ECE 4981/4983/4987: Senior Design I

DRR Report

Design Requirements Review

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1 System Description

1.1 System Overview

The PowerPack is a backpack that supplies the user with 120 VAC voltage. This product aims to eliminate the need for extension cords and gives Ego owners more functionality with their Ego batteries. Extension cords are a nuisance to use and a safety hazard. 4,000 injuries associated with electric extension cords are treated in hospital emergency rooms. About half of the injuries involve fractures, lacerations, contusions or sprains from people tripping over extension cords (1). People only mow their lawns 25-30 times a year (2). So even if the Ego owner has multiple Ego products, they barely reach 50 uses a year on their batteries. So for most of the year, Ego users will have fully charged powerful batteries just sitting in their garage ready to be used, but without a needed purpose.

Objectives:

The objective of this system is to create a portable sine wave inverter that will reside inside a backpack. This will allow the user to wear a power supply on their back, carry it in a safer position, and still provide a reliable power source. This will eliminate (or heavily reduce) the need to use extension cords, as well as give Ego battery owners many more use cases. Since Ego is a popular brand with lighter-weight batteries, we will use them for our DC input voltage. We will then use a microcontroller and an H bridge circuit to create our desired 120 VAC in a sinusoidal wave. All this will be designed to fit in a backpack, so we will take precautions against heat. Also, since we are using high voltage, relevant safety measures will be placed within the circuit (e.g. breakers). Our main objectives are to: turn DC voltage into AC voltage, be mindful of total weight so the product is not too heavy for the user, create an easy plug-in and take-out feature for the Ego batteries, and provide the user with a stable continuous power to run their tools for some appreciable duration.

Functions:

The primary functions of the PowerPack are: the system must invert the 168 volt DC source to generate 60 Hz 120 RMS output and the system must contain functional battery mounts for easy connect and disconnect of the batteries. To do these we must do the following below:

1. Batteries in series to get the needed DC voltage
2. Correct H bridge MOSFET circuit for accurate switching
3. Microcontroller setup to create our PWM waves going to the H bridge to get our desired sine wave
4. Safety measures placed to ensure safe usage of our product
5. Display on the bag to tell user information
6. All stored in the backpack for convenient use with easy access to batteries
7. A 15 A fuse was added for safety

Major Components:

Microcontroller (Tiva C-series Launchpad)

- 32-bit ARM Cortex-M4-based microcontroller
- 256-kB Flash memory, 32-kB SRAM
- 80-MHz operation
- Two PWM modules capable of generating 16 PWM outputs

Gate Drivers (IR2110)

- Floating channel designed for bootstrap operation
- Fully operational to +500V or +600V
- 3.3V logic compatible

MOSFETs(IRF740)

- Drain-source voltage 400V
- Drain current (continuous) at TC = 25°C 10A
- Drain current (pulsed) 40A

Testing(Analog Discovery 2)

- 100MS/s USB Oscilloscope
- Variable Power Supply
- ± 25 V differential digital oscilloscope

Power Supply(Ego Batteries)

- 56V ARC Lithium™ Battery

- ARC Lithium™ design keeps battery from overheating so equipment runs longer at full power

- Shock-resistant design protects batteries and electronics from drops and the elements

- Intelligent power management optimizes individual battery cells for maximum power, performance, and runtime

PWM Code (Code Composer Studio)

