

Solar Powered Patio Umbrella

Design Review
Group #37

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ECE 445

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1. Introduction

1.1 Statement of Purpose

In recent years, electricity prices have skyrocketed and will continue to increase in the future. What better way to save money than to use solar energy. In addition to financial benefits, the use of renewable energy, in particular, solar energy will benefit our environment. Nowadays, the majority of the world depends on electricity supply generated from fossil fuels. These means of electrical production have raised growing environmental concerns over the climate change risks. It is time to make a change and Go Green!

The goal of this project is to develop a solar powered patio umbrella that has a multitude of features that include USB ports, LED lighting system, and a solar tracking system for optimal power generation. This product will be powered entirely on solar energy.

1.2 Features

Currently, there is no product like this in the market. Unlike other commercially available solar powered umbrellas, this patio umbrella will include several other features as discussed below:

- 1- Maximum power point tracking (MPPT) built in
- 2- LED lighting system
- 3- USB ports
- 4- Sun tracking ability

1.3 Benefits

- 1- Save the environment by using renewable energy
- 2- Save money
- 3- Charge devices anytime using the USB hub
- 4- Optimize solar power using the sun tracking capability
- 5- Lighting system that is controllable through a dimmer
- 6- Optimize the charging capabilities for the battery by using an MPPT control

2. Design

2.1 Block Diagram

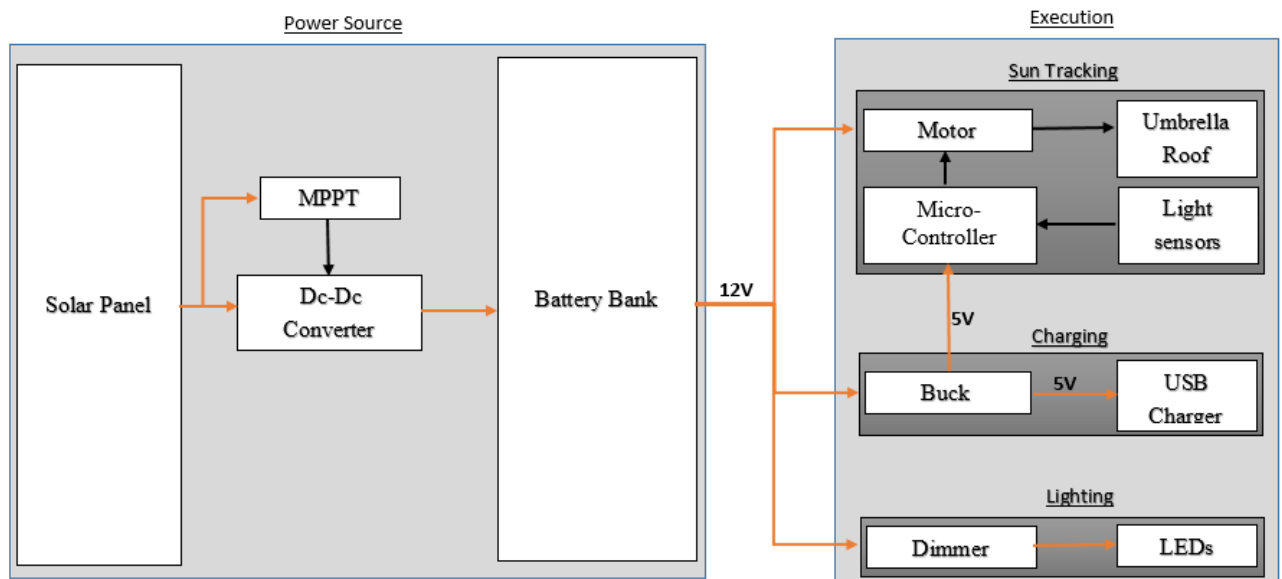


Figure 1: Block Diagram

2.2 Power Module Block Description

The purpose of this module is to absorb the sun's energy through a solar panel and efficiently convert that energy into electrical energy, using a maximum power point tracker (MPPT) controller which will charge the battery bank. The block diagram for the Power module is displayed in Figure 2 below.

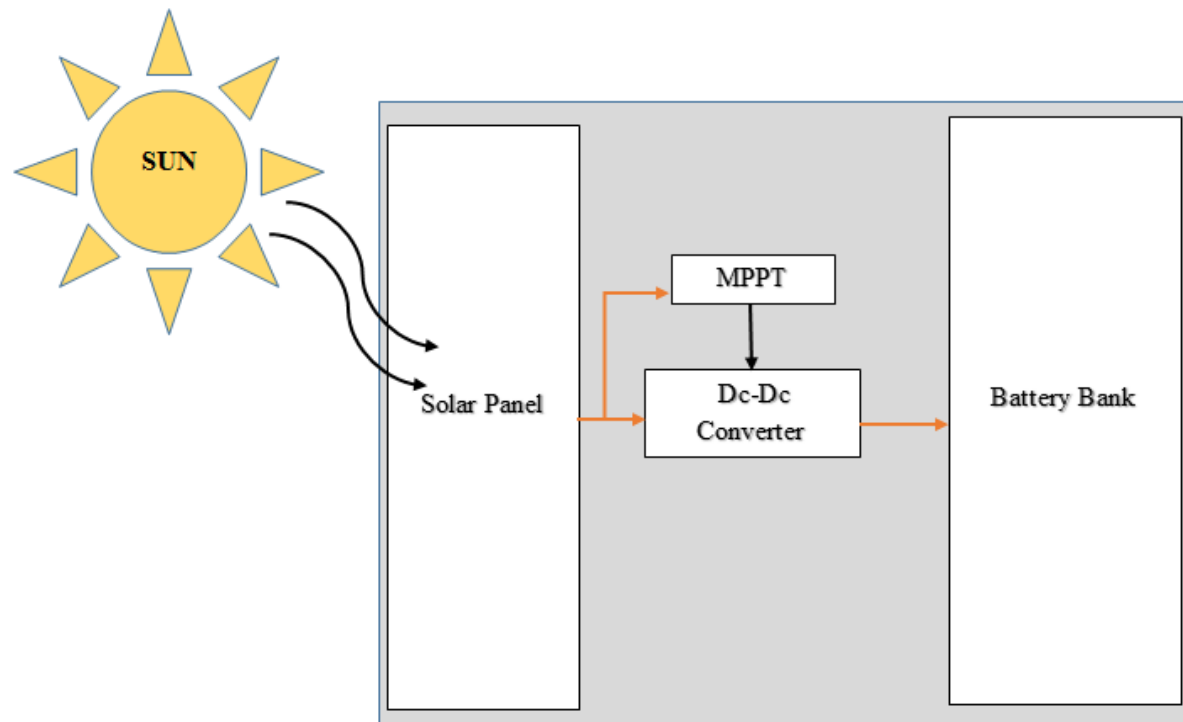


Figure 2: Power Module Block Diagram

Black: Signal Output
Orange: Power lines

2.2.1 Solar Panel

The Solar Panel is designed to absorb the sun's rays as a source of energy for generating electricity. This design will make use of 5 solar panels where each will output 5V and 230mA to the MPPT control. These five Polycrystalline Solar Panels from Sundance Solar will be connected in series giving us an output of 25V and 230mA. They will be mounted on the roof of the umbrella. They measure 160mm X 62mm or about 6.25" X 2.5" each.

2.2.2 MPPT

An MPPT, or maximum power point tracker, is an electronic DC-DC converter that optimizes the match between the PV panels and the battery bank. The controller looks at the output of the panels and compares it to the battery voltage. The controller then figures out what is the best power that the panel can output to charge the battery. ^[6]

The power point tracker takes the DC input from the solar panels, inverts it to a high frequency AC and then converts it back to a different DC voltage and current that the battery needs for it to be optimized. ^[6]

The curve below in Figure 3 shows the PV module voltage vs the PV module power. The sharp peak to the right represents the maximum power point. The MPPT controller looks for this point and then does the voltage/current conversion to change it to what the battery needs to charge.

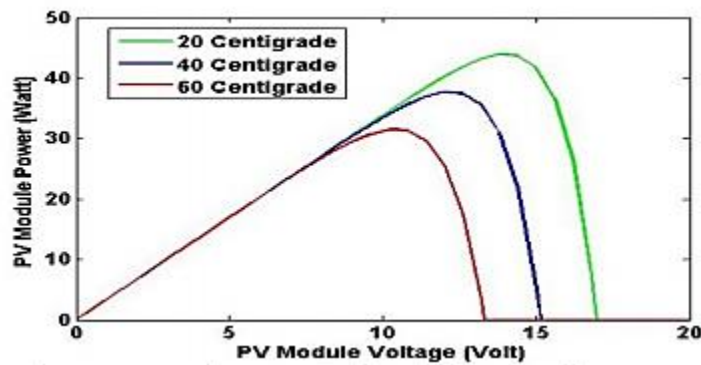


Figure 3: Power vs Voltage Curve for Solar Panel

A Genasun GV-5-PB-12V, 5A MPPT controller will be used in this design. The Genasun has a peak efficiency from 96% to 99.85% with a built in DC-DC converter that will step down the voltage to charge the battery and a smart controller for battery voltage monitoring. The specifications of the MPPT is given in Table 1.

Table 1: Genasun MPPT Specifications

Model: GV-5-Pb-12V	
Max. Recommended Panel Power	65W
Rated Battery (Output) Current	5A
Nominal Battery Voltage	12V
Max Panel Voltage	27V
Recommended Max Voc at STC	22V
Min. Battery Voltage for Operation	7.2V
Input Voltage Range	0-27V
Recommended Max. Input Short Circuit Current (for Solar Use)	5A
Continuous Rated Load Current	5A
Maximum Input Current (that could be drawn from an unlimited source)	9A
Absorption Voltage	14.2V
Absorption Time	2 hours
Float Voltage	13.8V
Load (LVD) Disconnect/Reconnect Voltage	11.4V / 12.5V

2.2.3 DC-DC converter

This module is intended to step down the nominal voltage from 25V to 12V to charge the battery. The Genasun MPPT mentioned above has a built in DC-DC converter that will do this.

2.2.4 Battery Bank

The function of this device is to store up to 22 Ah of energy that it receives from the DC-DC converter and distributes 12V and up to 45W of power to the other devices within the system. This design will use a 12V, 22 Ah lead acid battery from Battery Shark.

2.3 Execution Module Block Description

The purpose of this module is to execute the difference features of the solar-powered umbrella. The three features are the sun tracking capability, the charging station and the lighting system. The individual block diagrams are shown below in Figure 4.

