Design for Manufacturing, Reliability, and Economics

Team 2 – Cummins Electric Vehicle Optimization

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Abstract

The Electric Vehicle Optimization was designed to simulate a “hotel system of charging” to model an issue Cummins is having with their semi-trucks. Cummins would like to develop a battery-engine package that would eliminate truck engines running the entire night to ensure the battery is not depleted when cabin electronics are powered by it. In order to avoid this, a battery monitoring system will be designed and integrated into the electric golf cart to model this system. When the batteries are depleted to a certain threshold, chosen by experimental testing, the microcontroller signals to the relays to turn on the generator. The temperature of the batteries is also monitored to ensure proper operation in cold weather conditions. If the batteries are too cold, heating pads will be used to warm up the batteries to an optimal temperature to ensure they do not get damaged when charging. The system contains two major design aspects which include the mechatronic circuit to control the power supplied to the golf cart as well as the mounts that were fabricated for the generator, generator battery, propane tank, and the power supplies. The contents of this report discuss the manufacturing, assembly, reliability, and economic analysis of the developed design.

Acknowledgments

Team 2 would like to thank Dr. Michael Hays and Cummins for providing the budget and design assistance to make this project a reality. Dr. Hays has helped the team tremendously with receiving the golf cart and generator that was provided by Cummins, as well as facilitating the purchase request for the power supplies that have been utilized in the design.

Team 2 would also like to thank Dr. Gupta and Dr. Camilo Ordonez for the endless hours of advice and design considerations with the circuitry components of this project. Dr. Gupta has also helped with presentation preparation and has provided constructive feedback to better the team's presentation skills.

1. Introduction

Semi-truck drivers are being faced with getting a hotel room, or sleeping in the truck cabin. These cabins can include a TV, heating and AC as well as a bed for them to sleep. These electronics are powered by the trucks battery, which in cold weather conditions poses a potential threat. In order to stay warm and not deplete the batteries, the truck engine must remain on throughout the night. Cummins provided the design team with an electric golf cart to model this issue. The electric golf cart was modified and designed as a proof-of-concept for a "hotel system of charging" that Cummins would like to integrate into their semi-truck engines. The golf cart design consists of two major aspects, the mechanical design portion and the mechatronic/electrical design.

The mechanical design includes the mounts that were fabricated for the different components that were integrated into the cart. The generator that was provided by Cummins runs off of a propane and a 12 volt battery. The team carefully designed and selected materials for these mounts to ensure these components are securely fastened to the cart. Two power supplies were also utilized in this design to convert the alternating current of the generator to the direct current required by the golf cart. These components were also mounted with the 12 volt battery for the generator.

The mechatronic design includes the complete circuitry to ensure the generator turns on/ depending on the battery voltage and temperature and turns off depending on the current from the charger. For this design portion, various circuit components such as the microcontroller, diodes, relays, and power supplies were carefully selected depending on the current and voltage through the circuit. To ensure the system does not fail, the team designed the circuit with factors of safety as well as conducted FMEA on the major components. This portion of the design process was extremely meticulous to ensure no part of the circuit would burn out and cause damage to any other part of the system.

2. Design for Manufacturing

2.1. Mount Fabrication

The mechatronic design utilizes a QG 2800 Cummins generator to power the golf cart when the batteries need charging. This generator is fueled by propane and utilizes a 12 volt battery to operate. The generator outputs AC current which is converted to DC via two power supplies. Mounts for these components were constructed and are detailed below.

2.1.1. Generator

The generator and propane tank mount was fabricated out 2 in x 2 in x 1/8 in steel angle iron. The generator mount is composed of two U shaped brackets and two support pieces. With a U shaped bracket secured each side of the generator with 5/8" steel bolts. Each U shaped bracket is attached to a piece of steel angle that lies across the rear seat support again using 5/8" steel bolts. This ensures that the generator is secure under the back seat and does not move when the cart is in motion.

