Controllable Voltage Rechargeable Battery Pack with Battery Management Display

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2 Introduction

2.1 Objective

Batteries exist in many different forms. However, they are inherently inflexible storage devices, only delivering a set DC voltage level. It is no wonder that there are so many different batteries on the market, each one fulfilling a specific purpose. Instead of needing to carry a multitude of different battery pack units, it would be more convenient to have one package with the flexibility to deliver different voltages. Another fault of many battery packs is that they do not provide feedback to the user. Most batteries do not tell the user how much charge is left or how much power is being drawn. This information could be useful to a user, and could help prevent them from running out of energy at an inopportune moment or accidently drawing large amounts of power.

Our goal is to construct a portable power pack that could be used to power most consumer electronics, such as computers, camping equipment, cellular devices, etc. It could even be used to charge other batteries. We see this being useful when stuck with a dead car battery with no other vehicle around to provide a jump start. This power pack would be rechargeable from a standard AC wall outlet. It would have enough capacity for at least 10 Amp Hours, while still being light enough and small enough to be carried by a person. The power pack would be able to supply DC and AC voltages, and the user will be able to specify the voltage output they need. A battery measurement system will inform the user of information such as the charge level, the temperature, the voltage and current output of the device.

2.2 Background

As technology has progressed, people have new opportunities for work, life, health, and communication, but all of these developments are dependent on the availability of energy to supply them, in particular, electricity. In the developed world, we have created an expansive electrical grid that is able to supply electricity on-demand all over the country. However, in many parts of the world, the grid is underdeveloped and people lack this ready access to the energy that supplies much of the technological progress of the past century. As many as 1.2 billion people don't have access to electricity [1] and many more lack access to quality electricity. This limits access to electronics, medical equipment, and communications. Even in the developed world, there are places where a person can be removed from the power grid, but still require electricity. Since building up the electrical grid to cover everywhere is expensive and time-consuming, it is simpler to provide a portable battery pack that can be charged where electricity is available, and used where electricity is needed. This project is also for people who just want power on the go and want a portable yet fairly large and flexible power supply.

2.3 High-Level Requirements

- The battery pack must be able to supply DC voltage 3.3-40V and AC voltage 40-170V(peak amplitude) at a maximum of 200W for DC and 240W for AC
- The battery pack must be rechargeable from a standard wall outlet
- The battery pack must provide a display to the user, informing them of the charge level of the battery, the output voltage, and output current

3 Design

To fulfill our mission statement we require a system with four sections: an input power module, a control unit, an output power module, and the batteries. The input power module is required to charge the battery and provide power for the rest of the circuitry. The control unit is responsible for interfacing between the machine and the user. It interprets the user input through a control knob potentiometer, measures the battery and output power parameters and displays them to the LCD screen. Finally, it is responsible for directing the operation of the output power module based off user input. The output power module consists of a DC/DC flyback converter in series with an inverter. The user will be able to draw power from either the DC/DC converter or the inverter. The voltage level of both the DC and AC output is controlled by the output of the DC/DC converter, as directed by the control unit. The lead acid batteries store the electrical energy from the input power module and supply energy to the control unit and output power module.

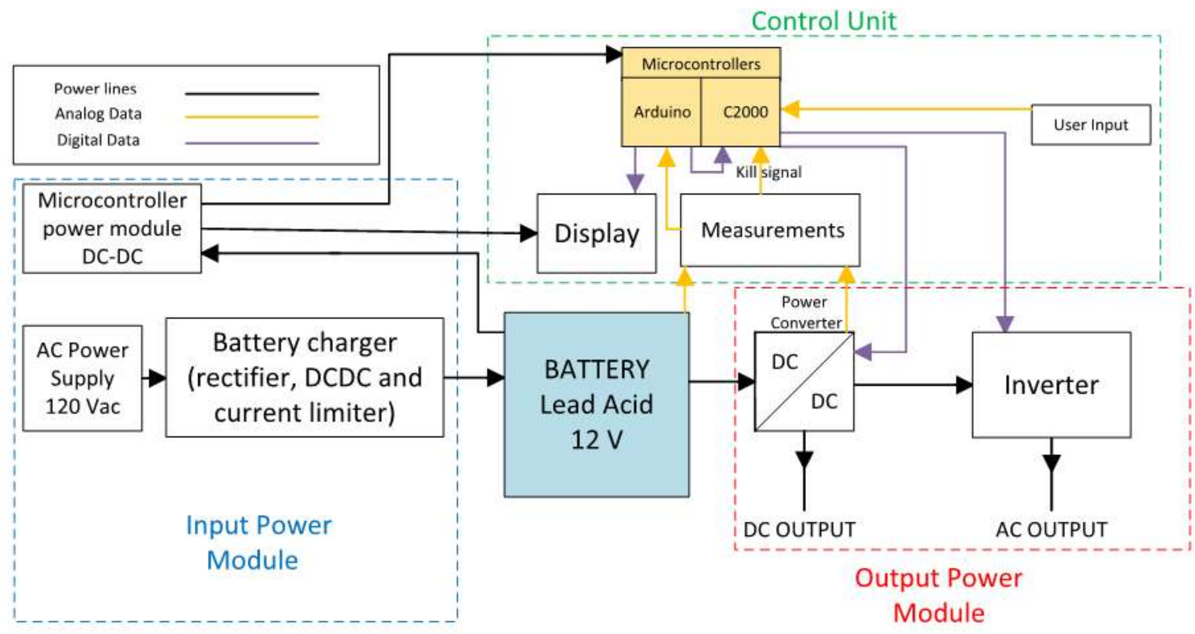

Figure 1: Block Diagram

The entire system will be in a boxed enclosure of 10 x 7 x 6 inches. There will be two electrical outputs, one for high AC Voltage, and the other one for low DC Voltage. The input will have a common plug in order to be connected directly to the grid. The user will be able to choose the desired output voltage by using a rotary potentiometer. The box will also have a LCD display in charge of showing output voltage, output current, battery charge, and box temperature. The cover will also have ventilation apertures to prevent the buildup of explosive gases.

The two batteries will be secured on the bottom of the box. The PCBs and microcontrollers will be placed above them.

