Solar Powered Rechargeable Battery Pack with Controllable Voltage Output

ECE 445 Design Document - Spring 2018

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1 Introduction

1.1 Objective

We are now at the crossroad of our industrial civilization. The traditional power sources like oil or other fossil fuels can no longer fulfill our expanding demand for energy. Therefore, more and more people are using renewable resources like solar, wind, or tide. There are two usually ways to deal with this kind of energy: we use it or we store it. Most of the power generated from large solar farms or wind farms would directly merge into the power grid while using the thermal generator sets to perform the frequency regulations. This method is deficient, since the motor start-up and spin-down would cost large amount of extra energy, which is both economically and physically inefficient. So, considering of this situation, the alternative would be storing the power generated from renewable resources to batteries or pumped storages.

Unlike the diversifying input resources, the output of electricity is stagnant comparing to the explosively increasing use of all kinds of electrical devices. Cell phones, electric vehicles, and smart home devices are surrounding modern people. However, the various charging voltage levels really confuses most of the people, requiring additional converters or inverters, which is inconvenient for people with no general knowledge about electricity.

Therefore, the goal of this project is to develop a battery pack that could be self-recharged by solar cells and outputs controllable voltages at different levels. The solar cells would be mounted on the system in a portable box. The output of the battery is controlled and monitored by microcontroller and is adjustable and visible for users. Users could select the prefered voltage level on the user interface. This project aims to provide user oriented battery with portability, flexibility, and endurable capacity for the increasing use of battery today. By using batteries with different capacities and small configurations on the design, this system could be applied to various situations like electrical vehicles, cell phones, or smart home batteries.

1.2 Background

Modern society and industry thrive on top of electricity. Electrical energy could be generated from and converted to various source of energy. It has the most sophisticated system to transmit the energy safely and efficiently. However, even though the uses of batteries are increasing and diversifying, the technology of battery is stagnant. People today would really suffer from such problems. Those who want to set a solar panel for the house would really confused on which batteries to be used. Since most of the batteries output standard dc voltages, it is hard for people with no technical backgrounds to adapt the batteries to ac voltages. So, this system is developed in order to make better use of battery that could self-recharge and have the ability to output different voltage levels to accord with different demand.

The system could apply to various situation. The system with a larger battery could be applied to electric vehicles. With self-recharging, vehicles could have greater endurance, and with the ability of outputting different voltage levels, the single system could be used as power source for driving, electrical devices on the vehicles, or mechanical operations.

1.3 High-level Requirements

- The system is able to be recharged from both the mounted solar panel and wall plug.
- The system need to be able to discharge 5V - 48V DC power, and 120V AC power based on user selection.
- The system need to display the voltage, current, and power on the LED screen while charging or discharging.

