Battery Management System Final Report

ECE Senior Design Team 9

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Department of Electrical and Computer Engineering

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Executive Summary

ECE Team 9 and ME Team 2 worked in tandem to prototype a 'hotel system of charging' in an electric vehicle. A 'hotel system of charging', as defined by the project sponsor, Dr. Michael Hays of Cummins, Inc., is a potential future battery management system that would allow truck drivers to avoid leaving their engines on overnight to recharge their truck batteries, as the system would automatically start and stop the engine to recharge it as needed. The design teams were tasked with implementing a Cummins, Inc. generator into the electric vehicle, and to use it to recharge the batteries while the vehicle is in operation. In addition, the design teams were to extend the operable temperature range of the vehicle down to -29°C.

The design teams accomplished these goals by dividing the main problem into subtasks and developing solutions for each. In this manner, the design teams selected an appropriate generator and mounted it unobtrusively into the vehicle, devised a battery-heating scheme using heating pads, and modified the existing vehicle circuitry to accommodate the new battery charging system. The design teams programmed a microcontroller to activate each component as needed using transistor-controlled current relays. The electric vehicle is thus capable of activating its generator via the microcontroller, and the microcontroller furthermore decides whether to activate the heating pads (if the system temperature is below an acceptable boundary) or the charger (if the battery state of charge is below an acceptable boundary). The microcontroller determines what systems to activate based on input from temperature sensor connected to the batteries, a voltage divider signal connected to the batteries, and a current sensor in series between the battery charger and the battery pack.

The design teams rewired the vehicle circuitry so that when the generator activates, it always assumes responsibility for driving the vehicle, with the batteries becoming completely disconnected from the motor to minimize the change of their becoming damaged. As a side effect of the small generator size necessary to fit in the vehicle, this means that when the generator is active, the vehicle is limited to only approximately 6mph.

Near the end of the project, the design teams realized that their chosen method for reading the battery of state of charge could not function as implemented. With too little time left to fix it, a temporary solution was installed instead at the sponsor's suggestion in the form of a manual switch for activating and deactivating the generator. While this prevents the design from being truly automatic, it is a feature that can be fixed by future design teams. However, the design teams are satisfied in their work, as all other systems have been tested and verified to function, and the vehicle is capable of running from the batteries or from the generator.

Acknowledgments

ECE Team 9 thanks Dr. Michael Hays and Cummins, Inc. for sponsoring this design project and helping these teams develop and implement their design solutions. The budget for this project came in great part from them, and they directly provided some of the critical components –the electric vehicle, the generator, the power supplies– needed to make this design work.

ECE Team 9 also thanks Dr. Rajendra Arora, Dr. Pedro Moss, Dr. Hui Li, and Dr. Jerris Hooker for their advice on developing the project, their willingness to help, and their feedback on the team's presentations. Through their help, the team gained the feedback it needed to proceed more smoothly through the project.

Finally, ECE Team 9 acknowledges ME Team 2, the sister team assigned to this project. ECE Team 9 and ME Team 2 worked together for the duration of the project, and are proud of their mutual accomplishments.

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Chapter I: Introduction

Project Definition

Tractor-trailer drivers often need to sleep in their truck cabins, either due to lack of accommodations, to save money, or for simple convenience. Since the drivers typically need to use the cabin's heating and cooling systems, and because they don't want to drain the battery overnight, they usually leave the truck's engine on at night, causing it to idle the entire time. This action wastes fuel and causes wear on the engine, making it a non-ideal solution. In response, Cummins, Inc., is investigating the development of a 'hotel system of charging' to implement as part of an engine package. This system would be a battery management system, whereby a microcontroller would control the periodic activation of the engine to recharge the battery as its state of charge decreases, or if the ambient temperature makes it impractical to use the battery. Under this system, drivers may safely turn off their engines at night and power their systems through the truck battery, knowing that the engine will activate as necessary to reactivate the battery and then shut off again.

Dr. Michael Hays of Cummins, Inc. has provided the design teams with an electric vehicle, which the design teams will use to develop a prototype, proof-of-concept design for the system outlined above.

Design Requirements and Objectives

Problem Statement

Dr. Michael Hays has specified that the purpose of this project is to simulate a 'hotel system of charging' by using an electric vehicle's battery pack and an attached generator, both provided by Cummins, Inc. The requirements are relatively simple: the electric vehicle must use its battery pack as its main power source, but once the battery pack state of charge is too low, a generator –attached by the design teams– must activate during the vehicle operation, providing power to recharge the batteries. In addition, the vehicle needs to be temperature-proofed, allowing it to be used down to -29°C. The final system should be tested for functionality and compared against the original design. The most emphasized point of the design requirements is that the electric vehicle must be able to charge and operate simultaneously.

Operating Environment

As defined by the sponsor, the electric vehicle must be capable of functioning in an environment with an ambient temperature down to -29°C. However, this vehicle is not intended for road use due to its experimental nature and its slow speed when using its generator. The vehicle in no circumstances should be operated indoors, as its propane generator generates carbon monoxide and the propane tank itself poses a fire hazard.

Intended Use

This design project is a prototype of a battery management system later intended to be implemented in tractor-trailers. As such, the electric vehicle itself is not intended to have any use or functionality as anything other than a prototyping platform. Future teams may use the vehicle to inform the design of a battery management system for truck engines, as desired by the sponsor.

Limitations

The electric vehicle is not a perfect prototype of a tractor-trailer engine system due to the reduced output of the generator in the vehicle compared to a truck alternator. In addition, as mentioned elsewhere in this report, the current system is not capable of switching correctly between the natural state (with the generator off) and the charging state due to an issue with obtaining the battery state of charge reading. This means that, at present, the vehicle cannot operate in a completely automatic manner, requiring a manual switch.

Background Research

Batteries in Cold Usage

Team research shows that lead-acid batteries, the type of battery used in the vehicle, do not perform well at very low temperatures [1]. In fact, the electrolytes in lead-acid batteries freeze at very low temperatures such as -40℃, especially in the discharged state, which causes permanent, irreversible damage as the case gets cracked and the electrolyte leaks out [1]. However, there do exist battery chemistries that can work at these low temperatures, if only with greatly lowered efficiency. Lithium-based battery chemistries are the most promising, though even these are not ideal [1][2]. Other battery chemistries with promising low-temperature characteristics include magnesium-ion batteries (though these are largely still in development), and various nickel-based chemistries: NiCd, NiZn, and NiMH [1][3].