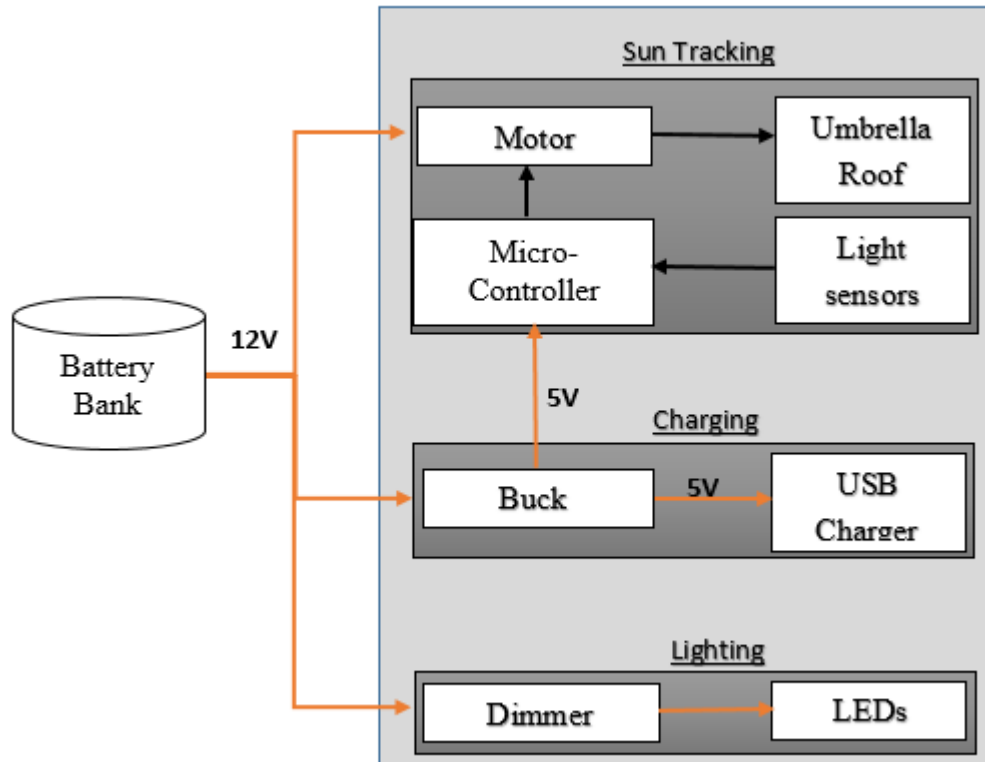


Figure 4: Charging Unit Block Diagram

2.3.1 Tracking

2.3.1.1 Light sensors

The purpose of the Light Dependent Resistors (LDRs) is to keep track of the position on the umbrella that receives the most light from the sun. This information is sent to the microcontroller which will position the umbrella such that the solar panel on the roof of the umbrella is facing the sun. The LDR is powered by the microcontroller.

LDR works in the way that when the light is shown on the resistor, the resistance of the sensor decreases, allowing current to pass through it. This drop in resistance is then communicated to the microcontroller, which in turns activates the motor to position the roof of the umbrella towards the sun.

We will be using 8 sensors in 4 different positions (labelled 1-8 in Figure 5 below). They will be positioned 90° away from each other. The solar panel (Red box in Figure 5) is placed in front of sensors 1 and 2 which are designed to receive the most light at any given time. The flowchart for the design is shown in Figure 5.

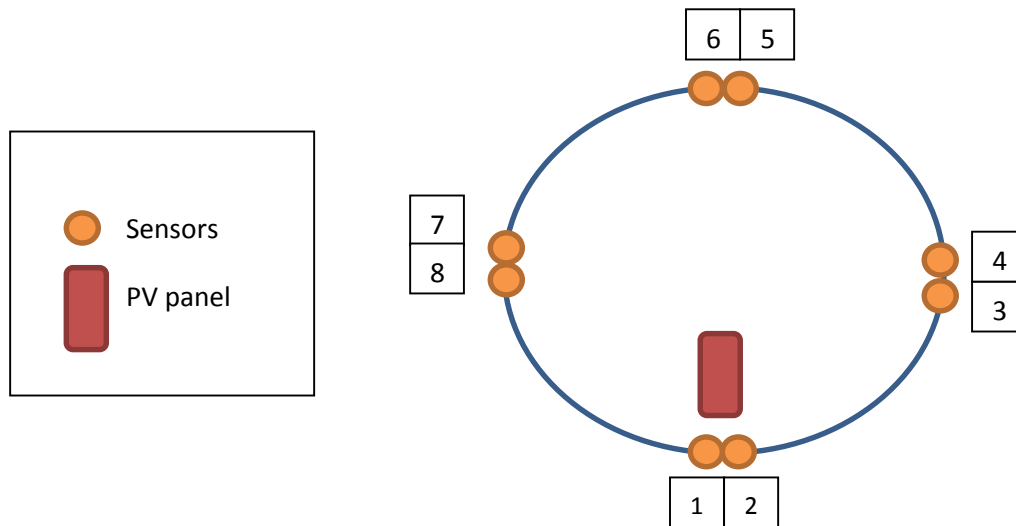


Figure 5: Top View of the Umbrella.

The LDRs used in this design are Photo cell (CdS photoresistor) from adafruit. They have a dark room resistance (10 lux) of 10k Ω and a maximum illuminated resistance at full day light (10,000 lux) of 100 Ω . The data of the LDR is given in Figure 6.

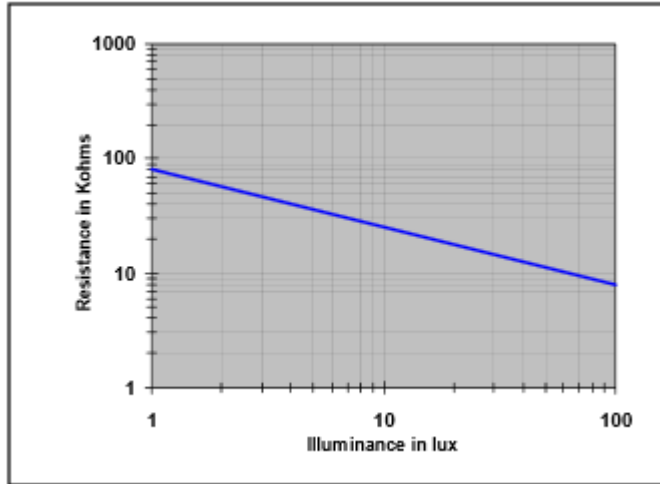


Figure 6: Characteristic Operation of the PDV-P8103 Showing the Cell Resistance Vs Illuminance ^[1]

2.3.1.2 Micro-controller

This design will use a TIMSP430 micro-controller, powered by the 5V from the buck converter to track the position that receives the most light.

Each sensor will be placed in series with a reference resistor as shown in Figure 14 to simulate a potentiometer like behavior. That is, the voltage across the LDR will be compared to the voltage across the reference resistor. Since the LDRs resistance decreases as the intensity of light increases, the voltage drop across it will decrease as well. Therefore, if the voltage across the LDR is higher or equal to the V_{ref} , the given LDR is receiving enough light intensity.

The micro-controller will take these V_{ref} values in sets, as shown in Figure 7, and average them and compare them with the reference voltage as well as the other sets of sensors and accordingly activate the motor. (See Figure 7 for flow chart)

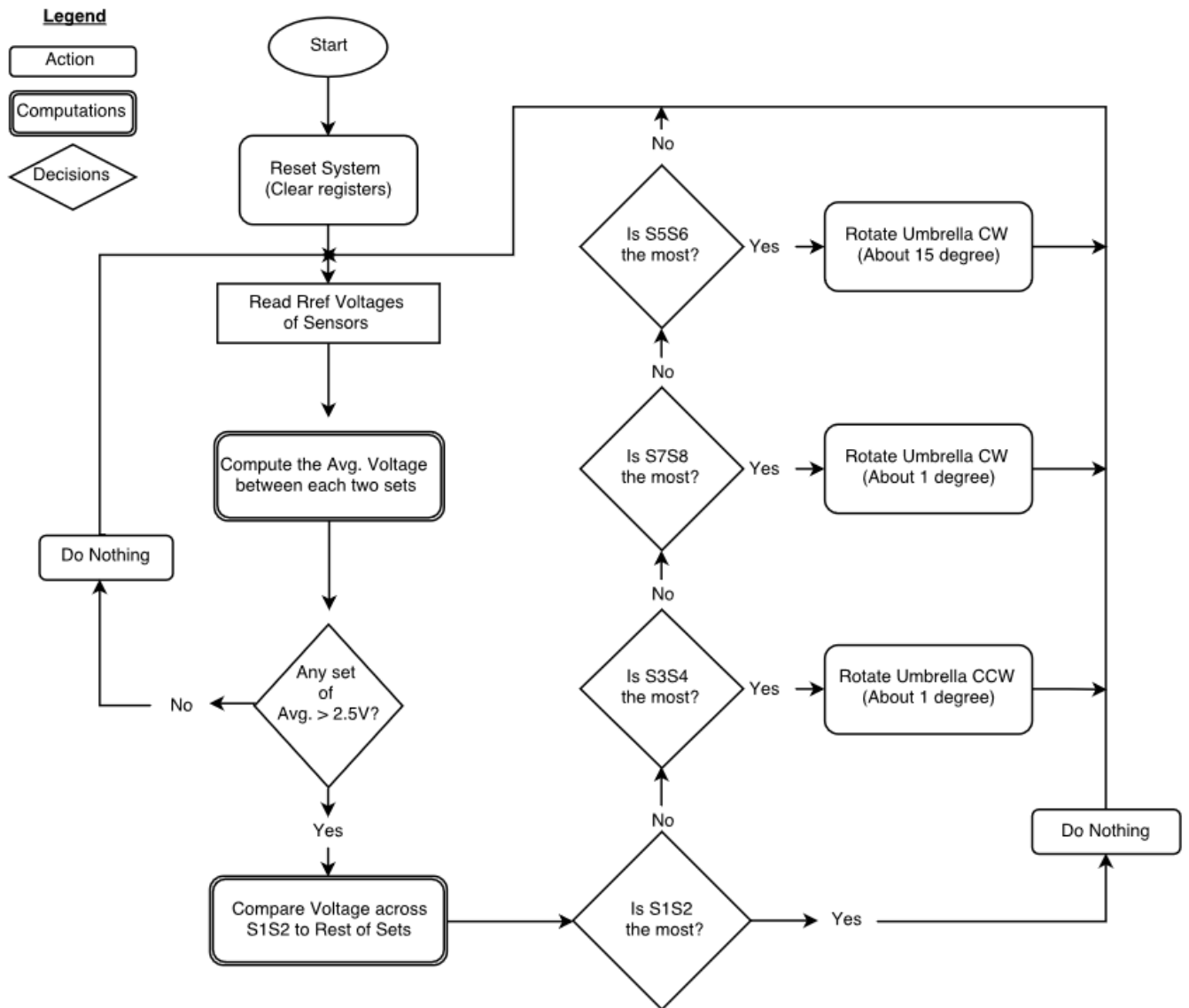


Figure 7: Flow Chart for Tracking Control

2.3.1.3 Motor

The purpose for the motor is to move the roof of umbrella towards the sun in order to maximize solar radiation captured by the solar panel. This module will be powered by 12V from the battery bank when triggered by the microcontroller. The motor used for this design is a 20W DC Motor.