2 Design

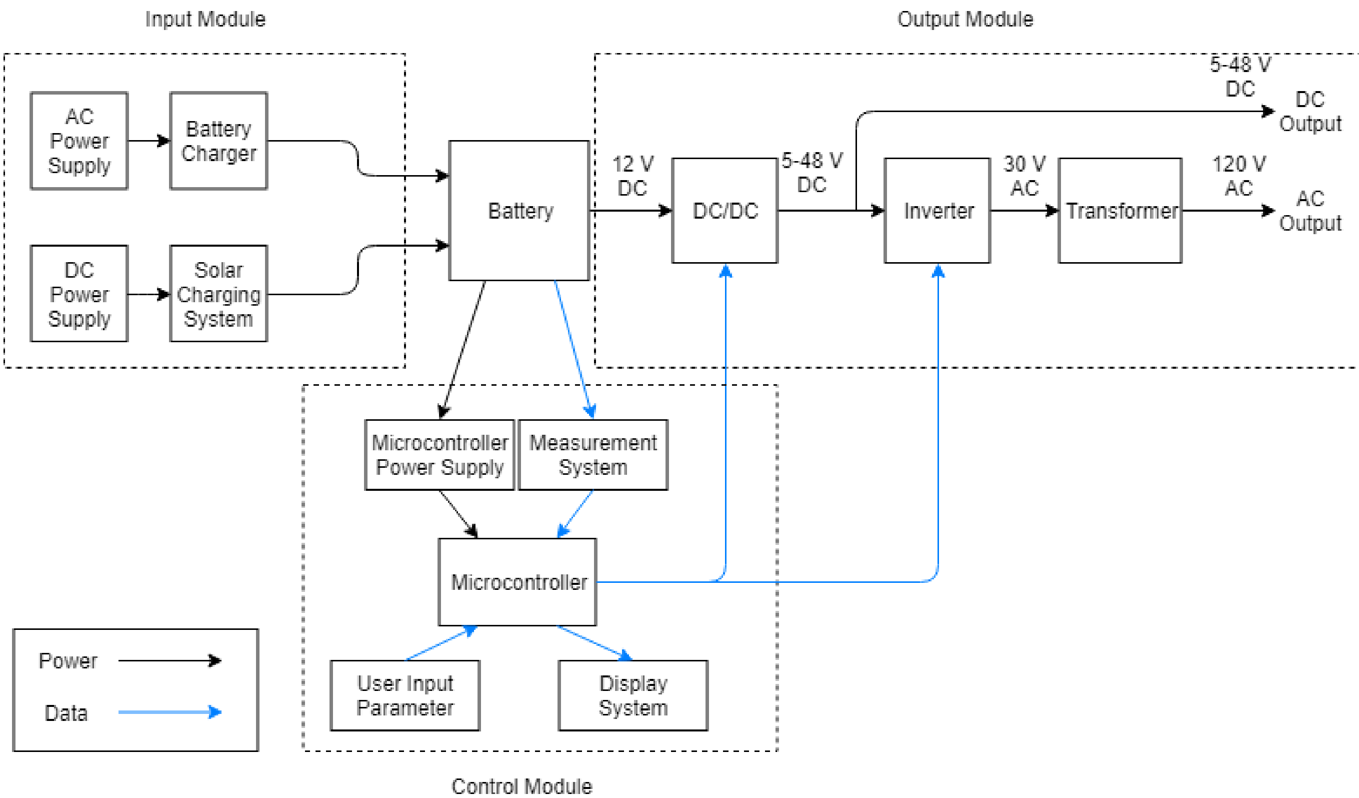

Figure 1: Block Diagram

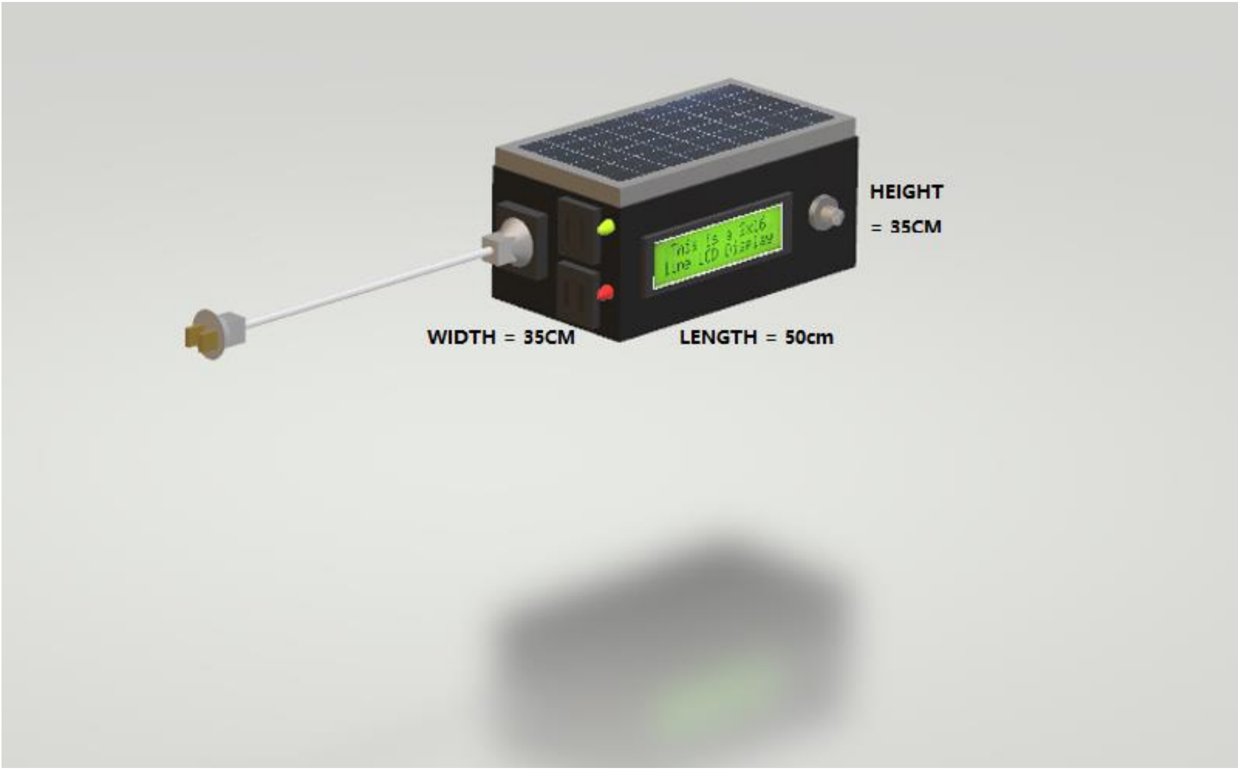

Figure 2: Physical Diagram

To achieve our goal of this project, we require four modules: an input module, an output module, a control module, and a battery pack. Figure 1 shows a block diagram for this project and Figure 2 shows the actual physical design of this device. The input module provides power supply for the system from some external sources. As you can see, the input module has two different input sources: an AC power supply from the wall outlet and a DC source directly from the solar panel. It contains a AC battery charger and a solar charging system.The output module contains a DC/DC converter in series with an inverter that can output either AC or DC voltage. The control module contains a microcontroller power supply module that can draw power from the battery and supply energy to the microcontroller, a battery measurement system that can monitor the charging and discharging process of the battery, a microcontroller that controls the input and output DC/DC converter to output the proper voltage level, and an user interface that can collect the user input parameter and display the system status. The battery pack contains several lead-acid batteries connected in parallel which stores the electrical energy from the external sources and supply energy to the whole system.

2.1 Input Module

2.1.1 AC Power Supply

The AC power supply for our project comes from the 120 V wall plug. This AC input will go through a rectifier to convert into a DC voltage, and this DC voltage will be fed into a DC/DC converter to buck down (or boost up) to the desired voltage level for charging the battery.

2.1.2 DC Power Supply

The DC power source for our project basically comes from a solar panel. The solar panel will be surface-mounted on a box that contains our whole device. Similar to the AC power supply, the DC input from the solar panel will also go through a voltage regulator and a DC/DC converter to output the proper voltage for charging the battery.

2.1.3 AC Battery Charger

For safety reason, we will not build our own battery charger because the lead-acid battery requires a extremely precise charging process [1]. Over-charging or incorrectly charge a lead acid battery can produce hydrogen sulfide which can become explosive at a concentration of 4 percent. Instead of building an ineffective, unsafe battery charger, we will use an off-the-peg battery charger to minimize the risk of incorrectly handling the battery. Another advantage of using a commercial battery charger is that it is equipped with built-in reverse polarity, short circuit protection and over-temperature protection. This safety measure gives user piece of mind for their battery and this charger system.

Requirements	Verifications	Points