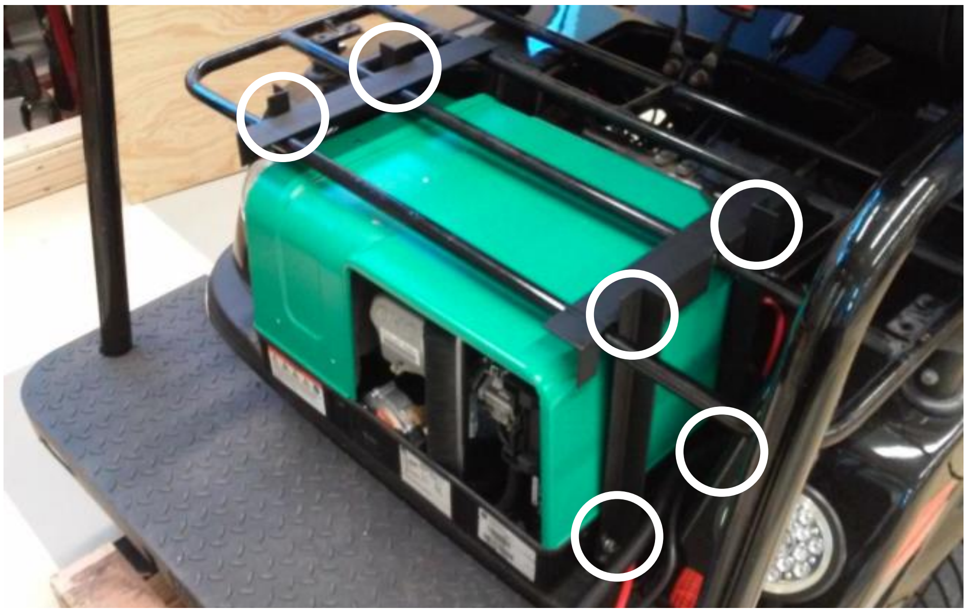

Figure 1. Photograph of generator mount. The locations of the bolts are circled. There are two bolts on the bottom left side of the generator that have not been circled.

2.1.2. Propane Tank

The propane tank mount was designed to mount to the rear hand-rail that hangs off the back end of the cart. Utilizing the steel angle iron that was purchased for the generator mount, the team designed a mount to securely fasten the propane tank to the back of the cart. The angle iron was bolted to the frame of the golf cart using 5/8” steel bolts. This design also allows for easy removability of the tank. Additionally protective material was added to the mount to ensure the metal does not rub against the tank and possibly cause sparks while in motion.

Figure 2. Photograph of the propane tank mount.

2.1.3. Power Supplies

The team utilized two power supplies in parallel to convert the generator's alternating current output into a direct current for powering the golf cart. These power supplies as well as the 12 volt generator battery were mounted to the recessed region inside the front seat where the other six batteries sit. The mount developed is made from sheet metal and sits flush next to the cart’s batteries. A portion of the metal was cut out to allow the power supplies to slide into the plate, as seen in Figure 3 on the following page. Brackets were added to secure the supplies to the housing with M4 screws. Additionally the supplies are joined together with steel strips, one on either side, that are bolted to the supplies also using M4 screws.

