Final Report 1: Detailed Design

Team Number: 2 Electrical Vehicle Optimization

Submission Date: December 7, 2015

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Abstract

Dr. Michael Hays of Cummins is directing group 2 in its efforts to maximize the operable range of an electric vehicle in extreme weather conditions. Cummins would like to develop a “hotel system of charging” that can be integrated with their diesel engines used in semi-trucks. This will consist of a battery engine mechatronic system, which will use the engine to recharge the batteries if the batteries are depleted to a certain threshold. The design team will develop this system for the electric golf cart provided by Cummins in efforts to apply this to the ISX-15 diesel engine. Group 2 is working in tandem with a group of electrical engineers. The electrical engineers are going to handle battery selection, circuit analysis, as well designing an AC to DC convertor. The mechanical team will be responsible for integrating the electrical components into the mechatronic system as well as selecting the generator that will simulate the ISX-15 diesel engine. A battery monitoring system will be integrated to control when the generator is turned on and off, based on the battery voltage. This system will send a signal to shut off the generator when the batteries are fully charged. Since the battery output is largely dependent on the temperature, a heating element will be integrated to ensure the batteries remain at an operable temperature. The design team has conducted research on possible routes for the project; however some of the programming aspects require more research. These programing concepts will remain the same for the semi-truck model; the difference is the secondary power source is the ISX-15 engine instead of a generator.

1 Introduction

The objective of the project is to enhance the system by improving the current range and operable temperatures of an electric vehicle, and then to model the improvements on an ISX-15 diesel engine. Semi-truck drivers are faced with getting a hotel or sleeping in the truck cabin. These cabins consist of a bed, TV, as well as heating and AC. This produces a potential threat in harsh weather conditions. The driver must keep the truck engine running through the night in order to stay warm as well as not drain the battery. To prevent this issue, Cummins would like to develop a “hotel system of charging”. This concept will include a battery/engine package that integrates a mechatronic system, in which the truck engine will turn on the charge the batteries when necessary. Cummins has provided the design team with an electric golf cart to develop a “hotel system of charging”, as well as a generator to simulate the ISX-15 diesel engine. The implementations done are the golf cart will be scaled appropriately and modeled for semi-trucks. The design team will keep in contact with Dr. Hays to ensure the mechatronic system developed for the golf cart will be compatible with the ISX-15 diesel engine. Dr. Hays has presented the design team with two main aspects for improvement on the golf cart. These include that the vehicle must be operable in low temperatures as well as increase the current range. The mechatronic system will be developed to ensure the batteries remain at an operable temperature by integrating heating pads, thus allowing operation in harsh weather conditions. This is cause for background research on battery technology and ways to regenerate power while in motion in order to meet the necessary design objectives for the vehicle. The team intends to document the current range and operating capacity of the vehicle and then use that data as a benchmark for further improvement.

2 Project Definition

Semi-truck drivers have been faced with a potential issue in harsh weather conditions. Rather than getting a hotel room, truck drivers will sleep in the cabin. These cabins usually consist of a bed, TV, heating and AC. However, harsh weather impedes the battery output, which is powering these electronics. The driver must keep the engine running through the night to ensure that the battery does not drain as well as stay warm. Cummins would like to develop a system that utilizes the engine power to recharge the batteries when necessary, in order to prevent the engine from running all night.

2.1 Background research

2.1.1 History of the Electric Car

The concept of a battery powered vehicle dates back to the 1800’s, where inventors from different countries were playing with the idea of electric locomotion. Robert Anderson, a British inventor, is accredited with generating a small-scale battery powered vehicle. From there, electric vehicles transformed, and by the 19^{th} century, electric cars were so popular that New York City had a fleet of 60 electric taxis. [1] The movement of the personal car played a big role in this evolution; however the electric car was competing with gasoline powered vehicles. The first vehicles that were developed in the early 1700’s either ran off of steam or gasoline. [1] Soon, it was clear that steam would be impractical if applied to a small personal car, however gasoline seemed promising. Nonetheless, electric cars didn’t possess the same harmful side effects of gasoline powered vehicles. This includes pollutants from exhaust to the drilling of natural gases and oil. Electric cars provided a quiet, safe, and efficient way to travel around the city on short trips, and with the rise of availability in electricity, electric cars became more readily used. The fall of electric cars came with the production of the Model T. Henry Ford developed a highly efficient manufacturing line that lead to extremely affordable gasoline cars. [1] By 1912, the electric car cost more than double what the Model T did, and with this, the electric car industry took a small fall due to supply and demand. [1] Once oil was discovered in Texas, electric cars began to disappear, and by 1935 there were no electric cars on the roads.

2.1.2 Modern Technology

With the recent shortages in oil reservoirs, electric cars are making a comeback. Clean energy is becoming a highly advanced technology that is being utilized for many applications, including transportation. Some of the leading transportations companies in the United States are moving towards a cleaner, efficient way of travel. With that being said, Cummins has provided the design team the opportunity to take part in improving the current operation of a small-scale electric vehicle. The concept of an electric powered vehicle is not farfetched, given that many companies today have electric cars on the road. However, a big challenge in the design process is the operation of these batteries in low temperatures. The design team was told the vehicle must

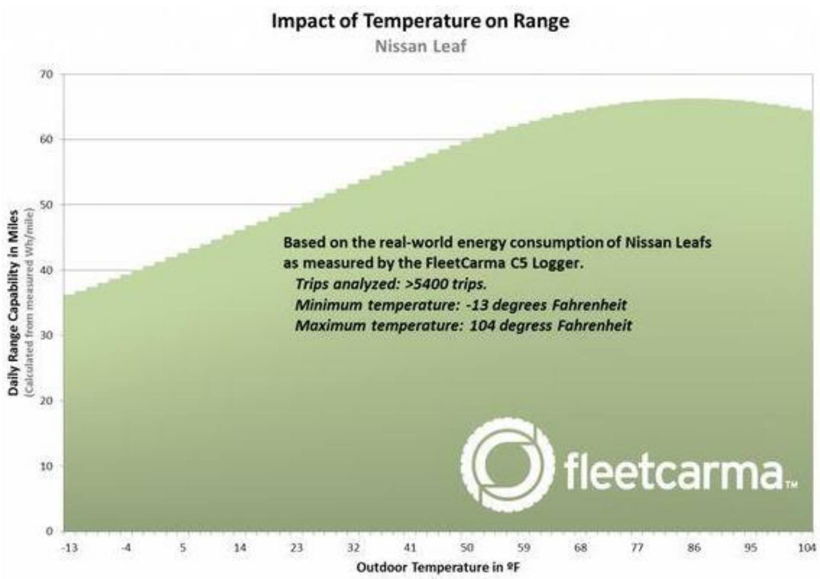

Figure 1. Impact of temperature on range tested on a Nissan Leaf. [2]

start and remain fully operation in -29˚C conditions. Current electric vehicles were researched in order to understand how temperature can affect the range of the vehicle. Figure 1 below shows that as the outside temperature decreases so to does the daily range of the vehicle. [2]

2.1.3 Hotel System of Charging

Semi-truck cabins can be custom equipped with all the essentials for living. A standard cabin will include a bed, TV, heating, AC, and small bathroom. However some cabins can be extremely elaborate with gaming systems, fully functioning kitchens and outdoor grills. [3] These cabin electronics run off the truck battery, however there is a risk with draining the battery. Harsh cold weather conditions also pose a potential threat to the battery. As temperature decreases, the output voltage of the battery drastically decreases. To prevent over draining the battery, truck drivers will run the truck engine the entire night. This allows the battery to charge up and the cabin heating. Cummins would like to develop a “Hotel System of Charging”, which would include a battery and engine package. The idea is that the cabin electronics would run of the battery, once the battery voltage reaches a certain threshold, a microcontroller will signal to turn the truck engine on to charge up the batteries. Once the batteries are charged, the engine shuts off. This prevents the driver from running the engine all night. [4]

2.2 Need Statement

This project is sponsored by Cummins under the supervision of Dr. Michael Hays along with the assistance of Dr. Claus Daniels from Oak Ridge National Laboratory. The team’s faculty advisor is Dr. Juan Ordonez. At present the electric vehicle cannot operate at cold temperatures, and its range is more limited that is desired. The purpose of this project is to simulate the issue of semi-truck cabins draining the battery. The design team needs to modify the current golf cart system by utilizing a secondary power source. This power source will represent the ISX-15 diesel engine. Dr. Hays informed the team that Cummins would be providing them with a generator to implement in their design. Since this is a small-scale simulation, Dr. Hays has provided the team with two issues with the current golf cart. The range needs improvement and the vehicle does not operate in harsh cold weather. As such Team 2 has formulated a need statement for the project:

“Semi-truck cabin electronics drain the batteries, and force the driver to keep the engine running. This is translated down to an electric golf cart, verifying the current range is unsatisfactory and needs to operate in cold weather conditions.”

