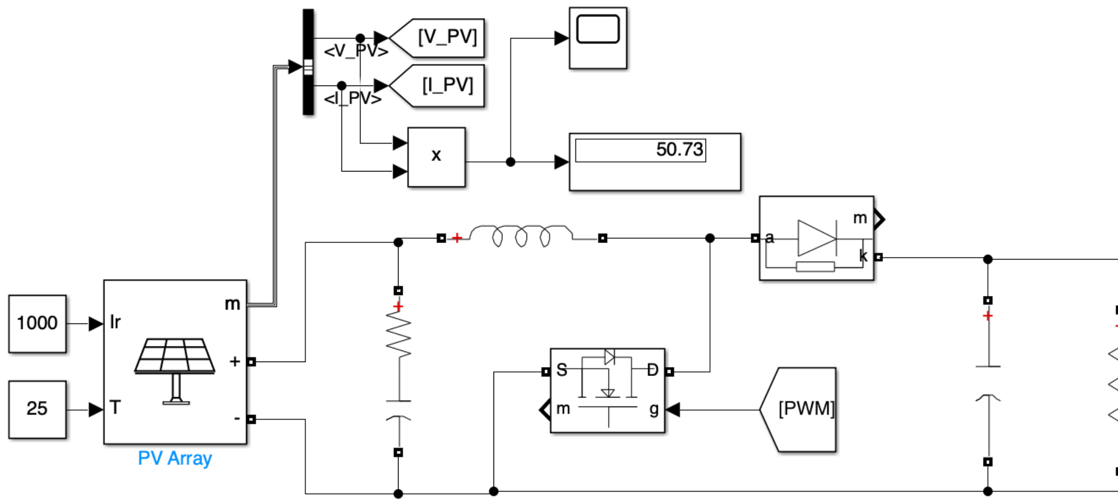

Figure 4.4 Simulink Simulation for Boost Converter with Maximum Power Point

Figure 4.4 is showing the Boost converter simulation on Simulink in which we were able to implement the MPPT algorithm. The figure shows that under ideal conditions, which are 1000 irradiance and 25°C temperature, the maximum power point is achieved. The power displayed is shown to be 50.73W. This is what was expected from the simulation as the panel is rated for this output power under the conditions. The simulation shows how the system would be connected. For this part of the project, the PWM labeled MPPT algorithm, which, again, will increase the power output from the PV system. It is important to note that our solar panels are connected in parallel which will be giving us the 50W output that is needed. The parameters from doing this were inputted into the PV array component on the simulation.

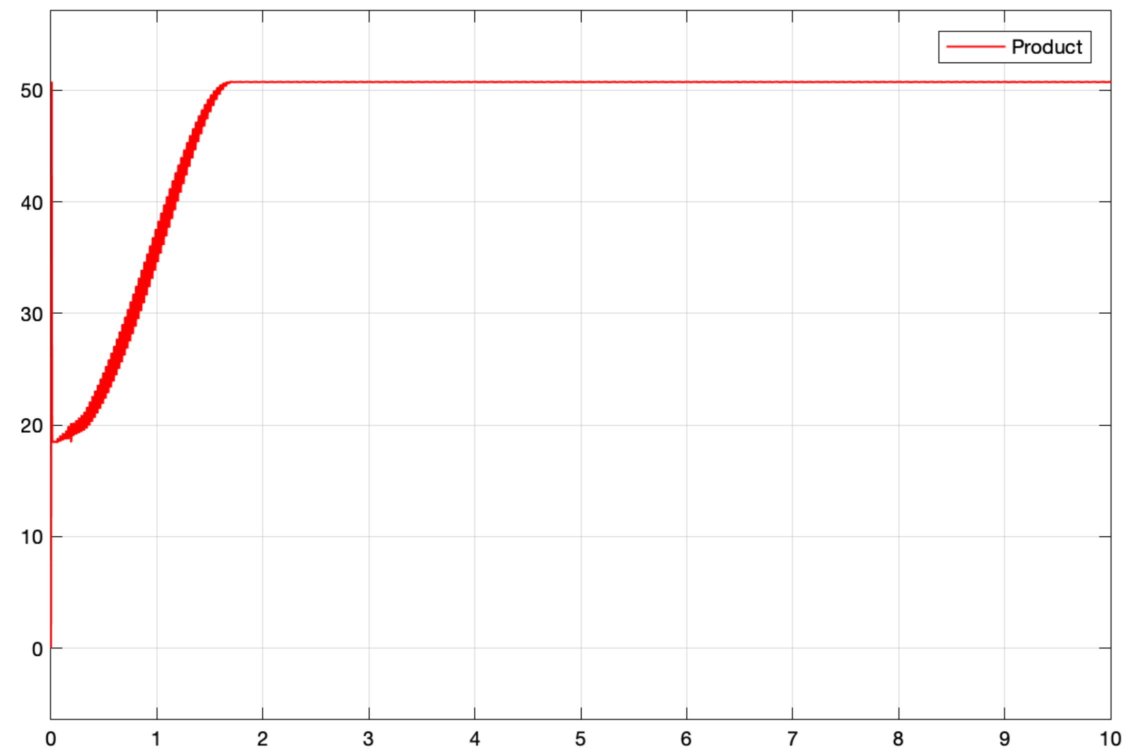

Figure 4.5 Simulation of Boost Converter w/ MPPT under Ideal Conditions

In Figure 4.5, we are able to see the MPPT algorithm at work. We are also able to see how the algorithm is working rigorously. At the start of the simulation, we can see the initial power from the PV system. With the implementation of the MPPT, we are able to see the power increasing over time. This graph is in relation to Figure 5.5, in which the conditions are considered ideal with the 1000 irradiance and 25°C temperature. We are able to observe that over time, the power increases. However, it is important to note that in application, the conditions are always changing which means that the controller will always be changing the power output.

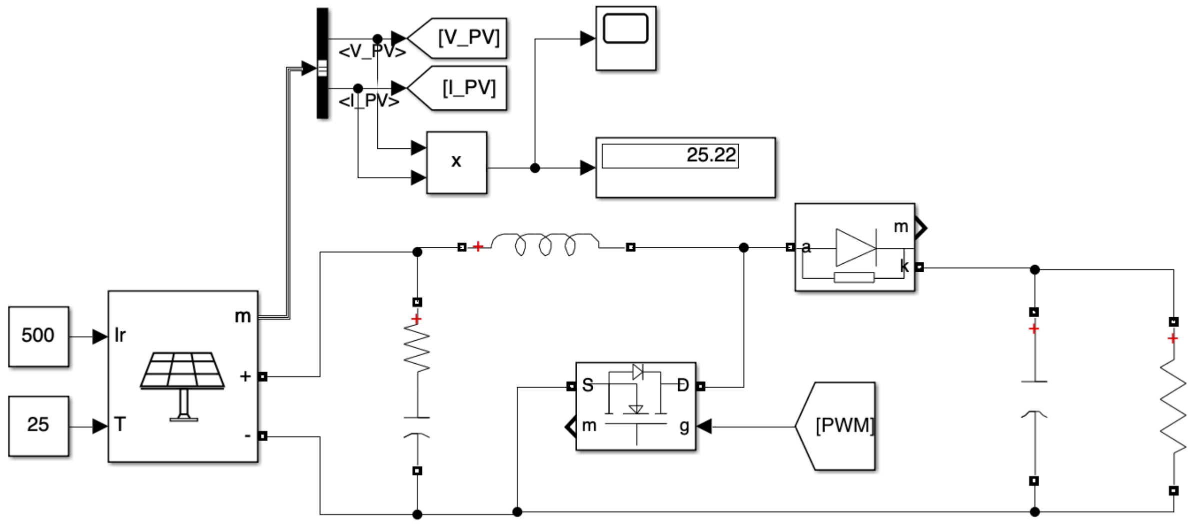

Figure 4.6 Simulink Simulation for Boost Converter with 500 Irradiance

In Figure 4.6 it shows the Boost converter simulation on Simulink with MPPT. However, it is showing the maximum power being achieved with the following conditions: 500 irradiance and 25°C temperature. The power displayed is shown to be 25.22W. This is what was expected from the simulation as the panel is rated for this output power under the conditions. The simulation shows how the system would be connected. For this part of the project, the PWM labeled MPPT algorithm, which, again, will increase the power output from the PV system. It is important to note that our solar panels are connected in parallel which will be giving us the 50W output. The parameters from doing this were inputted into the PV array component on the simulation.