2.3.2 Charging

These modules will provide the user the ability to charge various devices through a USB port.

2.3.2.1 Buck Converter

The purpose of the buck converter is to step down the voltage from 12V which is supplied from the battery box to 5V which is needed to power up the USB charger. The implementation of the buck converter is displayed in Figure 15. The buck converter works such that when the switch is turned on, energy is transferred directly from the input to the output and the diode operates as a reverse biased element preventing the current to flow through it. Sequentially, when the switch is open, the energy stored in the inductor creates a current that needs to find a path to flow causing the diode to turn on. The switching cycle of the buck converter will determine the output voltage of the converter as described in Equation 15. The buck converter has two operation modes, discontinuous conduction mode (DCM) and Continuous conduction mode (CCM). In this project, we will focus out design on CCM. CCM produces a continuous current pulse. ^[6] Refer to Figure 18 for circuit layout.

The components of the Buck Converter chosen for this design are:

- 1- Input Capacitor: A $47\mu\text{F}$ capacitor is placed in order to filter out the input voltage from the battery bank. ^[13]
- 2- FET: A power MOSFET IRF530N will be used due to its fast switching cycle and ultra-low on resistance ($90\text{m}\Omega$) because this will help reduce the switching loss and improve efficiency.
- 3- Schottky Diode: In order to reduce losses in the diode when the switch is off, a schottky diode NSR0320 is used due to fact that they have a small voltage drop across them. The diode is used to block the current when the MOSFET is conducting and provide an inductor current path when the MOSFET is not conducting. ^[8]
- 4- Inductor: Based on the calculations of our buck converter, it was determined that the minimum value of the inductor needed in order to keep the buck converter from operating in DCM was

approximately $15\mu\text{H}$. The inductor is the key element in determining the boundary between DCM and CCM operation since it controls the output current. Therefore, in order to avoid having the core from saturating and to reduce the output current ripple, a larger inductor of $47\mu\text{H}$ will be used instead. (See Figure 18)

- 5- Output Capacitor: A $50\mu\text{F}$ ceramic capacitor will be used in this design. The choice of the ceramic capacitor was due to the fact that they have a low equivalent series resistance (ESR). Hence, this will reduce the output voltage ripple ($< 50\text{ mV}_{\text{rms}}$), therefore protecting the device being charged. (See Figure 18)
- 6- Voltage regulator – The function of a voltage regulator to maintain a constant voltage level for our charging unit. We plan on using the TPS-7A85 chip from TI.

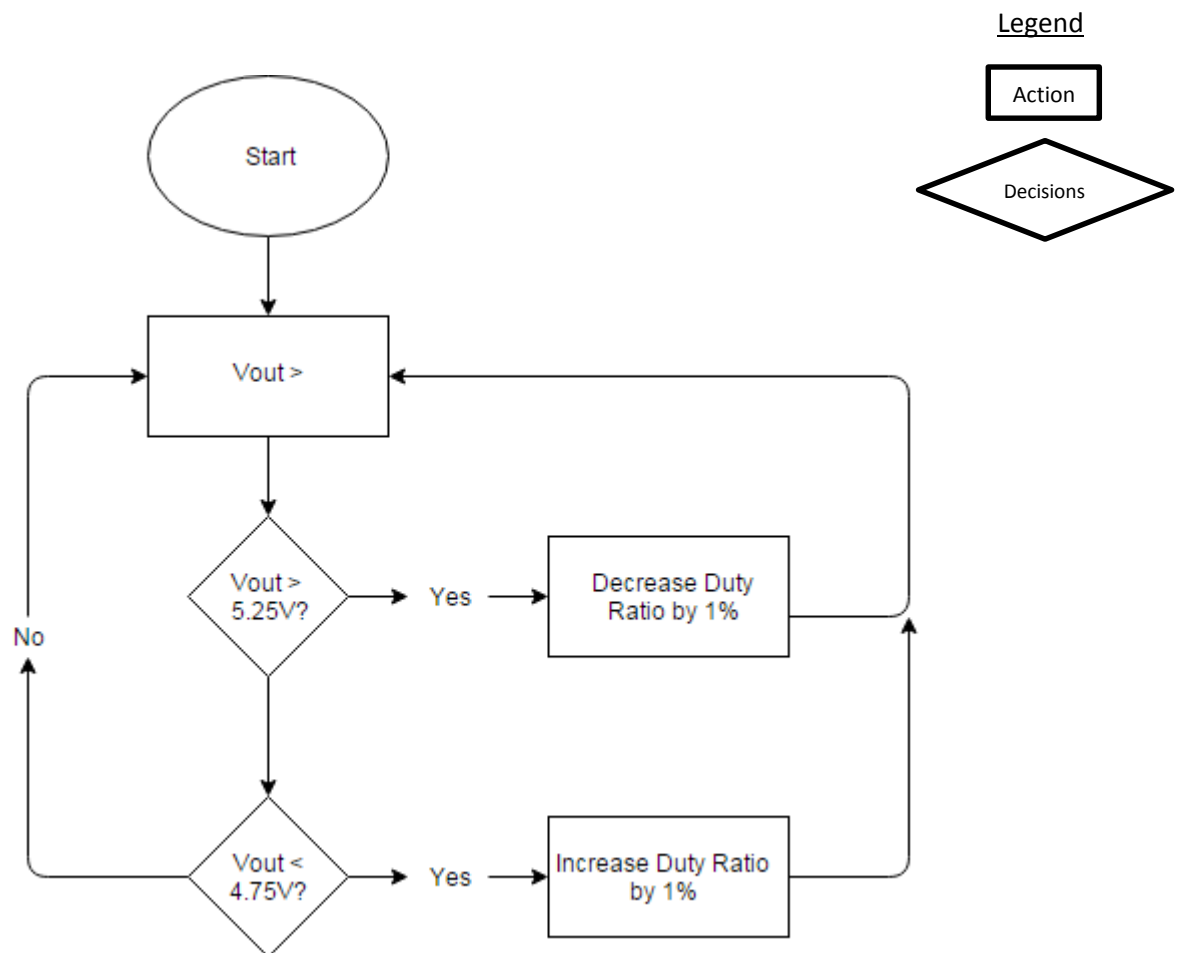


Figure 8: Flowchart for PWM Control for the Buck-Converter

2.3.2.2 USB port

This module is designed to receive 5V from the buck-converter and is intended to be used as a charging port. The USB port used in this design is a waterproof 151-1239-ND from EDAC Inc. The USB will be mounted on the pole. ^[3] ^[10]

2.3.3 Lighting

This module is used for lighting up the umbrella.

2.3.3.1 Dimmer

This module is used to control the intensity of the LEDs. This is done by using Pulse width modulation (PWM). For this design, the PWM will be generated by the TI-MSP430 microcontroller. ^[14]

The micro-controller reads the user's input and adjusts the PWM's duty cycle accordingly in order to provide the needed output voltage to the LEDs, so that different intensities of light are generated.

The vital factor here is the turn on time or 'duration'. That is, if we turn the light on and off too slowly the viewer will see the flashing of the LED and not a constant light output which appears dimmer. Therefore, when using PWM it's important to consider how slowly we can 'flash' the LED so that the viewer does not perceive the oscillation. The minimum speed of an LED oscillating which can be seen by the human eye varies from person to person. ^[2] However, for this design we will use a minimum speed of 100Hz, which is about twice as much as the speed used by some televisions, also not many people can notice the flicking at this frequency and more importantly in order to reduce switching losses in the MOSFET, it's important to keep the switching frequency at a "reasonable" rate (See Figure 9). ^[2] ^[11]