- C code that will vary the duty cycle signal sent to the gate drivers

- Controls the H-bridge circuit so the output is a sine wave

Backpack and Mounts

- Mechanical aspect of the project

- Have batteries mounted to the outside of the bag

- Have the circuit mounted in a secure location

- Heat sinks and other elements to avoid overheating

1.2 Block Diagram

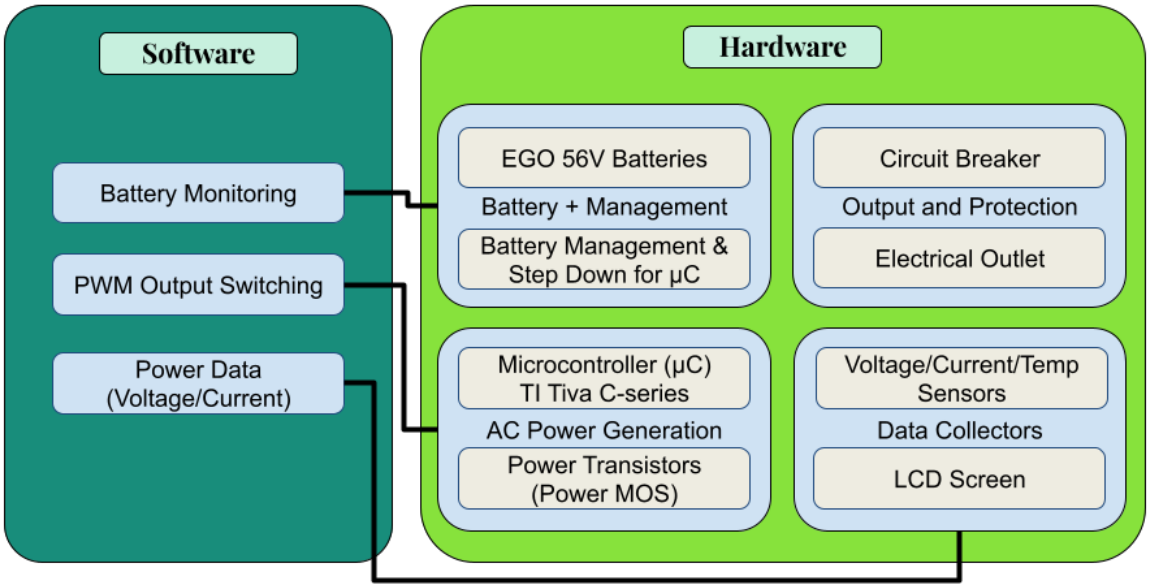

Figure 1: System Block Diagram

1.3 System Background

This project is multidisciplined so that it will have mechanical, electrical, and software aspects:

Mechanical: The two main mechanical parts are the battery/circuit mounts and the backpack itself. The plan is to buy a backpack and create mounts for the batteries and the circuit. There will also be a mount for the display on the bag, but that is not much of a concern. The batteries need to be mounted in a good position so the user can easily plug in and take out batteries. The circuitry needs to be mounted in a safe location so it does not overheat. The display just needs to be in a location where the user can see it.

Electrical: The electrical parts of this project include the sine inverter circuit, battery configuration, and display. The batteries need to be in series with each other to provide the desired DC input voltage. The sine inverter needs to be built accurately to create the desired AC output. Then the display needs to depict the needed information to the user. All of these different aspects are wired together to create our entire electric system.

Software: The PowerPack has 2 different software aspects. The first is the pulse width modulation created by the microcontroller to control our gate drivers/power MOSFETs. The second is the code to collect, calculate, and output the important information on the display.

Ethical or Safety Concerns: A high level of caution should be maintained while working on our high voltage application. Our group has attended a UMD High Voltage Safety Class.