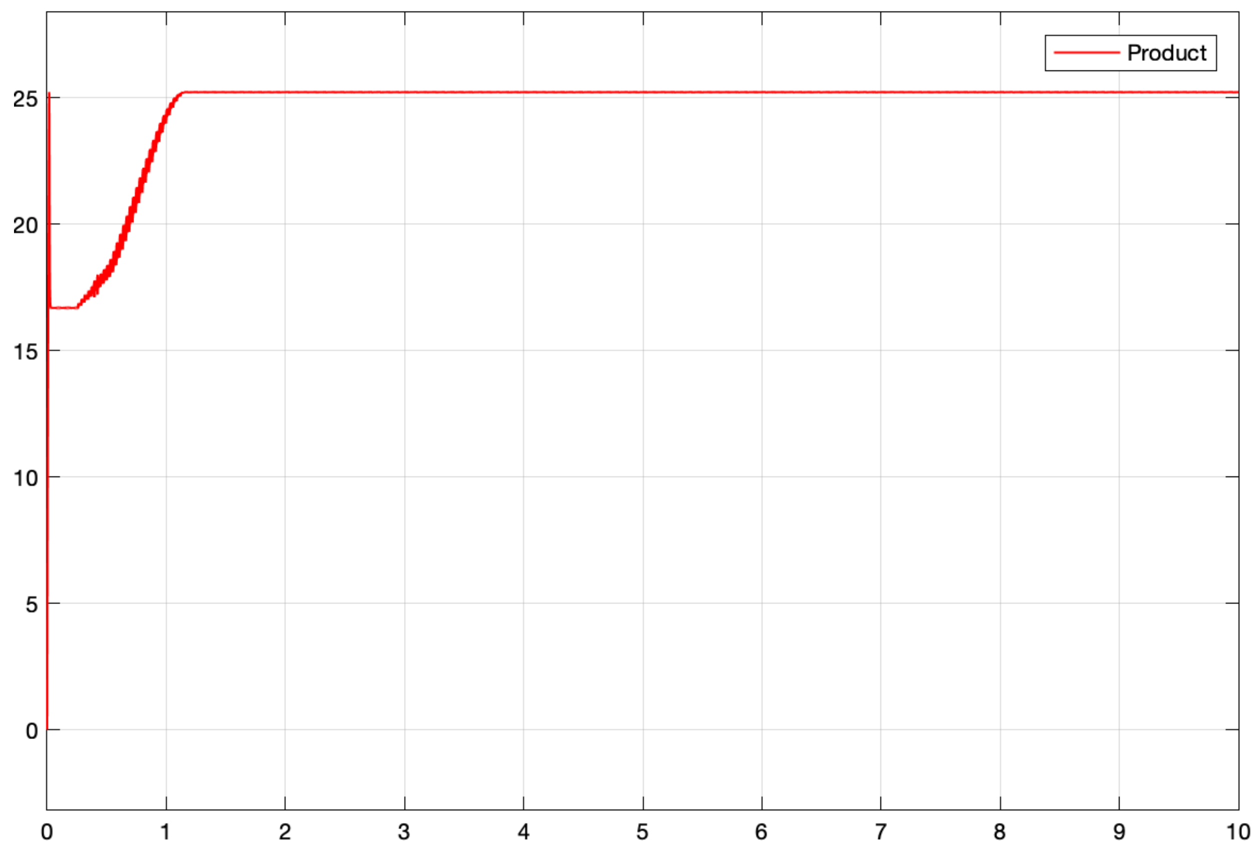

Figure 4.7 Simulation of Boost Converter w/ MPPT under Non-Ideal Conditions

In Figure 4.7, we are able to see the MPPT algorithm at work. We are able to see how the algorithm is working rigorously under non-ideal conditions. At the start of the simulation, we can see the initial power from the PV system. With the implementation of the MPPT, we are able to see the power increasing over time. This graph is in relation to Figure 5.7, in which the conditions are considered ideal with the 500 irradiance and 25°C temperature. We are able to observe that over time, the power increases.

4.3.3 Boost Converter at the Battery Calculations

The same formulas and processes done in section 4.3.1 were done for this section as well.

4.3.4 Boost Converter LTSpice Simulations

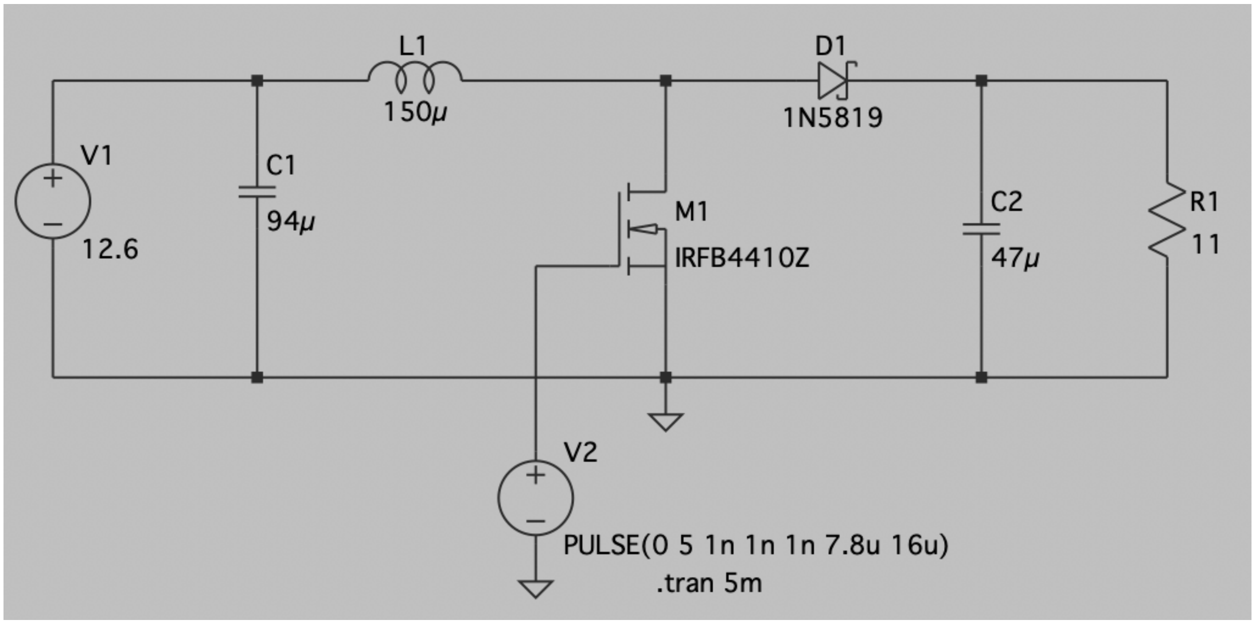

Figure 4.8 Boost Converter at the Battery LTSpice Schematic

The Boost Converter Figure 4.8 is for the battery side of the system. As shown, the input, which is the battery, has a voltage of 12.6V. This will be stepping up to 24V. The initial plan was to use a bidirectional converter as the form of discharging the battery, but we are unable to fulfill this converter. So, the team decided to use the boost converter as a form of discharging.

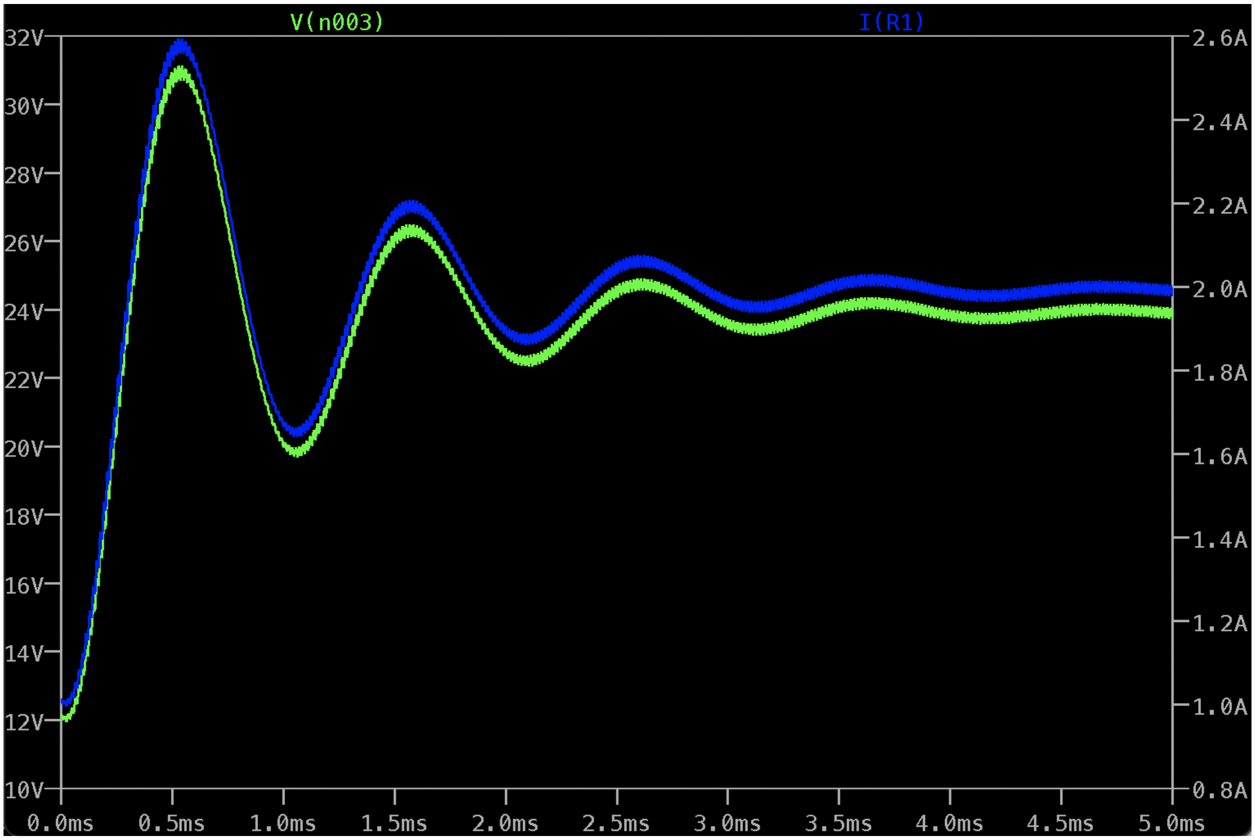

Figure 4.9 Boost Converter at the Battery LTSpice Simulation

Figure 4.9 shows the simulation output results for both the voltage and current. From the simulation, we can see that the output power is approximately 50W. This is due to the load used for efficiency verification.

4.3.5 AC/DC Converter with Voltage Regulator Calculations

For the AC/DC converter, it consists of a full-wave rectifier, filter & bleeder resistor, voltage regulator. The voltage regulator uses an input voltage of 34V which is the voltage from the transformer. The transformer is a 24V(AC) transformer. However, a 12V(AC) transformer will work as well.

The design of the power supply is done using the formulas below which is used for the full-wave rectifier, filter & bleeder resistor, and voltage regulator. The full-wave rectifier and filter & bleeder resistor is done using the following formula:

$$V_{nominal} = 1.414V_s - 2V_d$$

$$V_{nominal} = V_{in} + V_{ripple}$$

For the voltage regulator, we are using the LM317 voltage regulator. This is an adjustable voltage regulator that will be used to charge the battery. The formulas used are as follows:

$$V_{out} = 1.25V * (1 + \frac{R2}{R1})$$

$$I_{out(short)} = \frac{1.25V}{RS}$$

These calculations were done to satisfy the requirements to charge the battery. The voltage output was calculated for 14V in which the resistor values were used to determine the 14V.