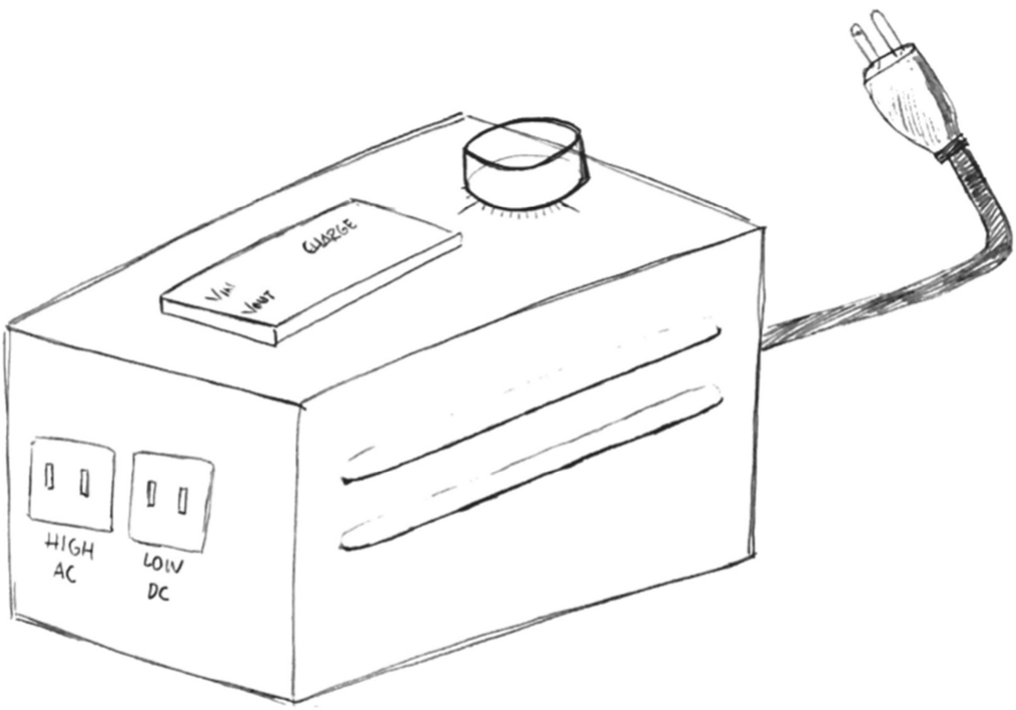

Figure 2: Physical Design

3.1 Input Power Module

The input power supply receives AC power from a standard US or European wall outlet. It provides that power to charge the battery and power the control circuitry.

3.1.1 Battery Charger

We are buying a commercial off-the-shelf battery charger. The main reason is for safety. As discussed in the section on Ethics and Safety, lead acid batteries pose an explosion hazard if improperly handled. When a lead acid battery is overcharged, or charged incorrectly, it can generate explosive gases through hydrolysis. Using a proven off-the-shelf charger, as opposed to designing our own, mitigates this danger. The battery charger uses a constant voltage and current method of charging until a certain cell voltage limit is reached and then the charger moves to a float charging state. Testing a lead-acid battery's charge level through voltage is a roughly linear but still not very accurate. The battery charger uses slightly more sophisticated measuring to know what stage to charge the battery in but for verification purposes we will use the voltage method because other options require expensive measurement tools and complicated techniques. A 12 Volt lead-acid battery's voltage will vary roughly from 11.5 to 12.7 volts, therefore if the voltage of the battery is 12.4 or higher, we can approximately know it has significant capacity left.

Requirements	**Verifications**
1. Safely charge a Lead-Acid battery 2. Charges a Lead-Acid battery to at least 90% maximum capacity, given a standard wall outlet source	1,2. A. Take a partially charged lead acid battery, of the same model used in the pack, and charge it from a standard AC outlet. When the charger indicates that the battery is charged, remove the battery and use a multimeter to verify the voltage is above 12.4 Volts

3.1.2 DC/DC Buck Converter (Microcontroller Power Module)

The microcontroller power module will tap DC voltage from the battery pack terminals and step it down to the 3.3V necessary to power the two microprocessors and the LCD display. This will be composed of commercial voltage regulators or buck converters.

Requirement	**Verifications**
Provide a voltage source for the microcontrollers within the supply voltage range indicated by their datasheets • C2000: 4.6V max, 3.3V operating [6] • Arduino: 7-12V raw input or 3.3V supplied directly to power pin [7]	A. Sweep an input voltage of 11-13V to the power module, check that the C2000 and Arduino is powered when supplied by the power module.

3.2 CONTROL UNIT

The control unit handles communication with the user. It is powered by the input power module, and its operation is directed by the microcontroller module. The microcontroller module processes signals from the user input. It displays battery information to the LCD screen according the battery measurements. Finally, it directs the operation of the switching power converters of the output power module. As a safety feature, the control unit will not allow the user to plug in an AC and DC load at the same time, so as to prevent the power output from exceeding 240W. We require this feature because we are designing our power converters and selecting components to sustain 240W and if the user connects two loads of around 200W, this could overstress out components.

3.2.1 Microcontrollers

The microcontroller module will be composed of two microcontrollers, a C2000 Piccolo and an Arduino Pro Micro. They will both be powered by the input power module, and they will split the workload of the control module.

The Texas Instruments C2000 Piccolo was selected for its optimized performance in closed loop feedback operations, and proven ability with inverters and converters. It also has multiple enhanced PWM outputs, which will be useful in controlling the converters by using it as the gate driver for the switching elements. This microcontroller will be programmed in Code Composer Studio, which allows for flexible control over the duty ratio and frequency of output PWM signals. The C2000's role is to receive the user input and direct the operation of the output power module.

The Arduino Pro micro was selected for its ease of integration with peripheral devices such as the LCD screen and the DC current sensor chip. This will be programmed with the Arduino IDE, which is better optimized for operating these peripherals than Code Composer Studio. The role of this microcontroller is to operate the battery measurement modules and display module.

Requirement	Verification
1. C2000 requirements A. Can simultaneously output two different PWM signals of at least 50 kHz with the ability to change duty ratios during operation B. Has ADC capability 2. Arduino Requirements A. Has ADC capability B. Can drive the LCD screen	1. To verify that the C200 can execute its required role: A. Connect two output pins of the controller to an oscilloscope. B. Upload a test program that directs the microcontroller to output two PWM signals C. Direct one of the PWM signals to change duty ratio without reprogramming, either based off an external analog input or periodic function 2.

	To verify the Arduino can execute its required role: A. Insert a variable DC voltage between 0-5V into an analog input pin. Wire the arduino to a HD44780 compatible LCD unit. B. Implement a program that performs an ADC conversion then displays the value on the LCD

3.2.2 LCD Display

An LCD screen will be a 16 by 2 serial enabled LCD operated by an Arduino microcontroller. It will display the output voltage, the output current, the battery charge, and the temperature.

Requirement	Verification
Must display the voltage, charge level, current, temperature, and power values dictated by the microcontroller	A. Isolate the display and microcontroller B. Program dummy test values for voltage, charge level, current, temperature into the microcontroller C. The display should match the dummy values

3.2.3 Battery Measurement

The battery measurements will provide analog voltage signals that can be interpreted as current and voltage readings by the Arduino microcontroller. We will use the 1N169 Adafruit Analog DC current sensor to measure the current outputs from the Flyback converter. We will use a TMP36 temperature sensor to encode the temperature within the device. Since the voltages are too high to be directly measure by the microcontroller, it must be scaled down by a voltage divider. This scaled down voltage can be safely measured, and by knowing the value of the resistors used in the divider, the microcontroller can calculate the true voltage.

Requirements	Verifications
1. Measure DC voltages within a range of 3.3V-40V for the low voltage branch, and 40V-170V for the high voltage branch with 10% accuracy 2. Measure a temperature between 0 to 40 Degrees celsius with an error of less than 3 degrees.	1. A. Ensure the maximum voltage output level of the voltage divider does not exceed 5V. B. Measure the load voltage and current with a multimeter. C. Confirm that the microcontroller is reading the same value, either by having the microcontroller print to console or to an LCD screen. 2. A. Connect the temperature sensor to a microcontroller with a test program loaded and connected to a computer B. The test program print to console, the temperature indicated by the sensor signal C. Compare the temperature reading provided by the sensor with that from a self-contained thermometer

3.2.4 User input

The user will be provided a externally mounted rotary potentiometer to turn with their hands. The magnitude of the resistance selected by the user is proportional to the magnitude of the output voltage level. The user will know which voltage they select by a dial scale drawn around the turn knob. The user input will be read by the Arduino microcontroller as an analog voltage. A simple ADC can be programmed into the microcontroller to relate the user input to the desired output voltage.