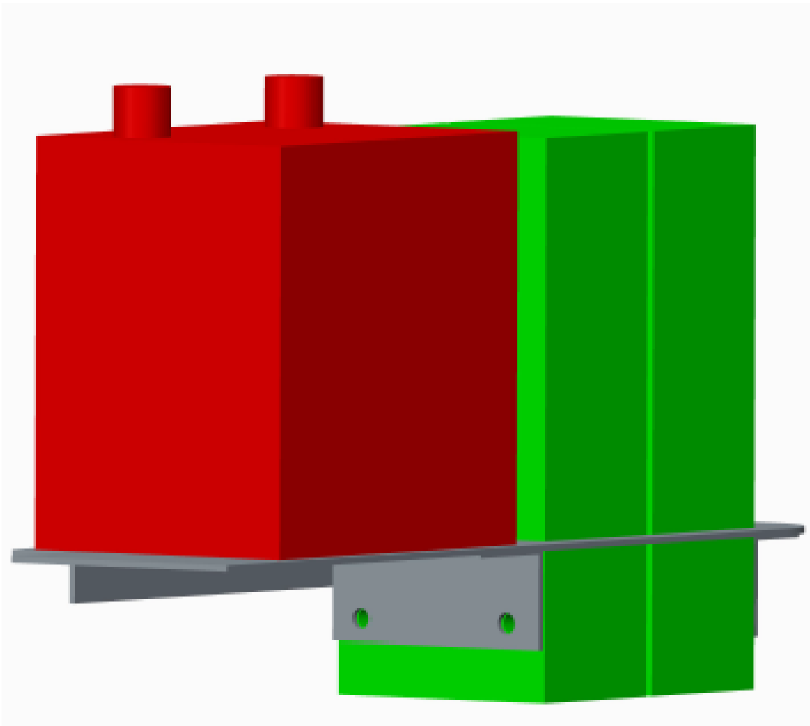

Figure 3. Assembly showing how the power supplies (green) are fastened to the plate and how the battery (red) rests on the plate. Steel strips not pictured.

2.2. Electrical Assembly

For correct operation of our system, many electric components were added to the cart. Some components added were relays, sensors, a microcontroller, a LCD display, and many feet of wiring.

2.2.1. Circuit

A majority of the circuit was composed of 2 gauge wire with crimped-on circle connectors. These wires run from the two AC to DC power supplies to two relays as seen on the following page in Figure 4. From the relays, the power runs to two terminal blocks and then to the golf carts motor. The majority of this circuitry is routed between the rear of the cart to the cart’s battery compartment underneath the front seat. This area stays dry and wire straps were used to fasten the wires to the cart.

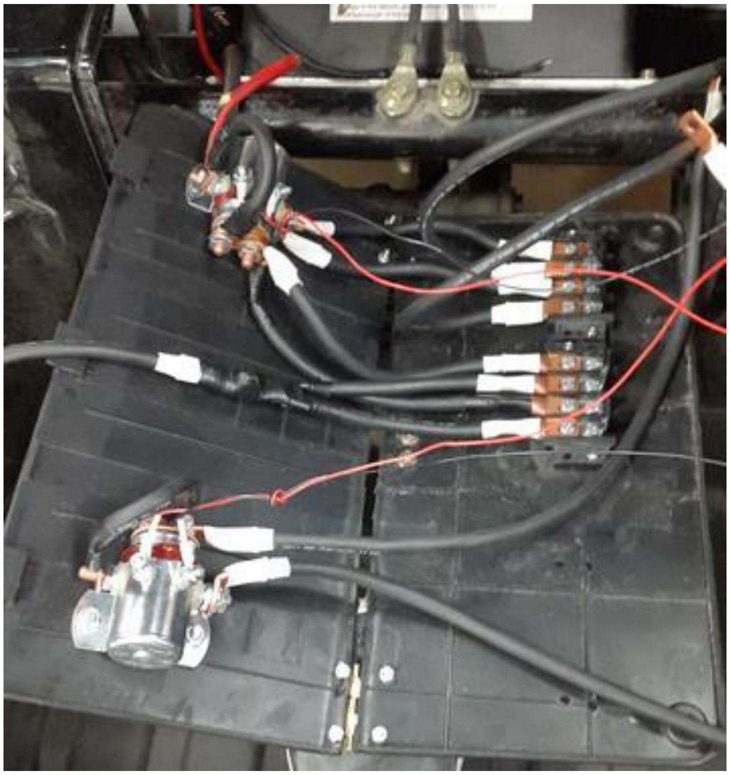

Figure 4. Access panel with the motor relays and terminal blocks mounted to it.

2.2.2. Relay Location

The motor relays shown above in Figure 4 were mounted on an access panel located on the rear of the cart, as indicated in Figure 5. This spot allows for quick and easy access while also keeping them protected from outside elements such as water.

Figure 5. Photo of the access panel indicated by the arrow.

Electrical equipment is very fragile thus it was very important to mount the relays in an area that will stay dry and clean. The charger and heating pads relays were mounted in the compartment below the front seat. They were fastened to the rear passenger wheel well using bolts and nuts. These relays are on the same side of the cart as the generator battery that powers them meaning less wire was needed. Additionally there is empty space around them making them relatively easy to access.