4.3.6 Parallel Boost Converter Simulations

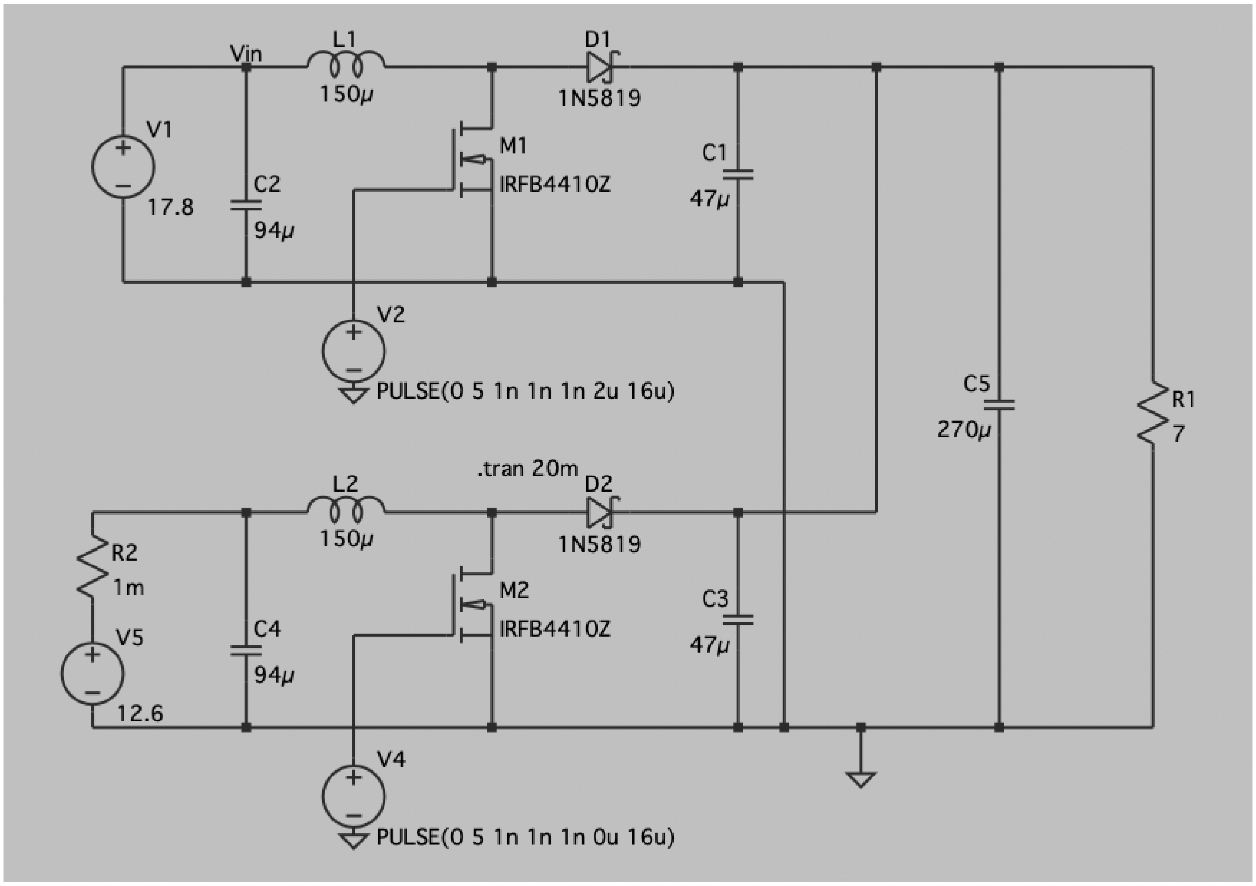

Figure 4.10 Boost Converters in Parallel LTSpice Schematic Panel Side "Active"

Figure 4.10 shows the boost converter configuration in parallel which is how the converters are configured in the system. This condition shows when the solar panel is satisfying the load, this is with the maximum voltage and current output. However, it is important to note that the load will not always be a 50W requirement. For the purpose of this project, we will be using a suitable load that will not be in excess of what the input provides.

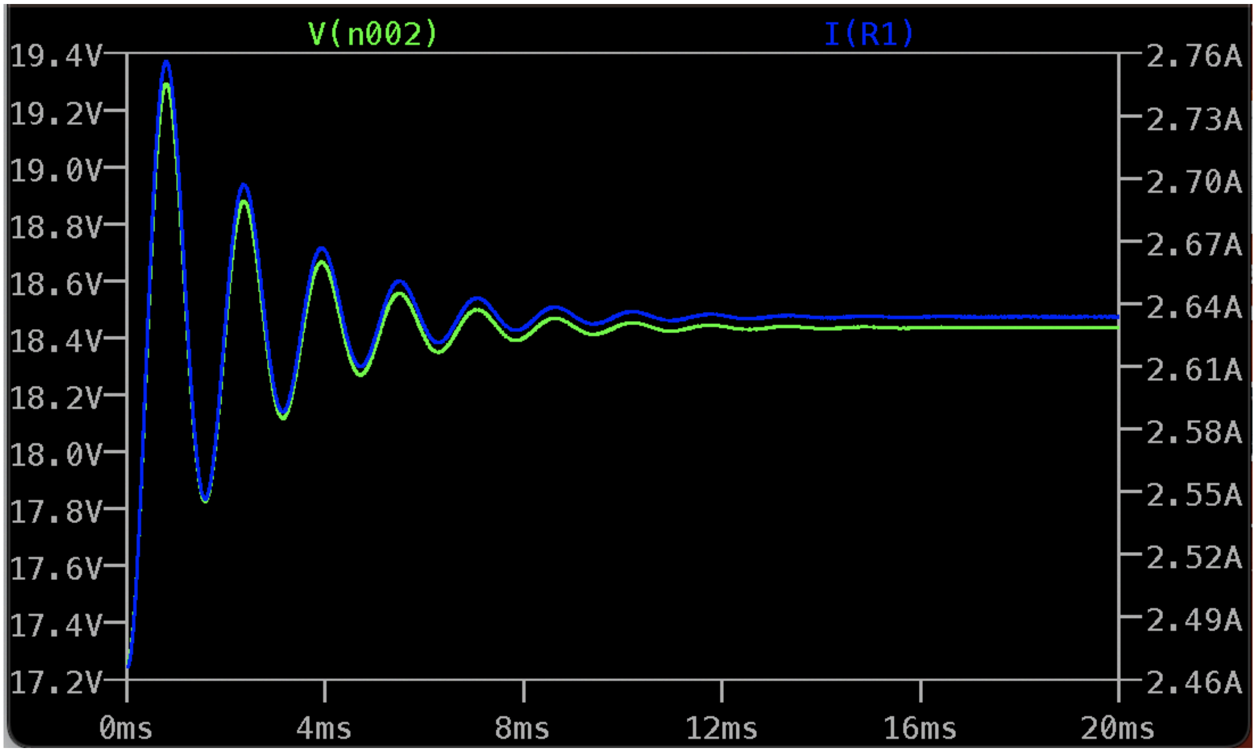

Figure 4.11 Boost Converters in Parallel LTSpice Simulation Panel Side "Active"

Figure 4.11 shows the simulation for the schematic in Figure 4.9. As shown in Figure 4.9, the boost converter at the battery(bottom converter) has a duty cycle of 0%

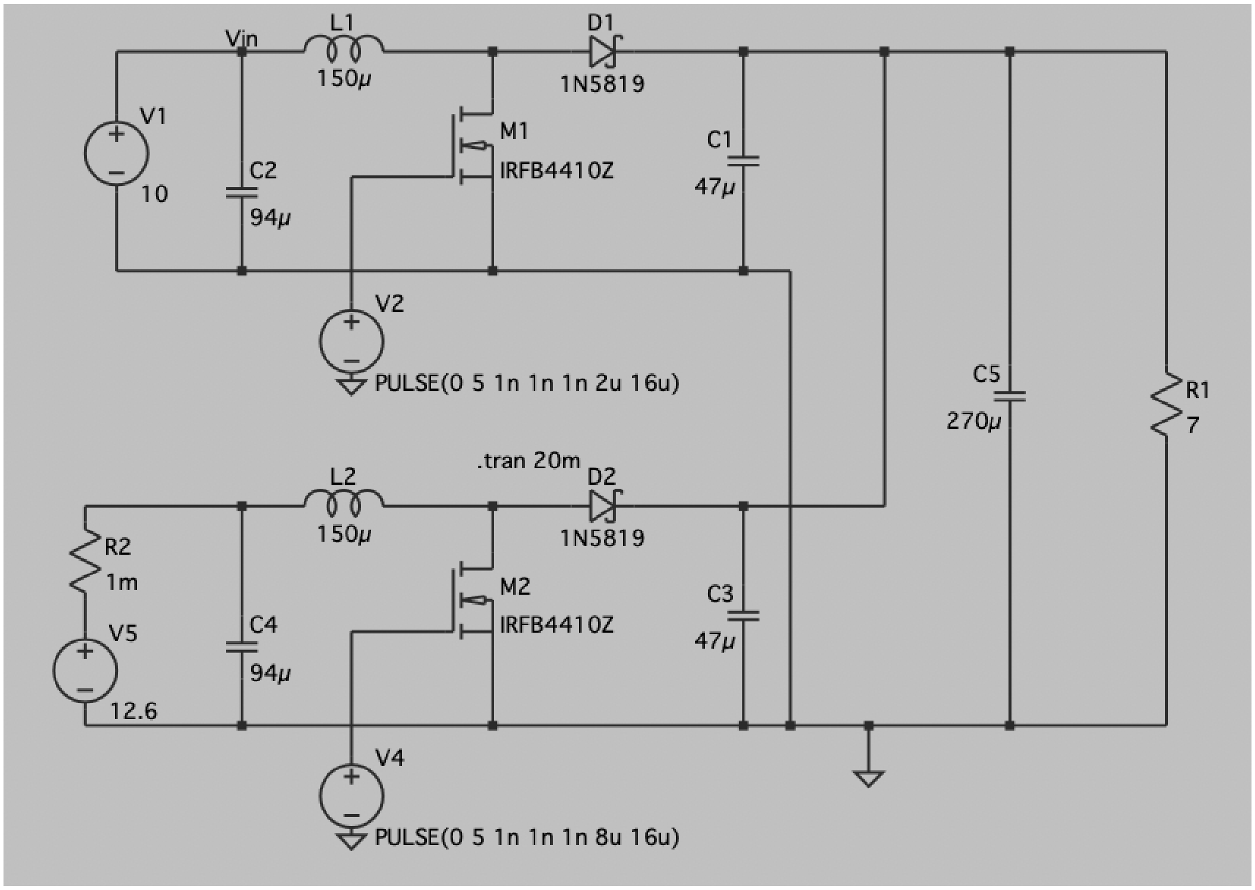

Figure 4.12 Boost Converters in Parallel LTSpice Schematic Battery Side "Active"

Figure 4.12 shows the same boost converter configuration in parallel as shown in Figure 4.9. This condition shows when the solar panel does not satisfy the load. In this scenario, the solar panel is producing approximately 17W while the boost at the battery is producing enough power to satisfy the load. However, it is important to note that the load will not always be a 50W requirement. For the purpose of this project, we will be using a suitable load that will not be in excess of what the input provides from the solar panel side.