Requirement	Verification
Turning the knob create a visible change in the output voltage displayed by the LCD	Rotate the potentiometer knob, while the control unit and output power module are integrated. Verify that turning the knob results in a linear change in displayed voltage level

3.3 Output Power Module

3.3.1 DC/DC Power Converter (Flyback)

The Flyback converter receives the battery voltage as input. It directly provides the DC output voltage and supplies the input source for the inverter. The Flyback converter is operated by a closed loop feedback algorithm from the microcontroller module.

The Flyback converter is an isolated buck-boost converter. We chose this typography for two reasons: First, our range of output voltages dictated that our circuit must be able to step up or step down the battery voltage. That limited our options to variations of buck-boost of boost-buck. We then chose an isolated variation to accommodate the wide range of output voltages the converter had to meet. Isolated converters can take advantage of their transformer turns ratio to produce larger, or smaller, output voltages with the same duty ratio as a non-isolated converter. Another benefit of the transformers, that we have taken advantage of, is the option to have multiple secondary windings for multiple outputs. In our design, we have one secondary winding whose turns ratio is optimized to produce a high voltage for our inverter (40 to 170V), and the other secondary winding has a turns ratio optimized to produce the lower voltages for the DC output (3.3 to 40V). The third benefit is galvanic isolation, which offers a bonus layer of circuit security. We will have a switching frequency of 80 kHz. Because we are switching at that value, our transformer core needs to be a powdered iron core or ferrite.

In the figures 6 and 7 we can see how the duty ratios range for the expected output voltages.

Requirement	Verification
1. The converter must be able to deliver an output DC voltage from 3.3 V to 170 V. 2. The converter must be designed to survive a maximum current of 5 Amps 3. The duty ratio must be between 10 and 90 percent 4. The converter must have at least 75 % efficiency 5. The converter must have a voltage ripple of 5% or under	1,2,5 A. Test the converter in open-loop configuration, with a 12V source and a C2000 microcontroller producing a PWM frequency between 80kHz B. Hard-code duty ratios into the microcontroller and generate the control signal C. Measure the high voltage output terminals for test voltages 40-170V D. Measure the low voltage output terminals for test voltages 3.3-40V E. Check that the output voltage does not vary by more than 5 percent in steady state operation F. Operate a 5 A load continuously for at least 2 minutes 3 A. Setup the converter in open-loop with the C2000 microcontroller

	B. Attach a voltage probe and observe PWM wave-form from the C2000 with an oscilloscope C. Verify that, with a duty ratio of <.9 and an input voltage of 11.5, the converter can output the maximum required voltage D. Verify that, with a duty ratio of >.1 and an input voltage of 12.7, the converter can output the minimum required voltage 4 Measure average power input and average power output with external wattmeters. Verify that the output power is at least 75% the magnitude of the output power.

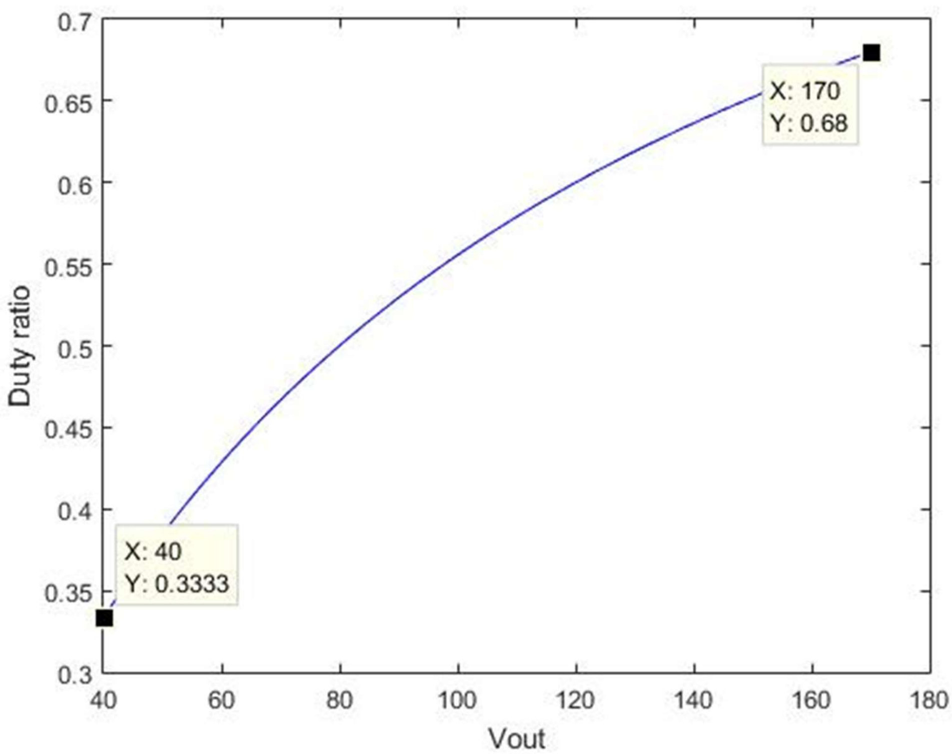

Figure 6: Flyback duty ratio and output voltage with turns ratio **1:7**

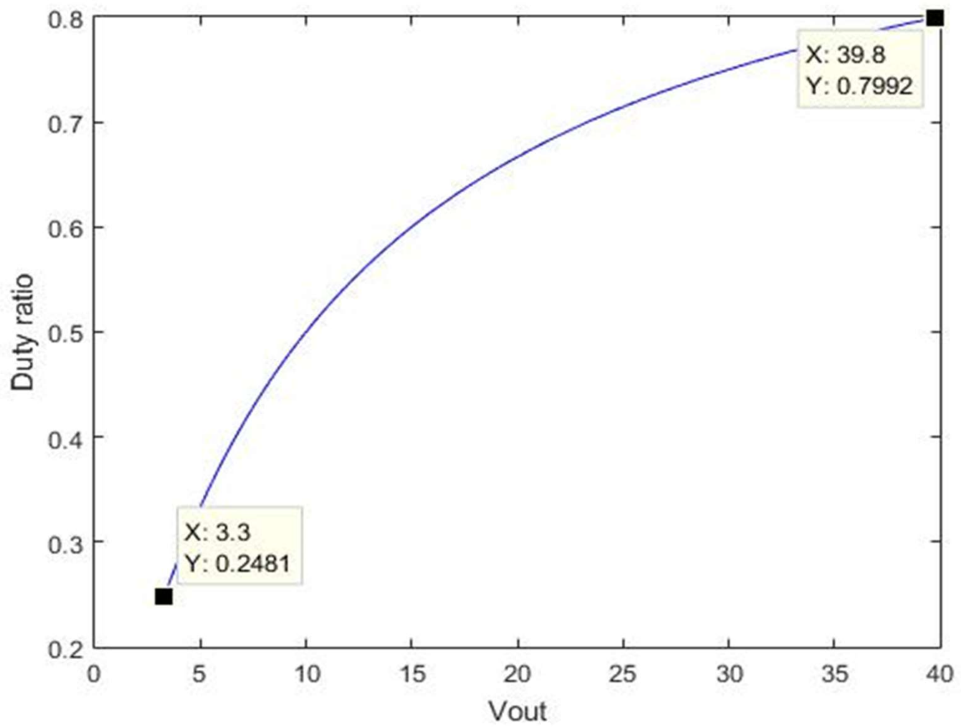

Figure 7: Flyback duty ratio and output voltage with turns ratio **1:1**

The calculations we have done for the Flyback converter are:

$$\frac{V_{out} + V_d}{V_{in} - V_{rdson}} = \frac{1}{N} * \frac{D}{1 - D} \quad where\ N = \frac{N_2}{N_1} \tag{1}$$

$$\Delta I_L = \frac{(V_{in} - V_{rdson})}{f_{sw} * L_\mu} \rightarrow L_\mu = \frac{(13 - 0.8)}{80 * 10^3 * 0.5A} = 305\ \mu H \tag{2}$$

$$C_{out1} = \frac{\Delta I_L}{8 * f_{sw} * \Delta V_{out}} \rightarrow \quad \frac{0.5}{8 * 80 * 10^3 * 0.033} = 24\ \mu F \tag{3}$$

$$C_{out2} = \frac{\Delta I_L}{8 * f_{sw} * \Delta V_{out}} \rightarrow \quad \frac{0.5}{8 * 80 * 10^3 * 0.4} = 1.95\ \mu F \tag{4}$$

$$C_{in} = \frac{24 + 1.95}{2} = 13\ \mu F \tag{5}$$

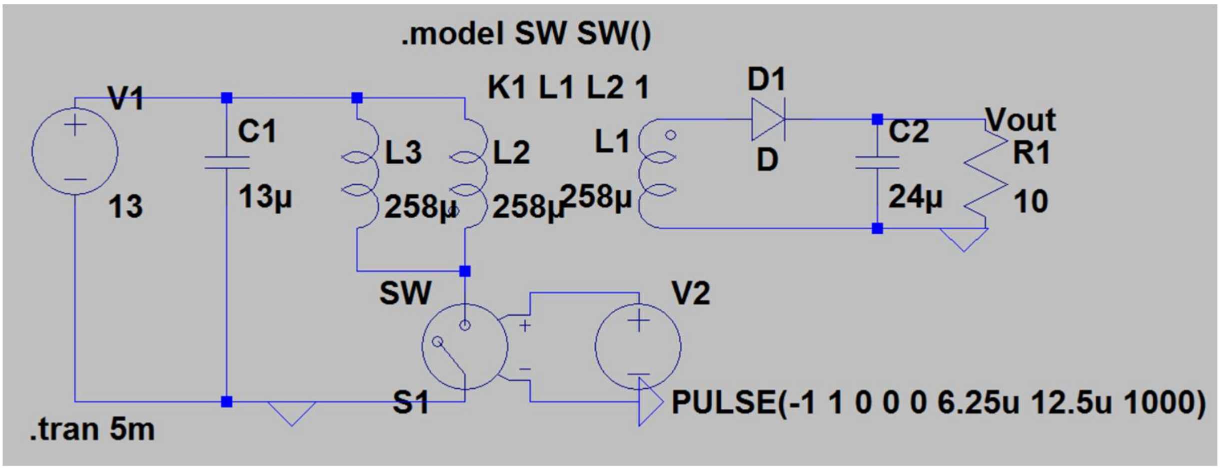

Figure 8: LTspice schematic for flyback modeling low DC output at 50% duty ratio

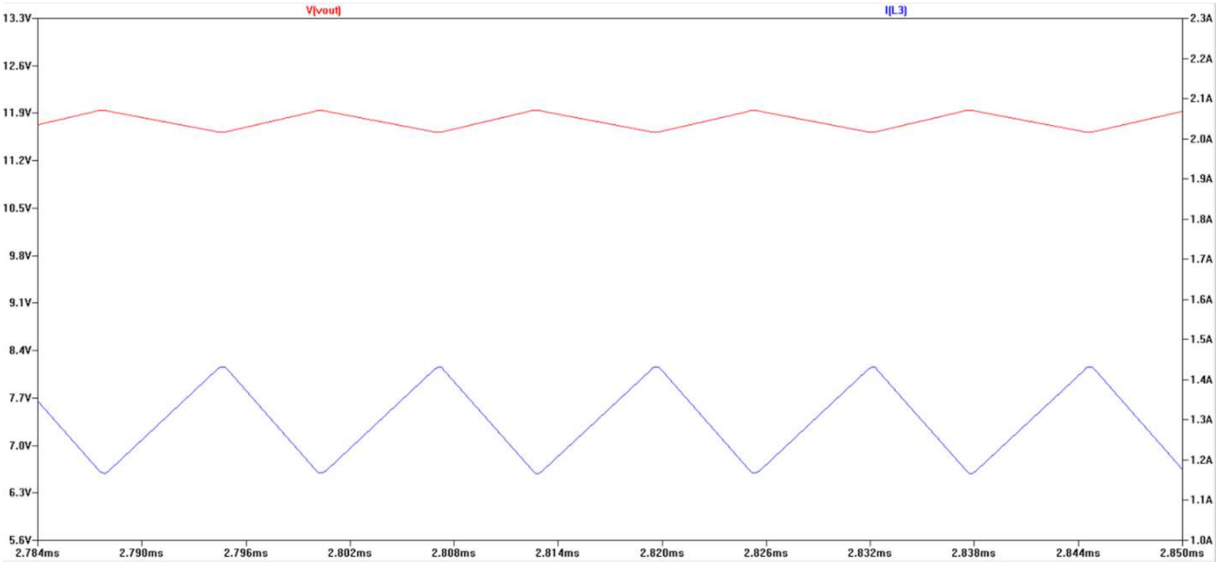

Figure 9: LTspice simulation of flyback output voltage (top) and transformer magnetizing current (bottom) meeting ripple requirements