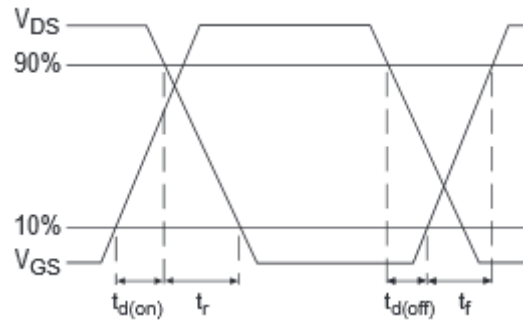


Figure 9: Switching Time Waveforms

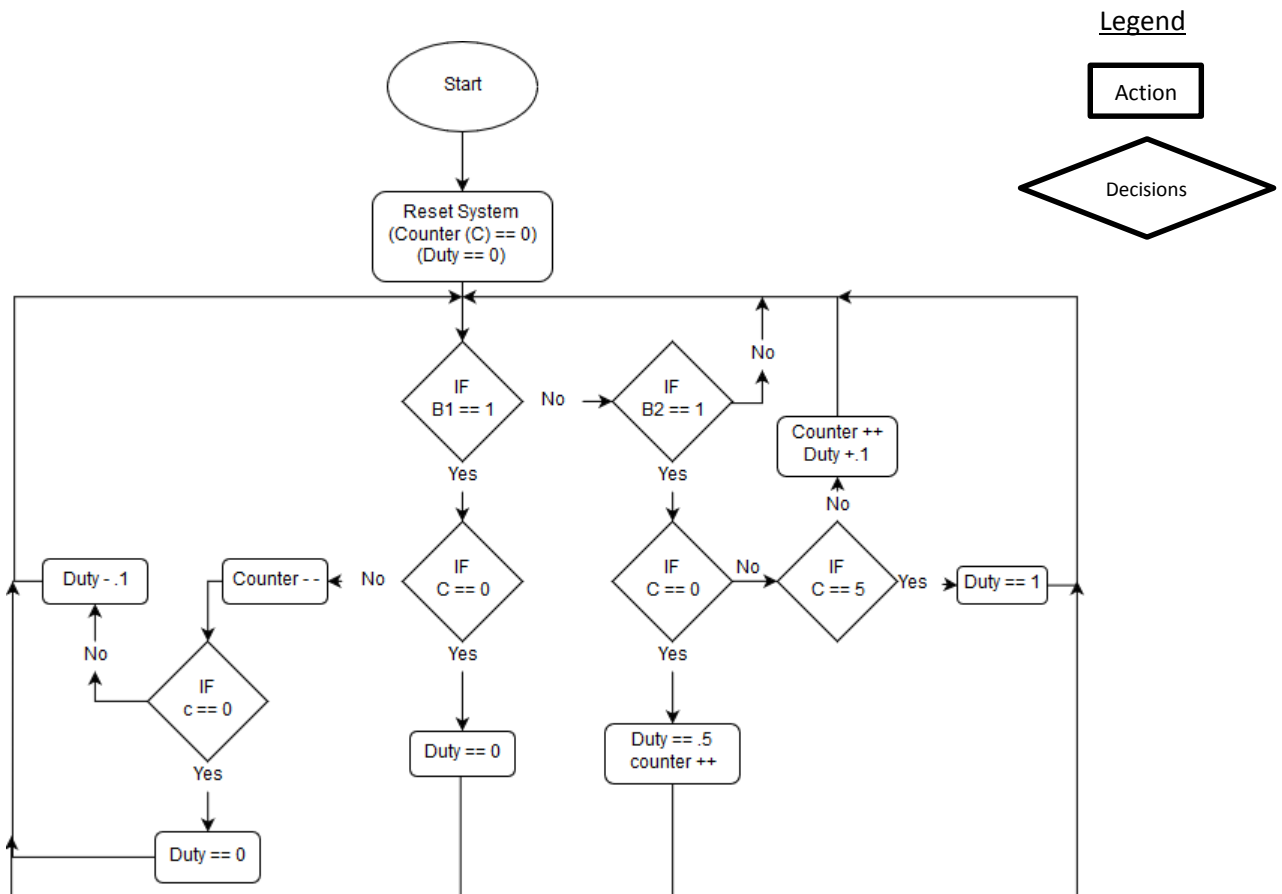


Figure 10: Flow Chart for Dimmer PWM

2.3.3.2 LED's

The role of the LEDs will be to give of light when turned on. It receives the set power from the Dimmer. 4 strips of LEDs will be connected in parallel. In each strip, there are 15 LED's connected

in series using total power of 14.4 W. It takes an input of 6-12V which accordingly adjusts the intensity.

2.4 Calculations

2.4.1 Power Module Calculations

The products used in the design are based on the calculations below. Our load output is about 45 W. The load calculation is shown in the Table below.

Table 2: Total Power from Load

Module	Specifications	Total Power (W)
LED's	4 branches, 15 LEDs in each branch 1 branch can take up to 12V, 0.3 A 3.6 W each branch	14.4 W
USB	5V, 1A	5 W
Motor	12 V, 20 W	20 W
	Total	44.4 W

As shown above, the approximate power that our loads need is 44.4 W. The amount of current needed by the system is

$$\frac{44.4}{12} = 3.7A \quad (3)$$

We want it to provide for 6 hours. Therefore, the amount of Ah needed by the battery is

$$6h * 3.7A = 22.2Ah \quad (4)$$

Assuming that the PV solar panels are working in its nominal conditions, they will provide:

$$P_{panels} = (5 * 5V) * 230mA = 5,750 mW = 5.75 W \quad (5)$$

The design includes a MPPT control, which optimizes the match between the solar array (PV panels), and the battery bank. The efficiency of this MPPT control is 97% +/- 1%. With an efficiency of 97%, it will provide the battery with,

$$P_{MPPT} = 5.75 W * 0.97 = 5.58 W \quad (6)$$

We plan to build our prototype using a LP12-22/NB battery, with a nominal output of 12V and a nominal capacity of 22 Ah. The battery will store

$$P_{Battery} = 12 V * 22 Ah = 264 Wh \quad (7)$$

Assuming that the battery is not ideal, its efficiency is around the 85%:

$$P_{Battery-Real} = 0.85 * 5.58 W = 4.74 W \quad (8)$$

To conclude, the time that the solar panels would work to fully charge the battery would be:

$$t = \frac{264 Wh}{4.74 W} = 55.7 h \quad (9)$$

Assuming now that the efficiency of the MPPT is 96% since the tolerance level is +/- 1%. Repeating the calculations made before:

$$P_{MPPT} = 5.75 W * 0.96 = 5.52 W \quad (10)$$

$$P_{Battery-Real} = 0.85 * 5.52 W = 4.692 W \quad (11)$$

$$t = \frac{264 Wh}{4.692 W} = 56.27 h \quad (12)$$

It can be observed that with a higher efficiency, a lower time is needed for fully charging the battery. If the efficiency goes below 96%, it will take longer time for the battery to be charge, which may interfere with the design of our system.

Also, we know that the voltage provided from the MPPT is not exactly 12 V as its tolerance is +/- 0.5 V. With this fluctuation in the input voltage to the battery, nothing would happen damage its cells, because the MPPT controller acts as a voltage monitoring device. If voltage is not monitored properly, this may damage battery cells, hence reducing the battery life.

2.4.2 Execution Module Calculations

2.4.2.1 Tracking

Calculations for sensor circuit

In order to estimate the reference voltage in Figure 14, which will be read by the microcontroller, we have to implement the voltage divider. Based on the value of V_{ref} , the microcontroller will activate the motor to move the umbrella's rooftop if the voltage drop across R_{ref} is higher than what we have determined. In this case, the determined $V_{ref} = 4.5 V$. So if the voltage drop across R_{ref} is greater than 4.5V, we move the umbrella. The critical value of LDR resistance is 100Ω , which is equivalent to 10,000 Lux which means that the sensor at that location is receiving enough light. The highest possible resistance is 1.5 k Ω , which means that the LDRs at that position are not

receiving enough light. The input voltage is also set, $V_{in} = 5\text{ V}$ by the microcontroller. As the design includes 8 LDRs, all of them in parallel, the resistance value across the entire circuit will be the same.

Keeping all of this in mind, R_{ref} is calculated below.

$$V_{ref} = V_{in} * \frac{R_{ref}}{R_{ref} + LDR} = 4.5\text{ V} = 5 * \frac{R_{ref}}{R_{ref} + 100\ \Omega} \quad (13)$$

$$R_{ref} = 1\text{ k}\Omega$$

In the case that the LDRs are not receiving light, $LDR = 10\text{ k}\Omega$, the voltage drop received by the microcontroller would be

$$V_{ref} = V_{in} * \frac{R_{ref}}{R_{ref} + LDR} = 5 * \frac{1\text{ k}\Omega}{1\text{ k}\Omega + 10\text{ k}\Omega} \approx 2\text{ V} \quad (14)$$

The table for the critical values used in this design is shown in Table 3.

Table 3: Values of LDR reading vs Lux

Ambient light like...	Ambient light (lux)	Photocell resistance (?)	LDR resistance (?)	Current thru LDR+R	Voltage across R
Moonlit night	1 lux	70 K Ω	71 K Ω	0.07 mA	0.1 V
Dark room	10 lux	10 K Ω	11 K Ω	0.45 mA	0.5 V
Dark overcast day / Bright room	100 lux	1.5 K Ω	2.5 K Ω	2 mA	2.0 V
Overcast day	1000 lux	300 Ω	1.3 K Ω	3.8 mA	3.8 V
Full daylight	10,000 lux	100 Ω	1.1 K Ω	4.5 mA	4.5 V

2.4.2.2 Charging ^[5]

All calculations were made under the assumption that we have an ideal buck converter. The chosen frequency of operation for the buck converter is:

$$f_{sw} = 100\text{ kHz}$$

The converter is also designed to charge a cellphone; hence, it should be able to give out the following outputs displayed below, where the cellphone load can be represented as a $5\ \Omega$ resistor load.

$$\begin{array}{ll} P_{in} = 5 \text{ W} & P_{out} = 5 \text{ W} \\ V_{in} = 12 \text{ V} & V_{out} = 5 \text{ V} \\ I_{in} = 0.417 \text{ A} & I_{out} = 1 \text{ A} \end{array}$$

$$R_{Load} = 5 \Omega$$

Firstly, we need to determine the component sizes of the buck converter. We begin by determining the needed duty ratio for the desired output voltage. Because the average inductor voltage has to be equal to zero, we can apply the volt-second balance to the inductor voltage, as shown in Figure 5, to obtain equation 1 below.

$$D = \frac{V_{out}}{V_{in}} = \frac{5}{12} = 0.417 \quad (15)$$

To know the critical inductor, we need to obtain the value of the inductor during boundary between CCM and DCM. (See Figure 6)

$$L_{crit} = \frac{R_{load} T (1-D)}{2} = 14.6 \mu H \quad (16)$$

$$< i_L > = 1 \text{ A} = \frac{1}{2} i_{peak} \Rightarrow i_{peak} = \Delta i_{Lpp} = 2 \text{ A} \quad (17)$$

The next step is to determine the input capacitance of the buck converter. Assuming an input voltage ripple of 1% of input voltage, we obtain:

$$0.12 \text{ V} = \Delta V_{cpp} = \frac{\Delta i_{Lpp}}{C_{in} f_{sw}} \Rightarrow C_{in} = \frac{I_{in}}{\Delta V_{cpp} f_{sw}} = 34.722 \mu H \quad (18)$$

For calculating C_{out} we know that $< i_c > = 0$ so all the ripple current will go into the capacitor. We can get ΔV_{cpp} without knowing the exact shape. Assuming a voltage capacitor ripple of 1%, we get:

$$0.05 \text{ V} = \Delta V_{cpp} = \frac{\Delta i_{Lpp}}{8 C_{out} f_{sw}} \Rightarrow C_{out} = \frac{\Delta i_{Lpp}}{8 \Delta V_{cpp} f_{sw}} = 50 \mu H \quad (19)$$

As previously stated, the above calculations were made under the assumption that 100% efficiency will be achieved; however, the buck converter is not ideal due to losses in various components. One such component is the capacitor in the converter, more precisely the output capacitor. As a result, we add a resistor in series (ESR) to the output capacitor because this ESR determines the ripple in the output voltage. We are not adding a resistor to the input capacitor because we know that we should focus on the output power which is the one that will be needed to charge the device. Looking

at the datasheet, we have obtained the loss tangent based on the chosen frequency and output voltage to determine the ESR as follows:

$$ESR = \frac{\tan \delta}{C_{out} \omega} = 0.8 \Omega \quad (20)$$

2.5 Schematics and Simulations

2.5.1 Power Module Schematic and Simulations

2.5.1.1 Solar Panels

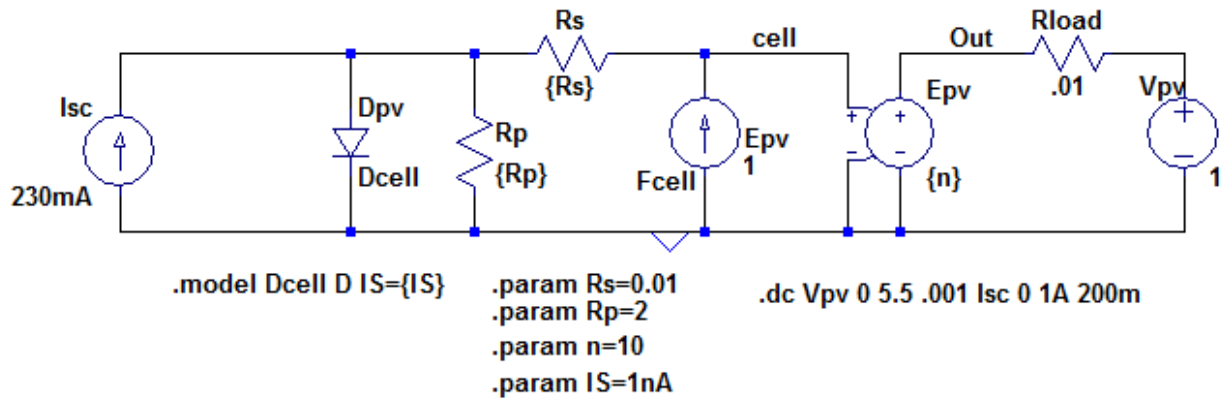


Figure 11: Ideal Model for PV System

Output of PV module Power (W)