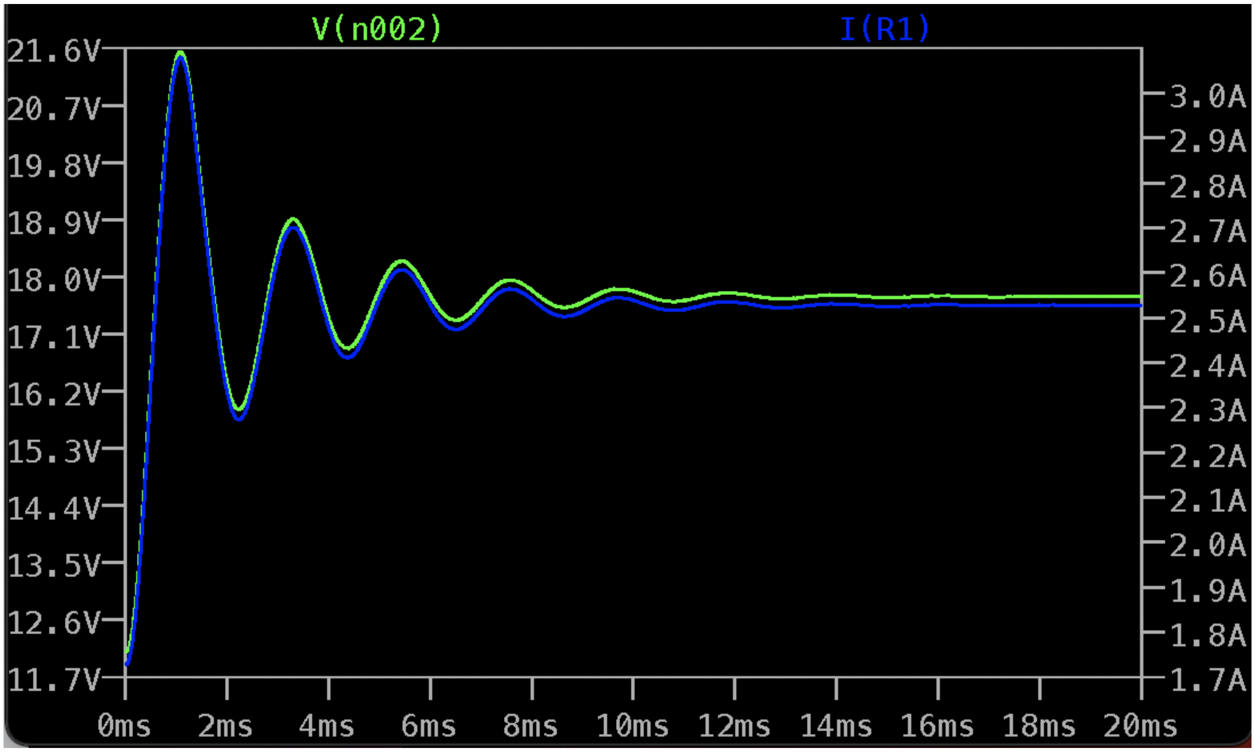

Figure 4.13 Boost Converters in Parallel LTSpice Simulation Battery Side "Active"

Figure 4.13 shows the battery side active when the solar panel is not able to fulfill the load. The battery will act only when the load is not satisfied, reasons for when this can happen is when the irradiance is not its most optimal state.

4.4 MPPT Controller

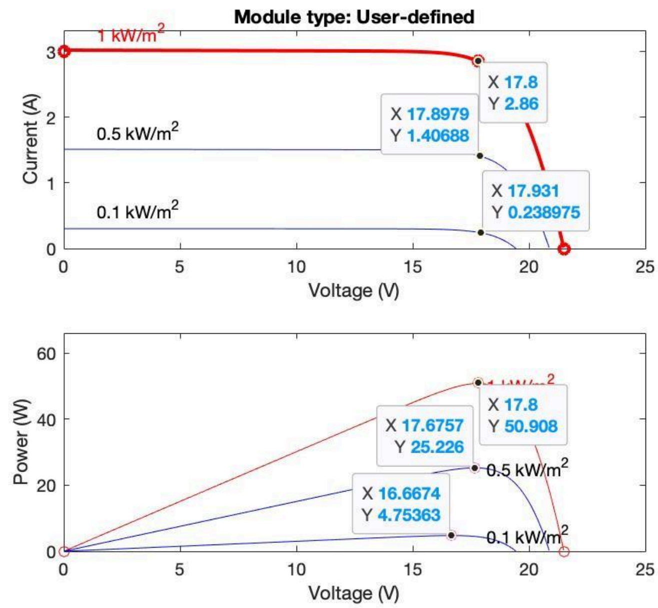

Figure 4.14 Maximum Power Point Tracking Graph for 50W PV System

Figure 4.14 shows the maximum power point from the solar panels that are being used. Since we are using two 25W solar panels in parallel to achieve 50W desired, the parameters were configured to show this happening. As shown in the graph, the irradiance is 1000 and the voltage and current is 17.8V and 2.86A respectively. This equates to 50.9W, which is also shown. The output power differs when the conditions change as see when the irradiance changes. At 1000 irradiance, the output power is shown to be 50.908W and when the irradiance is 500, the output power is shown to be 25.226W.

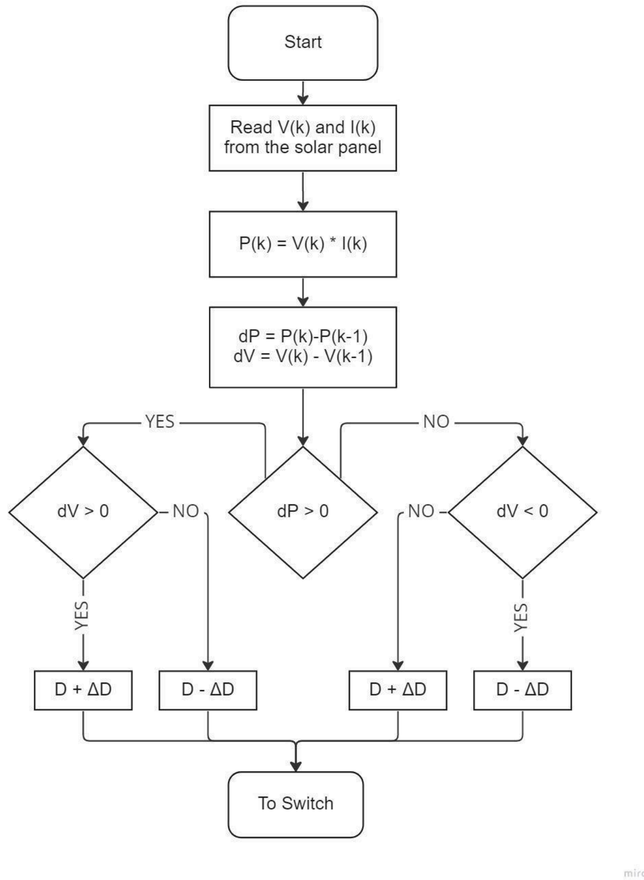

Figure 4.15 Maximum Power Point Tracking Flowchart for MPPT

Figure 4.15 shows the MPPT algorithm which will be used to change the power output from the PV system to its maximum power. The algorithm allows us to change the power even with varying conditions such as the temperature and irradiance. The algorithm will change the PWM according to the data that is being sent from the sensors to the Arduino.

4.5 Battery Controller

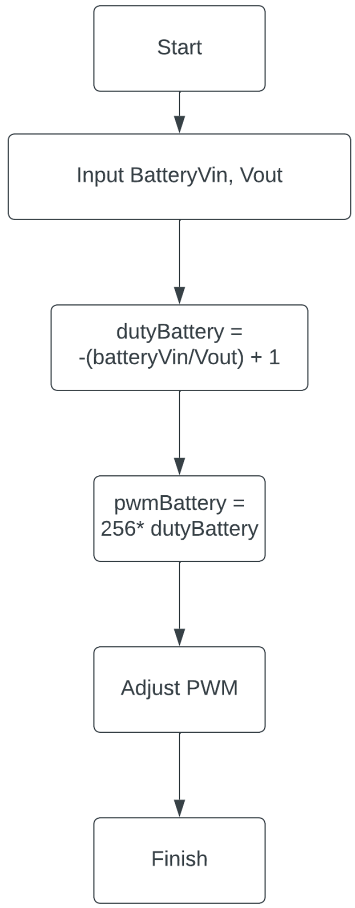

Figure 4.16 Battery Controller Flowchart

Figure 4.16 shows the flowchart for the controller of the boost converter at the battery which would be regulated at 17.8V. The purpose of this code is for when the load needs to be satisfied. This is when the panel is not producing sufficient power to satisfy the load.

4.6 Mobile Application

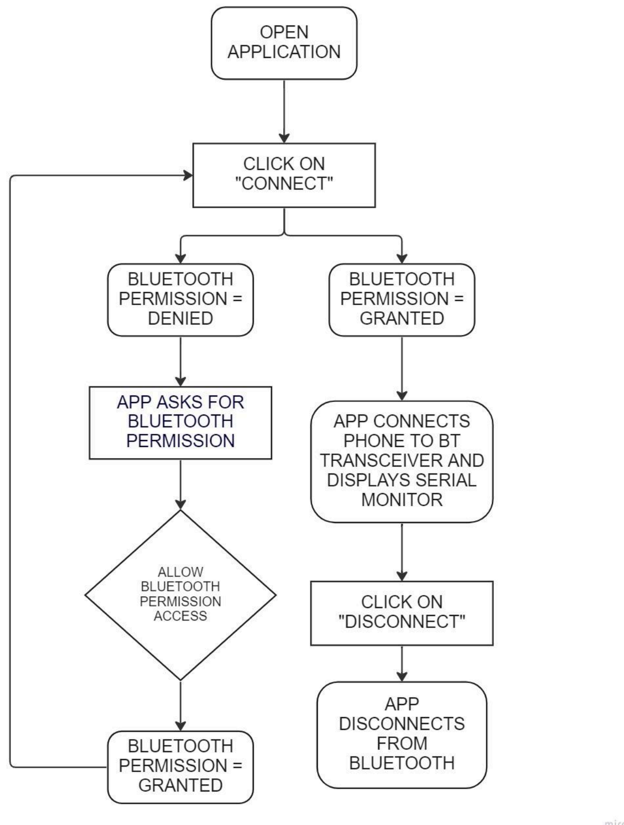

Figure 4.17 Flowchart for the Mobile Application

In Figure 4.17, we can see the flowchart for the mobile application. Upon opening the app, there is a two-second splash screen which transitions the user to the main information screen, where there are two buttons at the top of the screen. One button prompts the user to connect to the previously paired Bluetooth device. If the user has not already granted the application permission to access Bluetooth and nearby devices, the application will prompt the user to do so. If the user has already granted the app permission to use Bluetooth, the application will automatically connect to the Bluetooth device. In this case, it will be the HC-06 Bluetooth transceiver, which can be, and has been, renamed to “MicRoGV”. Once the user clicks on the

"Connect" button to pair with the Bluetooth device, the application connects to the device, and displays live data from the Arduino. The connection to the device will be lost once the mobile application is closed or the "Disconnect" button is clicked. Every time the user connects or disconnects, a Toast message pops up detailing that. It also displays errors if it can't connect.