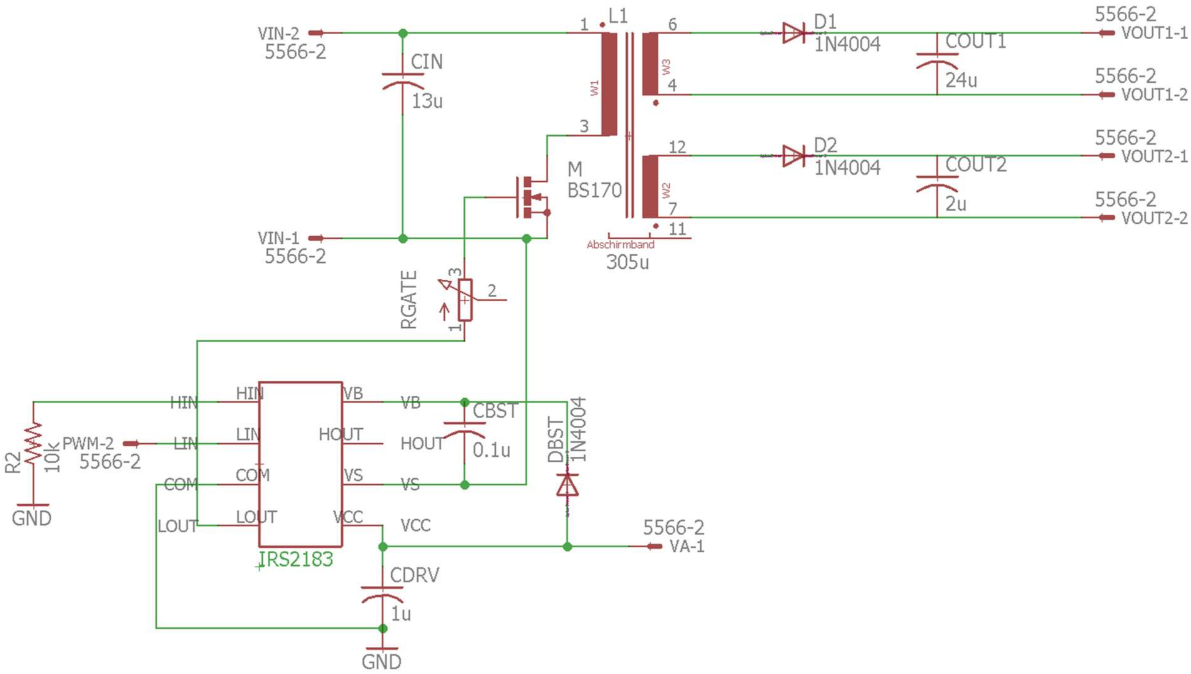

Figure 10: Output power module, Flyback converter schematic

3.3.2 Inverter

The inverter will be a full bridge inverter with four digitally controlled MOSFETS. The inverter will not have a feedback system. The magnitude of the inverter output will be controlled by the DC/DC converter that precedes it. The inverter switches will controlled by a periodic PWM function from the C2000. We will employ harmonic elimination, whereby the deadtime is introduced into the control scheme with a timing that eliminates certain harmonics. This technique requires a full-bridge inverter topography and precision phase control. We believe we can achieve the latter with the high switching frequency of the C2000 in addition to its enhanced PWM functionality. Our objective is to eliminate the 3rd harmonic, which will reduce the THD (Total Harmonic Distortion) to 9 percent, and this can be reduced even further with filtering. By this method, we hope to significantly lower the THD of our AC output. The THD is the square root of the sum of all other non-fundamental harmonic components squared over the magnitude of the fundamental frequency squared [9]. THD gives a good idea of how clean an AC waveform looks and is very important for devices that require low THD power like motors and the grid. The grid requires a THD of less than 5%. Since our device's output isn't being connected to the grid we will not follow such a hard requirement but we will still want a low THD to power devices that require low THD power.

To choose the values of the RCL filter, we have to focus on stability. Although our R is going to be changing depending on the load, we have to get a quality factor Q less than one. As Q=R/L/C we will try to solve this problem by selecting an inductance L much bigger than C, so the denominator will be bigger than the numerator.

Requirement	Verification
1. The inverter will be able to output an AC voltage waveform with a peak of 170V 2. The inverter eliminates the 3rd harmonic and filters the output to produce a roughly sinusoidal waveform	A. Operate the inverter with any DC input voltage between 40 and 170V with a harmonic elimination control algorithm B. Measure the inverter output on an oscilloscope. Check the harmonic content for the disappearance of the 3rd. Visually examine the waveform and verify that its shape is roughly sinusoidal