2.3 Goal Statement & Objectives

From the meetings with the sponsor the goal of the project was formulated. Dr. Hays desired that a generator be installed into the golf cart to serve as the charging power source for the battery. He also desired that the generator activate when the battery level drops below a certain threshold, and that the generator deactivate when the batteries are charged. In addition to the automization of the generator charging system he requested that a battery monitoring system also be implemented. Additionally all of these modifications would be made in efforts to apply this to semi-trucks. The project's goal statement was developed by generalizing these requirements and is given below:

Goal Statement:

"To increase the current range and operable conditions of the electric vehicle by utilizing a secondary power source in efforts to apply this to semi-trucks."

Objectives:

- **Increase the lower temperature limit to -29˚C.**
- **Document current system performance.**
- **Incorporate a generator.**
- **Integrate a battery monitoring system.**
- **Ensure that the golf cart can charge and be in operation simultaneously.**
- **Model design for the ISX-15 diesel engine.**

2.4 Constraints

- **The system must operate at -29˚C.**
- **Project budget is $2,000.**
- **Primary power source must be the 48V battery set.**

3 Preliminary Design

3.1 HOQ

When deciding on what aspects of a design are the most integral to the success or quality of a project, it is important to have some quantifiable measure that can be used to assess the relation between a customer's requirements and the necessary design functionality. In terms of design methods, a common method to determine this intricate relation is called a house of quality or HOQ for short, pictured in Figure 2. This tool allows an easy visual aid to quickly see the correlation between customer requirements alongside the firm engineering characteristics. In order to determine the most important customer requirements, the team spoke with Dr. Hays and asked him to rank his customer requirements on a scale of one to five; with five being the highest

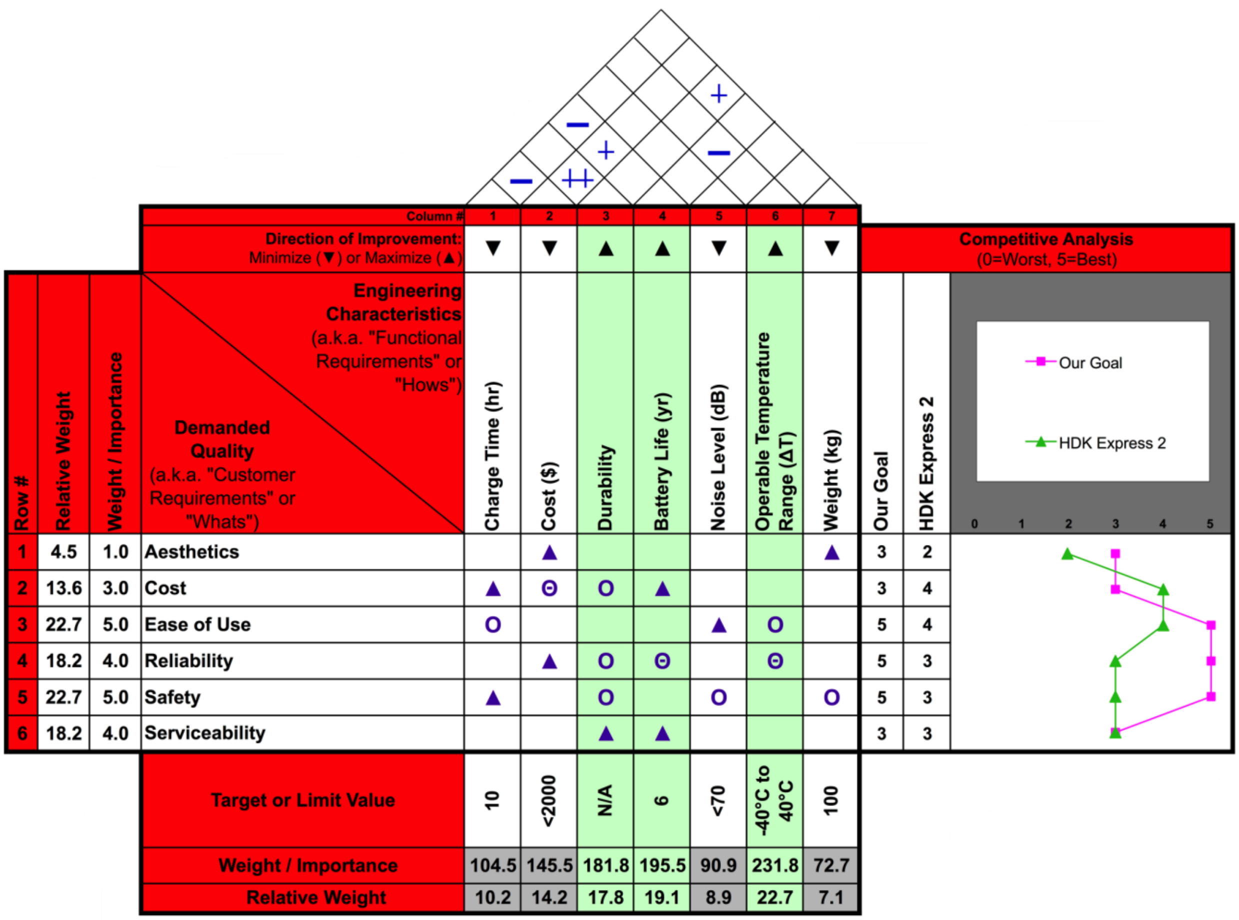

Figure 2. House of Quality

value, and thus signifying the criteria that is of the most importance to the customer. The customer requirements included the following: aesthetics, cost, ease of use, reliability, safety, and serviceability. The customer requirements with the greatest importance were ease of use and safety, which were both given a rank of five. Next up with ranks of four were serviceability and reliability. And with ranks of three and one respectively were cost and aesthetics. The engineering characteristics that were selected as firm aspects of the design were charge time, cost of improvements, durability, battery life, noise level, operating temperature, and weight. The benchmark that can be seen on the right is the average golf cart on the market, which is the HDK Express 2 golf cart. Team two compared the design goal with the HDK Express 2 and found that while the benchmark did cost less due to a lack of a generator, the design of team two was favorable in reliability, ease of use, and safety. The chart shows that there is a strong correlation between durability and battery life. As such it would make sense that more expensive materials will prove more durable and battery packs that have longer battery life will generally have a higher price as well. Once weights were given to the relationships between the characteristics, the relative weights were calculated along with the customer requirements. With this knowledge in tow, the highest ranked characteristics are operating temperature, battery life, and durability. As such, these shall be the most important parameters when attempting to improve the current system.

3.2 Concept Generation and Evaluation

3.2.1 Selection Criteria

The design was developed using the morphological method, which breaks up the overall design problem into simpler sub-problems and solution concepts are generated for them. [5] The sub-problems or parameters for this design include: where to locate the generator, how to warm the batteries to an operable temperature, how to ensure the generator will operate at -29°C, and what charging system will be used. Three possible solutions were developed for each of the problems and the best solution was chosen using a Pugh chart. The first option for each problem was set as the datum that the other solutions were weighed against. The solutions were rated using four criteria that are based on the project goals, objectives, constraints, as well as customer requirements. The four criteria are cost, weight of modification, noninvasiveness, and safety.

- **Cost:** Although the cost was not one of the most important of customer requirements it is a defining constraint of the project, which is why it was chosen as one of the criteria for the design selection.
- **Weight:** The HOQ shows that the weight is not one of the most important engineering characteristics, however to heavy of modifications would increase the strain on the batteries and in turn reduce the overall performance of the vehicle. Since improving the performance/increasing the range is one of the project objectives the weight was chosen as a design selection criteria.
- **Noninvasiveness:** This selection parameter was chosen primarily due to the project time constraint of two semesters. The more complex the design is the more time it will take to develop, therefore it was decided that the simplest solutions would be the best.
- **Safety:** One of the two most important customer requirements was the safety of the design therefore it is an important selection criteria.

A “+” indicates that the particular aspect is superior to the datum, a “-“ indicates that it is inferior to the datum, and an “S” indicates that the option is neither better nor worse. The total number of minuses was subtracted from the total number of pluses to obtain the score of the solution concept, with a positive score being the most favorable.

3.2.2 Generator Location

One possible location for the generator is under the back seat of the golf cart, as seen in Figure 3. The generator would be placed in this recessed region and would be mounted to the golf cart frame that runs under the rear seat and under the black plastic flooring. Figure 3 also shows another possible solution, which is that the rear seat could be removed and the generator mounted in its place. This of course eliminates the functionality of the rear seat which is not desirable. The third and final solution concept is that the generator could be placed on carriage, similar to that pictured in Figure 4, that would be pulled behind the cart. This solution presents a safety issue as the carriage could fishtail and potentially cause an accident.

Figure 3. Photograph of the back of the golf cart.

Figure 4. Carriage design concept. [6]

Table 1 is the Pugh matrix for the generator selection, and it shows that the best location for the generator is under the back seat with a score of 0 as compared to -4 and -1 for options 2 and 3, respectively. Not only is this solution the least invasive, it is also the safest because it is well secured and is well separated from the user.