It should be noted that batteries, regardless of type, lose a great deal of efficiency at low temperatures. This is partly because cold conditions increase the internal resistance of the material in the battery (partly through reduced reaction rate), reducing the voltage and current (and thus power) seen by the load. The material in the battery can be affected by the temperature as well, though the effect would depend on the specific battery chemistry [1][3].

Charging and Discharging

Similar to how batteries can only operate safely and efficiently within a certain range of temperatures, the act of battery charging must also be performed within a temperature range to prevent damage to the battery or charging system. Lead-acid batteries can generally discharge safely between -20°C and 50°C, but at lower temperatures, charging can be a more delicate process. For this reason, charging should ideally take place between -10°C and 30°C for optimal charging time [4].

'Smart' battery chargers, such as the one used in this design, are active in one of two modes: constant current (CC) and constant voltage (CV). For the majority of the charging process, the battery charger will maintain a constant current to the batteries, charging them quickly within 5 to 8 hours for a 70% to 80% charge. For the remaining charging process, the charger may take an additional 7 to 10 hours, where it applies a constant voltage across the battery terminals. CV-mode charging is slower than CC-mode charging, but it is necessary to perform to avoid overcharging or otherwise damaging the batteries [4]. An illustration of the CC-mode and CV-mode charging is shown in Figure 1 on the next page.

As a final note, the teams' research has showed that it is important to charge lead-acid batteries after each use. This ensures that the sulfuric acid does not crystallize, which may happen if the batteries are stored on a low state of charge.

End Product

The end product presented by the design teams is a highly-modified version of the original Tomberlin E-Merge series electric vehicle acquired at the project inception. The end product features six new 8V lead-acid battery packs and a replacement battery charger, and has a Cummins GQ2800 propane-powered generator mounted underneath its rear seats. This generator is connected via controllable relays to three loads: heating pads, the battery charger, and AC to DC power converters. The heating pads are wrapped snugly around the batteries, and are capable of warming them during cold-temperature usage. The AC to DC converter is in turn plugged to the vehicle's DC motor, allowing the generator to power the motor when it is active.

The control system is the most extensive portion of the modified vehicle. A microcontroller, powered by a 12V generator battery, controls the activation of six relays that turn the generator on and off, and relay power to the battery charger or the heating pads (or neither). Two of the relays it controls allow the electric vehicle to smoothly switch power sources when the generator activates, disconnecting the batteries from the vehicle entirely and allowing the generator to power it instead. The microcontroller makes these relay decision based on input it receives from three sensors: a current sensor that detects the battery charger output current, a temperature sensor connected to the batteries, and a voltage divider circuit connected to the batteries.

Unfortunately, the design is not completely automatic, as the teams had hoped. While the voltage divider sensor works as intended, the measured voltage across the battery pack can drop significantly when the batteries are used to power loads within the vehicle, even though the battery state of charge may remain unchanged. This causes the microcontroller to believe that the batteries are in constant need of recharging, so the design teams will soon add a manual switch to the design so that a user may activate the generator at will. Future design teams may expand upon this system to make it fully automatic by implementing an alternate method of determining battery state of charge, such as through Coulomb counting.

Despite this setback, the end product is largely finished. The design teams have tested all of the electronic components and verified that they all work as intended, apart from the switch to the charging state. Although the design teams had no time to test the system in a suitable cold-temperature environment, they are confident that the design would work in such a situation, and invite future teams to proceed with the cold-temperature testing.