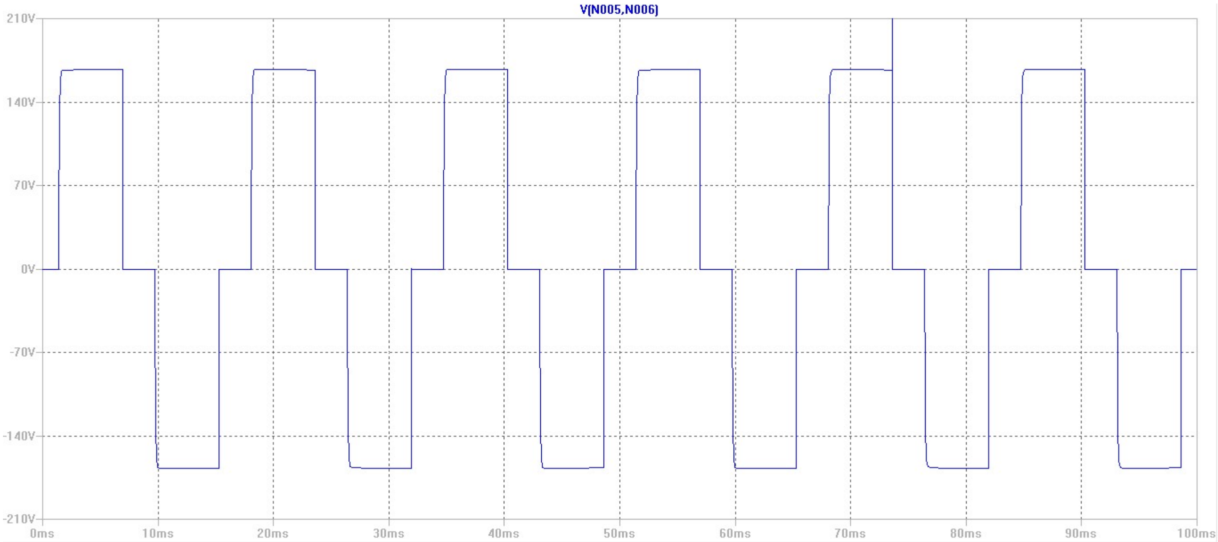

Figure 11: Output power module, inverter output with 3rd harmonic elimination

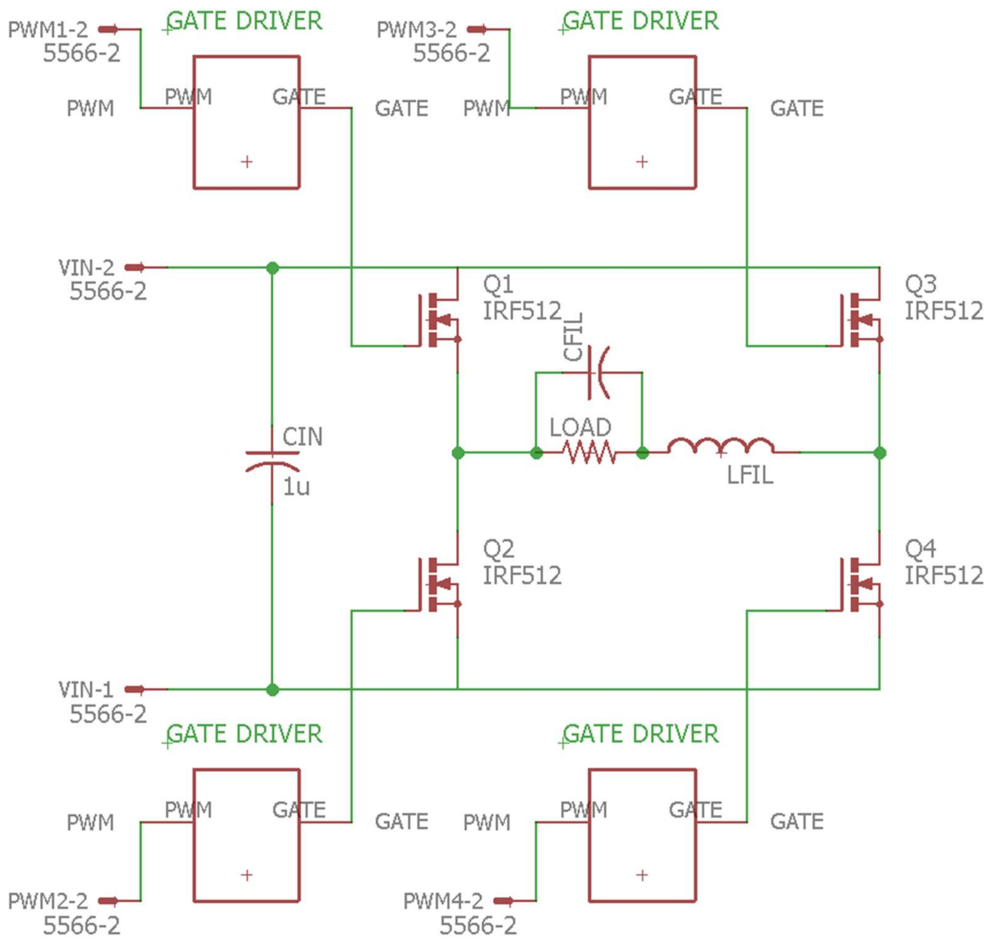

Figure 12: Output power module, inverter schematic

3.4 Battery

The energy storage of the system will be provided by two rechargeable lead-acid batteries, each with 7 Amp hour capacity, connected in parallel with a charged voltage of at least 12V. The voltage on 12V batteries usually varies between 12.7V when fully charged and 11.5V when depleted. Each battery weighs 4.5 lbs.

3.5 Software

The software will be divided between CCS and the Arduino IDE. CCS on the C2000 offers greater control over PWM outputs while the Arduino IDE is easier for integrating peripheral devices.

The arduino program receives information from one temperature sensor. It also measures the charge on the battery by monitoring the battery terminal voltage. It receives voltage and current information from both output terminals of the Flyback converter. It directs the display module to show the information measured by these sensors. One of the Flyback terminals is the DC output, the other supplies the inverter for the AC output. By monitoring the current outputs of both terminals, the program will know when a load has been connected. When it detects a load on the AC outlet, it will automatically order the display to show the RMS voltage for the AC output. When it detects a load on the DC outlet, it will order the display to show the voltage magnitude for the DC output. The arduino program also serves an important safety role. It checks the values to ensure they are within safe limits. If the temperature, voltage, or current exceed preset safety limits, the arduino will sent a “kill” signal to the C2000, which will in turn shut down the output circuitry by opening all power switches. If the user attempts to connect loads across the AC and DC outlets, a “kill” signal will also be sent, as we are concerned about overloading.

The C2000 is responsible for controlling the switching converters of the output power module. It will generate a periodic PWM control signal for the inverter. The program will control the inverter switches to eliminate the 3rd harmonics. The inverter will not require feedback control because voltage control will be executed on the preceding flyback converter. It will compare the output voltage specified by the user, and the actual output of the flyback converter. The program will either increment or decrement the duty ratio to correct the difference. The C2000 will have a communication line with the arduino, which is monitoring the system faults. If the arduino sends a “kill” signal, the C2000 will open all power switches, effectively shutting down the system.