Table 1 Generator Location Pugh Matrix

Criteria	Under Back Seat	On a Carriage	In Place of Back Seat
Cost	S	−	S
Weight	S	−	+
Noninvasive	S	−	−
Safety	S	−	−
Total	0	−4	−1

3.2.3 Battery Warming Method

Another sub-problem is the method of heating the battery up to an operable temperature. A possible solution is to use the generator exhaust to heat them. This solution would involve the

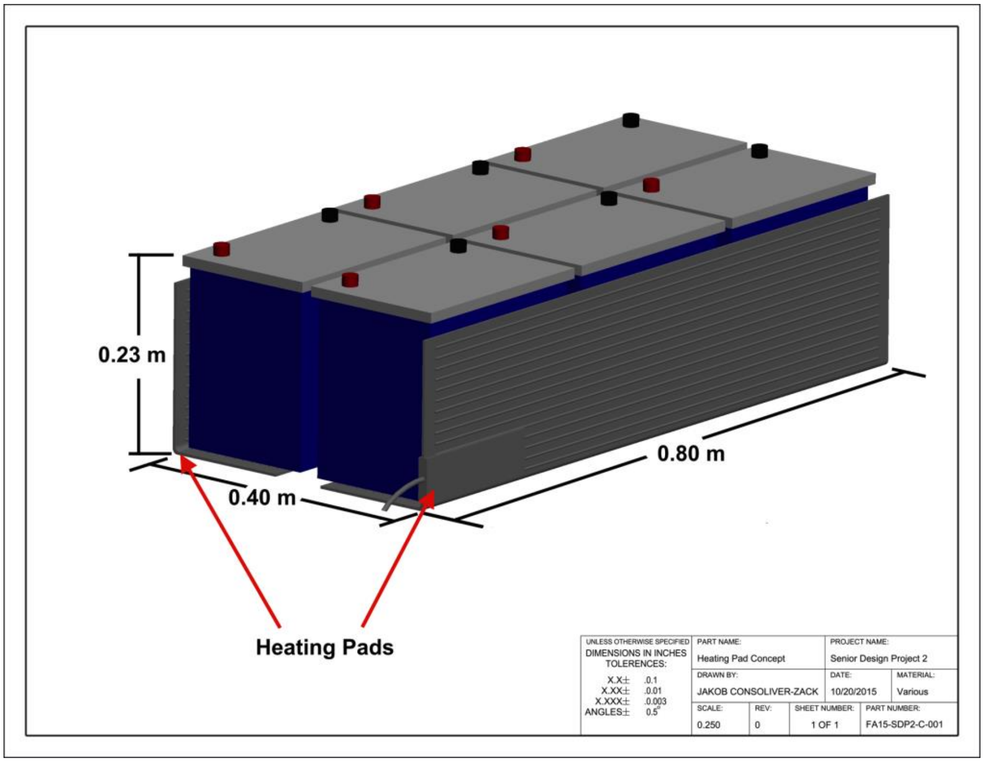

Figure 5. Heating pad design concept.

design of a system of tubing to maximize the amount of heat transferred from the exhaust to the batteries. Careful time intensive design would be needed with this solution so that the exhaust does not melt the battery casings. Another possible solution is the use of heating pads, which would be attached to the surface of the batteries, as seen in Figure 5 on the previous page. The last solution to this sub-problem is to encase the batteries in an insulating material. This method is the simplest of the three, however it is not as effective as the other two since the heat in the batteries will eventually dissipate given enough time.

The Pugh matrix for the selection shows that both the heating pads and the insulation are both better than using the exhaust. Although the heating pads and the insulation scored equally well, based on the selection criteria, it was decided to go with the former since it would be more effective due to the previously stated reasoning.

Table 2 Battery Heating Method Pugh Matrix

Criteria	With Generator Exhaust	With Heating Pads	With Insulation
Cost	S	+	+
Weight	S	+	+
Noninvasive	S	+	+
Safety	S	+	+
Total	0	+4	+4

3.2.4 Ensuring Generator Operation

The third problem to be solved is how to ensure that the generator would operate in subzero conditions. After speaking with Dr. Hollis about this matter he informed the design team that the most likely modes of failure would be an improper air-fuel ratio, the battery powered ignition system not operating, and the oil becoming to viscous. Although the specific choice of generator had not been decided when developing these design concepts it was known that the generator would be from Cummins. The vast majority of Cummins generators designed for mobile applications and recreational vehicles include an automatic choke, eliminating the first problem. Additionally the generators are also rated down to -29°C, which eliminates the second issue, leaving only the oil viscosity problem. [7] One possible solution is to use a synthetic oil that is rated down to the subzero temperature required. The other two solutions involve heating the oil with a device such as an oil dipstick heater or an oil pan heater. These two options however require a power source and present a safety hazard due to the high temperatures that they operate at. The Pugh matrix below shows that the best option is to use synthetic oil.

Table 3 Ensure Generator Operation Pugh Matrix

Criteria	Use Synthetic Oil	Use an Oil Pan Heater	Use an Oil Dipstick Heater
Cost	S	−	−
Weight	S	−	−
Noninvasive	S	−	−
Safety	S	−	−
Total	0	−4	−4

3.2.5 Charging System

The final sub-problem is the charging system that the golf cart will use. One of the primary objectives of the project is to have the generator activate when the battery charge drops below a certain level. At present the cart is equipped with a delta Q QuiQ Model: 921-48xx AC to DC charger. The charger works by supplying the batteries with power until it detects no increase in the voltage meaning they are fully charged and the charger shuts off. This presents a problem since an objective is to run the vehicle and charge at the same time. The rate at which the batteries are charged is less than the rate at which they are depleted, which means that the battery voltage will be slowly decreasing. The charger would then detect that the batteries are full and would stop even though they are not at full capacity. The second solution is that a new charging system would be designed. This solution would use a new on-board charger that uses a different mechanic that allows the voltage to decrease yet continue charging. The third option would be to modify the present charging system. This would be cheaper than developing a new system, because the currently equipped charger would be reprogrammed to meet the design needs. The problem with this solution is that the reprogramming poses a safety risk as various safety features could inadvertently be overridden. Additionally the manufacturer of the charger has not responded to emails and phone calls, which makes getting the necessary information to modify the present charger nearly impossible. All three of the solutions would include a microcontrolled system that would activate/deactivate the generator based on the measured voltage of the batteries. The Pugh decision matrix below indicates that the third solution – modifying the present charging system - is the best of the three.

Table 4 Charging System Pugh Matrix

Criteria	Use Present Charging System	Develop New Charging System	Modify Present Charging System
Cost	S	–	–
Weight	S	S	S
Noninvasive	S	S	+
Safety	S	+	+
Total	0	0	+1

After doing further research on how the charger works and weighing options on how to actually modify the present charging system, it was determined that a new method for modifying the way that the present charger interacts with the golf cart's batteries would have to be formulated. This was decided in order to avoid any potential issues involving the operator's safety and potentially damaging any of the cart's onboard electronics systems or the batteries themselves. The new method that would be chosen for the golf cart will be demonstrated in the next section.

3.3 Selected Design for Golf Cart

By determining the best solutions for the four sub-problems the initial design was developed. The design would store the generator under the back seat, warm the batteries with heating pads, the generator would use synthetic oil, and a modification of the present charger would be developed to meet the design goals. Below is a system diagram of the proposed design for the golf cart.