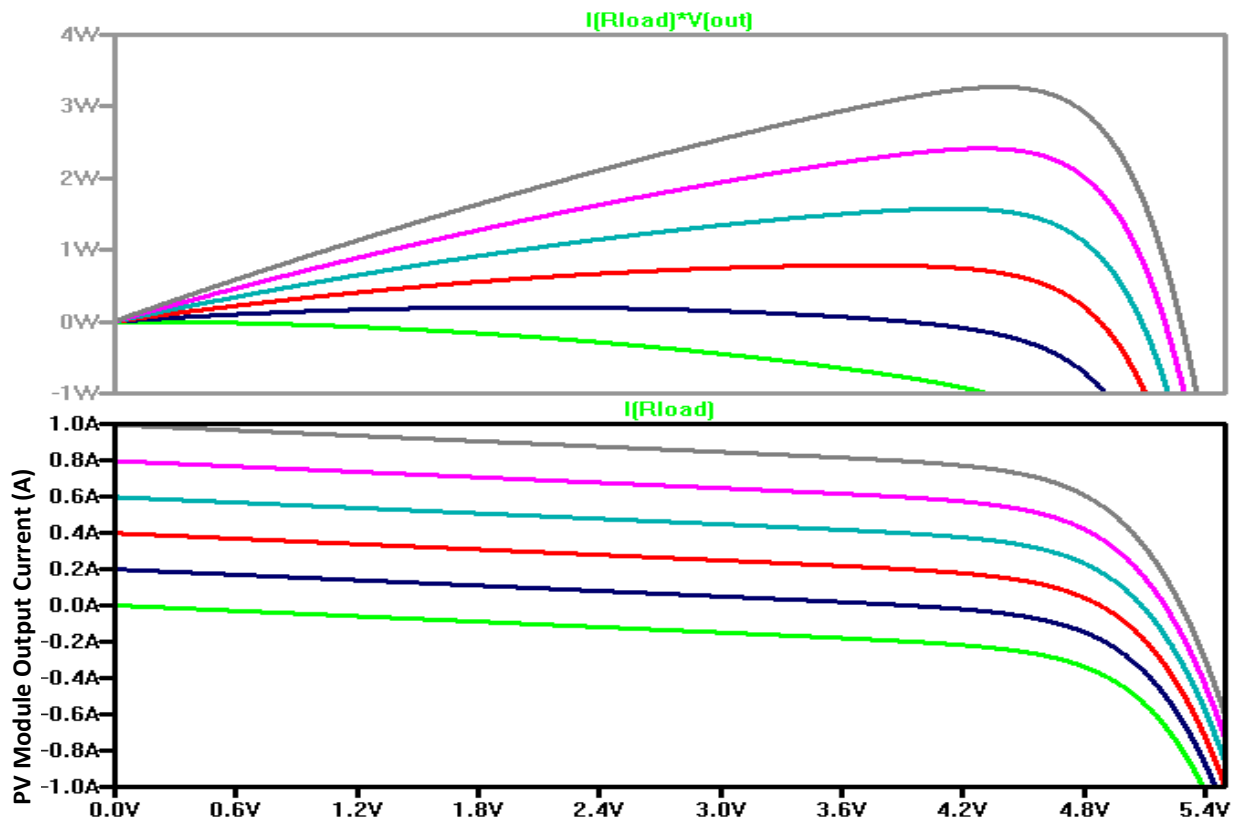


Figure 12: PV Output from Simulation. Output Power Curve on the Top and IV Curve on the Bottom