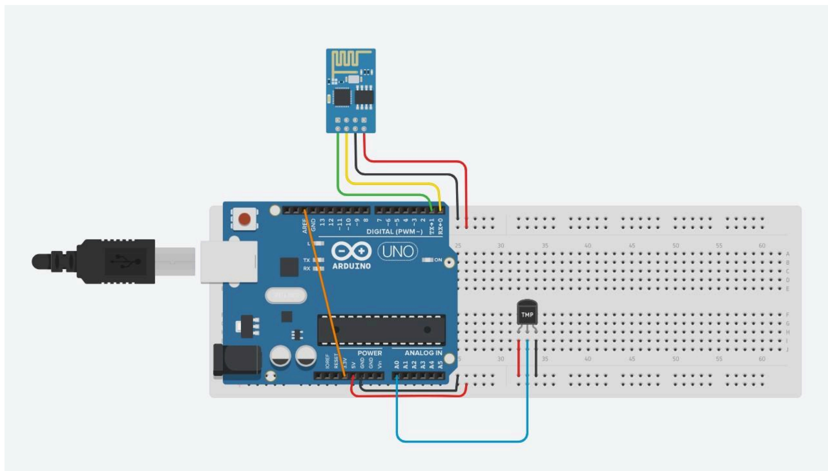

Figure 4.18 Connection Design for HC-06 and Temperature Sensor

The data being sent from the serial monitor to the application is controlled through the Arduino IDE. The Arduino is programmed to send the HC-06 Bluetooth transceiver specific data and can vary from the data being sent to the serial monitor on the computer. It is shown in Figure 4.18 how the connections are set up for both the HC-06 Bluetooth transceiver and the analog temperature sensor that was previously a stand-alone circuit, but is now connected to the voltage and current sensors that gather data from the PV system. The data gathered from the temperature sensor is in volts and the Arduino program translates the voltage into temperature in both Celsius and Fahrenheit, which then proceeds to display the information to the serial monitor on the computer. The data can also be outputted through the Bluetooth device, so it can then be used to send the data to the serial monitor of the application on a mobile device.

4.7 Mobile Application UI

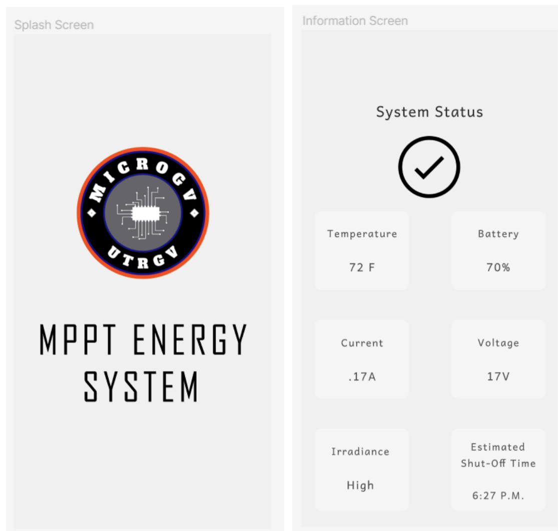

Figure 4.19 Figma Design for the Mobile Application

Figure 4.9 shows the Figma design for the mobile application. Before showing the data, the user must first connect to the HC-06 Bluetooth transceiver. Once connected, the app will show the live data from various sensors from the Arduino in a user-friendly and aesthetically pleasing fashion. This is intended to provide the user with a seamless experience to prevent an overload of information. The app constantly updates the information at intervals to continue supporting the intuitive experience.

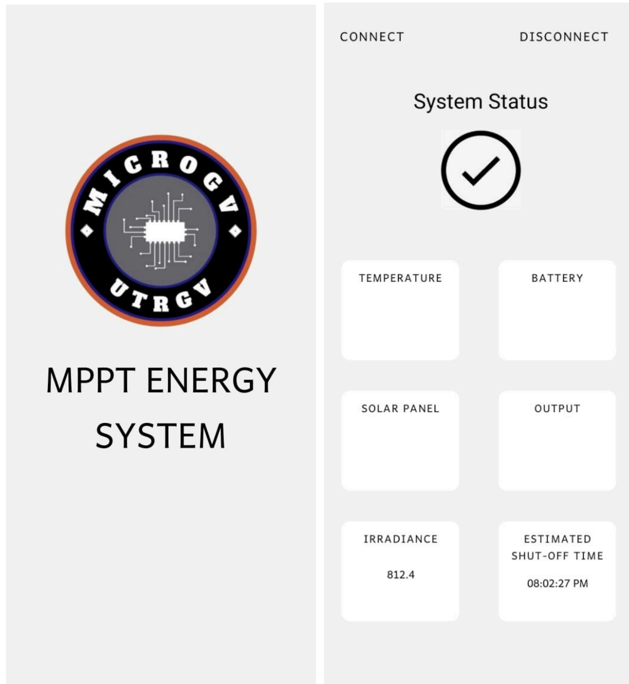

Figure 4.20 Current UI for the Mobile Application

Currently, as seen in Figure 4.20, the application is functional. Additionally, the HC-06 Bluetooth transceiver has been renamed to "MicRoGV" and is the only device that can connect to the app. Anything that is being displayed in the serial monitor can be sent to the application and can be shown under the corresponding and appropriate section. The application is coded in Java and uses Android Studio as well as XML. This choice of programming language was chosen due to its intuitive flexibility, ease of use, and mobile app connectivity with Arduino.

The current and voltage sensor data being displayed is accurate with a small percent error which can be corrected with simple rounding techniques. However, the temperature data falls short in terms of accuracy. There possibly can be multiple reasons as to why this occurs, but one probable reason is that the quality of the sensor results in an in-accurate reading when converting the voltage to celsius and fahrenheit.

For the estimated shut-off time, the sunrise and sunset times are determined using an API. The API call is currently hardcoded to Brownsville, Texas. The data gathered from the API call is in the Universal Time Zone. However, the needed time is in the Central Time Zone. Code was added to change the time zone as well as modifications so that the functions would take daylight savings into account. The final value was then set as a variable that is then displayed under the "Estimated Shut-off Time" section on the app. The reasoning behind using the time of sunset as the estimated shut-off time is because at that time, the PV system will have its last opportunity for sunlight to target the solar panels to extract energy before the sun will eventually set, resulting in no sunlight. The goal would be to have this update daily as sunset timings vary based on geographic location and time of year. Additionally, past sunset, the application displays the sunrise time for the following morning and the name of the sections changes to "Estimated Start-up Time".

For the irradiance, a separate API call is made that gathers the data. This API call was also made specifically for Brownsville, Texas. Prior to knowing what the API call would display, the Figma design showed "High" under irradiance, however that was not the case. Although the the "Irradiance" section could easily display "High", "Medium", or "Low" with a simple if else statement, the team felt that it was not enough information, nor would it be very valuable if only "High", "Medium", or "Low" were displayed.

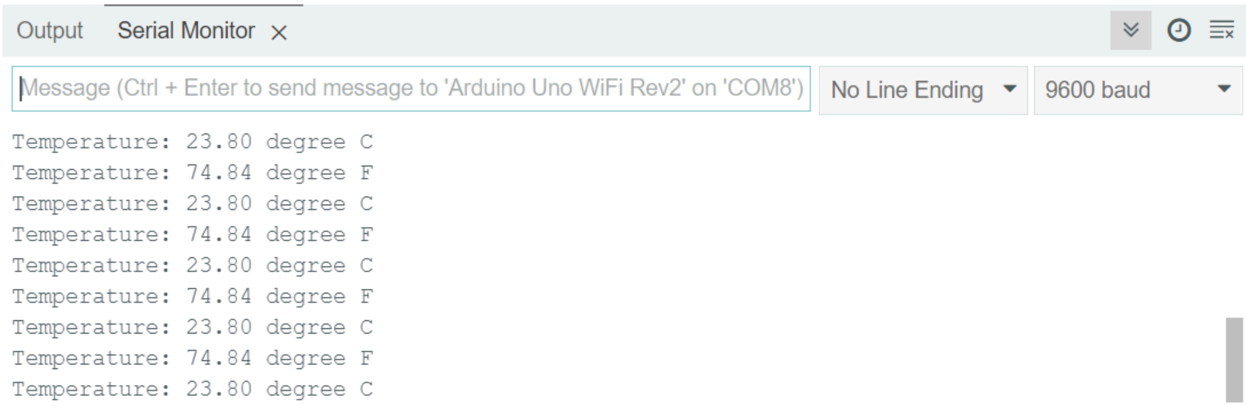

Figure 4.21 Serial Monitor for Arduino

The serial monitor on the Arduino IDE displays the data of the temperature sensor as seen on Figure 4.20. The mobile application should show the same data or relative values as the Arduino IDEs serial monitor. Since there are two Arduinos connected to the project, the data sent to the application can be compared to the data shown on the Arduino Mega that is also connected to the same voltage and current sensors. For the purposes of the project, the Arduino Mega is connected to a laptop, so the gathered values are displayed on the Serial Monitor and can be compared to the data displayed on the application. However, in practice, both Arduinos would be connected to a 9V battery and all of the data would be strictly shown on the application only.