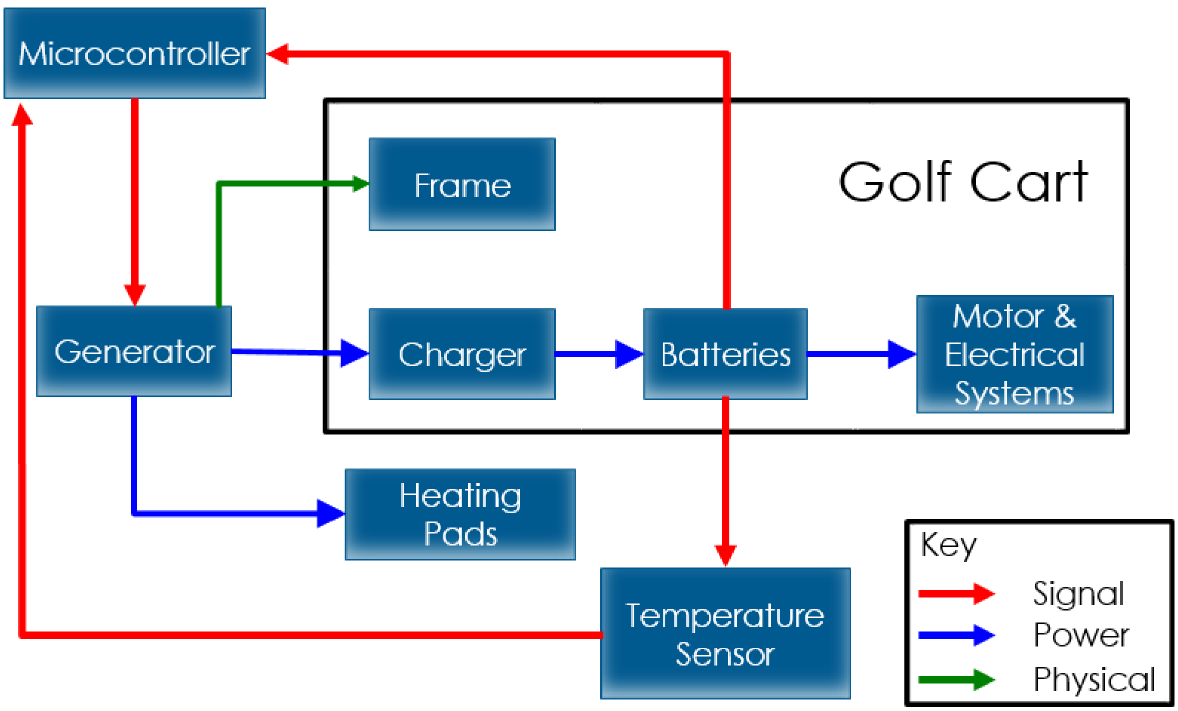

Figure 6. Initial system diagram of design for golf cart.

Everything contained in the black box represents the golf cart in its present state. The charger is connected to the batteries which in turn are connected to the golf carts electrical system and motor. The proposed design would mount the generator to the golf cart frame underneath the back seat. Connected to the generator is a microcontroller that measures the voltage of the batteries, measures the voltage from a temperature sensor, and controls the power supplied to the heating pads. When the batteries voltage drops below a certain threshold the microcontroller will send a signal to the generator turning it on. Once the generator is on, and the batteries are warm enough, the charger will follow suit and begin charging the batteries. The temperature sensor will measure the battery temperatures, and if they get too hot the microcontroller will turn off the generator and the heating pads if the latter are on. Additionally the mechatronic system will include a battery monitoring system so that the user will know the current level of charge/the remaining operational time of the cart.

As mentioned previously, since the modified charging system could succumb to potential safety risks and system damaging design flaws, the way that the charger interacts with the battery had to be reevaluated. What was decided upon as the most ideal solution is contained below in Figure 7.

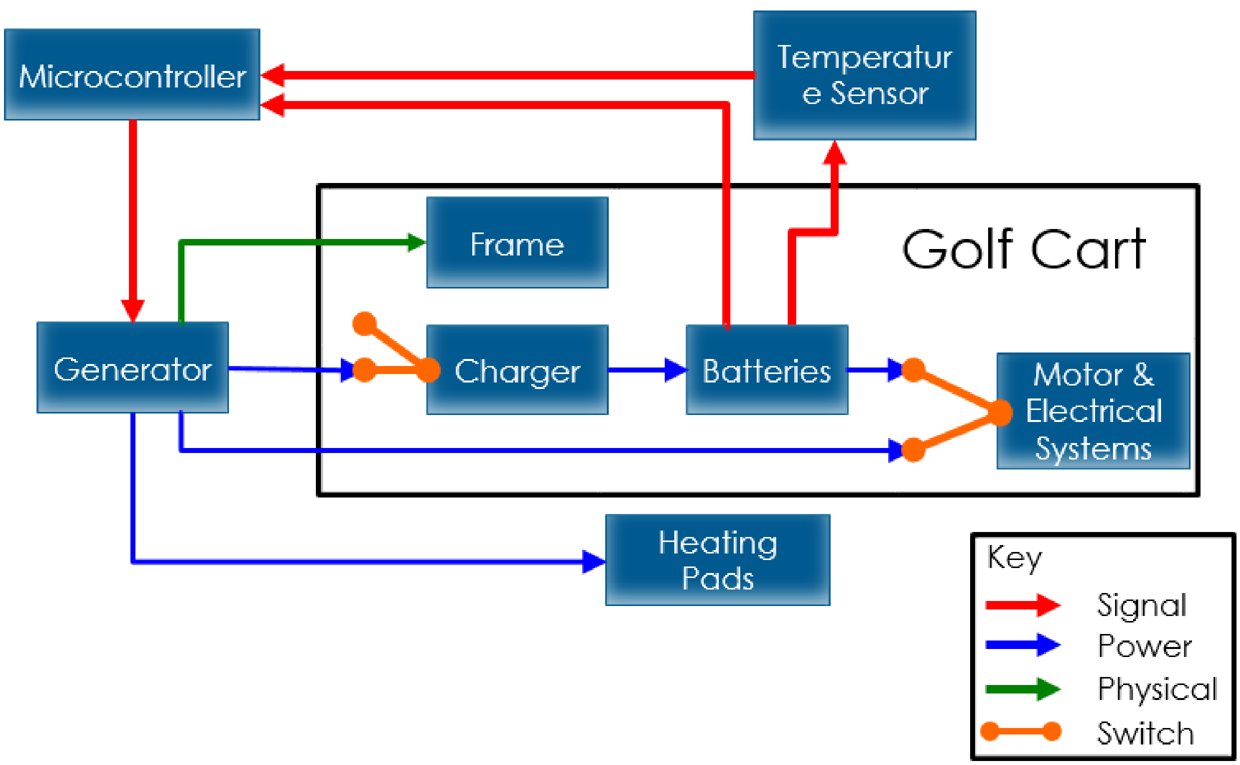

Figure 7. Revised system diagram of design for golf cart.

The system would function in a manner very similar to the initially selected golf cart system design. The generator would provide power through the onboard charger to the batteries and the batteries would still be able to power the cart when they were at their optimal operating temperature. The microcontroller would also still be responsible for measuring the current charge level and temperatures of the battery in order to activate the generator and heating pads when necessary. The major differences with this design are the addition of switches in the form of relays between the onboard charging system and the batteries to the motor. Also the generator would be able to provide power directly to the motor and electrical systems by the addition of a relay between those interfaces as well. The main reason for this change, as outlined before, is that since the batteries would be receiving less charge than they would be expending while in use, the onboard charger would not be able to charge while the batteries are providing power. This is because the charging system only provides charge if it sees that the voltage of the system is increasing. Due to this, this new system design would compensate for this by allowing the generator to charge the golf cart's batteries and supply power to the cart's motor and electrical systems at the same time while the batteries are disconnected from the motor by using the relays. This would allow simultaneous operation of the cart and charging of the batteries. And of course, when the battery is charged and at the operating temperature, the system could revert back to being solely battery powered at the switch of the generator's and charger's relays.

3.4 Adapting the Design for Semi-Trucks

One of the overall goals of this project is to be able to adapt this design for semi-trucks, specifically trucks with the Cummins ISX-15 diesel engine. The adapted system is very similar to that used by the golf cart however there are several differences, see Figure 8. Instead of the generator the ISX-15 engine will be the primary charging power source, additionally the charger will be replaced by the trucks' alternator. Heating pads are not needed in the adapted design because the battery will be warmed by the heat put off by the truck engine. Since the battery is needed to start the engine it is important that the charge threshold level at which the engine turns on is set high enough so that the battery will still have enough power to activate it. The required level of charge changes based on the temperature of the battery which is why the temperature sensor will still be used. The exact relationship between the battery power output and the temperature will have to be determined experimentally. Below is the system diagram for the adapted design for the semi-truck. As was the case with the golf cart design, the adapted design will also include battery monitoring systems letting the user know the level of charge.

The redesign of the golf cart system diagram does not actually affect the semi-truck's system for a couple of reasons. The ISX-15 diesel engine makes between 450-600 horsepower and over 2,000 pound-feet of torque so the power that this engine creates is far higher than the generator used in the prototype design. Due to this, the truck's engine will easily be able to supply enough power to charge the battery as the truck is being operated to the point that relays are unnecessary in this application. All of the other additions such as the microcontroller and temperature sensor will be retrofitted into the engines ignition and battery system respectively in order to provide the same level of control to be featured in the prototype design with the golf cart and supplied generator.