2.5.1.2 MPPT and Battery

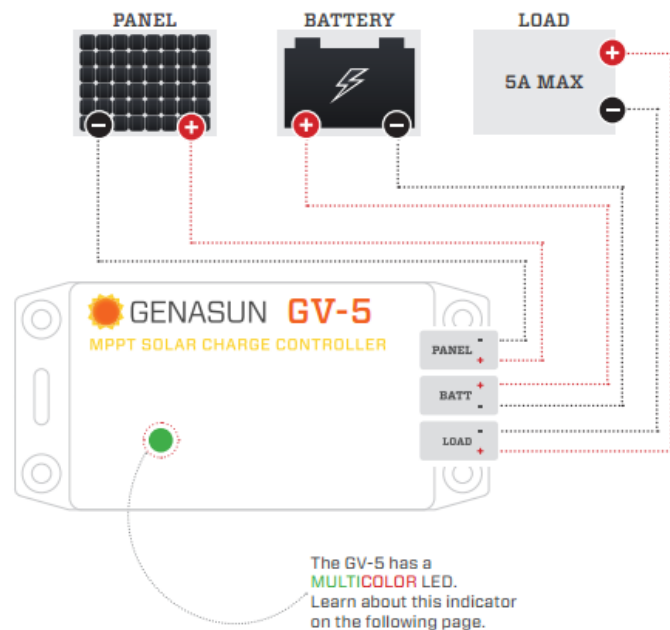


Figure 13: Wiring for MPPT and Battery

2.5.2 Execution Module Simulations

2.5.2.1 Tracking Simulations

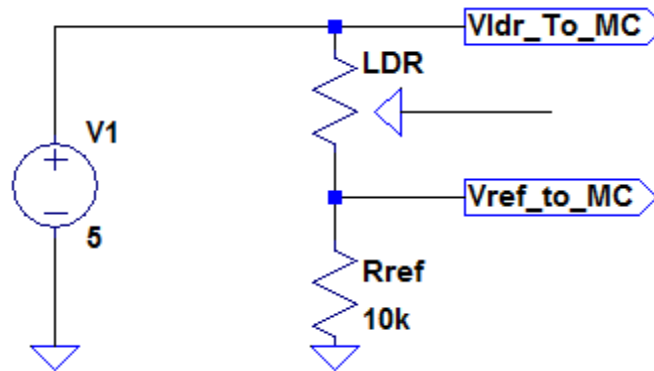


Figure 14: Circuit Simulation of Sensor Setup

2.5.2.2 Charging Simulations

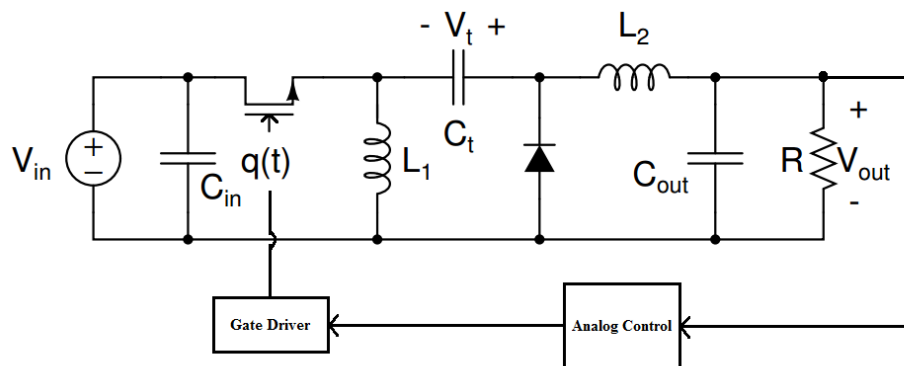


Figure 15: Top Level Schematic of a Buck Converter

Typical Connection

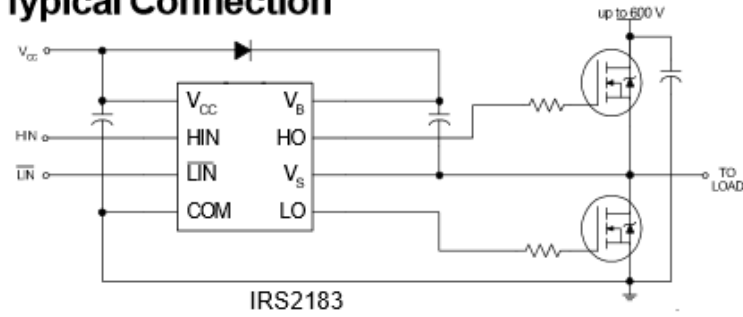


Figure 17: Typical Connection of a High Side Gate Driver

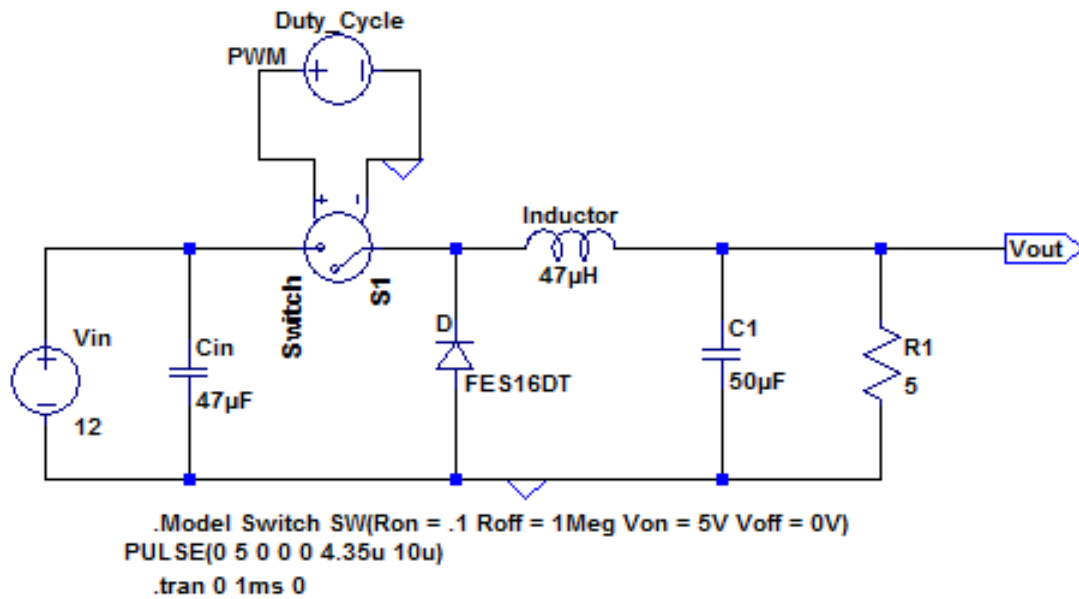


Figure 18: Buck Converter Circuit Design for CCM Operation

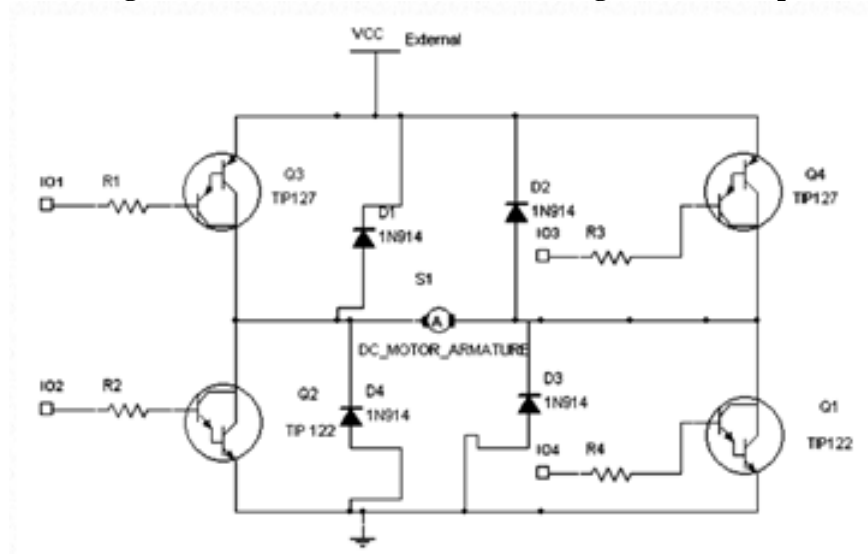


Figure 18.1 Motor Drive Schematic ^[17]