1.4 Interface

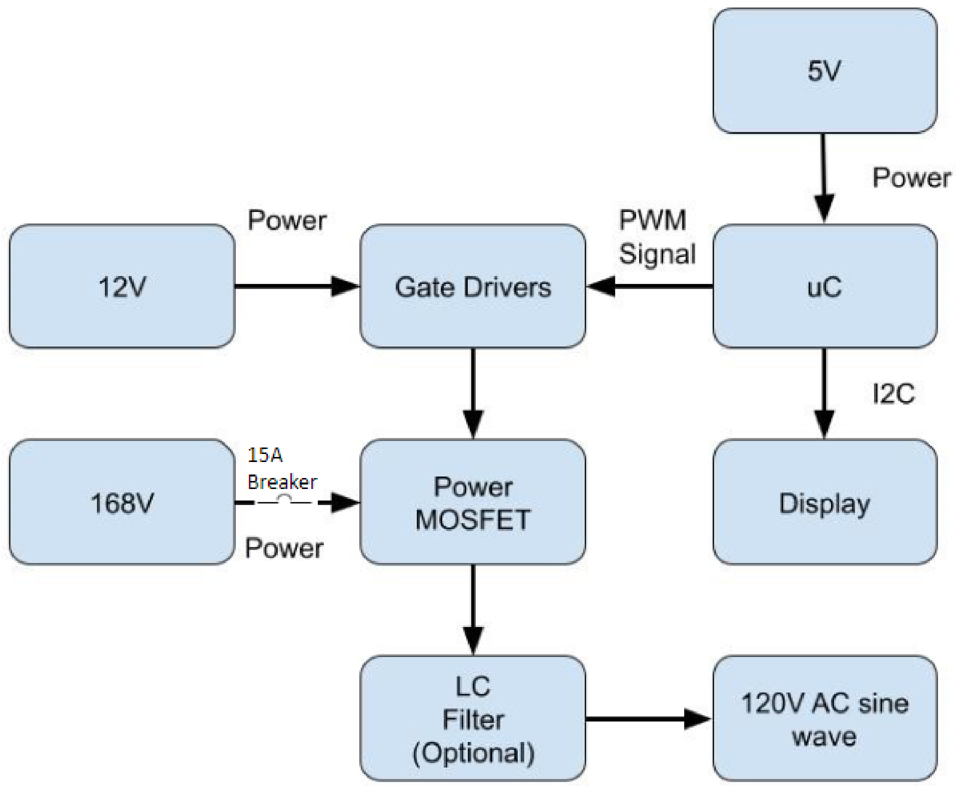

Figure 2: Major components and interconnects

2 System Requirements

For our system to work as intended it will have a few requirements:

1: Physical Properties

1.1: The total weight of our product must not be over 37 pounds. Our research found that this is a safe weight for adults to carry on their backs.

1.2: The other physical property is that the batteries, printed circuit board (PCB), and all other components must be mounted on or fit within the dimensions of a standard backpack. The product is supposed to be a hands-free power supply so all components must affix to the backpack. We are also aiming for an IP20 level of dust and water protection.

2: Output Voltage Accuracy

Because of the AC output voltage, we have to set the RMS value and the frequency.

2.1: The RMS value must be 120V with a tolerance of 10 percent.

2.2: The frequency must be 60 Hz with a tolerance of 2 percent.

3: Battery Life

3.1 The battery life must be feasible for homeowner use. The PowerPack must be able to run a 300-watt drill for 30 minutes. So, 150 watt-hour capability.

4: Display Requirements

4.1 The display will show two things, battery charge and current output. The accuracy of the battery charge must be $\pm 5\%$ and the current charge $\pm 5\%$

4.2 The display must not draw more than 30 mA of current

5: Safety Delay

5.1 Must have a delay of at most 10 us between MOSFET switching to prevent short circuits

6: Efficiency

6.1 The system must have an efficiency rating of at least 90%

7: Total Harmonic Distortion

7.1 The output sine wave should not have a harmonic distortion over 10%

8: Transient Response Requirement

8.1 When a load is applied to the system, it should not take more than 100 ms for the system to respond and return back to the desired voltage

3 Constraints

Some constraints are put in place for our product:

1: Environmental

The PowerPack is a student-engineered product so the intended use of it will only be during design reviews and senior design day. That means the product will only operate inside the IAVS. This means the environment for the product will be a room-temperature building with no interaction with weather. Given our IP rating goals, we are not testing the product to its limit.

2: Battery

For our sine inverter to work we need an input DC voltage of 168 volts. For our product, we will use 3 56V Ego batteries in series to get to 168 volts. The PowerPack will not work as intended if a different input voltage is used.

3: Weight

The intended customers for the PowerPack are adult homeowners. These customers will pick up and wear this product on their back, so the total weight must be safe for them to carry. A backpack should not exceed 20% of a person's bodyweight. Based on the average weight of an adult in the U.S., the PowerPack should not exceed 37 pounds.

4: Cost

The senior design budget this year was $400. We will keep the total cost of the PowerPack prototype within this budget.