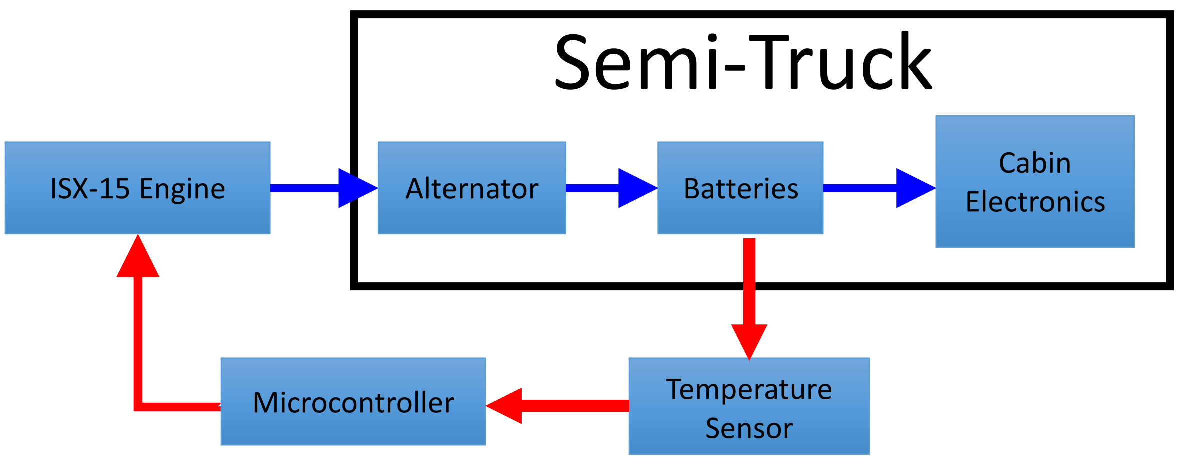

Figure 8. System diagram of adapted design for semi-trucks.

4 Detailed Design

4.1 Heat Transfer Analysis

One of the major constraints given to the design team is to ensure that the vehicle can operate in -29˚C. However, upon doing research of lead acid batteries, the output voltage is largely dependent on temperature. The ideal operating temperature of the 8 volt lead acid batteries is roughly 20˚C. As the temperature of the battery increases or decreases from this nominal temperature, the output voltage greatly decreases. The team conducted a heat transfer analysis to determine how long it would take to heat the batteries from -29˚C to the nominal operating temperature. Using the following formula the team performed a simple analysis:

$$q = mC_p\Delta T \qquad \text{Eq. 1}$$

The mass of one 8 volt lead acid battery is roughly 32 kg, resulting in a total mass of 192 kg for six batteries. Although the mass of the battery varies slightly depending on the charge and temperature, an average value was used in this calculation. The temperature difference using the ideal operating temperature is 49˚C. From here, the team researched the heat capacity of lead acid batteries. Not many experiments have been conducted to determine an average heat capacity of lead acid batteries, however by knowing the composition and relative weights, an average value can be calculated. One source determined the heat capacity of a lead acid battery is roughly $2{,}869\,\frac{J}{kg^{\circ}C}$ [8]. Another value of $1{,}100\,\frac{J}{kg^{\circ}C}$ was found [9]. The team averaged these two values together to determine an average heat capacity of $1{,}985\,\frac{J}{kg^{\circ}C}$. By knowing the total power supplied by the heating pads, using 1 pad per battery, the team calculated the time required to raise the battery temperatures. The time required for a 49˚C temperature change is over 5 hours. The design team did not see this as a feasible waiting period, so the temperature difference was changed. Using -10˚C as the operating temperature, the new temperature difference would be 19˚C. However this would take roughly 2 hours before the driver can presume operation. Again, this time was too long for the project application. The design team solved this issued by adding a temperature sensor to the mechatronic system. The sensor would be communicating with the microcontroller to ensure the batteries never go below -10˚C . The microcontroller would determine when the heating pads are turned on depending on the temperature sensor output. Please see Appendix A for full calculations of this analysis.

4.2 Mechatronic System

4.2.1 Objectives/Requirements

The Mechatronic system must be able to control six different operations. The system will need to monitor the battery voltage and temperature. If the batteries voltage drops below a certain operating threshold or the batteries temperature drops below -10° C, the microcontroller must turn the generator on to either power the charger or the heating pads appropriately. Correspondingly shutting down the generators operation when its power is unnecessary. When the batteries are being charged, the generator will be the main power source for driving the golf carts electric motor. Therefore the mechatronic system must be able to control the motor power source switching.

4.2.2 System Description

In order to meet the objectives a mechatronic system consisting of four possible states was developed. Depending on the charge and temperature of the golf cart batteries the system will be in one of these four states. On the following page is a state diagram which shows each state as well as how to get to and from each state. When the batteries are charged and their temperature is between -10°C and 49°C on startup the system will be in state 1. This is the normal operational state of the mechatronic system and is the default startup state. In the event that the batteries do not require charging but they are too cold to safely operate the system will be in state 2. In this state the generator is on and powering the heating pads as well as the motor. Because the generator can only output 2,800 W the maximum speed of the golf cart in this state will be reduced. When the temperature of the batteries exceeds 20°C the generator will turn off and the system will transition back to state 1. If the batteries charge drops below 50% and are

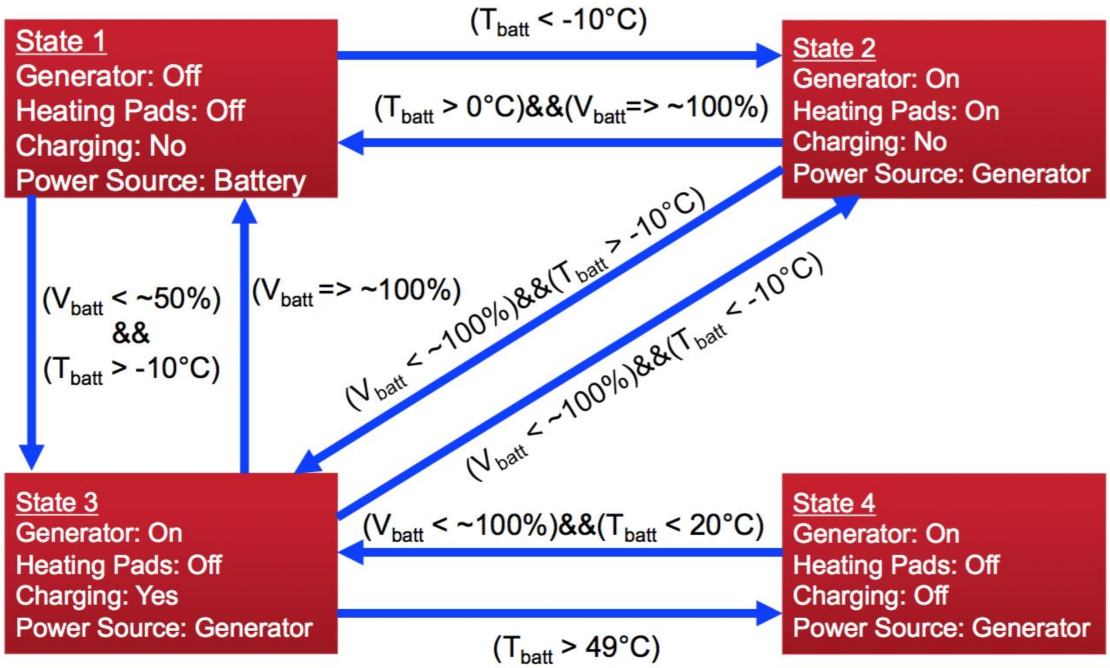

Figure 9. State diagram of proposed mechatronic system. The states are represented as red boxes and the requirements to transfer between states are given by the blue arrows.

sufficiently warm enough the system will be in state 3. In this state the generator is on and is powering the on-board charger and the motor. As was the case in state 2 the maximum speed in this state is also reduced. When the batteries are charged to 100% the system will again transition to state 1. The final state of this mechatronic system is state 4, which is the failsafe state of sorts. If at any time the battery temperature exceeds there maximum safe operating temperature of 49°C the generator will kick on and power the motor. Since the batteries are too hot the generator will neither heat nor charge them and will simply power the motor. When the batteries cool down below 20°C they can then again be used to power the motor at which point the system will transition to whatever state is required.

4.2.3 Detailed System

Since it is necessary to control the motor power source as well as when power is supplied to the charger and heating pads a method of controlling the power flow is required. The design for this system utilizes a collection of relays that are controlled by the microcontroller to accomplish just this. The specific relays selected as well as the requirements of the relays will be addressed in latter sections. A more detailed system diagram than the one given in Figure 7 which includes this relay system can be found below. This figure is in no way the final circuit design but it shows more aspects of the design that were not included in the previous diagram. One of these aspects is the interface between the accelerator pedal and the speed controller. As mentioned in previous sections the maximum speed of the golf cart is reduced depending on whether it is in states 2, 3, or 4. This will be accomplished by intercepting the accelerator signal to the speed controller and attenuating it down so that even if the pedal is fully pressed down the signal sent will be equivalent to that if it was only halfway down, or something similar. Another aspect that was not included in the previous figure is the AC to DC power converter. The generator outputs AC power however the motor is DC therefore a power conversion is required. The independent team of electrical engineers that we are working with are in the process of designing this converter. The third and final difference between this figure and figure 7 that will