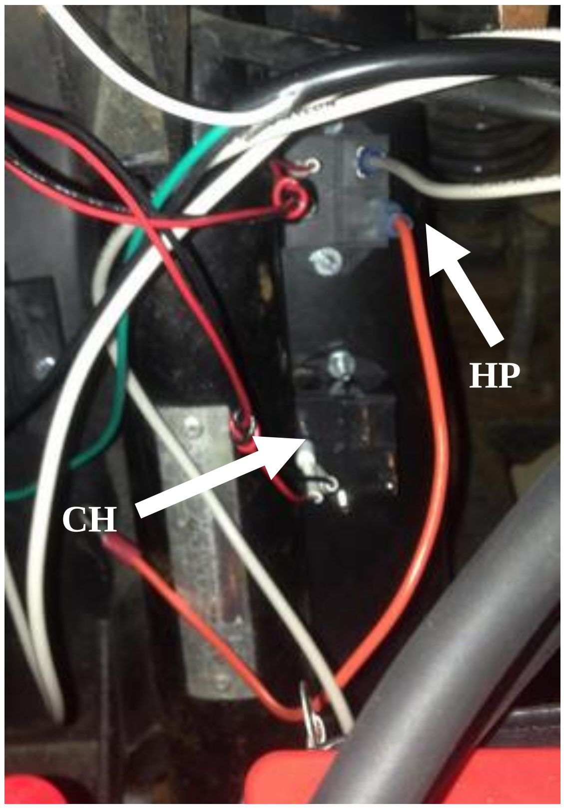

Figure 6. Heating pad (HP) and Charger (CH) relay location with relays indicated by the arrow.

The generator requires one relay to activate it and another to turn it off. These relays were mounted on the back side corner of the generator, attached directly to the generator's green housing. This location can been seen in circled in Figure 7 on the following page. The location of the relays allows for easy access and ensures the relays will not be open to the elements.

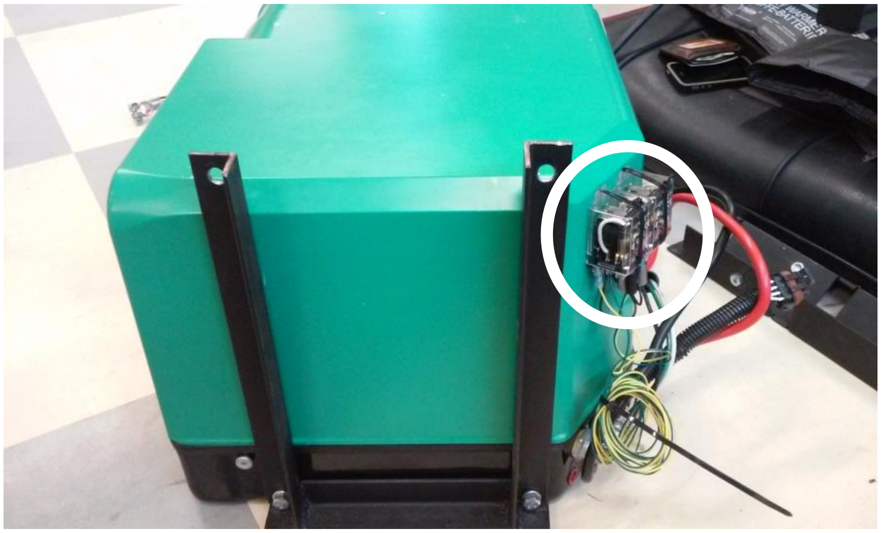

Figure 7. Photograph of the generator with the relay location circled.

2.2.3. Sensor Location

The mechatronic system includes two sensors, a current sensor and a temperature sensor. The temperature sensor is mounted on top of the golf carts batteries near the positive terminal. The current sensor is mounted under the front seat on the golf cart controller housing.

Figure 8. Photograph of where current sensor, circled, is mounted.

2.2.4. Microcontroller and LCD Display

Due to a recent setback, leaking 8 volt battery, we have not finished testing the carts system. Having the LCD display in an easily accessible area will allow for easy testing of certain systems. Therefore a permanent spot has not been selected. For the microcontroller, we plan on mounting it in a tupperware container. This will guarantee that no water, dust and other contaminants will be able to come in contact.