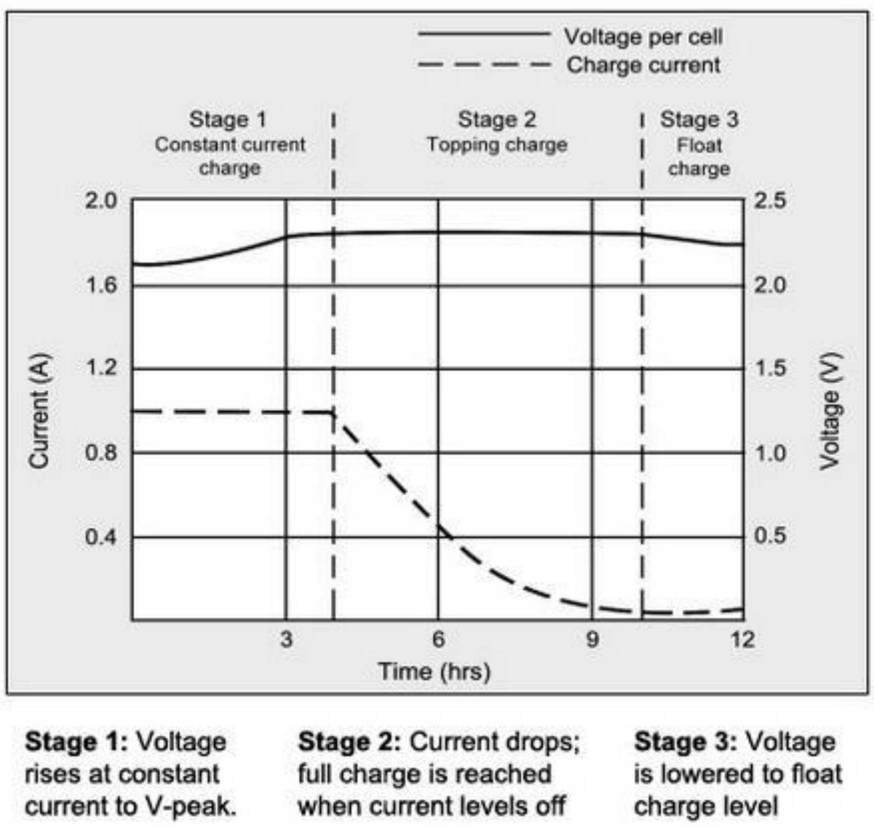


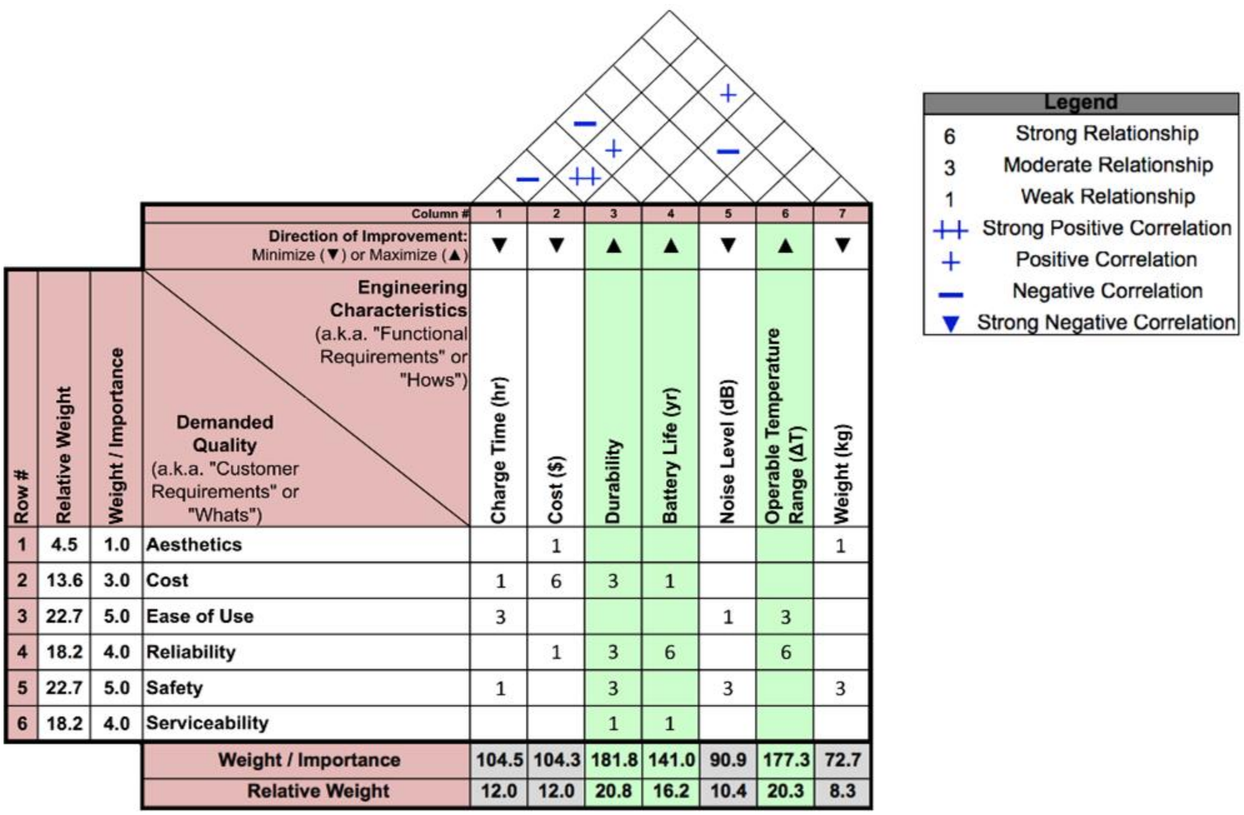
Figure 1: Battery Charger Operation over Time

Chapter II: System Design

Quality Function Deployment (QFD)

After the team sponsor informed the teams of the basic problem at hand –the incorporation of an extensive battery management system within an electric vehicle, as described in Chapter I–, it was necessary for the teams to perform a QFD analysis to determine the most important engineering characteristics for the design. The teams performed this analysis using a House of Quality (HoQ) diagram, seen in Figure 2. The teams asked the sponsor to rate the importance of six salient qualities (aesthetics, cost, ease of use, reliability, safety, and serviceability) from unimportant (a '1' on the scale) to highly important (a '5' on the scale). From these qualities, the engineering teams selected seven characteristics to develop for: charge time, cost, durability, battery life, noise level, operable temperature range, and weight.

The sponsor rated ease of use and safe as the most important factors, reliability and serviceability as next important, cost as slightly less important, and aesthetics of no importance. From this selection, the teams determined that the most important characteristics in the design would be its durability, its battery life, and its operable temperature range.



Row #	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Engineering Characteristics (a.k.a. "Functional Requirements" or "Hows")	Charge Time (hr)	Cost ($)	Durability	Battery Life (yr)	Noise Level (dB)	Operable Temperature Range (ΔT)	Weight (kg)
			Column #	1	2	3	4	5	6	7
			Direction of Improvement: Minimize (▼) or Maximize (▲)	▼	▼	▲	▲	▼	▲	▼
1	4.5	1.0	Aesthetics		1					1
2	13.6	3.0	Cost	1	6	3	1			
3	22.7	5.0	Ease of Use	3				1	3	
4	18.2	4.0	Reliability		1	3	6		6	
5	22.7	5.0	Safety	1		3		3		3
6	18.2	4.0	Serviceability			1	1			
			Weight / Importance	104.5	104.3	181.8	141.0	90.9	177.3	72.7
			Relative Weight	12.0	12.0	20.8	16.2	10.4	20.3	8.3

Figure 2: House of Quality (HoQ) Diagram

Design Solutions

Due to the nature of the sponsor's problem statement, the design offered relatively little room for inventing many alternative solutions to the problem. The design teams needed to work their solution around the electric vehicle, knowing that it needed to retain its batteries as its main power source and that it needed to incorporate a generator to recharge them. It was not possible for the teams to replace the batteries with an alternate power source, or to implement different charging options than the required generator, such as solar cells or regenerative braking. The only open-ended portions of the project were the design of the charging and heating systems, and how the generator would connect to them.

In this regard, the design teams faced two main options. The first option was to keep the electric vehicle mostly intact; the addition of the generator would be seamless in the sense that no major redesign of the existing system would be necessary. In this situation, the design teams would plug the vehicle battery charger and heating system (if any) to the generator, and when the generator activates, it would provide power to the vehicle indirectly through the charger. The vehicle would still draw current from the motor's connection to the batteries, but the batteries would be recharging under generator power, with the charger providing additional current to the motor to power it.