● The input voltage must be 120 V, 60 Hz, AC. ● The output voltage must be 12 (± 0.5) V DC. ● The charger must be able to charge the battery safely. ● The charger must provide some safety protection to minimize the potential hazard. ● The charger must be adaptive for a conventional wall outlet.	● Charge the battery using this charger from the conventional wall outlet. ● After fully charging the battery, measure the battery voltage using a multimeter to verify that the battery has reached its maximum voltage rating.	0

2.1.4 Solar Charging System

The solar charging system contains a DC/DC converter that convert the input DC voltage generated from the solar panel into a constant DC voltage (12 V). This system will receive power from a solar panel and supply energy to the battery. In addition to the DC/DC converter, it also contains several protection circuits that provides short-circuit, spark and polarity protection which reduce the potential hazard.

Requirements	Verifications	Points
● The output voltage must be 12 (± 0.5) V DC. ● The charger must be able to charge the battery safely. ● The charger must provide some safety protection to minimize the potential hazard.	● Charge the battery using this charger from the conventional wall outlet. ● After fully charging the battery, measure the battery voltage using a multimeter to verify that the battery has reached its maximum voltage rating.	0

2.2 Output Module

2.2.1 Output DC/DC converter

The DC/DC power converter will output a constant DC voltage based on user's requirements. It will be a buck-boost converter that can buck down or boost up the input voltage to the desired output voltage level. There are 5 main types of dc-dc converters. Buck converters can only reduce voltage, boost converters can only increase voltage, and buck-boost, Cúk, and SEPIC converters can increase or decrease the voltage. Since our desired output voltage will be in the range of input voltage, the topology we are considering about for this converter is SEPIC buck-boost converter. Buck-boost converters can be cheaper because they only require a single inductor and a capacitor. However, these converters suffer from a high amount of input current ripple. This ripple can create harmonics; in many applications these harmonics necessitate using a large capacitor or an LC filter. This often makes the buck-boost expensive or inefficient. Another issue that can complicate the usage of buck-boost converters is the fact that they invert the voltage. Cúk converters solve both of these problems by using an extra capacitor and inductor. However, both Cúk and buck-boost converter operation cause large amounts of electrical stress on the components, this can result in device failure or overheating. SEPIC converters solve both of these problems. The SEPIC converter is a buck-boost converter with a coupled inductor which can split into two isolated inductors. It provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage. For our project, the DC/DC converter is responsible for drawing power from the battery at 12V and converting this voltage to a range of output voltage (5 - 48 V). The microcontroller will generate the PWM signal and send this signal to the converter's gate driver which will control the output voltage level of the converter. Figure 3 shows the schematic of the SEPIC converter.