2.3. Challenges

As we were building the circuit for the mechatronic system, we were testing different aspects of the design simultaneously. Every aspect of the mechatronic system has been tested individually and the final system will be tested by the week of 4/4. All of the circuitry has been built and mounted, aside from the microcontroller and LCD display. For the brackets and mounts, they were built as needed to continue testing. Building the mounts at a group members shop decreased the turnaround time from design to final product from weeks to a matter of days. The finally assembly has taken longer than expected, this is due to setbacks such as an 8 volt battery cracking and having to order a new one.

3. Design for Reliability

A very important aspect of the design of this system is the reliability of the system and its various components. There are many different portions of this design that must interface with one another in order for the system to function as intended. As such, it is a necessity to ensure that the system can function reliably in order to minimize downtime and be used without any hindrances. There are mechanical and electrical subsystems that include the generator, DC motor, various transistors, diodes, relays, and the batteries that power the electronics that must interact with one another continuously to provide a trouble free experience and as such the reliability of these systems needed to be taken into consideration in the design of the system.

3.1. Factors of Safety

One of the most critical portions of the design is the various relays, transistors, and diodes that make up the electrical subsystem. If these components are not able to tolerate the loads that the design will subject them to, then the system will not be able to function as intended. Therefore, it's very crucial to know that these components are able to withstand the current that they will be loaded with.

3.1.1. Relays

The relays in the system regulate power distribution to the various components. In order to make sure that the relays would be able to function as intended, the safety factors for each were calculated by taking the current that the relay was rated for and dividing that by the current that would be flowing through it. As long as this safety factor is above one, then the relay should be able to consistently be used without damage and the higher the value, the better the amount of safety built into the system. The relay controlling the heating pads has a safety factor of five. The charger relay that controls the charger circuit has a safety factor of two. Lastly the relays that are completing the circuit between the cart's batteries and the motor are rated at a safety factor of four. Thus, all of the team's relays should be more than capable of seeing the sustained current levels that will be distributed amongst them.

3.1.2. Transistors

Another important component of the system's circuitry are the various transistors which are used in order to switch signals and amplify currents in order to allow equipment with different operating currents to be connected. In order to calculate the factors of safety on the various transistors, a similar approach was taken to that which was done for the relays. The current that the transistor is rated for was divided by the current that the transistor would actually see and that calculated value was taken as the factor of safety. Since there is 12 volts through the transistors and the resistances of each are known, the current was simple to calculate by dividing the voltage by the resistance of each transistor. The transistor for the heating pads and charging system have a factors of safety of 2.7. The generator circuit transistor has a factor of safety of 1.7. And lastly the transistor for the power supplies has a factor of safety of 5.8. Therefore, all of the transistors are able to meet the demands of the design and will be able to operate reliably at the current levels of the system.

3.1.3. Diodes

Diodes are installed in the system in order to keep the current from flowing backwards and thus allowing for the two power supplies to be connected in parallel without interfering with one another. The same convention was used as before with current as the measure to account for the factors of safety. In the end, the two diodes were rated with a factor of safety of 1.4. Additionally due to the possibility of inductive kickback during power switching diodes capable of withstanding 1.4kV were selected.

3.2. FMEA

In addition to using factors of safety to ensure reliability FMEA was conducted in order to determine the possible ways the system could fail and how their failure would affect the system. Table 1 is a compilation of this analysis. The main reliability concerns over the system's various components were each placed in the first column. The second column consists of the potential failure modes of the system which are essentially the different ways that the system components can fail. The third column further expounds upon the failure modes with the potential effects that can occur from the failure mode. The fourth column details the severity of the aforementioned failure mode and its effects on a scale consisting of low, medium, and high ratings. Lastly, the fifth and final column lists all the possible causes for the failure modes.

Table 1. FMEA of design components.