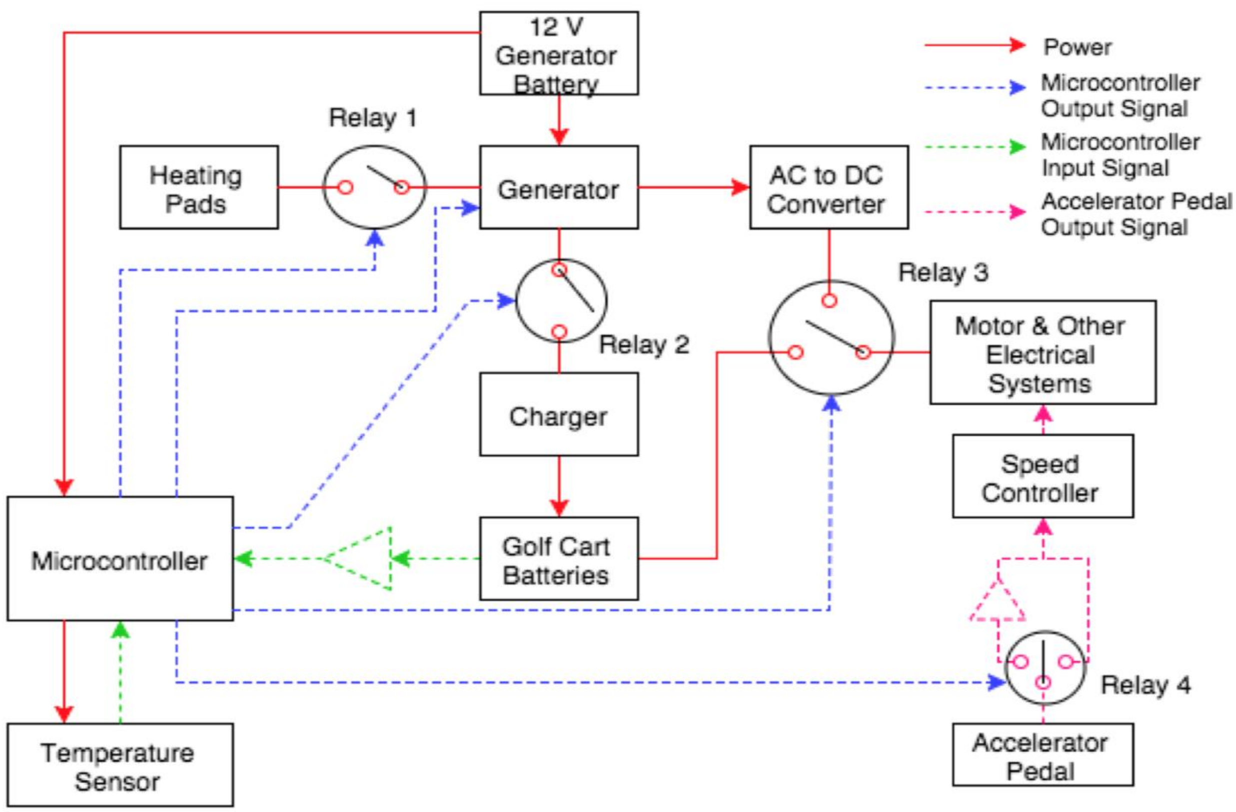

Figure 10. Detailed system diagram of revised design for golf cart. This diagram shows how the various relays that regulate power to other components in the system are controlled by a signal from the microcontroller.

be discussed is the inclusion of the generators 12V battery. This battery will be used to power not only the microcontroller but also various relays in the design. The specific configuration and circuitry to connect these various components is still under development however several components have already been chosen and will be ordered to test several aspects of the design.

4.3 Component Selection

4.3.1 Generator Selection

To meet the requirements set for us by our project advisor, Dr. Hays, group two is retrofitting a Cummins generator to the golf cart. The generators purpose is to improve the range of the current golf cart. Cummins is supplying our group with a generator of our choice. The generator must be able to operate within the desired temperature range, -29° C. Operation at this extreme temperature is the most important requirement that needs to be satisfied. Secondly, power output of the generator must be sufficient to run the system we plan to implement. The installed onboard battery charger uses 1200 W of power to charge the battery, and although a new charger will be implemented this value is considered a good estimate of the necessary power. The generator must also power the heating pads, which have been estimated to require approximately 1,000 W in total. These estimations were made so that a generator could be chosen without having to complete the entire design. The estimations are conservative and most likely overshoot the actual power requirements, which ensures that the selected generator can supply at least the power required. The generator must also be able to fit in the recessed region underneath the back seat, which means that its dimensions should not exceed 685 mm x 360 mm x 400 m. The operating temperature range, power output, and size are the three main requirements that need to be fulfilled when selecting a generator. Secondary criteria for the selection are that the generator should be relatively inexpensive and lightweight. These last two criteria are more of guidelines for the selection rather than constraints.

Exploring generators supplied by Cummins, they come in multiple sizes and power outputs. With the three main constraints described above, group two decided on a small selfregulating propane generator, Cummins model number: QG2800 pictured in Figure 11 on the following page. This generators operable temperature meets our -29°C range. It is rated also with

Figure 11. Cummins QG2800 Generator that will be used in the design. [7]

a max output of 2800 W, thus supplying more than sufficient power needed for the design selected. This generator is also fairly small and compact with dimensions of 560 mm x 415 mm x 325 mm. The width of the generator does exceed the initial size constraint however the region underneath the seat is made of plastic and the space can be increased by cutting away material. This will not affect any of the golf carts other systems. This generator is also fairly light, weighing 56.7kg, the lightest of any Cummins generator. With the main requirement criteria fulfilled and our secondary criteria optimized, the Cummins QG2800 is an ideal fit for our design.

4.3.2 Microcontroller Selection

In addition to the generator the microcontroller used in this design has been selected. An important requirement of the microcontroller was that it must be able to operate at -30°C. Not many preassembled microcontroller boards can operate at this temperature, however the Ruggeduino ET pictured on the following page can. This board can operate from -40°C to 85°C which is in fact more than what is required. Additionally the board has 14 digital I/O pins and 6 analog input pins. The former type of pin will be used to signal the activation of the relays and the latter type will be used by the voltage and temperature sensors. This microcontroller board

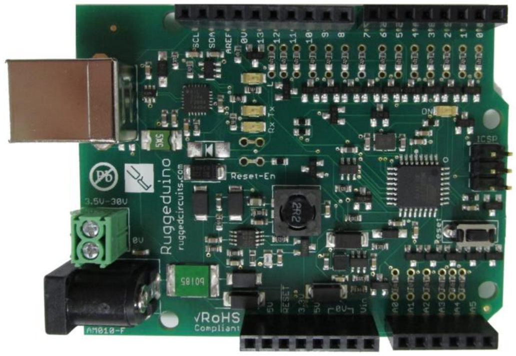

Figure 12. Ruggeduino-ET microcontroller board that is to be used in this design. [10]

has more than enough input and output pins for our design and is relatively inexpensive costing only $50. [10]

4.3.3 Temperature Sensor Selection

The temperature sensor that will be used in this design is the TMP36 linear analog sensor which works from -50°C to 125°C. This sensor has a very low operating voltage and requires very little power meaning that it can be powered directly by the microcontroller simplifying the required circuitry. Because this sensor converts the temperature to a voltage via a linear relationship the required programming is simplified. Lastly this sensor is only $1.50 making it the ideal temperature sensor. [11]

4.3.4 Relay Selection

As mentioned previously the power flow in the system will be controlled with relays which in turn are controlled by the microcontroller. The loads that the relays must regulate differ depending on whether they are used to manage the motor power source or restrict the flow of current to the charger and heating pads. As such two different relays will be used. The relays used in the power switching interface must be able to withstand a constant load current of 104A at 48V therefore two heavy duty golf cart solenoids will be used. Two relays of this type are required in order to be able to have two separate motor circuits one for each power source (i.e. the batteries and generator.) These relays will be bought from a supplier found on Ebay for $66.00 apiece. [12] The relays used to control the heating pads and charger only need to be able to control a maximum load of 20A at 48V so smaller ones can be used. The relays selected for these two functions are rated up to 30A and cost only $4.76. [13] All of the relays used in this design have an operating coil voltage of 12V so that they can all be powered using the 12V generator battery.

5 Challenges and Risks

Like any design project, there have certainly been challenges up to this point for team two. The first challenge that the team had to surmount was the fact that the golf cart came with batteries that were not in operable condition. The batteries, which should have all been able to output eight volts each in peak condition were only showing one volt or less after being charged for hours. Due to this, it wasn't possible to actually test the golf carts current performance since the current batteries are incapable of powering the cart no matter how long they're charged. Due to this setback, similar batteries had to be borrowed from Dr. Harvey in order to at least ensure that other functions of the cart work properly. New batteries will be chosen by the EE team, and purchased in order to complete the baseline testing of the system. All other challenges that team two face are down the road in the design process and are more so potential risks. One potential risk is that the system can be short circuited by several different factors if any problems occur with the wiring or other integral systems. As such, it is crucial to conduct a detailed FMEA analysis of the system. When the motor power source is changed there will be a large spike in the voltage known as inductive kickback therefore safeguards must be implemented to prevent damage to critical components. Another potential issue that will have to be addressed later on in testing the new system additions is that the system must be tested at the low temperature of -29˚C. Due to the team being based out of Florida, the temperature outside will never actually be that low so one way that the team can do this is to maybe place the batteries in a freezer and then install it in the cart to see if the system can still function as intended. Lastly, the system must be compatible with a Cummins ISX-15 diesel engine although we are testing with a smaller generator since that is the intended, real world application for this project. Due to this constraint, it is important that the requirements of this engine must always be considered during the design and integration of all other components. Since the project is near the end of the conceptual design phase there have not been too many risks other than those few listed. A risk assessment has been generated for the proposed design and is found in Appendix A. The assessment is rather simple as all the details of the design have not yet been worked out, but when they are the risks will be revaluated.