The second major option involved redesigning the way the electric vehicle drew power for its motor. In this situation, the heating system and charger would still be connected to the generator, but the generator would have an additional connection to the vehicle motor. The batteries would be completely isolated from the motor while recharging, and the motor would draw power from its connection to the generator only. The design teams conceived of this idea initially as a solution for avoiding placing undue stress upon the charger and the batteries, reducing the risk of failure and potentially extending battery life, but the complexity and increased cost of this option compared to the other made it an unattractive choice. However, due to a limitation in the functionality of the charger system that made the first idea impossible to implement (discussed in more detail in Chapter III: Design of Major Components), the design teams chose this idea as the final system design. Figure 3 below shows the final block diagram of the system design.

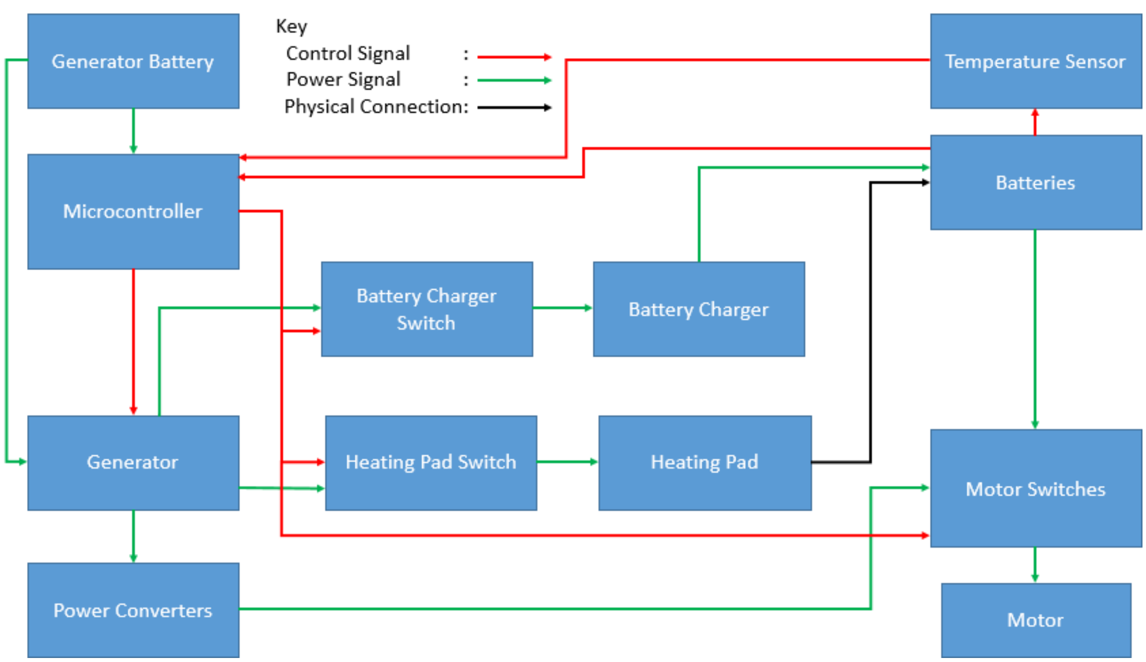


Figure 3: Final System Block Diagram

As a final note on the design teams' search for design solutions, it is important to mention the selection of the replacement main batteries. When the electric vehicle arrived, its batteries had crystallized. The design teams needed to choose between replacing them with the same type of battery or replacing them with a different chemistry altogether. The design teams identified two possible alternate battery chemistries: Li-ion and NiCd. These battery chemistries offered not only greater energy density, but also had promising low-temperature operation characteristics, avoiding the need for a heating system [1][3]. Unfortunately, however, battery packs of the size needed for the project in those chemistries were unobtainable with the design teams' budget, and the design teams additionally feared that the on-board charger would be incompatible with the new battery type. Due to these factors, the design teams chose to replace the old batteries with similar lead-acid batteries.

Final Design

As shown in Figure 3, the final system design relies heavily on the use of a microcontroller to activate the major components. The microcontroller is the 'brain' of the system, running code that analyzes input from the batteries and temperature sensors to determine whether it should activate the generator, as well as which switches it should flip. Chapter III: Design of Major Components contains a detailed state diagram of the microcontroller operation, and Appendix A: Major Components contains the code it runs. In words, the microcontroller is meant to ensure that when the ambient temperature is within the operable range, and when the battery state of charge is acceptable, the motor runs on the batteries and the generator is inactive. When either condition changes –when the ambient temperature rises above or drops below the acceptable range, or when the state of charge becomes unacceptably low–, the microcontroller activates the generator and switches the motor to generator power. In this circumstance, it also decides whether to switch the heating pads on and, if not, whether to switch the charger on. When the state of charge and ambient temperature return to acceptable conditions, the microcontroller deactivates the generator and allows the motor to operate from the batteries. A user interface is also included for diagnostics and troubleshooting purposes, displaying the voltage across the battery pack, the ambient temperature, and the current sent to the batteries through the battery charger.

A 12V battery supplies power to the microcontroller, and the same battery also activates the generator. The design teams installed power converters into the vehicle to convert the generator's AC output into a DC signal that the motor can use. The control signal sent from the batteries to the microcontroller ideally informs the microcontroller of the batteries' state of charge. Unfortunately, this aspect of the design does not yet work, as mentioned earlier. The design teams, at the sponsor's suggestion, used a voltage measurement across the batteries as an indication of state of charge, but activating peripherals or pressing the accelerator causes the measured voltage across the battery terminals to drop significantly, by up to 30V. This causes the microcontroller to believe that the batteries are in need of charging even when their state of charge is acceptable. As a result, the microcontroller will have the generator activated at nearly all times, meaning that the design is yet unfinished.

As a quick fix to the problem, at the sponsor's suggestion, the design teams intend to add a manual control switch for the user to activate the generator directly. In this way, when the user notices that the on-board state of charge indicator displays a low state of charge, the user may then flip the switch to activate the generator, preventing the microcontroller from needlessly activating due to bad inputs. While this has the unfortunate effect of rendering the design non-automatic, this only affects one part of the control system. All the other components, and the rest of the control programming, are satisfactorily completed, and so there is room for future design teams to continue from this point, completing and refining the state of charge measurement to make the system truly automatic.