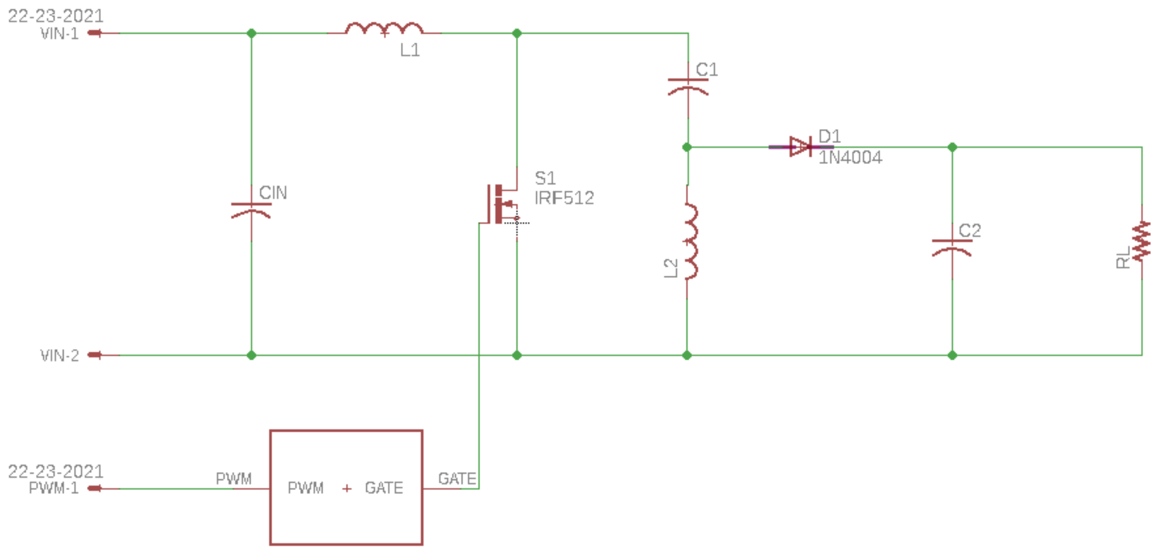

Figure 3: SEPIC converter schematic

The passive component sizes are calculated below.

$$\frac{V_{out}}{V_{in}} = \frac{D}{1-D} \Rightarrow D = \frac{V_{out}}{V_{out}+V_{in}} \tag{1}$$

$$\begin{aligned} D_{\max} &= \frac{48}{48+12} = 0.8 \\ D_{\min} &= \frac{5}{5+12} = 0.294 \end{aligned} \tag{2}$$

$$I_{in(\max)} = I_{out(\max)} \frac{D}{1-D} = 1 \times \frac{0.8}{1-0.8} = 4\text{A} \tag{3}$$

$$\Delta I_L = k \times I_{in(\max)} = 0.3 \times 4 = 1.2\text{A} \tag{4}$$

$$L_a = L_b = \frac{D_{\max} \cdot V_{in}}{\Delta I_L \cdot f_{sw}} = 80\mu\text{H} \tag{5}$$

$$C_{out} = \frac{I_{out} \cdot D_{\max}}{\Delta V_{C_{out}} \cdot f_{sw}} = 16\mu\text{F} \tag{6}$$

$$C_{in} = \frac{\Delta I_L}{8 \cdot \Delta V_{C_{in}} \cdot f_{sw}} = 1.25\mu\text{F} \tag{7}$$

$$C = \frac{D_{\max} \cdot I_{out}}{\Delta V_C \cdot f_{sw}} = 16\mu\text{F} \tag{8}$$

Requirements	Verifications	Points
• The converter must be able to handle a variable input voltage range (12 - 12.8 V). • The converter must be able to output a variable DC voltage (5 - 48 V). • The converter must be able to handle a maximum current of 1 A. • The efficiency of this converter must be no less than 70%. • The output voltage ripple must be less than 5%.	• Adjust the input voltage from 12 V to 12.8 V and change the duty ratio by hand to verify that the output voltage is constant all the time. • With constant input voltage, adjust the duty ratio to verify that the output voltage can vary from 5 V to 48 V. • Connect a 1 A load in the output end and operate the converter for several minutes to verify the operation status of the converter. • Calculate the output efficiency to verify that the efficiency of this converter is larger than 70%. • Probe the output voltage waveform to verify that the output ripple is less than 5%.	15

2.2.2 Inverter

The inverter will convert the input DC voltage into a sinusoidal AC voltage. We will use a full bridge inverter with four MOSFETS. We use full bridge inverter instead of half bridge inverter because the half bridge inverter has the disadvantage of being unable to produce the zero crossing dead-time which is required for harmonic elimination. According to IEEE THD Limitations, the total harmonic distortion should be less than 5%. For this project, we will try our best to reduce the THD as low as possible. To reduce the THD, we decided to eliminate the 3rd harmonic which will significantly reduce the THD. The input of the inverter comes from the output of the converter. And the output of the inverter will go through a transformer to step up to the high AC voltage level. The gate drives of these MOSFETS are controlled by a periodic PWM function from the microcontroller. Furthermore, an output RLC filter will also reduce the THD. Figure 4 shows the schematic of the output inverter with MOSFET drivers.