5: Knowledge

In ECE 4951, we used the Texas Instruments Tiva C-series microcontroller and did many labs with it. Our group feels comfortable working with this microcontroller so we will use it to run our PWM code and send data to the display. We are also using an Arduino Uno for rapid prototyping because of the ease-of-use.

4 Risk Assessment and Mitigation

The identified failures and issues associated with the project are as follows:

1. Coding failure
2. Battery failure
3. Circuitry failure
4. Heating issue
5. Mounting issue
6. Filter issue
7. Display issue

The risk of these failures and the penalty of these risks are shown in Figure 3.

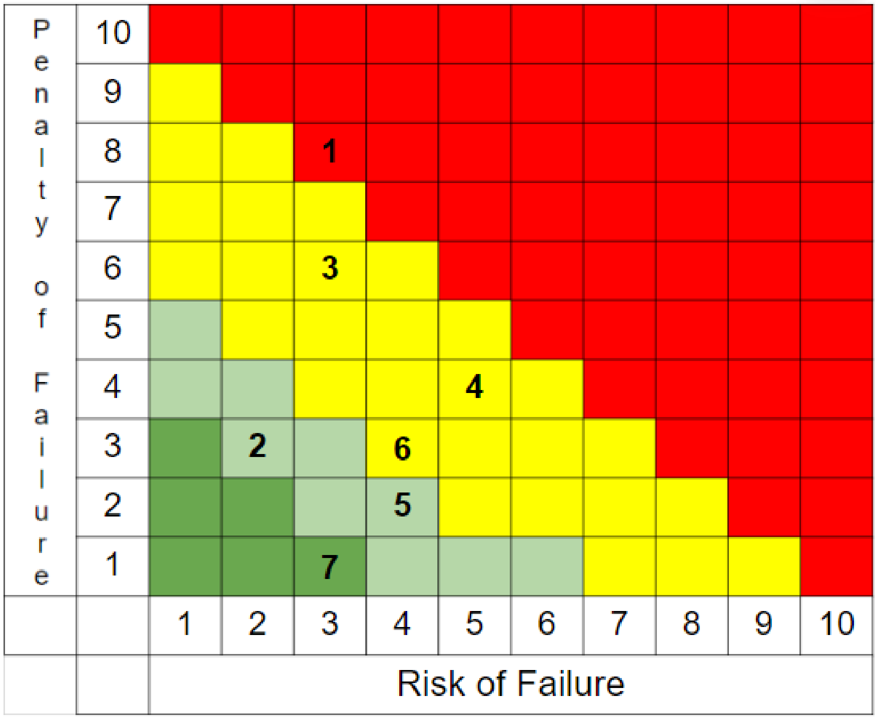

Figure 3: Risk Mitigation Table

From Figure 3, it is shown that a coding failure would result in a total loss of function for the widget, so the penalty for this failure is great. However, the risk of encountering a complete coding failure is on the lower side because all group members have experience with the Tiva C-series Launchpad and there is numerous opportunities to test the code before finalizing it, but we are implementing our own delay for safety so there is room for error.

The risk of a battery failure is low because we are using 3 56V batteries from EGO, which is a reliable product that has been on the market for some time. The penalty of this failure is moderately low because we only have access to 3 batteries total, so we would need to order more if an issue occurs.

The risk of a circuitry failure occurring is low since we are able to simulate our circuit and make adjustments as needed before finalizing the design. However, the penalty of a circuitry failure is moderate because if we encounter this failure, the widget will not yield the desired output, but it will still function.

The occurrence of a heating failure is moderate because group members have the least experience with thermal optimization of PCBs. The penalty of heating issues is also moderate because the widget will still function, but it may not be able to run for as long as desired. The risk of encountering a mounting issue is low and the penalty of this issue is low because the mounting does not affect the electric or software disciplines of the widget.

The risk of filter issues can occur but will not ruin the project. The filter will be added if we have high distortion. If the filter fails, we will just have more distortion than we would want.