Chapter III: Design of Major Components

With the customer needs analyzed, the design teams next focused on creating a solution that adequately satisfied the desired characteristics. The design teams divided the design into several component parts: the generator selection and installation (largely overseen by ME Team 2), the temperature range extension, the charging system, the power system necessary for the generator to power the motor, and the overall control system. The design teams used Pugh charts to inform decision-making regarding the first three sub-problems. A Pugh chart compares design options by weighing each option relative to each other in terms of important criteria. A '+' in the chart shows an advantage in one option compared to another, a '-' shows a disadvantage, and a '0' shows no difference. The option with the most positive score is generally the best-suited for the design.

Generator Selection and Installation

The generator used in the final design needed to be capable of supplying enough power to all of the electronic systems in the vehicle, in addition to powering the vehicle's DC motor. It also needed to be small enough for the design teams to mount it to the cart, and light enough that it would not bring the vehicle to a weight so large that it would significantly reduce the battery life. The design teams explored three possible mounting options: attaching the generator to a towed carriage, mounting it in place of the rear seats, or mounting it beneath the rear seats. ME Team 2 chose the third option, mounting the generator beneath the rear seats. Please refer to the final report submitted by ME Team 2 for a full analysis, including Pugh chart, of the generator selection and installation. Figure 4 shows the generator in its mounted position. Its propane tank is not shown in the image.

The generator used in the vehicle, a Cummins GQ2800, has a maximum output current of 20.8A at 120VAC for a maximum of 2500W of power. This is less than the 7200W that would be necessary to run the 5000W motor and 1200W charger at full load, but due to size and weight constraints, the design teams deemed this an acceptable trade-off.

Figure 4: Mounted Generator

Temperature Range Extension

The design teams investigated three different possibilities for extending the vehicle's temperature range: insulating the batteries, diverting generator exhaust to heat them, and wrapping them in electric heating pads. The relevant Pugh chart is shown below in Table 1.

The design teams used the selection criteria of cost, weight, simplicity, safety, and effectiveness to perform the comparison, partly informed from the results of the HoQ seen in Figure 2. Cost is an important factor because the design teams needed to design the system with a limited budget; low-cost options were therefore preferable to higher-cost ones, if possible. Although the HoQ shows that weight is not a very high-ranked characteristic in relation to the customer needs, it is still an important consideration due to the need to avoid placing excessive strain on the batteries, as explained in the Generator Selection and Installation section above. Simplicity is a selection factor because of the design teams' need to work on a limited schedule of only two semesters; complicated solutions necessitate additional time to implement, reducing the time the team has available to work on other systems. The design teams used safety as a selection criterion because of its high importance in the HoQ in Figure 2. Lastly, the design teams chose effectiveness as a criterion because it is important for the design choice to perform its intended role in a satisfactory manner.

Table 1: Temperature Pugh Chart - Compare to Exhaust

Criteria	Generator Exhaust	Heating Pads	Insulation
Cost	0	+	+
Weight	0	+	+
Simplicity	0	+	+
Safety	0	+	+
Effectiveness	0	+	0
Total Score	0	+5	+4

The Pugh chart analysis showed that heating pads presented the best solution to the problem, and generator exhaust the worst. Using generator exhaust to heat the batteries would have been costly, heavy, and complex because of the need to purchase tubing to run from the generator to the batteries. It would also have been unsafe because of the chance for exhaust fumes to leak into the seating area, and it would have been relatively ineffective because of the need to wait for the generator to produce enough waste heat to warm the batteries. The reason for which the design teams chose to use heating pads instead of insulation material is due to effectiveness: heating pads provide a continuous source of heat, whereas merely insulating the batteries would see their temperature slowly drop away.

Figure 5 shows the heating pads in their final position in the vehicle, seen as the thick black pads wrapped around the batteries. Only one heating pad is visible in the image; another heating pad is located underneath the one seen on top. Figure 6 shows the location of the heating pads in a circuit diagram implemented in the vehicle. The heating pads are both placed in parallel with the generator, as they have an AC input. Their control relay is rated to 30A, well over the 20.8A maximum current the generator can output.

Figure 5: Heating Pads in Vehicle

Charging System

The design and implementation of the charging system presented the greatest challenge in the project. The battery charger equipped in the vehicle operates under the assumption that the batteries are not in use while charging. Its built-in functionality is to only charge the batteries for as long as it detects that the battery voltage is increasing, making it impossible to charge the batteries while they are in use. Using the battery charger as-is would therefore require completely disconnecting the batteries from the motor when in need of charging. Alternatively, the teams considered replacing the charger with one that would allow the desired functionality, recharging the batteries even during use. Under this system, the generator would supply power through the new charger to simultaneously recharge the batteries and move the vehicle. The team also considered a third option: reprogramming the provided charger so that it would function in the manner desired. This would again allow the generator to power the vehicle and charge the batteries by only providing power to the charger, and would avoid the added cost of purchasing a new charger. As with the heating system, the teams used a Pugh chart to inform the selection of the best option, seen below in Table 2.

Table 2: Charger Pugh Chart - Compare to Using Present Charger

Criteria	Use Present Charger	Acquire New Charger	Reprogram Present Charger
Cost	0	-	0
Weight	0	0	0
Simplicity	0	+	0
Safety	0	0	-
Effectiveness	0	0	0
Total Score	0	0	-1

The Pugh chart analysis shows that of the three options, reprogramming the present charger was the least attractive option, mainly due to the safety issue it posed. Namely, if the teams attempted to reprogram the charger, they may inadvertently damage the charger, or, worse, override safety features that could later on damage the equipment or cause harm to the user. The teams found no clear advantage between the remaining two options: using the present charger had the advantage of reducing the impact on teams' budget, but acquiring a new charger would be far simpler to implement. The teams considered both designs to be equally safe: although the teams thought that acquiring a new charger and using it to power the motor through the generator had the potential for failure, since it is not meant to be used in that manner, the teams also considered the other option potentially failure-prone, since it necessitates adding several relays and cables into the design. The teams considered both of these safety risks less significant than the risk associated with reprogramming the present charger.