Team Number	2
Project Description	Improving the range of an electric vehicle

Component	**Potential Failure Mode**	**Potential Failure Effects**	**Severity**	**Potential Causes**
What is the primary component affected?	In what ways can the component fail?	What is the impact of this failure mode?	How severe is this failure to the user? (Low, medium, high)	What causes the component to fail?
Heating pads	Not activating	Batteries will not be heated in cold climates	Medium	Loose wire Inaccurate/no temperature sensor reading
	Remaining active	Heating pads will stay on Might overload the generator if charger is active	High	Damaged transistor
Charger	Not activating	Batteries aren't receiving a charge	High	Loose wire Lack of power from generator
	Remaining active	Charger remains active, but won't overcharge batteries	Low	Damaged transistor
Generator	Not starting	Generator is inactive, but the system will still switch to generator powered state	High	Loose wire Low/no oil No/poor propane connection Insufficient battery charge Circuit breaker tripped
	Won't shut off	Generator will remain on unnecessarily, potential damage to generator	Medium	Damaged transistor

Power supplies	Not activating	Power supplies will be inactive	High	Loose wire
	Remaining active	Power supplies will remain active, potential damage to power supplies	Medium	Damaged transistor
Microcontroller	Not activating	System isn't switching states	High	Installation error Improperly code Damaged pins Sensor error
Temperature sensor	Not giving accurate temperature readings	System will incorrectly switch states	High	Manufacturing defects Improperly coded Installation error
Current sensor	Not giving accurate temperature readings	System will incorrectly switch states	High	Manufacturing defects Improperly coded Installation error

3.3. FEA

A focal point of this design is the integration of the generator with the golf cart and its electrical systems. As such, it was important to ensure that the generator was safely mounted to the vehicle in a manner that would allow easy access and also keep the generator attached when the cart was in motion. As can be seen in Figure 9, the final generator mount design can be seen along with the stress and displacement analysis that was performed on it.

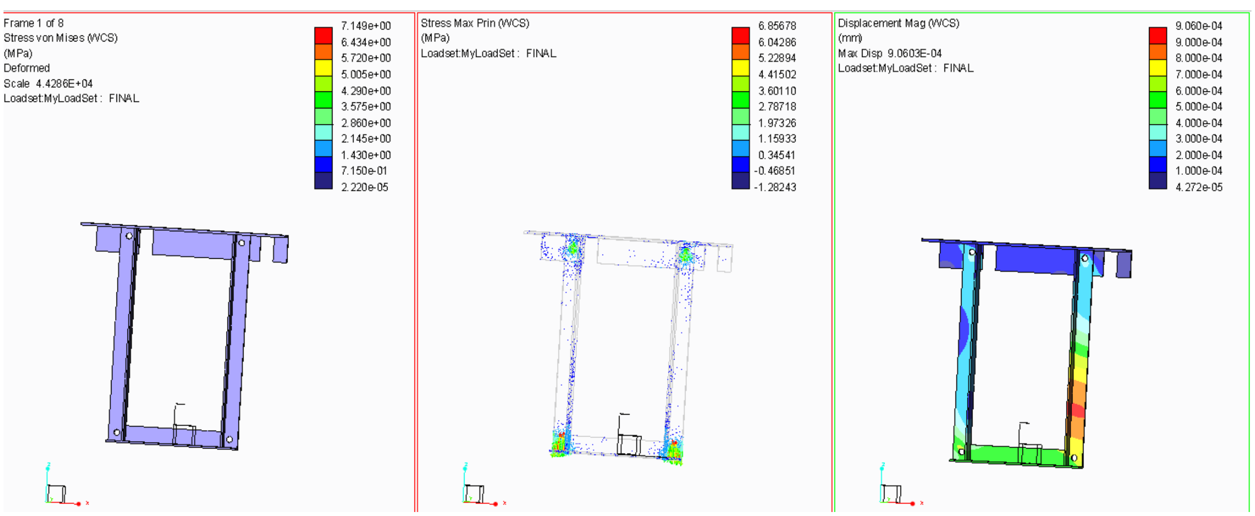

Figure 9. FEA conducted on generator mount.

Here it can be seen that the stresses on the mount are minimal with the greatest concentration of stresses being at the joints where the mount's individual pieces are connected. However, even this maximum stress is negligible and is not a cause for concern over the reliability of the mount.