Charging module Simulations

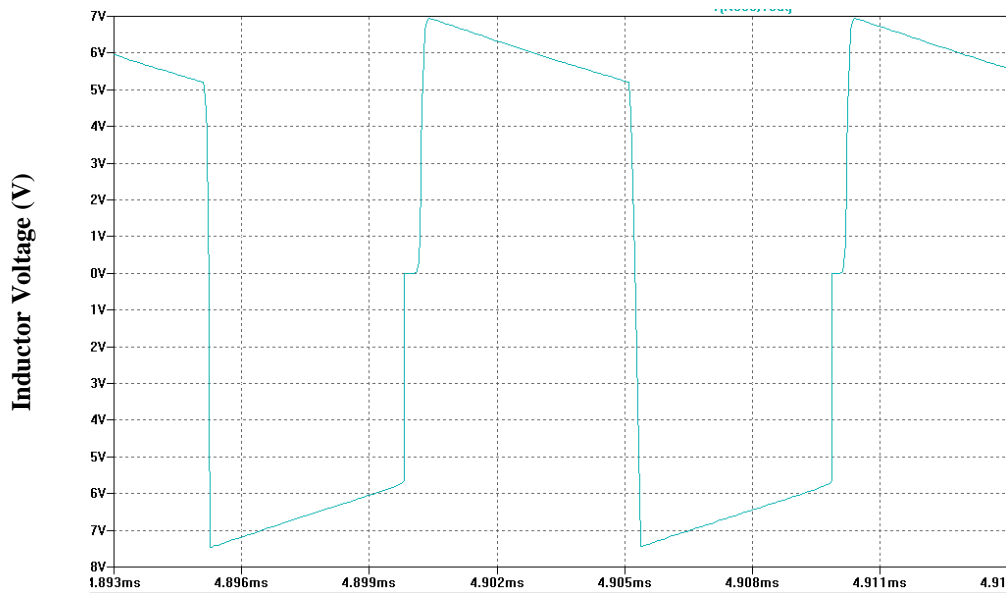


Figure 19: Simulation of Inductor voltage at DCM-CCM Boundary Vs. Time

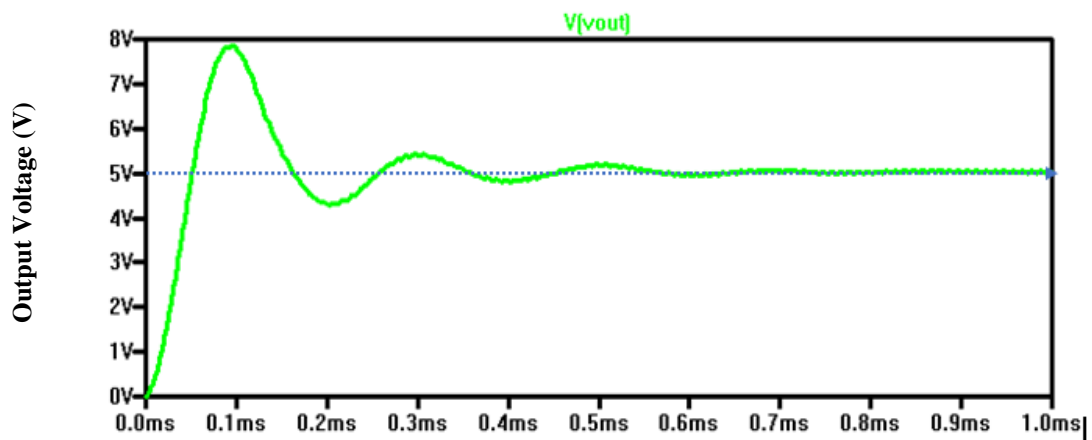


Figure 20: Output Voltage of Buck Converter vs. Time

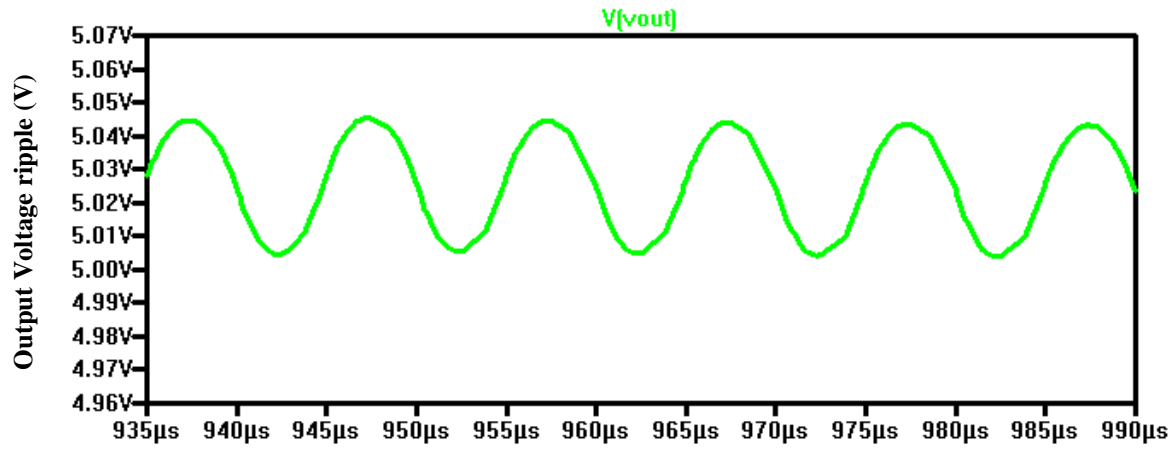


Figure 21: Output Voltage Ripple (< 50 mVrms) Vs. Time

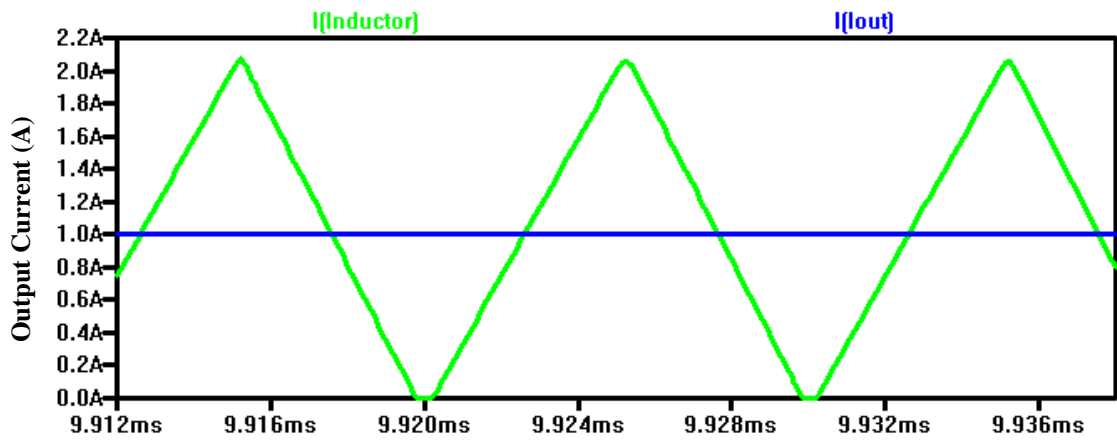


Figure 22: Output Inductor Current at CCM, DCM Boundary Vs. Time

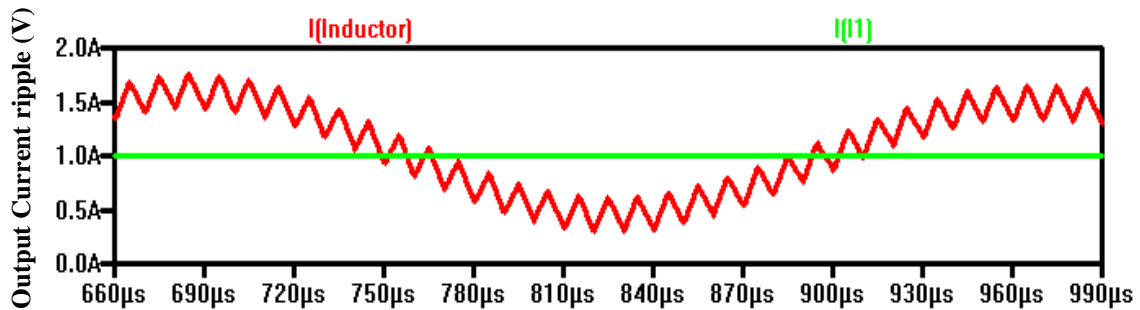


Figure 23: Output inductor current in CCM operation Vs. Time

2.5.2.3 Lighting Simulations

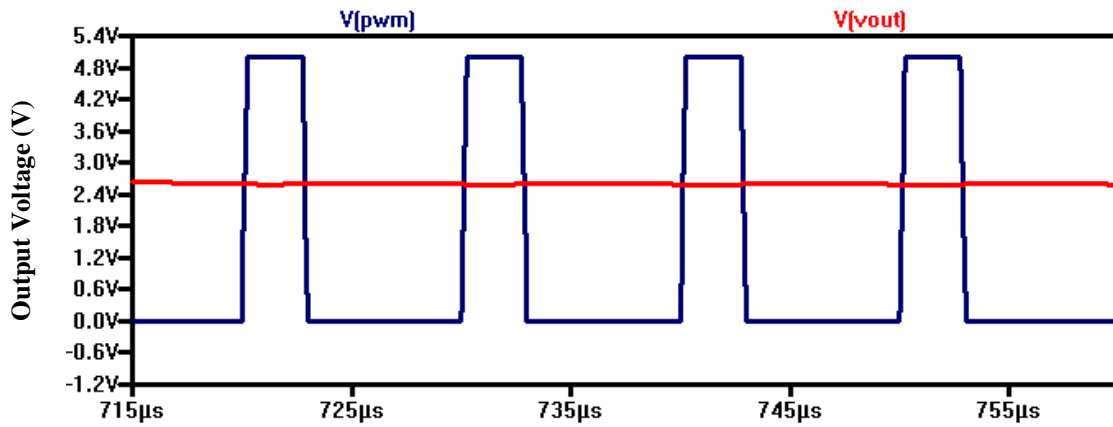


Figure 24: PWM output at 25% Duty Cycle Vs. Time

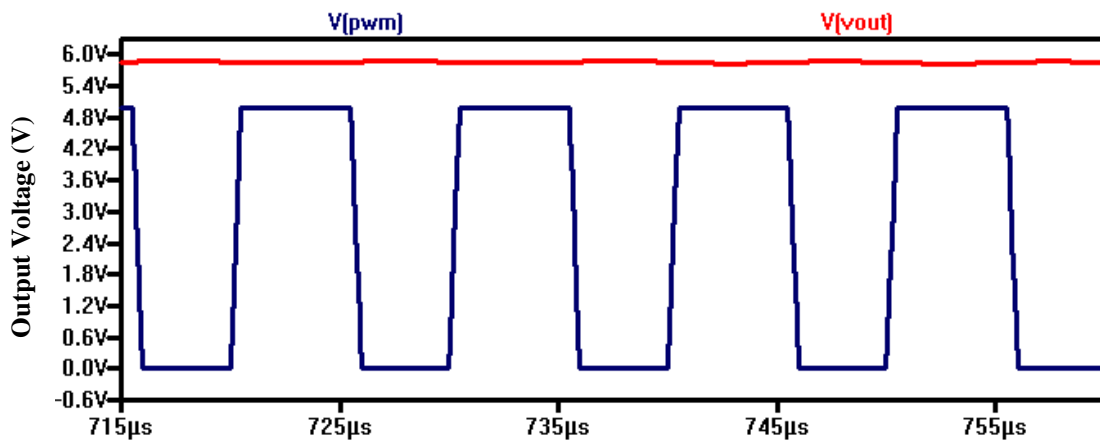


Figure 25: PWM output at 50% Duty Cycle Vs. Time

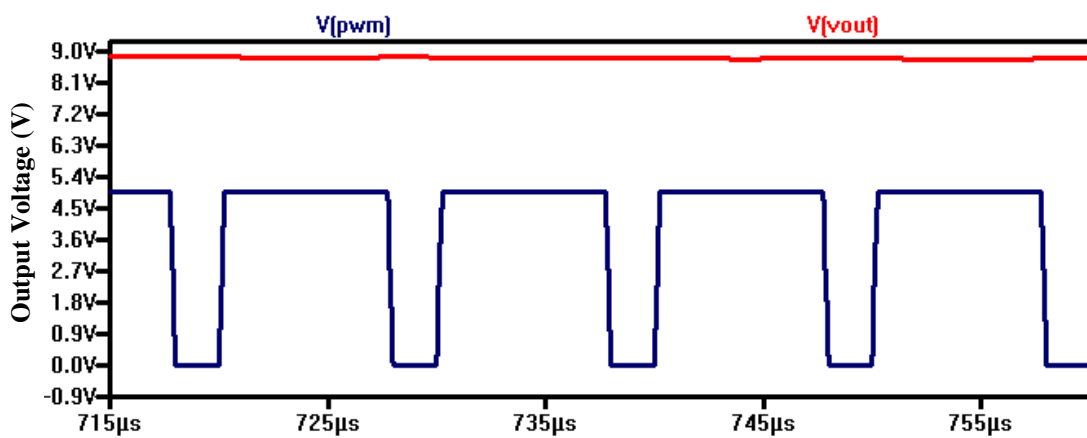


Figure 26: PWM Output at 75% Duty Cycle Vs. Time

3. Requirements and Verifications

	Requirement	Verification	Points
Solar Panel	1- Output a voltage 5V +/- 1V 2- Output a current 215 mA +/- 15 mA	1- Connect a multi-meter in parallel with the output terminals of the solar panel and verify the output voltage to be between 3 - 5 V. 2- Connect a multi-meter 1-in series with the output terminals of the solar panel and verify the output current to be between 200-230 mA.	5
Genasun MPPT	1- Supply the battery with 12 V +/- 0.5 V 2. Outputs maximum power point voltage	1- Change the input voltage of the MPPT using a voltage source and observe to see if we are still getting 12 V +/- 0.5 V on the battery 2. Plot the output (P vs V) curve of the solar panel on an oscilloscope. Make sure the MPPT output the Maximum power point as displayed on the oscilloscope	5
Battery	1- Output a constant 12 VDC +/- 1 V 2- Output 45 W +/- 5W at any given time	1- Connect a multi-meter in parallel with the output terminals of the battery and verify the output voltage to read 12V +/- 1V 2- Measure the current and voltage across the battery using a multi-meter and compute the power using $P = IV$ and make sure the output power is 45W +/- 5W	5

Sensors	<p>1- When light is shown directly into the LDR, the resistance will decrease to $100\ \Omega \pm 10\ \Omega$. When no light is shown to the LDR, the resistance will increase to $10k\ \Omega \pm 1k\ \Omega$.</p>	<p>1- Measure the resistance outputted by the sensors with a multi-meter and make sure that that the 'light room' resistance is $100\ \Omega \pm 10\ \Omega$ and the 'dark room' to be $10k\ \Omega \pm 1k\ \Omega$.</p>	10
Microcontroller Voltage Sensing	<p>1- Microcontroller's AD converter takes an analog voltage between $0-5V \pm .1V$ and converts to digital data in range 0-1023.</p> <p>2- Controller senses input voltage in the range of 0-5V. If $V_{ref} > 4.5V \pm .3V$, the controller activates motor to rotate the umbrella's roof-top with appropriate duty cycle. If $V_{ref} < 4.5 \pm .3V$, the controller disables motor.</p>	<p>1- Power microcontroller with 5V. Sweep the input to the ADC from 0-5V. Record the digital data being outputted by the microcontroller and make sure it corresponds to the analog data with a tolerance of 2%.</p> <p>2- Power microcontroller with 5V. Provide the sensor circuit with 5V Vdd. Simulate shading on the sensor by covering the top and slowly removing the hand. Observe with a multi-meter that the reference voltage is fluctuating. If $V_{ref} > 4.5V$, with a tolerance of 5%, then motor must be activated. If $V_{ref} < 4.5V$, with also a tolerance of 5%, then the motor is not activated.</p>	20
Microcontroller Dimmer	<p>1- Microcontroller ADC reads High (5V) when push button is closed (Pressed).</p> <p>2- Microcontroller' ADC reads Low (0V) when push button is open (Unpressed).</p> <p>3- Observe that light intensity is changing based on input from the push button.</p>	<p>1- Power microcontroller with 5V. Provide the push button with access to 5V and ground with a 10K resistor in series. When pushbutton is closed (pressed), make sure the micro-controller is reading 5V.</p> <p>2- Power microcontroller with 5V. Provide the push button with access to 5V and ground with a 10K resistor in series. When pushbutton is open (Unpressed), make sure the micro-controller is reading 0V.</p> <p>3- Use a multi-meter and observe the input voltage to the LEDs as well as the brightness changing.</p>	5

Microcontroller Buck converter	1- Provide a PWM with a duty cycle of 43% +/- 2%	1- Power microcontroller with 5V. Using an oscilloscope, observe the period of the duty cycle the generated is 43% with a tolerance of 2%.	5
Motors	1- Output 20W +/- 1W and 2A +/- 0.1A	1- Find the voltage, current using a multi-meter. Calculate $P=IV$ and ensure it produces 20W +/- 1W at full duty ratio from PWM. Lower the duty ratio by half and see if the motor produces 10W +/- 1W.	5
Buck Converter	1- Outputs 5V +/- 0.5V and 1 A +/- 0.1A 2- Ensure Inductor does not saturate and send the buck converter into DCM 3- Gate driver is operational	1- Connect a multi-meter in parallel with the output terminals of the buck converter and verify the output voltage to be 5V +/- 0.5V. 2- Connect a multi-meter 1-in series with the output terminals of the buck converter and verify the output current to 1A +/- 0.1A. 3- Send in a signal into pin 2 of IRS2183 and vary the duty cycle. Observe the output in pin 7 using a oscilloscope and make sure the output is switching accordingly	15
USB	1- Outputs 5V +/- .5V and 1A +/- .2A	1- Using a multi-meter, observe the voltage being outputted by the USB port and ensure that 5V, 1A is being outputted with a tolerance of 5% and 20% accordingly.	10

Dimmer	1- Outputs Voltages based on duty cycle of PWM varying from 20% to 80%.	1- Observe the PWM output on the oscilloscope as well as the output voltage of the dimmer. We should see that the output voltage of the dimmer changes from 2.4V to 9.6V +/- 0.4V.	10
LED	1- Brightness increases with different voltages	1- Press Button 1 a couple times and see if brightness increases. Press Button 2 and see if brightness decreases.	5

3- Tolerance Analysis

The most critical part of our design is the power module. In order to successfully design this module, we need to efficiently convert the sun power into electrical power. There are three separate items (The solar panel, the MPPT device, and the Battery) that we need to take into consideration for the efficiency of this module. Their efficiencies are listed below

$$\eta_{Solar\ Panel} = 10 \%$$

$$\eta_{MPPT} = 96 \%$$

$$\eta_{Battery} = 85 \%$$

Therefore, it can be concluded that the total efficiency of this module would be

$$\eta_{Power\ Module} = 0.1 * 0.96 * 0.85 = 0.0816 = 8.16 \% \quad (21)$$

An efficiency of 8.16% is a normal value for a charger module using Solar Energy. If in some case, we do not meet this efficiency, our battery will not receive enough power to power up the features in the device.