Requirements	Verifications	Points
• The inverter must be able to output an AC voltage of 30 V_{rms}. • The inverter must have a THD as low as possible (ideally, less than 5%).	• Adjust the input DC voltage from 5 V to 48 V to verify that the inverter is able to output an AC voltage waveform. • Probe the output waveform to verify that the 3rd harmonic is eliminated.	10

2.2.3 Transformer

The transformer is connected with the output of the inverter to step up the output voltage level. Since our inverter's output is 30 V_{rms}, we will use a 1:4 transformer to step up the output voltage to the desired maximum value of 120 V_{rms}.

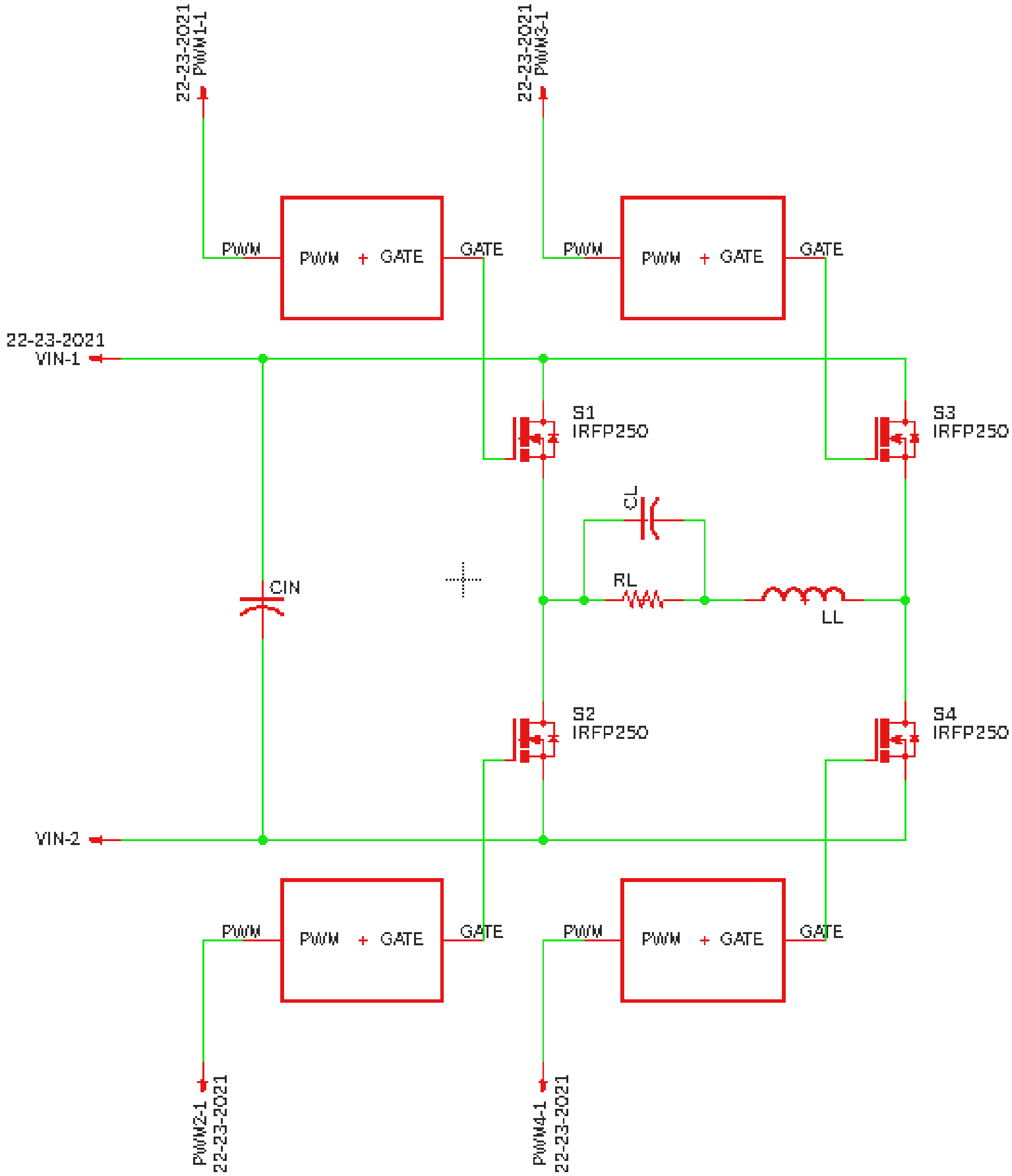

Figure 4: Inverter schematic

2.3 Control Module

2.3.1 Microcontroller Power Supply

This device will draw power from the lead-acid battery pack and supply the power to the microcontroller and the display system. It will contain a voltage regulator that regulates the input voltage to the desired voltage level for powering the microcontroller.