6 Environmental Safety & Ethics.

Any application dealing with potential environmental hazards must take extra precautions to ensure safe operation. A major aspect of this project involves six lead acid batteries. Lead acid batteries consist of lead plates that are submerged in a sulfuric acid, and these components are contained by a polypropylene plastic casing. The plastic casing is there to protect anyone using lead acid batteries from the potential risks of the materials inside. [14] Lead, a major material in the batteries, is a highly toxic metal and has been linked to a range of health conditions due to absorbing it. Lead poising can cause learning disabilities, behavioral issues, or in extreme cases can cause seizures. [15] The other main component to the battery is sulfuric acid, again a highly corrosive solution. This acid can cause burns to the skin or irritation to the upper respiratory system. [14] Since these materials are highly toxic, proper disposal is crucial to the environment. If these batteries were disposed in a traditional waste landfill, the toxic chemicals can seep into the soil, causing potential risks to drinking water and surrounding land[1]. Some safety measures are taken when disposing of these batteries. When buying a new car battery, retailers will take your old one and properly dispose of it. Scrap metal dealers also collect old lead acid batteries. When the batteries are properly disposed, they go through a recycling process. The lead plates and plastic cover can be recycled and used for new batteries and the sulfuric acid is neutralized. [14]

Another potential environmental hazard for this project includes the emissions of the propane powered generator. Portable generators cause a risk by emitting carbon monoxide, which is a highly dangerous gas if inhaled. [16] These portable generators have been recommended to only be used outside due to this emission. However, certain codes have been enforced to any machine that emits a gas, to reduce this toxic waste. To ensure safe operation the generator selected for this project has been approved and meets the U.S. EPA standards for emissions.

7 Methodology

In order to improve the overall range of the vehicle, a methodology of how to accomplish the ultimate goal was developed. The steps in the process are highlighted below.

- **Perform general research on charge while running and low temperature operable batteries.**
- **Document performance of the vehicle.**
- **Formulate proposed design.**
- **Design generator mounting system**
- **Conduct heat transfer analysis on heating pad interface**
- **Develop mechatronic system**
- **Order components**
- **Assemble prototype.**
- **Document final performance of the vehicle.**

7.1 Schedule

In order to ensure that the project be completed in a timely manner a schedule was developed. The schedule is in the form of a Gantt chart, which includes ME deliverables and Team deliverables. ME deliverables are items that team 2 will turn in for a grade, such as reports and presentations. These items are not included on the Gantt Chart. Team deliverables are items that must be completed however they are not directly turned in. Tasks such as, performing general research, begin detailed design, and order components all fall into this category. The team deliverables are in blue on the Gantt Chart. The arrows on the chart show the relationship between tasks, the arrows indicates that the earlier task must be completed, or at least underway before the proceeding deliverable can be started. Tasks in green such as thermal analysis, programming, and circuit design are subtasks of the blue item preceding them. The team meetings were not included in the Gantt Chart.

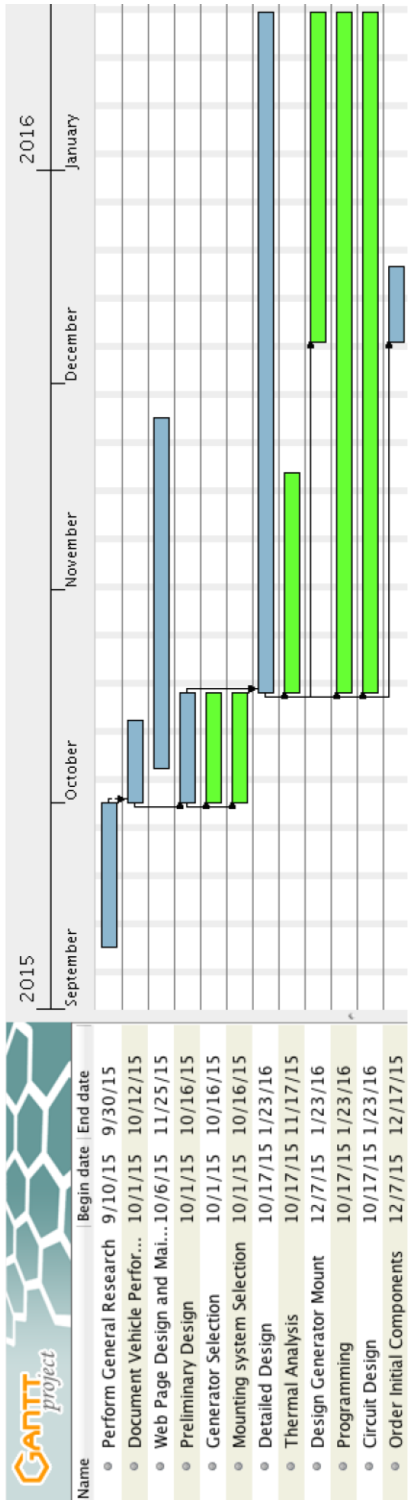

Figure 13. Gantt chart showing the various project tasks.

7.2 Resource Allocation

While the Gantt Chart is a good representation of the schedule it does not include who is assigned to each task. Table 5 shows which team member is assigned which task. For ME deliverables every member of the team will work equally to complete them, however certain team deliverables and presentations, will be completed by specific team members. In addition to their specified tasks team members have also been assigned general roles.

Jakob Consoliver-Zack is the Project Leader. He manages the team as a whole; develops a plan and timeline for the project, delegates tasks among group member according to their skill sets; finalizes all documents and provides input on other positions where needed. He keeps the communication flowing, both between team members and Sponsor. The team leader takes the lead in organizing, planning, and setting up of meetings. Finally he gives or facilitates presentations by individual team members and is responsible for overall project plans and progress.

Samantha Beeler is the team Treasurer. She manages the budget and maintains a record of all credits and debits to project account. Any product or expenditure requests must be presented to the advisor, whom is then responsible for reviewing and the analysis of equivalent/alternate solutions. They then relay the information to the team and if the request is granted, order the selection. A record of these analyses and budget adjustments must be kept.

Tyler Mitchell is the lead ME. He takes charge of the mechanical design aspects of the project. He is responsible for knowing details of the design, and presenting the options for each aspect to the team for the decision process. Keeps all design documentation for record and is responsible for gathering all reports.

Jeremy Randolph is the team Webmaster and Historian. He is responsible for maintaining website and electronic records. Any and all digital documentation will be filed, stored, and catalogued electronically for easy access through the webpage. In addition, he is responsible for keeping a record of all correspondence between the group and ‘minutes’ for the meetings. Lastly the historian distributes the meeting minutes to the group via email.

Eugene Moss is the Electrical Engineering Liaison. He is in charge of the electrical engineering team that is working independently from the mechanical engineering team. He is responsible for communication between teams to ensure that no design modifications by either team inhibit the other.