3.5.1 Software Algorithm Flow Chart

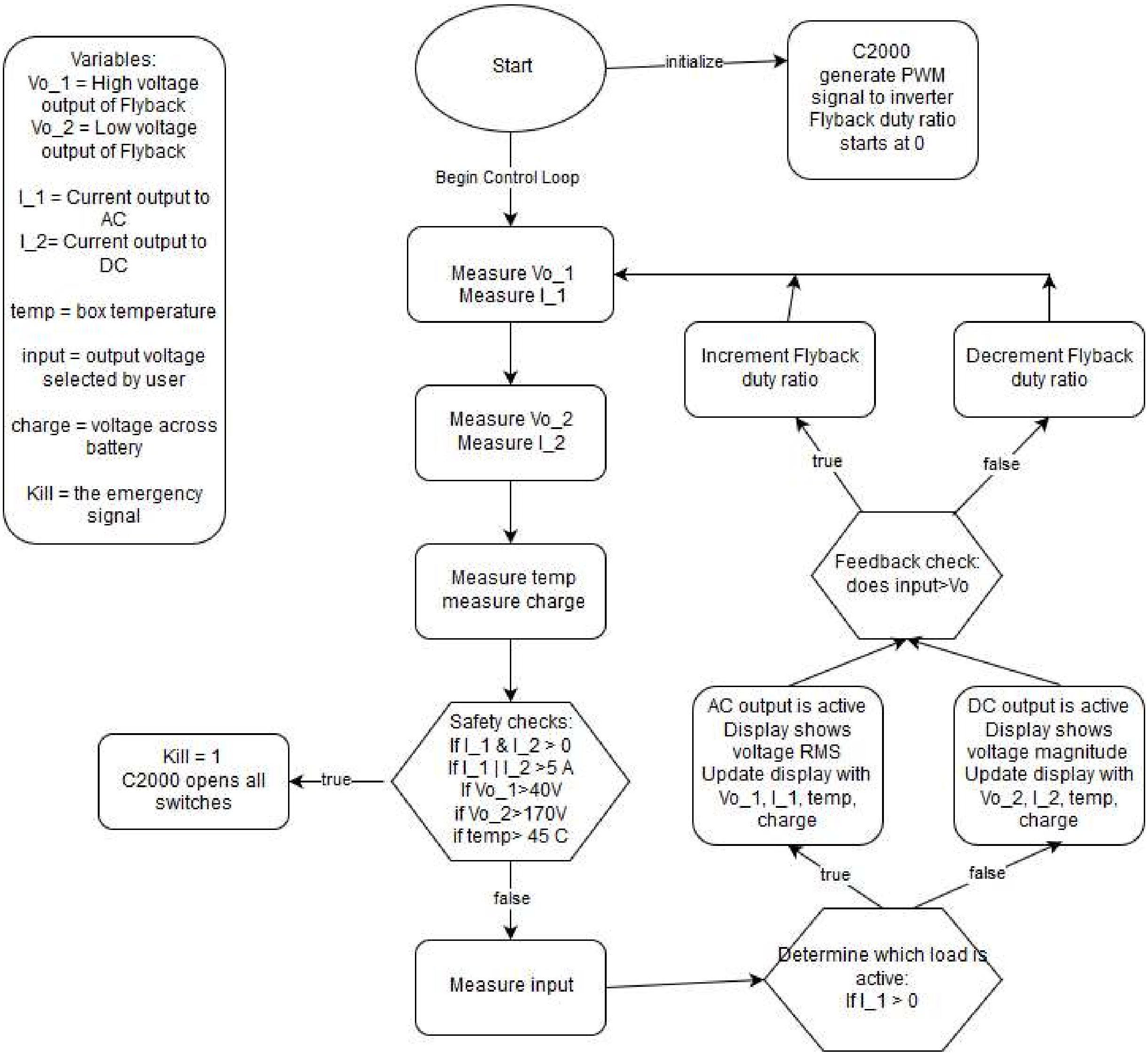

Figure 8: Software Algorithm flow chart

3.5.2 Software Data Flow Chart

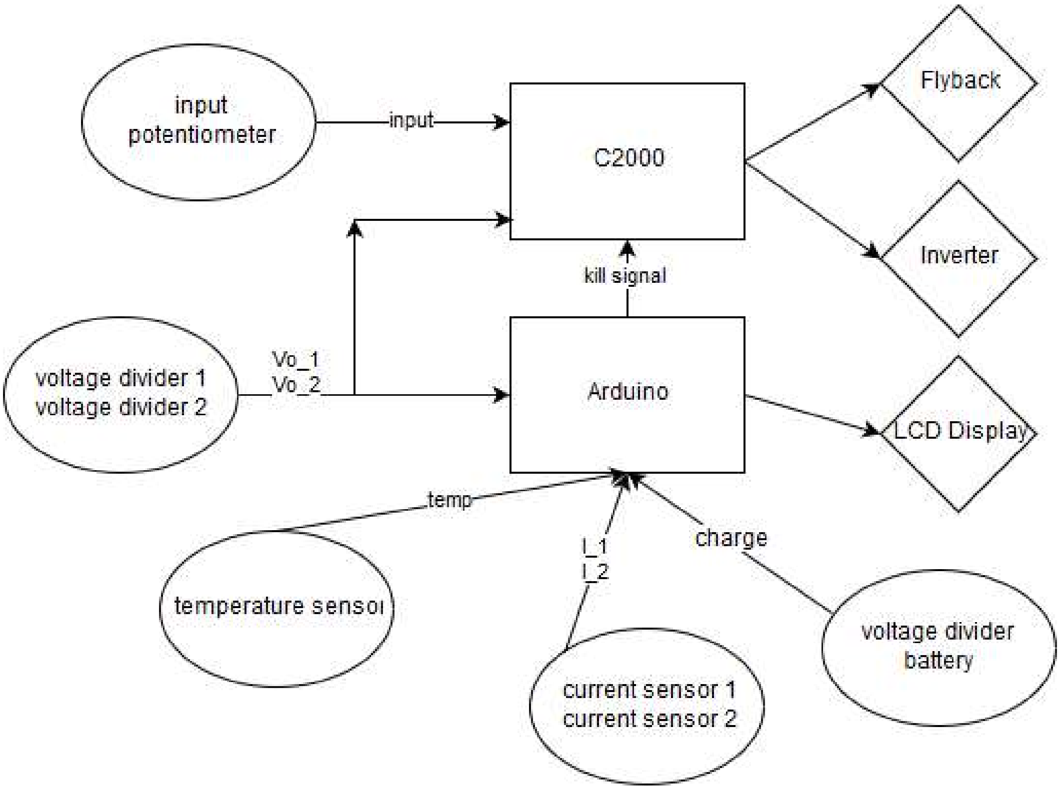

Figure 9: Software Data Flow Chart

3.6 TOLERANCE ANALYSIS

The most critical requirement of our project is that the voltage output selected by the user closely matches the voltage output from the output power module. Large deviations in displayed power parameter values from their physical values would lead to improper function of our product and could possibly damage the user's materials they are trying to power with our device. Imprecision in measurements, and sensors, processing, and component characteristics pose challenges to making sure our device is accurately displaying operation parameters. In this tolerance analysis, we will explain and discuss all the elements that could interfere with this requirement. We will also demonstrate countermeasures to maintain output voltage precision to within acceptable deviations. We define acceptable deviations as errors that are not severe enough to compromise the user's load. This will vary from load to load, but we will give estimated definition of acceptable deviation for the purposes of this analysis: The acceptable deviation for voltage and current values is a 5% ripple from the nominal required value. To illustrate this point: consider a microprocessor whose manual says it requires 5V power. It is often possible to operate it with slightly more, or less, voltage than 5V, such as 4.875 V.

The user selects the output voltage by providing an analog signal. They turn a rotary potentiometer to the voltage that they desire. This method is simple and intuitive, but it's physical implementation and analog nature creates opportunities for imprecision. The physical markings on the dial will have imprecision based off how well placed the markings are. They must be evenly spaced and accurately marked. The reliability of the analog signal depends on the correlation coefficient between the rotation and the resistance. Ideally, that coefficient is 1, indicating a perfectly linear relationship. However, the manufacturer specifies that the device has a 10 percent tolerance. For this reason, in a worst-case scenario we have a .9 correlation coefficient from the potentiometer. Let us also estimate that dial marking imprecision introduces a 2% error. In total, the analog input signal sent to the microcontrollers may have as much as 12 percent imprecision in the worst case. Therefore, we believe the user input will be the greatest source of error in meeting our critical requirement. We have a system in place to compensate for this imprecision. The LCD display will show the user the actual output voltage. The user can then adjust the dial using the display as their guide, bypassing the mechanical imprecisions of the rotary potentiometer and dial markings. However, this compensation relies upon the precision of the output voltage measurements and the microcontrollers.

Once the analog signal arrives at the microcontroller module, it is compared with the output voltage of the load. The microcontroller then tries to make the two match as closely as possible by manipulating the Flyback switch duty ratio in a closed loop feedback program. The precision of this program is dependent on two elements: the ADC measuring the output voltage, and the resolution of the duty ratio. The accuracy of the voltage measurements largely depends on the tolerance of the resistors that make up the ADC. These can range from less to 1, to over 20 percent. However, we believe we can largely mitigate this source of error. If available, we can use low tolerance resistors (under 5 percent), and any errors will be too insignificant to affect the ADC. If we do not have those resources, we may still recover precision by measuring the actual resistances and adjusting the ADC code accordingly.

The resolution of the duty ratio depends on the clock frequency of the microcontroller and the switching frequency of the PWM signal. Duty ratio resolution improves with a high clock frequency and a low PWM frequency. We selected a PWM frequency of 80kHz. The C2000 Piccolo that will drive the PWM has a 60MHz clock. Dividing the clock frequency by the PWM frequency yields 750. The duty ratio is between 0 and 1. Divide 1 by 750 gives the duty ratio resolution of .00133. The maximum imprecision would occur when the required duty ratio for a perfect match occurs between two resolution points. Therefore, the worst-case duty ratio error is half of .00133 or .067% error.