Lastly, if the display does not work as intended then our display fails. The display is an isolated part of the project, so everything else will function as intended.

5 Project Deliverables

Semester One Deliverables

- Design low voltage proof of concept circuit (12V DC input)
- Attend high voltage safety training
- Select the microcontroller and program it to control our PWM and frequency
- Build low voltage circuit and display sine wave with 12V peaks
- Test to ensure circuit design is correct
- Start PCB design and research into solutions for high-heat

Semester Two Deliverables

- Once the circuit is confirmed safe, change out 12V DC with 168V and implement safety elements
- Retest circuit and confirm sine wave with 120 RMS
- Configure prototype into the backpack
  - Make battery mounts

- Make enclosure for circuit
- Find the optimal location for the plug

- Test PCB to ensure the board works as it did in the previous testing
- Test circuit to confirm it can power desired applications without damaging the circuit or overheating

6 Schedule

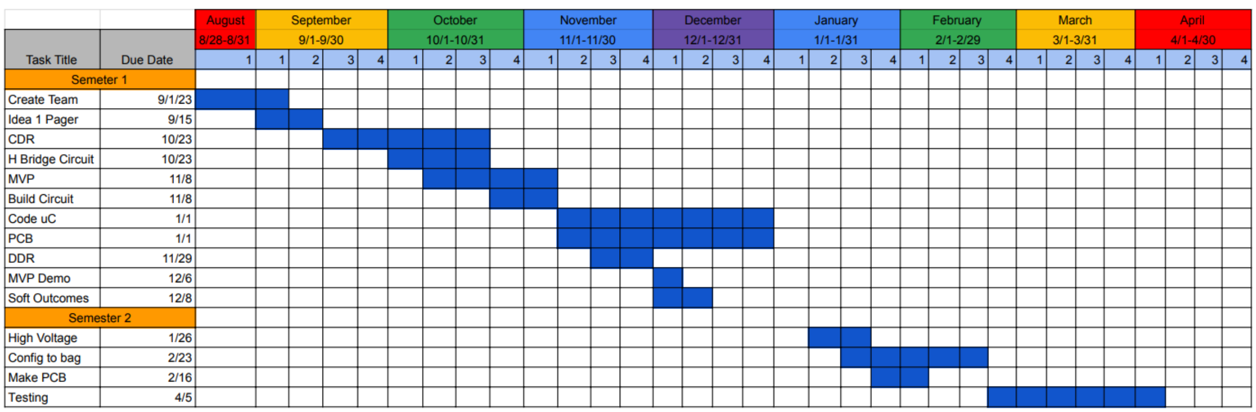

Figure 4: Gantt Chart

7 Budget Information

#	Item	Vendor	Model/Part #	Unit Cost	Qty	Sub Total Cost
1	Analog Discovery 2	Digilent	AD2	Sponsorship	1	0
2	Microcontroller	Professor Putty	Tiva C series Launchpad	0	1	0
3	Gate Drivers	Professor Putty	IR2110	0	2	0
4	Mosfets	Professor Putty	IRF740	0	4	0
5	Bootstrap Capacitors	Professor Putty	0.22 uF	0	2	0
6	Diodes	Professor Putty	1N4148	0	4	0
7	Resistors	George	4 10 ohm and 1 1k ohm	0	5	0
8	Power Supply	George	12V plug in power source	0	1	0
9	Wires	George	Box of jumper wires	0	1	0
10	Electrolytic Cap. Kit	George	Box of electrolytic capacito	0	1	0
					Total Cost:	0

Figure 5: Budget Chart

As of right now, we have not spent any of our budget on the project. But this will change in the future of the project. We are looking into purchasing MOSFETs that can handle a higher impulse current, as well as printing our own PCB board, buying a backpack, and sourcing materials to mount the battery and PCB onto the backpack.

8 Referneces

1: Extension Code Safety

`https://www.facilities.udel.edu/safety/5110/#:~:text=The%20U.S.%20Consumer%20Product%20Safety,people%20tripping%20over%20extension%20cords`

2: How many cuts per year

`https://www.lawnsite.com/threads/how-many-cuts-per-year.346952/`

3: Backpack Basics

`https://kidshealth.org/en/teens/backpack.html#:~:text=Use%20the%20bathroom%20scale%20to,than%2012%20to%2024%20pounds`

4: How Much Should Your Pack Weigh?