4- Cost Analysis

3.1 Labor

Name	Hourly Rate	Hours Invested	Total = Hourly Rate x 2.5 x Total Hours Invested
Viren Mascarenhas	\$ 27.5	150	\$ 10,312.5
Christian Ngeleza	\$ 27.5	150	\$ 10,312.5
Luis Pe-Ferrer	\$ 27.5	150	\$ 10,312.5
TOTAL	-	450	\$ 30,937.5

3.2 Parts

Item		Quantity	Cost
Patio Umbrella		1	\$56.99
Solar Panel		5	\$49.75
Battery		1	\$44.89
MPPT		1	\$67.50
LDRs		4	\$3.16
Microcontroller		1	\$10.37
Motor		1	\$10.50
Buck Converter	Capacitor	4	\$2.20
	Diode	2	\$0.34
	High side gate driver	1	\$3.19
	Inductor(47 μ H)	2	\$2.20
	Resistor(.5 Ω)	2	\$1.50
	Resistor(.1 Ω)	2	\$1.50
USB		1	\$9.66
LEDs		1 strip	\$6.99
		TOTAL	\$270.74

3.3 Grand Total

Section	Total
Labor	\$ 30937.5
Parts	\$ 309.52
Grand Total	\$ 31292.26

5- Schedule

Week	Task	Responsibility
2/8	• Set up Meeting With Solar Expert	Christian Ngeleza
	• Look Up Parts for Project	Luis Pe-Ferrer
	• Complete Proposal	Viren Mascarenhas
2/15	• Design interaction between sun tracking modules	Christian Ngeleza
	• Order Parts	Luis Pe-Ferrer
	• Design Test Environment for Power Source	Viren Mascarenhas
2/22	• Assemble Charging modules	Christian Ngeleza
	• Assemble Lighting modules	Luis Pe-Ferrer

	<ul style="list-style-type: none"> Start PCB Design 	Viren Mascarenhas
2/29	<ul style="list-style-type: none"> Begin Writing logic code for sun tracking modules 	Christian Ngeleza
	<ul style="list-style-type: none"> Assemble Power Source Modules 	Luis Pe-Ferrer
	<ul style="list-style-type: none"> Continue PCB Design 	Viren Mascarenhas
3/7	<ul style="list-style-type: none"> Continue writing Logic code for sun tracking module 	Christian Ngeleza
	<ul style="list-style-type: none"> Start Test for Power Source 	Luis Pe-Ferrer
	<ul style="list-style-type: none"> Finalize PCB Design 	Viren Mascarenhas
3/14	<ul style="list-style-type: none"> Finalize logic code for sun tracking module 	Christian Ngeleza
	<ul style="list-style-type: none"> Optimize Power Source Interaction based on test results 	Luis Pe-Ferrer
	<ul style="list-style-type: none"> Assemble Motor, LDR, Micro-controller and Umbrella Interface 	Viren Mascarenhas
3/21 Spring Break	<ul style="list-style-type: none"> Optimization of dimmer PWM code based on results 	Christian Ngeleza
	<ul style="list-style-type: none"> Optimization of tracking code based on suggestions. 	Luis Pe-Ferrer
	<ul style="list-style-type: none"> PCB design for LDR and Dimmer 	Viren Mascarenhas
3/28	<ul style="list-style-type: none"> Starting test of sun tracking modules based on code 	Christian Ngeleza
	<ul style="list-style-type: none"> Start testing interaction between power source and Execution modules 	Luis Pe-Ferrer
	<ul style="list-style-type: none"> Start assembling modules together 	Viren Mascarenhas
4/4	<ul style="list-style-type: none"> Modular Testing for lighting modules 	Christian Ngeleza
	<ul style="list-style-type: none"> Final optimization of Power Source and Execution modules interface 	Luis Pe-Ferrer
	<ul style="list-style-type: none"> Modular Testing for charging modules 	Viren Mascarenhas
	<ul style="list-style-type: none"> Assemble all modules 	Christian Ngeleza

4/11	• Prepare Demos	Luis Pe-Ferrer
	• Optimize code based on test results	Viren Mascarenhas
4/18	• Finish Demos preparation	Christian Ngeleza
	• Finalize debugging of code	Luis Pe-Ferrer
	• Finalize circuit optimization	Viren Mascarenhas
4/25	• Start Final Paper	Christian Ngeleza
	• Make sure Demonstration is ready	Luis Pe-Ferrer
	• Start Presentation	Viren Mascarenhas
5/2	• Finish Final Paper	Christian Ngeleza
	• Finish Presentation	Luis Pe-Ferrer
	• Proof read all documentation	Viren Mascarenhas

6- Safety Statement

The solar power umbrella designed in this project uses a battery bank which will be providing 45 W, with a maximum of 3.7 A. According to OSHA standards, the effect of current on the human body is shown in Table 3. Because of this, necessary safety precautions will be needed when assembling the system due to the fact that these conditions can be deadly.

Table 3: Effects of electrical shock

Dc Current Level (mA)	Probable Effects
0-4	Perception
4-15	Surprise, Slight shock felt
15-80	Reflex Action, “let-go” range, Painful shock
80 - 160	Muscular Inhibition, Extreme Pain
160 - 300	Respiratory Block, Ventricular fibrillation
Over 300	Cardiac Arrest, Sever Burns, Usually Fatal

From the Table 3, we can see that will be working with nearly 12 times the needed current to cause fatal injuries. We must ensure we take all the necessary safety precautions are taken when performing experiments as well as making sure the final built can withstand the various outdoor environments it will be subjected too.

In order to reduce the risk of injuries will follow the set of rules already imposed by the power electronic lab (ECE Building 4024) as listed below ^[7]:

Please follow the safety precautions to avoid injury, discomfort, lost lab time, and expensive repairs.

- **GROUND! Be aware of which connections are grounded, and which are not.** The most common cause of equipment damage is unintended shorts to ground. Remember that oscilloscopes are designed to measure voltage relative to ground, not between two arbitrary points.
- **RATINGS!** Before applying power, check that the voltage, current, and power levels you expect to see do not violate any ratings. What is the power you expect in a given resistor?
- **HEAT!** Small parts can become hot enough to cause burns with as little as one watt applied to them. Even large resistors will become hot if five watts or so are applied.
- **CAREFUL WORKMANSHIP!** Check and recheck all connections before applying power. Plan ahead: consider the effects of a circuit change before trying it. Use the right wires and connectors for the job, and keep your bench neat.
- **WHEN IN DOUBT, SHUT IT OFF!** Do not manipulate circuits or make changes with power applied.
- **LIVE PARTS!** Most semiconductor devices have an electrical connection to the case. Assume that anything touching the case is part of the circuit and is connected. Avoid tools and other metallic objects around live circuits. Keep beverage containers away from your bench.
- **Neckties and loose clothing should not be worn when working with motors.** Be sure motors are not free to move about or come in contact with circuitry.
- Remember the effects of inductive circuits --high voltages can occur if you attempt to disconnect an inductor when current is flowing.
- **EMERGENCY PHONE NUMBER:** 9-911

The laboratory is equipped with an emergency electrical shutoff system. When any red button (located throughout the room) is pushed, power is disconnected from all room panels. Room lights and the wall duplex outlets used for instrument power and low-power experiments are not affected. If the emergency system operates, and you are without power, inform your instructor. It is your instructor's task to restore power when it is safe to do so. Each workbench is connected to power through a set of line cords. The

large line cords are connected to two front panel switches labelled “3 ϕ mains” and “dc mains.” The standard ac line cord is connected to the switch on the bench outlet column. Your bench can be de-energized by shutting off these three switches.^[7]

Additionally, there are more protocols that we must follow, especially when working with the motor, as giving by the Electric machine laboratory safety manual^[9]:

1. Do not make circuit changes or perform any wiring when power is on.
2. Assume that panel jacks on your bench are electrically live unless power is off.
3. Be sure you understand the function and wiring of an instrument before using it in a circuit.
4. Do not repeat the same mistake.
5. Do not guess — know! If in doubt, see 2 above.
6. Do not wear loose - fitting clothing or jewelry in the lab. Rings and necklaces are usually excellent conductors in excellent contact with your skin.
7. It is wise in electrical labs to wear pants rather than shorts or skirts. Ties are also dangerous.
8. Powered equipment can be hot! Use caution when handling equipment after it has been operating.

Additional key precautions

1. Acquaint yourself with disconnect switches, especially those at your bench.
2. Work slowly and deliberately. Think as you act.
3. Do your wiring, setup, and a careful circuit checkout before applying power.
4. *Use wires of appropriate length.* Do not allow them to drape over your equipment. Avoid splices, which create live surfaces. When running a pair of wires to adjacent terminals, twist the wires together so they do not dangle. This also neatens your work and will save time.
5. Keep your bench organized and neat. It should be clear of coats, extra books and papers, and unused equipment.
6. *Use your bench.* Avoid long connections by using the bench transfer wires. Plug instruments
7. Into the bench, not into the wall. This gives you the protection of the bench switches.
8. No smoking in the lab, and no food or beverages on or near the workbenches. *If you smell smoke, turn off power.*
9. Do not touch anything if your hands are wet. The “one-hand” approach is safest.
10. Do not pull wires out until you are absolutely sure that the circuit is completely dead. Shocks can occur if an inductive load (motor or transformer) is disconnected while conducting.

In the event of an accident or emergency:

- Do not panic.
- Shut off all power.
- Call for assistance. Fire Department and emergency services 9 - 911

Finally, more precautions will be needed in order to insure that the final built can withstand the various weather conditions it may encounter. That is, we will need to pick our components carefully and make sure that proper wiring procedures are followed, as well as the right amount of insulations. One way to account for this is that we plan on using a waterproof USB hub.

We will ensure to watch out for ourselves, our peers, professors and everyone who will be working on this project with us.

7- Code of Ethics

Since this product is a commercial product that will be used by consumers in hotels etc., it is important that it meets all safety requirements and its 100% safe to use. Therefore, as we go ahead and design this project, we will comply to the first code of ethic in IEEE Code of Ethics. ^[12]

1. To accept responsibility in making decisions consistent with the safety, health, ad welfare of the public, and to disclose promptly factors that might endanger the public or the environment.

As we go ahead and design this project, we will be learning a lot on solar panels, MPPT, power converters and control mechanisms for solar tracking. This relates to the 6th IEEE Code of Ethics

6. To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations.

In this class, we are required to peer review other groups and give our opinion on things. Also, we will be needing help from other groups and TA's to complete our project. This correlates to the 7th IEEE Code of Ethics.

7. To seek, accept and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others.

Our main objective is to stay safe and to ensure that we meet lab safety requirement. We must look out for our peers and professors that share the lab with us. This correlates to the 9th IEEE Code of Ethics.

9. To avoid injuring others, their property, reputation, or employment by false or malicious action.

Lastly, that being said, we promise comply to all the IEEE Code of Ethics regardless if its mentioned in the above statement or not.

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