5. Final Design and Test Results

5.1 System Components

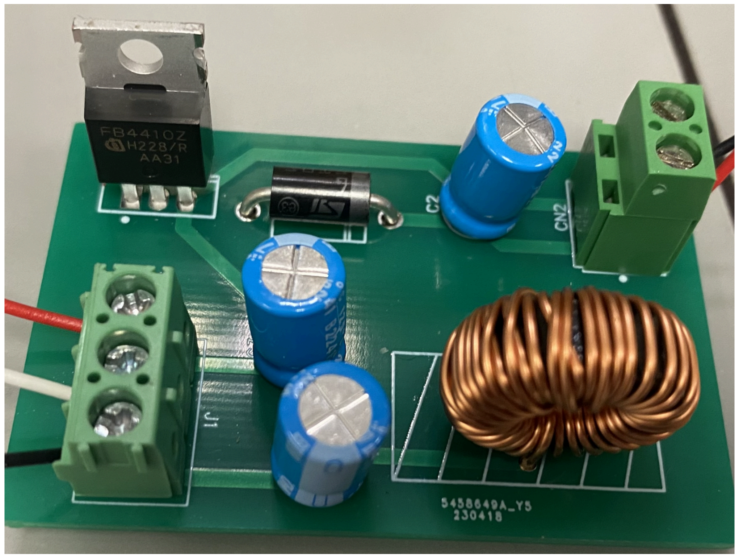

Figure 5.1 Boost Converter PCB

Figure 5.1 shows that the boost converter PCB is complete and functional with an approximate efficiency of 90%. The boost converter is a classic configuration with a MOSFET, diode, inductor as well as capacitors. Not seen is the presumed load as well as where the input source would be coming from which in this case would be the solar panels that are being used. The boost converter circuitry has been designed and optimized for maximum power point tracking (MPPT) to extract the maximum power output from the solar panel under varying conditions.

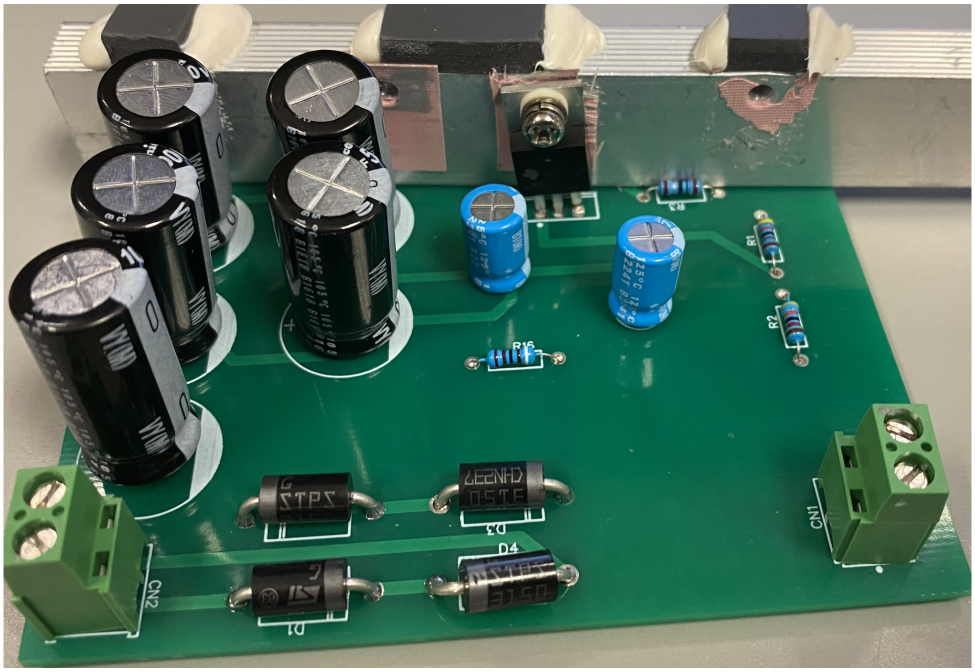

Figure 5.2 AC/DC Converter with Voltage Regulator PCB

Figure 5.2 shows the AC/DC with voltage regulator PCB design which will be the charger for the battery. We are using an AC/DC converter and a voltage regulator which consists of a full-wave rectifier, filter & bleeder resistor, and voltage regulator. The voltage regulator is set to put out 13V this is to charge the battery with an approximate 1.25A short circuit current output.

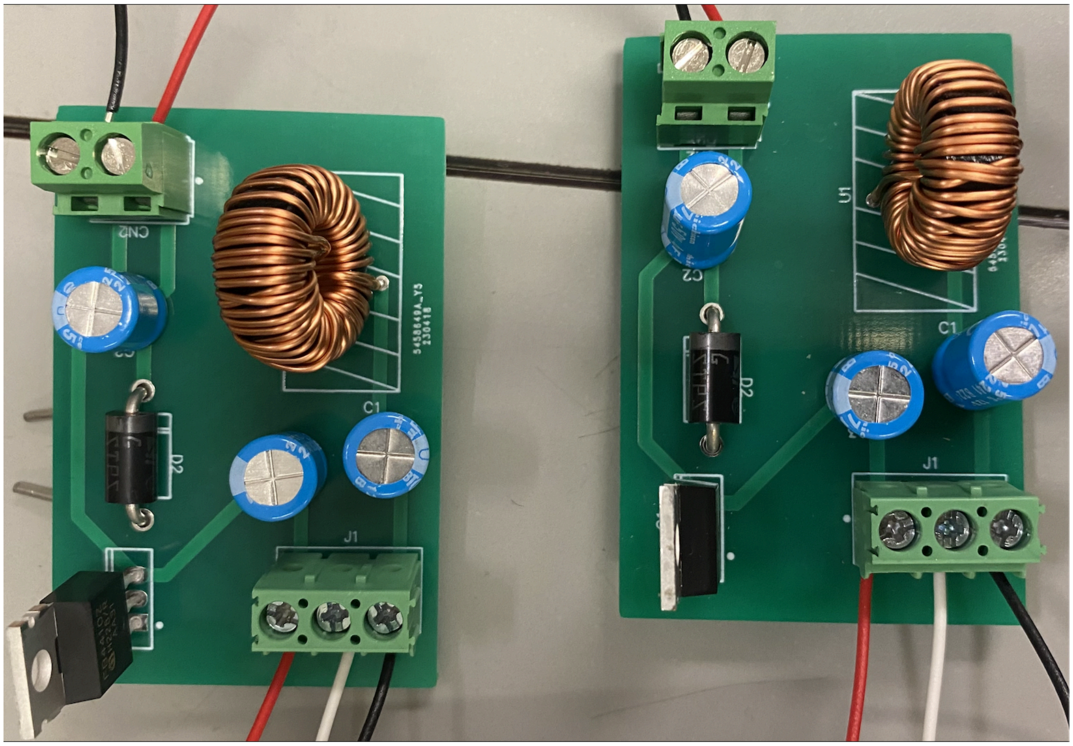

Figure 5.3 Parallel Boost Converters

Figure 5.3 shows the boost converters in parallel being used in the system. These converters will be using as their inputs solar panels and a battery for these outputs we are using loads which will be discussed later. To ensure an efficient system, the converters were designed to handle the varying input voltages from the solar panel and the battery. The MPPT controller plays a crucial role in ensuring the boost converters operate at their maximum efficiency by tracking the maximum power point of the solar panels. In addition, the boost converters are connected in parallel to meet the power demands of the loads. This design ensures that the system is scalable, allowing additional loads to be added without affecting the performance of the existing loads.

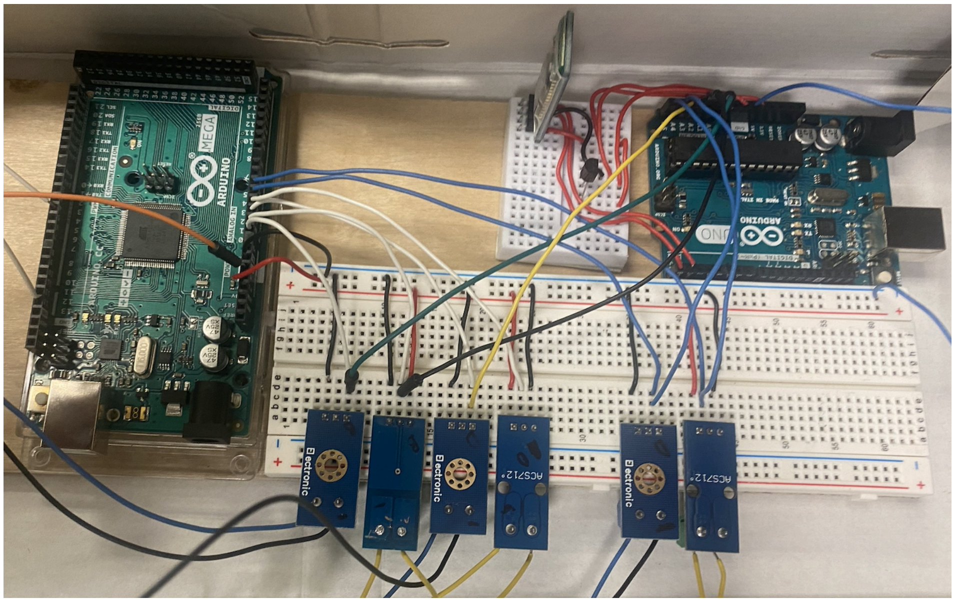

Figure 5.4 Arduino Setup with Sensors

Figure 5.4 shows the Arduino setup which includes the sensor connections along with the Bluetooth module. The Arduino setup includes the necessary components to communicate with the mobile application. The mobile application is designed to display the data collected by the sensors in a user-friendly application. the Arduino setup also includes the necessary code for the MPPT controller and the voltage regulator. Overall, the Arduino setup plays a crucial role in the system by collecting data from the sensors, controlling the MPPT and voltage regulator algorithms, and communicating with the mobile application.

Figure 5.5 Solar Panel and Battery Input Sources

Figure 5.5 shows the input sources that we are using which include the solar panels and the battery. The solar panels are the input at one side of the boost converters while the battery is the input of the other converter. The solar panels are connected in parallel to provide the necessary voltage and current to the system. These input sources provide the necessary energy to the system which is then converted and regulated by the boost converters. The efficient management of these input sources is crucial to the overall performance and sustainability of the system.