Requirements	Verifications	Points
● The input voltage range is 11 - 13V DC. ● The output voltage is 3.3 V for both the microcontroller and the Arduino.	● Adjust the input voltage from 11V to 13 V to verify that the output is constant at 3.3 V.	0

2.3.2 Battery Measurement System

This system contains some sensors that can monitor the voltage and current levels during the discharging process. The Arduino range of microcontrollers provides analog inputs that can be used to measure voltage. We can use this to build a voltmeter. We will use an analog DC current sensor to measure the current. For safety concern, we will also use a temperature sensor to monitor the temperature of the system. This system will provide all the necessary data to the microcontroller that will control the DC gain of the output DC/DC converters, as well as the LCD display information.

Requirements	Verifications	Points
● The system must be able to measure the output DC voltage from 5 V to 48 V. ● The system must be able to measure the output current with a maximum value of 1 A.	● Measure the voltage, current and temperature information using the microcontroller and print the information to the console. ● Compare the data with the	5

• The system must be able to measure the temperature from 0 to 60 degrees celsius. • The measuring error must be less than 5 %.	value measured by a multimeter and a thermometer to verify that the measurements match the actual value with less than 5 % error.	

2.3.3 Microcontroller

The microcontroller will collect all the data from the battery measurement system, and compare these data with user's input parameters to determine the operation mode of the output power converters. In addition, it can also monitor the charging process to prevent batteries from overcharging. We will use the Texas Instruments C2000 Piccolo and Arduino because of their optimized performance in different operations. The C2000 has advantage in closed loop feedback operations. It also has multiple enhanced PWM outputs, which can be used as the gate driver for the switches. The Arduino has advantage in measuring the voltage and current using some analog sensor and displaying these parameters through a LCD screen.

Requirements	Verifications	Points
• The microcontroller must be able to output multiple PWM signals to control the inverter switches. • It also need to control the duty ratio for the SEPIC DC converter.	• Probe the output PWM waveform of the microcontroller to verify that each PWM signal has a 180-degree phase shift.	10

2.3.4 User Interface

This device includes a control panel for user to control the output power mode. The control panel contains a rotary potentiometer connected with the microcontroller which will send the input parameters to the microcontroller. The user input will be read by the microcontroller as an analog voltage. User can choose the output power mode (either AC or DC) and adjust the output voltage level (5 - 48 V DC, 120 V AC) based on specific requirements. It can also control the output current limit to meet the output power requirements.

Requirements	Verifications	Points
• The user can change the output power mode using the control panel. • The output voltage level can be controlled by the control panel.	• Use the control panel to change the output power mode to verify that the output voltage can be either AC or DC. • Measure the output voltage and current with a multimeter, set different output voltage using the control panel to verify that the output voltage can be varied from 5 V to 48 V DC, 120 V AC.	5

2.3.5 Display System

This device is also part of the control panel that can display all the important information to the user. The microcontroller will send all the measured information to the display system. This system contains a basic 20x4 character LCD display which is controlled by the microcontroller. It will display the output voltage, the output current, and the temperature to the user.

Requirements	Verifications	Points
• This system must be able to display the correct information which is controlled by the microcontroller.	• Program the microcontroller to display some test value to verify that the system can display the same value.	5

2.4 Battery

The battery we will use is a 12 Ah rechargeable lead-acid battery. The rating voltage for charging the battery is 12 V. The battery voltage will be varied from 12 V (fully depleted) to 12.7 V (fully charged). Care must be taken in order to prevent batteries from overcharging.

Requirements	Verifications	Points
• The battery voltage must be varied between the range of 12 - 12.7 V.	• Measure the voltage across the battery for both fully-charged and full-depleted conditions. • Verify that the battery voltage is within rating range.	0

2.5 Tolerance Analysis

This project implemented in order for batteries to provide controllable voltages. Users could select preferred voltage levels and expect to be provided corresponding voltages. That is, we are using DC/DC converters to adjust the voltage levels from a steady DC output source. Since we will use an extra transformer to amplify the ac voltage, there is no need to use a fly-back converter dealing with high dc voltages that would cause potential safety problems. Also, since the buck-boost converter will flip the polarity in the load end, we choose to use the SEPIC converter. Therefore, the most important design in this project would be the SEPIC converter. If the output voltage levels deviate from the selected voltages, it has potentials for the output to excess the rated input for devices using this system. This may cause potential safety concerns especially dealing with high voltages and currents. In order to eliminate the potential harm, tolerance analysis of the DC/DC converter is performed. The tolerance of the SEPIC converter outputs would be 5%. Since we will use the 40V converted voltage as the input of the inverter, a 12V/40V SEPIC converter simulation is performed. The acceptable output voltages should be in the range of 39V to 41V. One resistor, two inductors, and three capacitors with tolerance of 1% would be used. The input would be 12V 4A, so the duty ratio would be