The design teams chose to use the present charger instead of acquiring a new one. The teams made this decision based on two considerations. First was budgetary concern: relatively early in the design process, the teams realized that they needed to spend a significant portion of their budget on replacement batteries, making it important to conserve as much of the budget as possible. Second was a more practical concern: intelligent battery chargers like the one originally installed in the vehicle shut themselves off to prevent overcharging the batteries. If the design teams had purchased a 'dumb' charger that did not have this functionality, they would have made it impractical for the user to charge the vehicle batteries overnight, as the new charger would overcharge and thus damage the batteries.

Figure 6 below shows the final design for the battery charger and heating pad circuit connections. The battery charger is placed directly in parallel with the generator, since it has an AC input. Its control relay is rated for 30A, well over the 20.8A the generator is capable of outputting. The teams placed a current sensor in series between the charger and the batteries in order to obtain data for the control system, discussed later.

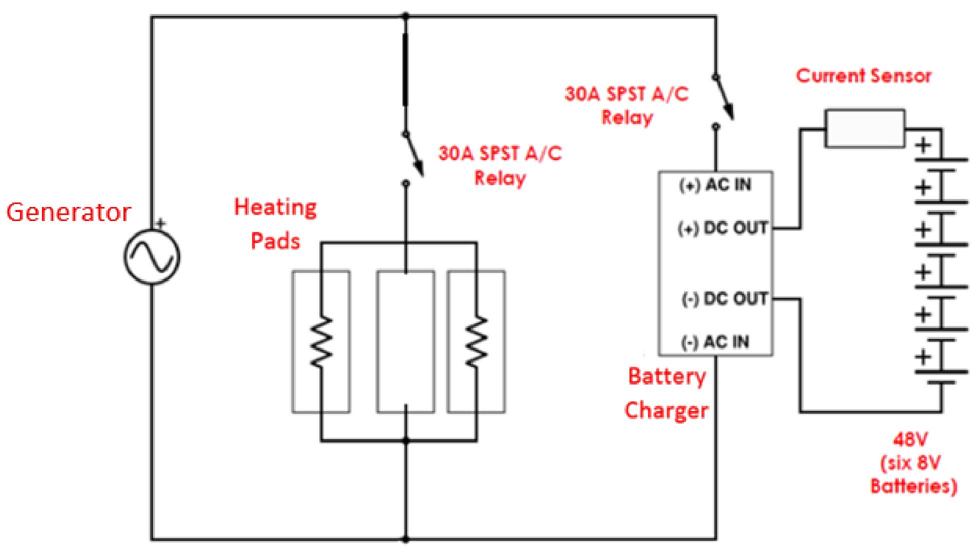


Figure 6: Heating Pad and Charger Circuit

Power System

The decision to retain the battery charger that came with the vehicle and refrain from reprogramming it meant that the design team would need to rewire much of the electric vehicle's power circuit. Not only would the design teams need to incorporate relays in the design for the motor to switch between battery power and generator power, but the teams would also need to design an AC to DC conversion system. The AC to DC conversion system would convert the generator's AC output, which has a maximum output of 20.8A at 120VAC, to a 48V, variable current DC output. To accomplish this, the design teams considered two possible ideas:

designing a custom power electronics control system, or using parallel combinations of commercial power supplies.

Dr. Hui Li graciously made available her equipment for the design teams to borrow should they decide to design their own power electronics system, but the design teams would need to program the rectifier on their own. Since the decision to implement the chosen charger system came relatively late in the design process (explained in Chapter V: Project Schedule), the design teams judged that programming the rectifier, which would have involved a lengthy learning process, would take too long for the project to finish on time. The design teams therefore instead investigated how best to implement the power system using commercial power supplies.

Commercial DC power supplies typically are not meant to work in parallel with each other. This kind of operation is prone to imbalance, where slight differences in inputs can lead to one power supply feeding back into the other, causing damage to the components. With this safety consideration in mind, the design teams identified a commercial power supply with a rated output of 48V and 32A and with a built-in 'current sharing' feature, which allows it to work safely in parallel with an identical power supply. For two such power supplies working in parallel, their maximum shared current is 57.6A, which exceeds the 52A maximum the motor could draw from the generator. The design teams informed Dr. Hays of this development, and he generously purchased the two power supplies for the teams. As a result, the design teams were able to design and implement a power circuit to power the motor, shown below in Figure 7. The DPDT (double-pole, double-throw) relays seen in the figure are rated for 150A. When the relays activate, a potentially damaging voltage spike occurs in the system, so both the battery output and power supply output are routed through high power diodes rated for 75A at 1.2kV.