3.4. Reliability Summary

The reliability of any system is an important aspect that should be heavily analyzed in order to have a successful design that functions as intended. After considering this and designing the circuitry and mechanical components in a manner that will allow reliable operation of the golf cart, the prototype will perform as intended from the first time to an undetermined number of cycles. The total life span of this system has not been determined due to lack data on the lifetime of various components including the on-board charger, power supplies, as well as the various preexisting components in the golf cart. Despite this the best design efforts were made to select components with a high factors of safety so they can operate over many cycles of use without any ill effect.

4. Design for Economics

4.1. Budget Breakdown

Cummins provided the design team with a budget of $2000 to generate a proof-of-concept design to model the "hotel system of charging". Team 2 has been working with an independent team of electrical engineers, in which the Electrical Engineering department provided a $700 budget.

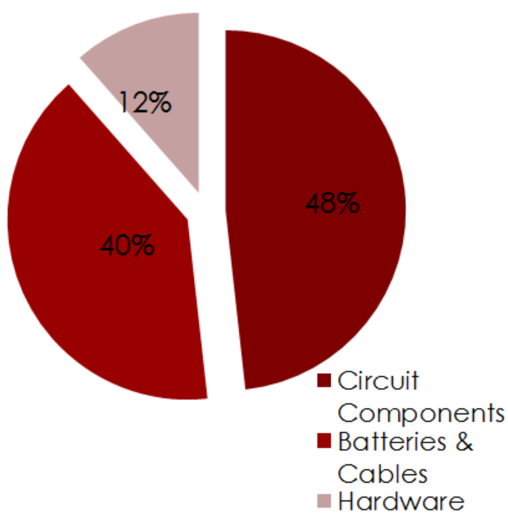

Figure 10. Pie chart of budget breakdown.

This budget was broken down into three main components. The circuit components include all of the necessary parts to build the circuit for the mechatronic design. This includes the microcontroller, and various wires, diodes, and resistors that were utilized. As well as the relays that will be turning on and off the generator, power supplies or charger. The heating pads to warm the batteries also fall under the circuit components. A LCD screen was purchased to ensure easy programming and to ensure the monitoring system is user friendly. The various parameters such as voltage, current and temperature are displayed on the screen, as well as the state at which the cart is in. A replacement Delta Q charger for the chart was also purchased because the one that was received with the cart did not work.

The batteries that were received with the cart had been sitting for too long and had crystalized, therefore the team had to purchase six 8 volt lead acid batteries to replace the old ones. The team of electrical engineers purchased three while the mechanical engineers purchased the remaining three. The 12 volt for the golf cart is also included in the batteries purchased, as well as the cables to connect the terminals.

Additionally the components for the hardware assembly were accounted for in this budget. These include the raw angle iron steel that was purchased for the generator and propane tank mount. The team had to purchase the fittings and hose to connect the propane tank to the generator as well as various nuts and bolts to secure the mounts onto the cart. Additionally, the mount fabrication was done by the team members, so sandpaper, drill bits, and cut off wheels were purchased to finalize these mounts.

4.2. Market Hybrid Golf Carts

On the market today, the Bad Boy buggies are the leading manufacturer of hybrid electric karts. The hybrid cart they manufacture is the AMBUSH ® iS which utilizes an electric or gas

Figure 11. Bad Boy AMBUSH iS hybrid cart. [1]

mode. The cart uses dual gas and has a four wheel drive option. It runs off a 16 hp direct current motor and uses four 12 volt batteries. This model starts at $14,999 and has customizing options such as bucket seats, convertible rear seat kit, and folding windshield. [2]

5. Conclusion

The design team's sponsor Cummins presented the issue that the current range of the golf cart was unsatisfactory and that it would be ideal to increase the range of the current system through the addition of a generator. Analysis of different circuitry and mechanical mounting methods yielded the final design that has been detailed in this design manual. The final design has been analyzed and engineered in order to be reliable, easy to reproduce and manufacture, and economically sound with the end goal of making the design applicable to the current Cummins ISX-15 diesel engine and operational in a capacity that is streamlined for mainstream use by the operators and users of Cummins powered vehicles.

References

[1] http://www.vipgolfcarts.com/new_cart_pages/n86.html

[2] http://www.badboybuggies.com/Ambushis