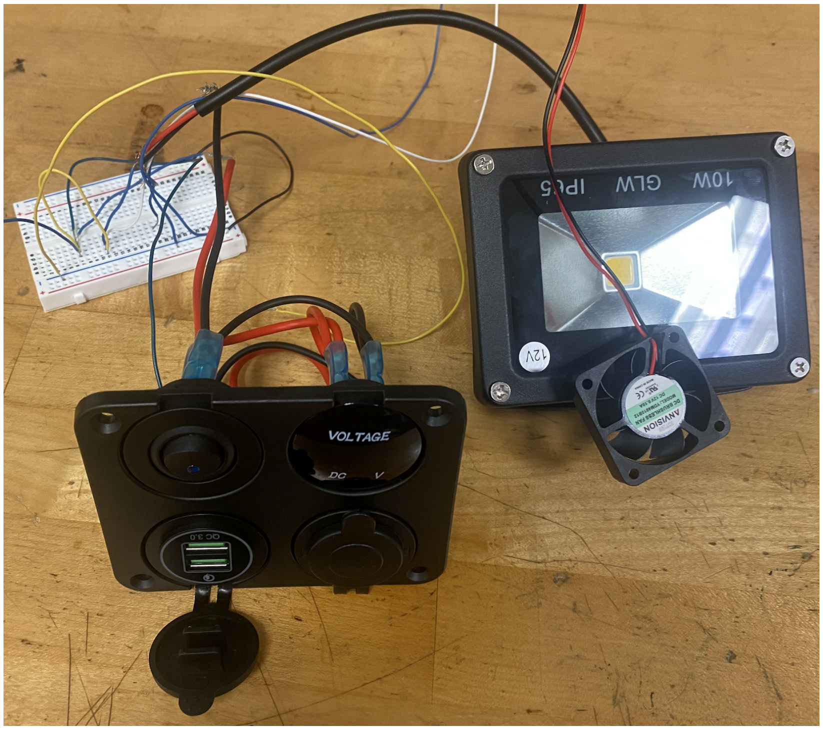

Figure 5.6 Loads

Figure 5.6 shows some of the loads that we are using for the system. Here, we see a DC LED light, a DC charger panel, and a small fan. It is important to note that any DC loads will work in our system. To further enhance the system, additional loads can be added based on the requirements of the user. These could include devices such as DC water pumps, DC refrigerators, and DC air conditioners, making it a versatile and efficient power source for various applications. The system is designed to handle different loads, and the MPPT algorithm will adjust the system accordingly to optimize the output power. The ability to handle different loads makes it a great solution for both residential and commercial applications, providing an environmentally friendly and cost-effective power source.

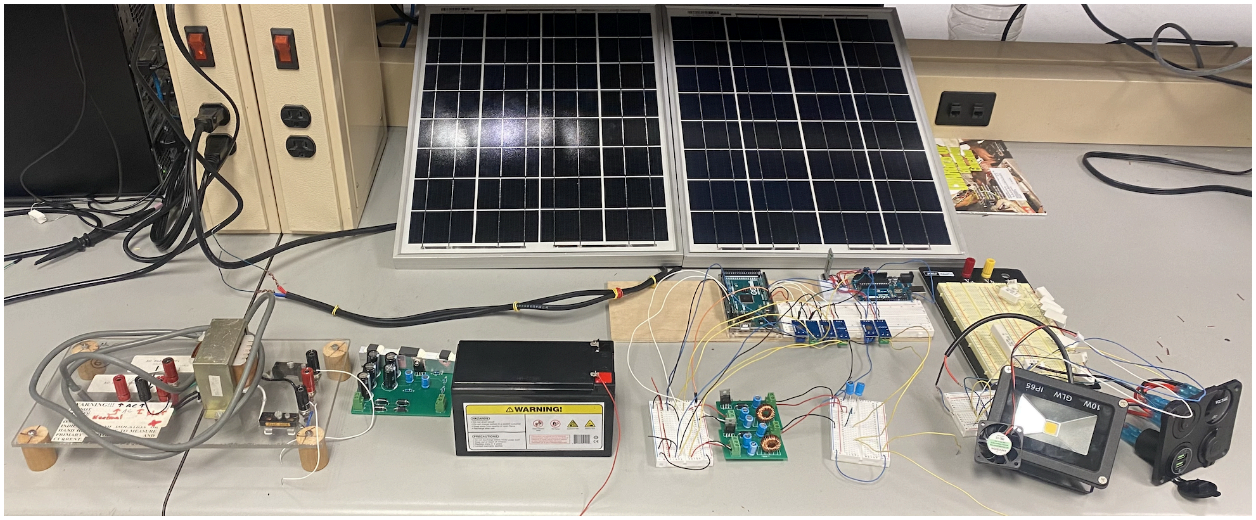

Figure 5.7 Entire System

Figure 5.7 shows the entire system together, with our input sources, converters, loads as well as a transformer which is our input of the AC/DC converter. The transformer can either be a 120V(AC) to 12V(AC) or 24V(AC) converter. The AC/DC converter will convert the AC voltage from the transformer into DC voltage which is then regulated by the voltage regulator. The regulated voltage is then fed to the battery to charge. This complete system is designed to ensure efficient power management and optimization of energy from renewable sources.

5.2 Testing

Table 5.1 Boost Converter at the Solar Panel Unit Test

Duty Cycle %	Input Voltage	Input Current	Input Power	Output Voltage	Output Current	Output Power	Efficiency
20%	17.8	2.65	47.17	19.6	2.17	42.53	90.16%
25%	17.8	2.7	48.06	20.9	2.08	43.47	90.45%
30%	17.8	2.8	49.84	22.3	2.02	45.05	90.39%
35%	17.8	2.84	50.55	23.9	1.9	45.41	89.83%

Table 5.1 shows the unit test for the boost converter on the solar panel side. This unit test was conducted to ensure that it meets the performance requirements. The test was performed using a power supply to simulate the maximum input rating of the converter. The test results were recorded and analyzed to determine the efficiency of the converter at maximum load. The test results were used to identify any potential issues or limitations of the converter, allowing for any necessary adjustments to be made to the system design. Overall, the unit test played a crucial role in ensuring the overall performance and reliability of the boost converter in the system.

Table 5.2 Boost Converter at the Battery Unit Test

Duty Cycle %	Input Voltage	Input Current	Input Power	Output Voltage	Output Current	Output Power	Efficiency
20%	12.6	1.35	17.01	13.90	1.11	15.29	89.89%
25%	12.6	1.53	19.28	14.73	1.18	17.38	90.14%
30%	12.6	1.73	21.80	15.70	1.25	19.63	90.05%
35%	12.6	1.99	25.074	16.75	1.34	22.45	89.53%

Table 5.2 shows the unit test for the boost converter on the battery side. This unit test was done for this converter as well to ensure that it meets the performance requirements. The test was performed using a power supply to simulate the maximum input rating of the converter. The test results were recorded and analyzed to determine the efficiency of the converter at maximum load. The test results were used to identify any potential issues or limitations of the converter, allowing for any necessary adjustments to be made to the system design. Overall, the unit test played a crucial role in ensuring the overall performance and reliability of the boost converter in the system.

Table 5.3 AC/DC Converter with Voltage Regulator at the Battery Unit Test

Time Charged	Open Circuit Voltage Before	Open Circuit Voltage After
0 Minutes	12.590	12.590
1 Minutes	12.590	12.591
5 Minutes	12.591	12.593
10 Minutes	12.593	12.609

Table 5.3 shows the data for the charging of the battery using the AC/DC converter with a voltage regulator.. As seen in the table, the voltage increases after some time of charging. By no means is this charger meant to be charged at a fast rate. However, it does charge the battery as needed.

Table 5.4 Acceptance Test using System and Mobile Application

Status of Solar Panel	Status of Battery	Output Voltage	Output Current	Load Status
Disconnected	Disconnected	0V	0V	OFF
Covered	Disconnected	8V	0V	OFF
Uncovered	Disconnected	15.76V	0.69	ON
Uncovered	Connected	14.76	0.75	ON

Table 5.4 shows the acceptance test on the system. The table shows the status of the solar panel and the battery. For example it shows whether the battery is connected/disconnected or in the case of the solar panel, covered/uncovered as well. This was tested in outdoor conditions while using the mobile application, based on what was observed.

6 ABET Criteria

6.1 Economic

With the initial cost in any project always being substantially more than the final product cost, the final cost should cost at most $300. In a realm where the system is being produced for the public, labor costs may not be extensive once this system is mass produced and better manufacturing processes are developed to help bring manufacturing costs down. Equipment costs for the components will most likely go down once manufactured in bulk as well as smaller components being implemented in the design using PCB design technology and other manufacturing methods. There is almost no operating cost involved in this energy management system. Service and maintenance costs are most probable to impact the economics related to the project. As there are various components and circuitry used in this system, it would be naive to assume this system is free from any servicing of parts due to normal wear and tear. It is highly likely that maintenance will drive the cost of having this system assuming that there are some parts of this system that may need replacement or servicing when needed, requiring labor and parts fees that the consumer would have to face.

6.2 Environmental

With our project being an energy management system, the use of a photovoltaic system is used due to it being a renewable energy source. However, there are several environmental constraints that this project can produce. Another environmental constraint to the project could potentially be the temperature range for operations. While a cooling mechanism can be implemented in this system, it is possible that at high temperature, the operation of the energy management system can be seized due to overheating of MOSFETS and heatsinks. As iterated before, the system will mostly have its components in a box. But in operating conditions that are not ideal like high temperature environments, it can possibly overheat if a proper cooling system is not implemented.

6.3 Sustainability

The PV system has low emissions due to its renewable energy source. The system provides a clean energy solution that is able to provide the necessary power to a load. There are potential sustainability constraints to this project. The first is the use of a battery. While the use of a battery in this system is to charge up its capacity and use that electrical energy to power another equipment, batteries have a negative impact on the environment when it needs to be disposed of. Improper disposal of a faulty or dead battery can lead to pollution in areas that are crucial to the environment such as water and air pollution. If the batteries are disposed of improperly in situations like landfills, the cells can corrode, leaving them to leak and decay. When this occurs, the chemicals used in the battery such as lead, and acid can be absorbed into the ground and potentially contaminate the groundwater and soil. This can lead to a domino effect, where one problem will create another problem and so on and so forth. To avoid this issue, the best action to take would be to recycle the faulty batteries in order for them to be properly disposed of. The second constraint would be the replacements of electronics in this system. With a growing rise in electronic waste in the world today, replacing faulty components and electronics from the system when they go wrong can contribute to the increase in this global phenomenon. As this system has multiple components like the Boost Converter and the Bi-Directional Controller, replacing components like heat resistors and MOSFETS with newer ones will increase the electronic waste.