4 Costs and Schedule

4.1 Costs

NAME	*HOURLY RATE*	*HOURS INVESTED*	*TOTAL=HOURLY RATE* HOURS INVESTED*2.5*
Mason	$35	150 h	$13125
Javier	$35	150 h	$13125
Jeffrey	$35	150 h	$13125
TOTAL		450h	$39375

ITEM	Quantity	Total Cost ($)
Battery charger(Batterystuff)	1	44.99
12 Lead Acid Battery(Amazon: Expert Power)	2	33.98
16v2 LCD Display (Sparkfun)	1	24.95
C2000 Piccolo Lauchpad(Texas Instruments)	1	17.05
Arduino Pro Mini 328 (Sparkfun)	1	9.95
Resistors, capacitors, inductors, and ICs(Digikey, ECE supply; Estimated)	NA	20.00
1NA169 Analog DC Current Sensor Breakout (Adafruit)	2	19.90
TMP36 Temperature Sensor(Sparkfun)	1	1.50
Rotary potentiometer (Digikey, RV4N502C-ND)	1	9.77
Completed prototype	**1**	**182.09**

SECTION	COST
Labor	**$39375**
Components	**$182.09**
TOTAL	**$39557.09**

4.2 Schedule

WEEK	TASKS	DEADLINE
02/20	Mason: Work on DC-DC buck converter	Design Document
	Javier: Work on Flyback converter	
	Jeffrey: Select microcontrollers	
02/27	Mason: Order parts, and start building breadboard circuits for testing	Design Review
	Javier: Design PCBs	
	Jeffrey: Start building software algorithm	
03/06	Mason: Finish breadboard testing	Soldering Assignment
	Javier: Order PCBs	
	Jeffrey: Design and test the battery measurement module and LCD display	
03/13	Mason: Begin physical assembly and layout	All the components ordered
	Javier: Testing PCBs and correcting errors	
	Jeffrey: Design and troubleshoot microcontroller software	
03/20	Troubleshoot problems discovered in previous testing	Springbreak

03/27	Mason: Continue physical assembly and testing	Individual Progress Report
	Javier: Help with the physical assembly	
	Jeffrey: Continue work on microcontroller software	
04/03	Mason: Power range testing	Revised PCB
	Javier: Testing all the components separately	
	Jeffrey: Integrate control module components with microcontroller	
04/10	Mason: Continue power range and performance testing	
	Javier: Correcting errors about hardware testing	
	Jeffrey: Begin system integration between control module,output power module, and input power module	
04/17	Mason: Perform Safety and Environmental Tests	
	Javier: Testing all the components together	
	Jeffrey: Continue system integration work. Ensure system can operate independent of laboratory supplies	
04/24	Mason: Ensure product power performance and durability	Demonstration and Mock Presentation
	Javier: Ensure all the components work as supposed and artistic design	
	Jeffrey: Resolve software and system integration issues	
05/01	Mason: Write the final paper	Final Papers Lab Notebook Lab Checkout
	Javier: Finish writing final papers	
	Jeffrey: Write on final report	

5 Ethics and Safety

5.1 Battery safety and ethics

The lead acid batteries we plan to use as the energy storage element come with environmental and health risks. We must disclose these risks and seek to mitigate them in accordance with the IEEE code of ethics, #1: “to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment”[8].

Our principal safety concern is an explosive failure of the lead acid battery. Lead acid batteries may produce trace amounts of hydrogen gas, that in concentrations above 4% could be explosive. In addition, when lead acid batteries are overcharged they undergo hydrolysis, producing oxygen and hydrogen [2] and this presents an explosion risk. An explosion could cause total destruction of the system, leak lead into the environment, and cause potential harm to end users. The hydrogen risk is minimal, so long as the gas is not allowed to concentrate. We may mitigate this risk by providing a small ventilation port that could also be used for thermal management. The risk of an hydrolysis-induced explosion is too high to tolerate, so we have decided to acquire a battery charger commercial off-the-shelf instead of building our own. These charger come with inbuilt safety functionality to prevent overcharging, and thus mitigate the electrolysis risk.

In compliance with the Federal Hazardous Substances Act, a cautionary label must be provided for hazardous substances such as wet cell batteries containing sulfuric acid, a category that can include lead-acid batteries [3]. Lead acid batteries come with warning labels already attached, but since we plan to place it the battery in an enclosure, we may have to provide our our warning labels onto the enclosure to disclose the presence of a hazardous substance.

5.2 Electrical safety

Our circuitry will handle high voltages (up to 170V peak) and currents (up to 5 Amps). These are high enough to pose a potential health risk to people. However, our circuitry will be isolated from the end user within an enclosure. Unless this enclosure is compromised, we do not anticipate that our device poses an electrocution hazard.

In the event of a failure, the most serious risk is that a short circuit will cause a current of large magnitude to flow. This may initiate thermal events and propagate damage to other components. We have determined to place fuses in at the terminals of the batteries to prevent such an occurrence, so that if the system fails, the damage is mitigated and potentially repairable.

In addition to the fuse, the control module offers another layer of electrical safety. The control module will be monitoring the current, temperature and voltage output. If safety ranges for these three parameters are violated then all the switches will be opened and current will cease to flow.

5.3 Lab Safety

We believe we can mitigate lab hazards by testing components in isolation. We can test our power converters independently of the battery within a controlled power laboratory environment where we have access to emergency kill switches. If our converters work with a laboratory power source, they will work with the battery, so we do not need to risk too much time with the battery. We will however, need to use the battery in lab to test the functionality of our measurements and displays, but we can conduct those tests independent of the power converters. By having modular components that can be tested independently of each other, we minimize the testing risk, as the failure of one module in testing will be isolated and not cause damage to other modules.

5.4 Safety Plan

We will follow the following rules to ensure personal safety during testing and verification.

1. The battery will only be charged through a proper battery charger
2. All hardware testing will be conducted with at least two group members
3. Safety glasses will be worn when the battery is in active use, or if the tested circuitry includes electrolytic capacitors
4. Circuitry will be verified using laboratory power supplies before being applied to the battery
5. If the battery starts to bulge we will move to a safe distance, and request assistance.

6 References

[1] International Energy Agency, “Access to Electricity”. 2016[Online]. Available:http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/. [Accessed: 22-Feb-2017]

[2] Battery University, “Charging Lead Acid”. 2016[Online]. Available: http://batteryuniversity.com/learn/article/health_concerns. [Accessed: 5-Feb-2017]

[3] Legal Information Institute, “1500.121 Labeling requirements; prominence, placement, and conspicuousness.” 198[Online]. Available :https://www.law.cornell.edu/cfr/text/16/1500.121 [Accessed: 5-Feb-2017]

[4] Texas Instruments, “Basic Calculation of a Buck Converter’s Power Stage” August 2015 [Online]. Available: http://www.ti.com/lit/an/slva477b/slva477b.pdf. [Accessed 24-Feb-2017]

[5] Unitrode Products from Texas Instruments, “Reference Design: Isolated 50 Watt Flyback Converter Using the UCC3809 Primary Side Controller” 2001 [Online]. Available: http://www.ti.com/lit/ug/sluu096/sluu096.pdf. [Accessed 24-Feb-2017]

[6] Texas Instruments, “Launch XL-F28027 C2000 Piccolo” Datasheet. June 2016 [Online]. Available: https://docs.google.com/document/d/1AXRE6ak4QTq-wlovMKqiN2dOv2vt8lSD_kvlB9GQJOY/edit [Accessed: 9-Mar-2017].

[7] Sparkfun, “Pro Micro & Fio V3 Hookup Guide” 2016 [Online]. Available: https://learn.sparkfun.com/tutorials/pro-micro--fio-v3-hookup-guide [Accessed 9-Mar-2017]
[8] IEEE.org, “IEEE Code of Ethics,” 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 5-Feb-2017]
[9] Electrical Engineering Portal, “Essential Basics of Total Harmonic Distortion” 2015 [Online]. Available: http://electrical-engineering-portal.com/essential-basics-of-total-harmonic-distortion-thd
[Accessed 9-Mar-2017]