`https://www.rei.com/learn/expert-advice/backpacking-weight.html#:~:text=Pack%`

20Weight%20for%20Backpacking%20and%20Hiking&text=A%20loaded%20backpacking%20pack%20should,percent%20of%20your%20body%20weight.

5: Body Measurement

https://www.cdc.gov/nchs/fastats/body-measurements.htm

6: The Best Power Inverters of 2023 (LifeWire)

https://www.topfirearmreviews.com/post/best-portable-power-station

7: The Best Portable Power Stations in 2023 (Top Firearm Reviews)

https://www.lifewire.com/best-power-inverters-4160503

8: Safety Precautions when working with High Voltage Electricity

https://www.nistglobal.com/blog/2022/08/safety-precautions-when-working-with-high-volta

9: Identifying High Voltage Hazards

https://www.worksafe.qld.gov.au/safety-and-prevention/hazards/electricity/hazardous-elec

identifying-high-voltage-hazards

10: Microcontroller Data

https://www.digikey.com/en/products/detail/texas-instruments/EK-TM4C123GXL/3996736?utm_adgroup=&utm_source=google&utm_medium=cpc&utm_campaign=PMax%20Shopping_Product_Low%20ROAS%20Categories&utm_term=&utm_content=&utm_id=go_cmp-20243063506_adg-_ad-__dev-c_ext-_prd-3996736_sig-Cj0KCQiA6vaqBhCbARIsACF9M6lR3gbW_21VVScIt_NMHcA5sIkMFiPF

bT-S-D5MpSwd_lJEaAj9mEALw_wcB&gad_source=1&gclid=Cj0KCQiA6vaqBhCbARIsACF9M6lR3gbW_21VVScIt_NMHcA5sIkMFiPF8vywhu_bT-S-D5MpSwd_lJEaAj9mEALw_wcB

11: Gate Driver Data

https://www.digikey.com/en/products/detail/infineon-technologies/IR2110/296047?psafe_param=1&utm_adgroup=Integrated%20Circuits&utm_source=google&utm_medium=cpc&utm_campaign=Dynamic%20Search_EN_Product&utm_term=&utm_content=Integrated%20Circuits&utm_id=go_cmp-120565755_adg-9159612915_ad-665604606683_dsa-171171978315_dev-c_ext-_prd-_sig-Cj0KCQiA6vaqBhCbARIsACF9M6mPOsAGwWF1nHpwfVC80hMfe3-PGVDgq-cEzFUSYCA

wcB&gad_source=1&gclid=Cj0KCQiA6vaqBhCbARIsACF9M6mPOsAGwWF1nHpwfVC80hMfe3-PGVDgq-cEzFUSY

wcB

12: MOSFET Data

https://www.digikey.com/en/products/detail/stmicroelectronics/IRF740/634695?utm_
adgroup=Semiconductor%20Modules&utm_source=google&utm_medium=cpc&utm_campaign=
Dynamic%20Search_EN_Product&utm_term=&utm_content=Semiconductor%20Modules&utm_
id=go_cmp-120565755_adg-7526266035_ad-665604606641_dsa-57463687395_dev-c_ext-_
prd-_sig-Cj0KCQiA6vaqBhCbARIsACF9M6kZvKTGgxBEwwNOD9lUYQdQRtqrnrbzOaDL2AM9X2BgqBC0vQONA9g
wcB&gad_source=1&gclid=Cj0KCQiA6vaqBhCbARIsACF9M6kZvKTGgxBEwwNOD9lUYQdQRtqrnrbzOaDL2AM9X
wcB

13:AD2 Data

https://digilent.com/shop/analog-discovery-2-100ms-s-usb-oscilloscope-logic-analyzer-anc

14:Ego Battery Data

https://egopowerplus.com/battery-10-amp/