6.4 Manufacturability

Once the prototype is complete, it is easy to manufacture the system with it primarily consisting of PCB designs of the converters and sensors. However, manufacturing a system like this Energy Management System can bring in multiple constraints. The first would be the production of solar panels. It costs around $2-$4 to manufacture a solar panel, without considering size or brand type. While that may not seem like a lot, most of the costs will come from the installation and warranty. While this technology is not relatively new to the market as it has been here for several decades, its implementation in houses have currently skyrocketed in recent years due to its effective cost savings. Another manufacturing constraint that can occur would be simple PCB designs with quality materials. Simpler PCB designs can result in a much more seamless and cost-effective manufacturing environment. At the moment, we do not have a PCB design due to the prototype just being completed. However, if we were to effectively translate out current breadboards into a PCB layout, it would not be cost-effective at the moment. But, when we start designing the PCB, effort can be made to reduce the size and components needed to build the system, effectively reducing the manufacturing constraints with every new iteration.

6.5 Legal

Federal regulation with regard to solids and hazardous waste applies to solar panels array when being disposed of. When a solar panel reaches its end of life, it will become solid waste, which is regulated federally as well through state and local programs. There are possible safety codes that the government can enforce on the system, ensuring that it is safe for the consumer and the installer when the installation process takes place. If those safety codes are not complied with, possible complications can arise related to the consumer or even the installer which can result in legal action taking place. Another possible regulation could be the production of Solar Panels. The regulations can enforce that the use of sustainable, clean, and renewable materials as well as clean energy in the manufacturing process be implemented in this system. As the world moves closer to a net-zero and carbon neutral future, these legal constraints can pose an issue to the system, not in ability to produce green energy, but rather in its manufacturing process.

6.6 Safety

Safety is a very high priority from many aspects ranging from consumer user and installation to design and manufacturing. In application, the system will consist of solar panels which will need to be installed. These are typically placed on rooftops and the weight of these PV systems can cause dangerous hazards. If a panel is dropped, the shattered glass will spread everywhere and can pose a safety risk to the consumer or installer when they clean it up. The second safety constraint to be considered would be the possibility of electrical hazard. If the system is not properly grounded, the risk of electrocution is very high. This can cause detrimental harm to either the installer or even the consumer. Another safety constraint that should be considered would be the installation of the solar panels and the system. If the solar panels are not properly secured, in an event of bad weather conditions such as a hurricane or a tornado, the panels can possibly fly off and become a projectile hazard. If there is an event of flooding, there should be safety measures that the system should act on to prevent electrocution. One possible condition that can be considered could be an auto shut-off system that will activate when potentially dangerous weather occurs. This can prevent those events that pose risks like electrocution and others similar. In scaling the project, extra equipment and protection will be needed to ensure safety for all.

7. Project Budget Plan

Table 7.1 shows the cost for the items that were actually purchased and the items that were already owned by the team. The table also includes the tax cost at 0.0825 percent per USD. The total proposed cost of our project was $442.70. As the project was being developed and the system was changed, the budget expenditure was changed as well. For example, the original project was meant to include a solar panel and wind turbine. Due to time constraints and budget constraints, the wind turbine could not be included in the final project budget. Some of the items, such as the Arduino UNO, the solar panels, the battery clips, the 9V battery, among other miscellaneous items, were already owned by the team members and were generously lent out for the duration of this project. For the items that were previously purchased, the values are based on the price of the items currently, and could have been purchased for more or less.

Table 7.2 shows the final cost for the items that were purchased and the items that were already owned by the team. The table also includes the tax cost at 0.0825 percent per USD. The total cost of our project was $457.99. As the project was being developed, we started buying components and materials as needed thus changing the budget. Since some items didn’t need to be purchased, the budget was modified to include the current cost of the items in the market.

Table 7.1 Proposed Budget Plan

Item	Item Description	Vendor	Quantity	Cost	Cost + Tax
Solar Panel	25W Solar Panel	Amazon	2	$74.00	$80.11
Battery (12V)	12 Volt 7.2 AH, Rechargeable SLA AGM Battery	Amazon	1	$19.99	$21.64
Battery (9V)	9 Volt Battery for Arduino	Amazon	1	$6.04	$6.54
Battery Clip	Battery Clip for Arduino Battery	Amazon	1	$2.75	$2.98
Arduino Mega	Lorddream Arduino Uno R3 ATMega16U2	Arduino	1	$48.40	$52.39
Arduino UNO WiFi REV2	ARDUINO UNO WiFi REV2	Arduino	1	$53.80	$58.24
Temperature Sensor	TMP36 Precision Linear Analog Output	Amazon	1	$9.99	$10.81
Bluetooth Transceiver	HC-06 Bluetooth Transceiver	Amazon	1	$9.49	$10.27
Voltage Sensors	7-Count Voltage Sensors	Amazon	1	$15.99	$17.31
Current Sensors	5-Count Current Sensors	Amazon	1	$10.99	$11.90
LCD Display	2-Count LCD Display	Amazon	1	$8.99	$9.73
Transistors	10-Count Transistors	Digikey	1	$9.99	$10.81
MOSFETs	10-Count MOSFET	Digikey	1	$17.00	$18.40
Diodes	40-Count Diodes	Digikey	1	$22.80	$24.68
Capacitors x50	50-Count Capacitors	Digikey	1	$21.50	$23.27
Gate Driver x25	25-Count Gate Driver	Digikey	1	$36.75	$39.78
PCB	Boost Converter PCB	JLCPCB	1	$2.00	$2.17
Soldering Kit	Soldering Kit to solder PCB Components	Amazon	1	$50.00	$54.13
Misc	Wires, Pin Headers, etc.		-	$20.00	$21.65
Total:				**$408.96**	**$442.70**

Table 7.2 Final Budget

Item	Item Description	Vendor	Quantity	Cost	Cost + Tax
Solar Panel	25W Solar Panel	Amazon	2	$74.00	$80.11
Battery (12V)	12 Volt 7.2 AH, Rechargeable SLA AGM Battery	Amazon	1	$19.99	$21.64
Battery (9V)	9 Volt Battery for Arduino	Amazon	1	$6.04	$6.54
Battery Clip	Battery Clip for Arduino Battery	Amazon	1	$2.75	$2.98
Arduino Mega	Lorddream Arduino Uno R3 ATMega16U2	Arduino	1	$48.40	$52.39
Arduino UNO	ARDUINO UNO	Arduino	1	$29.95	$32.42
Temperature Sensor	TMP36 Precision Linear Analog Output	Amazon	1	$9.99	$10.81
Bluetooth Transceiver	HC-06 Bluetooth Transceiver	Amazon	1	$9.49	$10.27
Voltage Sensors	7-Count Voltage Sensors	Amazon	1	$15.99	$17.31
Current Sensors	5-Count Current Sensors	Amazon	1	$10.99	$11.90
MOSFETs	10-Count MOSFET	Digikey	1	$17.00	$18.40
Diodes	40-Count Diodes	Digikey	1	$22.80	$24.68
Capacitors x50	50-Count Capacitors	Digikey	1	$21.50	$23.27
Gate Driver x25	25-Count Gate Driver	Digikey	1	$36.75	$39.78
PCB	Boost Converter PCB	JLCPCB	15	$15.00	$16.24
PCB	AC/DC Converter w/ Voltage Reg PCB	JLCPCB	5	$14.00	$15.16
Soldering Kit	Soldering Kit to solder PCB Components	Amazon	1	$57.94	$62.72
Misc	Wires, Pin Headers, etc.		-	$20.00	$21.65
Total:				**$423.06**	**$457.99**

8. Project Summary

The Maximum Power Point Tracking (MPPT) Energy System is a renewable energy solution that tracks the maximum power at any given time. Using various techniques from Maximum Power Point Tracking while applying the Perturb and Observe method to using an AC/DC converter with a voltage regulator to charge the battery, this system is designed to work seamlessly with the intended customer. Additionally, a mobile application was developed to display various sensor readings, such as current, voltage, temperature, irradiance and shutoff time. Working on this project has allowed every team member to learn and understand topics from both the electrical/hardware and computer/software realms incorporated in the system. The project was a success, exceeding our expectations from the data and results that were collected from the tests. Although there were limitations and hindrances that occurred throughout the development of this project, the decisions that were made resulted in a successful system that hopes to bring efficient clean energy to different parts of the world.

9. Future Work

For future work, we plan on integrating all components of the project into PCB form. At this point, we have the main components of the project in PCB form. However there is still an excess of wire that is not practical which results in losses in the design. Since our design was for 50W, in commercial and residential applications the wattage is substantially more than the 50W. To be more practical in application, the system should be able to handle enough voltage and current for when the application is used in a commercial or residential setting.

We plan to further improve the efficiency of both the converters as well as the overall physical package of the hardware. We also plan to continue to develop the mobile application software with more features that are intuitive while continuing to uphold that status of a seamless experience for the user. We hope to carry this project past the bounds of this class and into the real-world where the idea of an energy system like this can help benefit an endless number of people around the world in various situations.

10. Acknowledgement

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11. Appendix

Arduino Code for Bluetooth Device:

```
#define aref_voltage 3.3
#include <SoftwareSerial.h>

SoftwareSerial BT(1, 0); // RX, TX
float voltage, temperatureC, temperatureF;
int tempPin = 0;
int tempReading;

void setup()
{
  Serial.begin(9600);
  BT.begin(9600);
  analogReference(EXTERNAL);
}

void loop()
{ char c;

while(true)
    {
        readSensor();

    }

 }

void readSensor()
{
  tempReading = analogRead(tempPin);

  voltage = tempReading * aref_voltage;
  voltage /= 1024.0;

  temperatureC = (voltage - 0.5) * 100;
  temperatureF = ((temperatureC * (9.0/5.0)) + 32);
  printSensor();
```

```
}

void printSensor()
{
  delay(2000);

  Serial.print("Temperature: ");
  Serial.print(temperatureF); Serial.println(" degree F");
  Serial.print("Temperature: ");
  Serial.print(temperatureC); Serial.println(" degree C");

  BT.print("Temperature: ");
  BT.print(temperatureF); BT.println(" degree F");
  BT.print("Temperature: ");
  BT.print(temperatureC); BT.println(" degree C");
}
```

Main Code for MPPT:

```
void loop()
{
  if (Power_now > Power_bef){
       if (voltageCal > voltage_anc)
       pwm = pwm - d;
       else
       pwm = pwm + d;
  }

  else{
       if (voltageCal > voltage_bef)
       pwm = pwm + d;
       else
       pwm = pwm - d;
  }
  Power_bef = Power_now;
  voltage_bef = voltageCal;
  if (pwm < 20)
       pwm = 20;
  if (pwm > 150)
       pwm = 150;
```