Table 5. Assigned Tasks

Category	Task Name	Duration	Start	Finish	Resource Names
Team Meeting	1	1	9/1/15	9/1/15	Jakob, Jeremy, Samantha, Tyler
Team Meeting	2	1	9/3/15	9/3/15	Jakob, Jeremy, Samantha, Tyler
Team Meeting	3	1	9/8/15	9/8/15	Jakob, Jeremy, Samantha, Tyler
Team Meeting	4	1	9/15/15	9/15/15	Jakob, Jeremy, Samantha, Tyler, Eugene
Team Meeting	5	1	9/22/15	9/22/15	Jakob, Jeremy, Samantha, Tyler
Team Meeting	6	1	9/24/15	9/24/15	Jakob, Jeremy, Samantha, Tyler, Eugene
Team Meeting	7	1	9/29/15	9/29/15	Jakob, Jeremy, Samantha, Tyler
Team Meeting	8	1	10/6/15	10/6/15	Jakob, Jeremy, Samantha, Tyler
Team Meeting	9	1	10/8/15	10/8/15	Jakob, Jeremy, Samantha, Tyler
Team Meeting	As Needed	1	As Needed	As Needed	Jakob, Jeremy, Samantha, Tyler, Eugene
ME Deliverable	Code of Conduct	6	9/5/15	9/11/15	Jakob, Jeremy, Samantha, Tyler
Team Deliverable	Perform General Research	20	9/10/15	9/30/15	Jakob, Jeremy, Samantha, Tyler
ME Deliverable	Needs Assessment Report	4	9/21/15	9/25/15	Jakob, Jeremy, Samantha, Tyler
ME Deliverable	Project Plan Report	9	10/1/15	10/10/15	Jakob, Jeremy, Samantha, Tyler
Team Deliverable	Document Vehicle Performance	11	10/1/15	10/12/15	Jakob, Jeremy, Samantha, Tyler, Eugene
Team Deliverable	Preliminary Design	15	10/1/15	10/16/15	Jakob, Jeremy, Samantha, Tyler, Eugene
Team Deliverable	Generator Mount Location	15	10/1/15	10/16/15	Tyler
Team Deliverable	Generator selection	15	10/1/15	10/16/15	Tyler
ME Deliverable	Midterm Presentation I: Conceptual Design	7	10/9/15	10/16/15	Jakob, Tyler
ME Deliverable	Midterm Report 1	13	10/17/15	10/30/15	Jakob, Jeremy, Samantha, Tyler

Team Deliverable	Detailed Design	85	10/17/15	1/23/16	Jakob, Jeremy, Samantha, Tyler, Eugene
Team Deliverable	Conduct Thermal Analysis	23	10/17/15	11/17/15	Samantha
Team Deliverable	Design rear mount system	42	12/7/15	1/23/16	Tyler
Team Deliverable	Mechatronic Programming	85	10/17/15	1/23/16	Jakob, Jeremy
Team Deliverable	Circuit Design	85	10/17/15	1/23/16	Jakob, Eugene
Team Deliverable	Initial Web Page Design	9	10/6/15	10/15/15	Jeremy
ME Deliverable	Final of Webpage Design	41	10/15/15	11/25/15	Jeremy
ME Deliverable	Midterm Presentation II: Interim Design	10	10/31/15	11/10/15	Samantha, Tyler
Team Deliverable	Order Components	10	12/7/15	12/17/15	Jakob, Jeremy, Samantha, Tyler, Eugene
ME Deliverable	Final Design Poster Presentation	11	11/20/15	12/1/15	Jakob, Jeremy, Samantha, Tyler
ME Deliverable	Fall Semester Final Report	15	11/16/15	12/1/15	Jakob, Jeremy, Samantha, Tyler

8 Conclusion

The final design will utilize a mechatronic system to activate and deactivate an installed Cummins QG2800 generator based on the measured voltage of the 6 8V batteries. In order to ensure that the batteries output enough power at cold temperatures, heating pads powered by the generator will be added. The current charger will be used in order to ensure that the vehicle can operate and charge simultaneously. The mechatronic system must be able to switch the power source of the golf cart for the generator to power the electric motor while the batteries are being charged. The mechatronic system will also include a battery monitoring system to inform the user of the current charge level of the batteries.

9 References

[1] The History of Electric Car. The United States Department of Energy. September 15, 2014. energy.gov/articles/history-electric-car

[2] How do Extremely Cold Temperatures Effect the Range of an Electric Car. Megan Allen. January 31, 2013. www.fleetcarma.com/electric-car-range-in-bitter-cold/

[3] "Custom Sleeper Design, Truck Sleepers Manufacturer, Custom Truck Products - Truck Sleeper." *Custom Sleeper Design, Truck Sleepers Manufacturer, Custom Truck Products - Truck Sleeper*. Indian Custom Truck, n.d. Web. 29 Oct. 2015.

[4] Dr. Michael Hays. *Conference Call*. 21 Oct. 2015.

[5] Dieter, George E., and Linda C . Schmidt. "6.6 Morphological Methods." *Engineering Design*. New York: McGraw-Hill, 2013. 217. Print.

[6] *Ironton Utility Trailer Kit*. Digital image. *Norther Tool + Equipment*. Norther Tool + Equipment, n.d. Web. 28 Oct. 2015.

[7] "Cummins Generators." *Cummins Power Generation*. Cummins, n.d. Web. 29 Oct. 2015.

[8] Kiessling, Reiner. "Lead Acid Battery Formation Techniques." Digatron Firing Circuits (n.d.): n. pag. Web. 4 Nov. 2015.

[9] *Handbook for Stationary Lead-Acid Batteries*. N.p.: GNB Industrial Power, Feb. 2012. Pdf.

[10] "Ruggeduino-ET." Rugged Circuits. N.p., n.d. Web. 09 Nov. 2015.

[11] "TMP36 - Analog Temperature Sensor." Adafruit. N.p., Web. 09 Nov. 2015.

[12] U.s.auto. "OEM Prestolite, Ametek, Continuous,200 Amp, SBD 4201G, 15-386." *EBay*. N.p., n.d. Web. 06 Dec. 2015.

[13] "12V 30A Normally Open Optocoupler Relay." *DX.com*. DX, n.d. Web. 06 Dec. 2015.

[14] "Lead-Acid Batteries- Hazards and Responsible Use." *Cal Recycle*. The State of California, n.d. Web.

[15] "About Lead-Based Paint." *US Department of Housing and Urban Development*. US Government, n.d. Web.

[16] Gromicko, Nick. "Generator Hazards and Inspection." *InterNACHI*. International Association of Certified Home Inspectors Inc., n.d. Web. 06 Dec. 2015.

10 Appendix A: Thermal Analysis

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11 Appendix B: Risk Assessment

Risk Assessment
Safety Plan

Project information:

Electric Vehicle Optimization	10/30/2015
Name of Project	Date of submission

Team Member	Phone Number	e-mail
Jakob Consoliver-zack	(850) 405-4102	Jic13@my.fsu.edu
Samantha Beeler	(904) 287-1279	Smb11g@my.fsu.edu
Tyler Mitchell	(813) 924-1594	Tm13c@my.fsu.edu
Jeremy Randolph	(305) 499-0274	Jsr13e@my.fsu.edu

Faculty mentor	Phone Number	e-mail
Juan Ordonez		

I. Project description:

The purpose of this project is to integrate a Cummins generator onto a golf cart. When the golf carts batteries drop below a certain charge level the generator will turn on and begin charging the batteries, and when the batteries are charged it will turn off. Also to be included in this design are heating pads that will be used to warm the batteries to a temperature at which they can operate. The batteries in the golf cart are also going to be replaced, the new batteries are being selected by an independent team of EEs. The Final objective of the project is to adapt cart design for a Cummins ISX-15 diesel engine powered semi-truck.

II. Describe the steps for your project:

1. Mount the generator to the rear of the vehicle
2. Attach the heating pads and temperature sensor to the batteries.
3. Install microcontroller and necessary circuitry.

III. Given that many accidents result from an unexpected reaction or event, go back through the steps of the project and imagine what could go wrong to make what seems to be a safe and well-regulated process turn into one that could result in an accident. (See examples)

When mounting the vehicle, any power tool being used can pose potential risks. The electrical components of the project can Possibly shock you if you're not careful when handling and modifying the system. Overheating the batteries could cause an Explosion.

IV. Perform online research to identify any accidents that have occurred using your materials, equipment or process. State how you could avoid having this hazardous situation arise in your project.

Lithium ion batteries have been known to explode when overheated, although they do not burn at a very hot temperature, the Explosion can send metal chunks flying through the air. To prevent this, the team will be utilizing a temperature sensor to ensure The batteries do not exceed a certain temperature.

V. For each identified hazard or "what if" situation noted above, describe one or more measures that will be taken to mitigate the hazard. (See examples of engineering controls, administrative controls, special work practices and PPE).

A team member must be monitoring the temperature sensor when operating the system, to ensure the temperature does not Exceed a certain point.

VI. Rewrite the project steps to include all safety measures taken for each step or combination of steps. Be specific (don't just state "be careful").

When mounting the generator, ensure that team members are wearing protective eyeware and pay close attention to their work.
When implementing heating pads for the batteries, the team memebers will be monitoring the battery temperature to ensure no Overheating.

VII. Thinking about the accidents that have occurred or that you have identified as a risk, describe emergency response procedures to use.

Stay calm and immediately contact 911 for emergencies. Then contact advisors.

VIII. List emergency response contact information:

- Call 911 for injuries, fires or other emergency situations
- Call your department representative to report a facility concern

Name	Phone Number	Faculty or other COE emergency contact	Phone Number
All Group Members		Dr. Gupta	(701) 306-1189
		Dr. Shih	

IX. Safety review signatures

- Faculty Review update (required for project changes and as specified by faculty mentor)
- Updated safety reviews should occur for the following reasons:
  1. Faculty requires second review by this date:
  2. Faculty requires discussion and possibly a new safety review BEFORE proceeding with step(s)
  3. An accident or unexpected event has occurred (these must be reported to the faculty, who will decide if a new safety review should be performed.
  4. Changes have been made to the project.

Team Member	Date	Faculty mentor	Date