$$D = \frac{V_{out}}{V_{in} + V_{out}} = 0.77 \tag{9}$$

And the inductance and output capacitance should be

$$L_a = L_b = \frac{D \cdot V_{in}}{\Delta I_L \cdot f_{sw}} = 77\mu\text{H} \tag{10}$$

$$C_{out} = \frac{I_{out} \cdot D}{\Delta V_{C_{out}} \cdot f_{sw}} = 4.62\mu\text{F} \tag{11}$$

$$C_{in} = \frac{\Delta I_L}{8 \cdot \Delta V_{C_{in}} \cdot f_{sw}} = 1.25\mu\text{F} \tag{12}$$

$$C = \frac{D \cdot I_{out}}{\Delta V_C \cdot f_{sw}} = 4.62\mu\text{F} \tag{13}$$

If the tolerance of these components is 1%, that is, the inductance is between 76.23 uH to 77.77 uH, the output inductance is between 4.57 uF to 4.67 uF, and the input inductance is between 1.24 uF to 1.26 uF. The maximum output voltage simulated is 40.36V and the minimum output voltage is 39.44 V. This is pretty close to the selected output. However, if the inductor is biased, the output voltages would be biased more. With the simulation, tolerance of 1% on the component should be fine for the SEPIC converter. In actual performance, we will accept output tolerance that is less than 10%.

3 Cost and Schedule

3.1 Cost Analysis

Table 1. Labor Costs for each Member in this Project

NAME	HOURLY SALARY	HOUR INVESTED	TOTAL
Zihao Zhang	$ 32	240 Hrs	$ 19,200
Zhuohang Cheng	$ 32	240 Hrs	$ 19,200
TOTAL COSTS	$ 38,400		

Table 2. Parts Costs

PARTS	SOURCE	QUANTITY	TOTAL
12V Lead-acid Batteries	Amazon.com: ExpertPower	2	$ 38.36
Sealed Lead Acid Battery Charger UPG D1724	Amazon.com: Universal Power Group	2	$ 18.99
Basic 20x4 Character LCD Display	Sparkfun.com	1	$ 17.95
12 Volt Solar Charging System with 5 Watt Panel and Desulfator	Amazon.com: BatteryMINDer	1	$119.99
Arduino Pro Mini 328 - 5V/16MHz	Sparkfun.com	1	$9.95
LAUNCHXL-F28027-C2000 Piccolo LaunchPad	Ti.com	1	$17.05
Current Sensor Breakout	-	-	~$20
Temperature Sensor	-	-	~$5

Rotary Potentiometer	-	-	~$5
Circuit Components	-	-	~$20
TOTAL COSTS			**$272.29**

Table 3. Total Costs for the Project

LABOR COSTS	PARTS COSTS	TOTAL COSTS
$ 38,400	$272.29	**$38,672.29**

3.2 Schedule

<table>
<tr><th>WEEK</th><th colspan="2">TASKS</th><th>DEADLINES</th></tr>
<tr><td rowspan="2">02/19</td><td>Zihao</td><td>Work on Design Documentation
Work on Mock Design
Start doing calculations
Select parts online</td><td rowspan="2">Design Documentation</td></tr>
<tr><td>Zhuohang</td><td>Work on Design Documentation
Work on Mock Design
Start designing converters
Select parts online</td></tr>
<tr><td rowspan="2">02/26</td><td>Zihao</td><td>Work on Design review
Complete rough calculations of the converters
Start simulation and building PCB</td><td rowspan="2">Design Review</td></tr>
<tr><td>Zhuohang</td><td>Work on Design review
Complete rough design of the converters
Start simulation and building PCB</td></tr>
<tr><td rowspan="2">03/05</td><td>Zihao</td><td rowspan="2">Work on Solering Assignment
Complete first simulation
Order parts
Order PCBs
Start design measurement module and LCD display</td><td rowspan="2">Solering Assignment</td></tr>
<tr><td>Zhuohang</td></tr>
<tr><td rowspan="2">03/12</td><td>Zihao</td><td>Start assembly input module</td><td rowspan="2">First Round PCBway Orders</td></tr>
<tr><td>Zhuohang</td><td>Do more simulations and tests on PCB</td></tr>
<tr><td rowspan="2">03/19</td><td>Zihao</td><td rowspan="2">Finish assembly
Start programming the microcontroller
Work on Individual progress reports</td><td rowspan="2">Spring Break</td></tr>
<tr><td>Zhuohang</td></tr>
<tr><td rowspan="2">03/26</td><td>Zihao</td><td>Continue work on programming the microcontroller</td><td rowspan="2">Individual progress reports