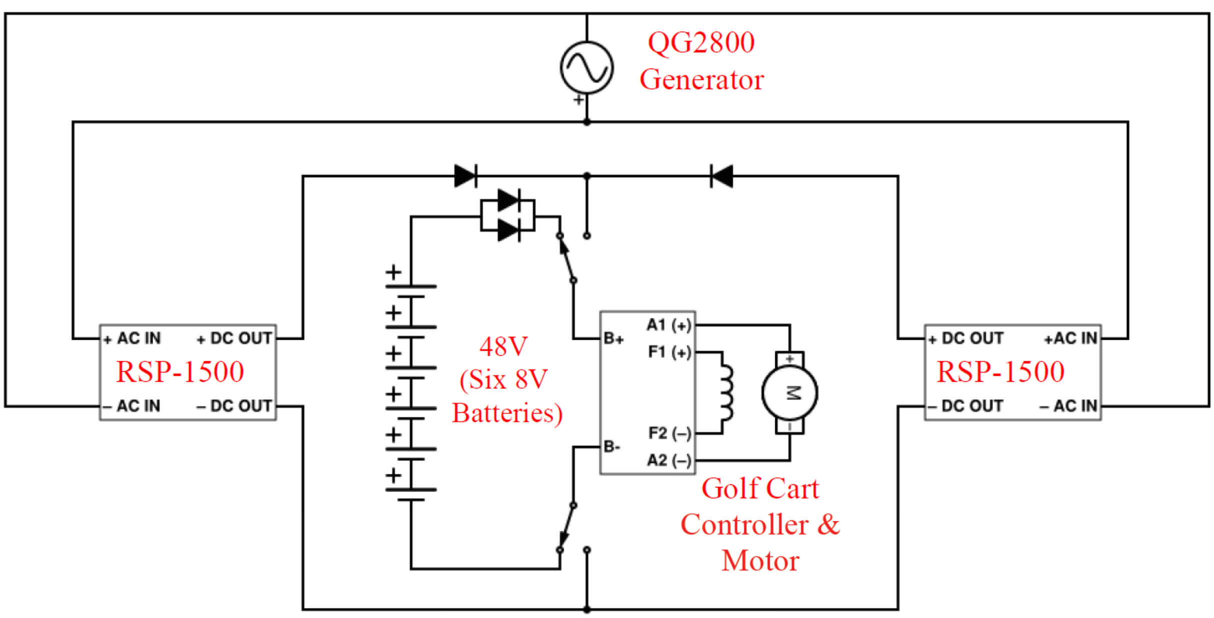


Figure 7: Power Circuit

Control Circuit

From the project inception, the teams always planned to have a microcontroller control the operation of all design components, as it is a highly practical, customizable method of implementing system control. The generator's 12V cranking battery supplies power to the microcontroller, which also accepts input from a voltage sensor connected to the battery pack, a current sensor in series between the charger and the battery pack, and a temperature sensor attached to the batteries. The voltage sensor is a simple voltage divider circuit, and the temperature and current are measured with off-the-shelf electronic components, as illustrated in Figure 8. The design teams chose to use a voltage divider circuit rather than a dedicated voltmeter to reduce cost and to reduce the risk of electronic components failing. The current sensor is a Hall Effect probe rated for 50A, and is important for the design because it allows the microcontroller to know when the charger is finished or nearly finished recharging the batteries, since the charger current will slowly decrease to 0 at full charge.

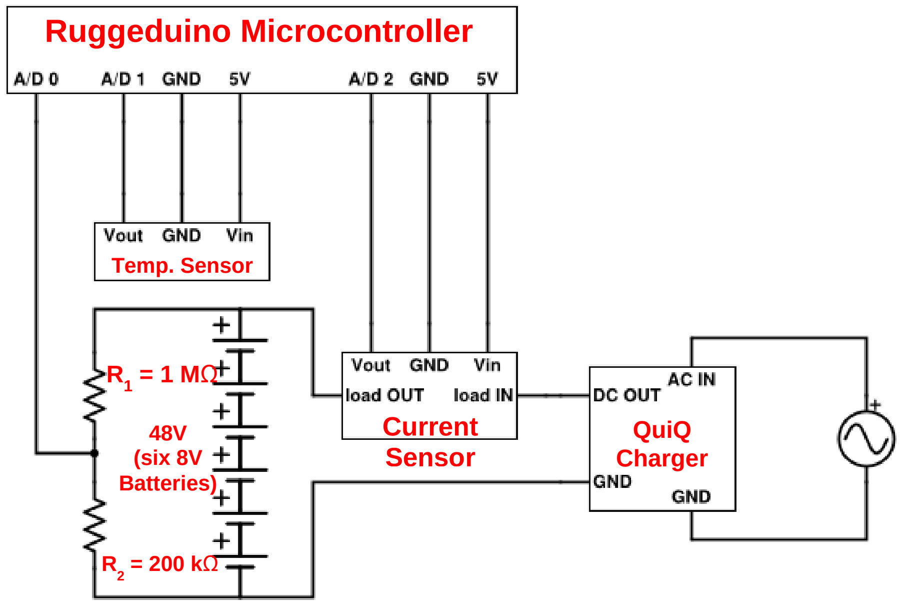


Figure 8: Microcontroller Sensor Inputs

The actual control circuit is shown below in Figure 9. The inductors seen in series with the transistors represent the control coils of the various relays present in the design. Each transistor is connected to an I/O port in the microcontroller. The leftmost branch of the circuit represents the generator battery, the next branch shows the microcontroller, and the AC source to the far right represents the generator. The three rightmost branches are equipped with voltage regulators to ensure that the developed voltage across those relays remains at 12V. From right to left, the relays in Figure 9 control the following functions: heating pad activation, charger activation, generator activation, generator deactivation, battery positive terminal, and battery negative terminal. The microcontroller controls the relay activations by applying a voltage to the base of the corresponding transistor, allowing current to flow and thus flipping the relay switch.

The code loaded in the microcontroller at the time of writing can be seen in Appendix A: Major Components. Due to complications in the last weeks of the semester, this code is not the final version of the code that will be implemented by the end of the project, but represents an earlier version of the design that uses the inaccurate voltage measurement system. The code that will be in the microcontroller by the final project completion date will activate the generator when the user flips a control switch on the dashboard, a temporary solution suggested by the design sponsor.