Final Round PCBway Orders</td></tr>
<tr><td>Zhuohang</td><td>Double check PCB</td></tr>
</table>

04/02	Zihao	● Integrate the microcontroller into the system	
	Zhuohang	● Test the system	
04/09	Zihao	● Debugging	
	Zhuohang	● Continue testing	
04/16	Zihao	● Prepare for the demo and presentation	Mock Demo Mock Presentation
	Zhuohang		
04/23	Zihao	● Prepare for the demo and presentation	Demo Presentation
	Zhuohang		
04/23	Zihao	● Work on the final paper	Final Paper Lab Notebook Lab Check-out
	Zhuohang		

4 Ethics and Safety

4.1 Ethical and Safety Issues

The Lead Acid Battery we are going to use in the project will cause health and environmental concerns. Therefore, in compliance with the IEEE code of ethics 7.1 *"to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment"*, it is our responsibility to disclose the potential harm of using this kind of batteries, and inform the proper method of recycling.

Health Concern: Lead is a toxic metal that can enter the body by inhalation of lead dust or ingestion when touching the mouth with lead-contaminated hands. If leaked onto the ground, acid and lead particles contaminate the soil and become airborne when dry. The sulfuric acid in a lead acid battery is highly corrosive and is more harmful than acids used in most other battery systems. Contact with eye can cause permanent blindness; swallowing damages internal organs that can lead to death. In order to ensure safety, batteries need to be locked away from small children to avoid potential ingestion.

Environmental Concern: Lead contaminations would cause lots of problems. If they are not recycled properly, they can leak into the surrounding soil and air. This creates an exposure hazard. Sulfuric acid can enter the water system and contribute to acid rain, according to an August 6th, 2002 report by the Environmental Protection Agency (EPA). As this acid flows through the ecosystem, it poses various dangers to the animal and plant life, as well as the soil. Within precipitation, sulfuric acid accelerates the decay of structures and paints, wearing down buildings and landmarks. It also causes damage to trees and acidifies lakes and other water bodies. In the atmosphere, sulfates are among the particulates released into the air, which can harm the public health.

Recycling: Since lead-acid batteries are so dangerous, states have made it easy to get them to recyclers. Stores that sell new lead-acid batteries should take the old one and recycle it for you. When you remove a lead-acid battery, leave the lead cable ends attached. Check the battery to make sure it is not leaking. If it is, immediately place it in a leak-proof container . Battery acid can eat through concrete, so if you must put it on the ground, see if you can find a sealed asphalt surface. Clean up any leaks with lime or baking soda (the cleanup materials must then also be treated as hazardous waste). While transporting the lead-acid battery to a recycler, place it in a leak-proof container and make sure you keep it upright so the acid cannot leak out. If you have more than one battery, separate them with a piece of wood or another material so the post terminals do not touch each other.

Also, since the system could be dealing with high level currents and voltages, there are several safety concerns needed to be specified.

Safety Concern: As for the solar panels/modules, these are generally, but not always, at a lower voltage and therefore safer. However, since we are using converter and inverter to deal with higher DC or AC voltages, we should know that the lowest voltage believed to have caused a person's death is around 60 volts. Also, the direct current (DC) is more dangerous to humans than an alternating current (AC) due to the ways it affects the muscles of the body.

Also, batteries pose a particular danger as they store a large amount of energy, and if that energy is dissipated (used or released) in a short period of time, the consequences can be substantial. If this energy is released over a period of minutes rather than seconds, a large amount of heat can be generated, possibly resulting in fire. In the case of a lead acid battery, acid could be released. There is also the potential for a large amount of arcing. A very important factor to consider is that lead acid batteries give off hydrogen while being charged (and for some time afterwards). Hydrogen is combustible, and when mixed with air, explosive. Any spark due to a short circuit or from connecting/disconnecting a battery while charging or soon after, can cause an explosion resulting battery damage and acid spillage.

4.2 Safety Manual

IEEE Standard 510-1983 have been included in this section in order to caution all personnel dealing with high voltage applications and measurements in this project and to provide recommended safety practices with regard to electrical hazards mentioned above.

1. All ungrounded terminals of the test equipment or apparatus under test should be considered as energized.

2. Common ground connections should be solidly connected to both the test set and the test specimen. As a minimum, the current capacity of the ground leads should exceed that necessary to carry the maximum possible ground current. The effect of ground potential rise due to the resistance and reactance of the earth connection should be considered.

3. Precautions should be taken to prevent accidental contact of live terminals by personnel, either by shielding the live terminals or by providing barriers around the area.

4. The circuit should include instrumentation for indicating the test voltages.

5. Appropriate switching and, where appropriate, an observer should be provided for the immediate deenergization of test circuits for safety purposes. In the case of dc tests, provisions for discharging and grounding charged terminals and supporting insulation should also be included.

6. High Voltage and high-power tests should be performed and supervised by qualified personnel.

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