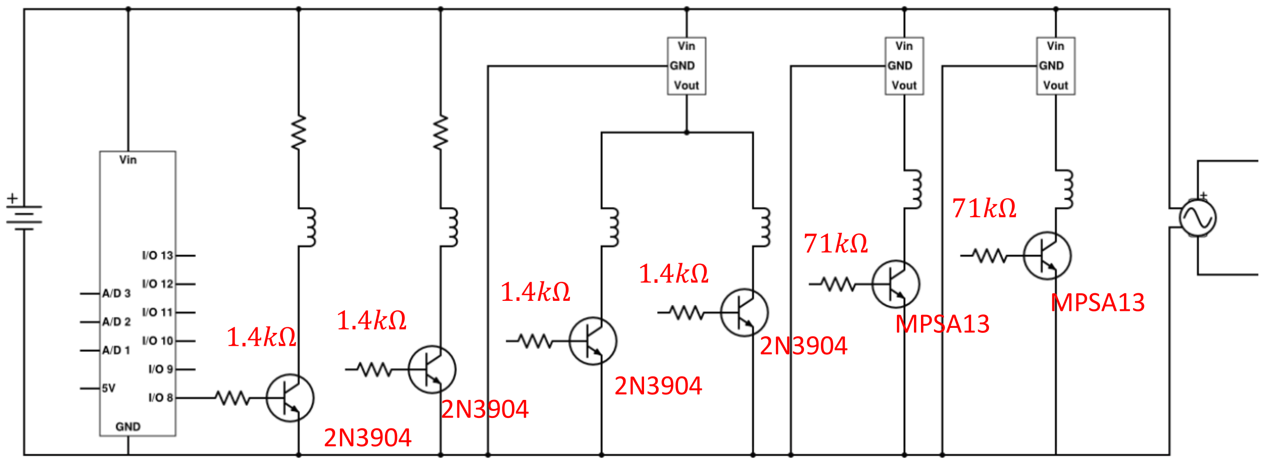


Figure 9: Control Circuit

A state diagram of the overall control system operation is presented in Figure 10. The design teams conceptualized the final design system to operate in one of four possible states, dependent on ambient temperature and battery state of charge. When the vehicle is started, it is by default in state 1, the normal operation mode where the generator is deactivated and the vehicle runs purely on battery power. If the battery temperature drops below the minimum safe operating temperature ($-10°C$), then the system will move to State 2, where the generator activates to power the motor and heating pads. If, on the other hand, the battery temperature rises above the maximum safe operating temperature ($49°C$), then the system will move to State 4, where the generator activates to power the motor and nothing else. If the battery temperature is within the operable temperature range, and if they also need to be recharged, then the system will move to State 3, where the generator activates to power the motor and the charger. If the battery temperature is within the operable temperature range, and if their state of charge is acceptable, then the system will remain in State 1, with the generator deactivated. Because the generator is only capable of outputting 2500W, the maximum speed of the electric vehicle will be reduced in State 2, State 3, and State 4, down to approximately 6mph. While this is a very low speed, there is no practical way of increasing it; increasing this speed requires installing a higher-power generator, which would be too large and heavy to install within the vehicle.

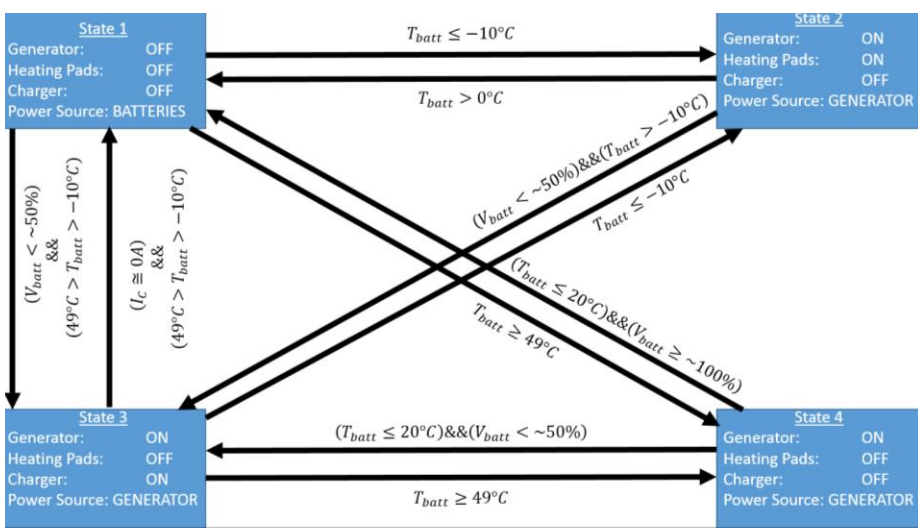


Figure 10: Control System State Diagram

Chapter IV: Test Plan

The mechatronics systems in the electric vehicle are the most important part of the project. The testing plans included cold weather testing, microcontroller function testing, and control circuit testing. In addition, the design teams tested the functionality of the sensors used in the design, seen in Appendix B: Test Plan Documentation.

Cold weather testing

One of the conditions given to by the sponsor was to have the complete system operate at -40°C without any delays or losses in the system. After a discussion with the team sponsor, it was agreed that the lead acid batteries that in use would not be operable in a -40°C environment, so the conditions were revised to -29°C instead. Based on the information provided by the data sheet on the vehicle battery, a plan was developed to confirm whether or not the batteries would perform at a minimum of -10°C. The optimal way to test this performance would be to subject the batteries to that temperature, and then complete a few cycles by charging and discharging the cell to observe the effects.

Being in Florida, using the natural environment was not possible for such testing, so the teams' intent was to create an artificial environment using a Styrofoam container filled with dry ice. To construct the testing environment, the teams needed equipment including dry ice, PVC pipe, tape/adhesive, a knife and a small electric fan. The construction process is very simple. A hole is cut for the PVC pipe to vent the cool air. Another hole is cut on the top, slightly smaller than the circumference of the fan. The fan is secured in place with the tape. Dry ice is deposited the dry ice into the cooler, and the fan is activated.

While the design teams were not able to construct this chamber, a similar cooling unit for a single battery was made. Using this cooling unit, measurements of temperature were taken by a thermometer, and voltage readings were taken by a voltmeter. As the battery was cooled, there was no notable change in voltage. Based on previous research, the teams expected that after the battery had been cooled by dry ice, there would be some significant change in voltage, but after a discussion with advisors and graduate students, the teams determined that this was not the case. To combat possible errors in the design of the cooling unit, it was suggested that the teams investigate the possibility of using a cooling oven in the Aero-Propulsion, Mechatronics and Energy Building (AME). Unfortunately, the oven that was found was too small to hold even one of the batteries, putting an end to the cold testing for this semester, as there was no more time at that point to pursue further options.

Microcontroller testing

The microcontroller functions as the brain of the system. It determines which state the system goes into depending on the reading it obtains from the temperature sensor, and it also monitors the voltage of the batteries to make sure that the pack stays within a safe operating range.

There were many instances of trial and error when testing the voltage monitoring circuit. To test the design, the circuit was first built on a breadboard and attached to a variable power supply to test the accuracy. The initial result varied as the voltage was increased. From 1 - 8 volts, the microcontroller reported a correct value, but as the voltage increased further, the error increased at an irregular rate. With the states of the system intended to rely so heavily on precise voltage readings, it was highly important for the design teams to correct this issue. After a period of debugging, the source of the error was revealed as a coding issue. After necessary changes were made to the software, the teams were able to get the reading within a +/- 0.06V reading. After this, the teams were able to demonstrate that the microcontroller interpreted its inputs as expected.

Control Circuit

The control system is divided into three sections: the transistor/relay control circuit, the power supply, and the switching circuit. The control circuit consists of a relay and transistor connected in a series configuration. In order to ensure that this configuration would work, the ability of the transistor to activate the relay was tested first. This was done by applying 12V to one end of the relay coil and attaching the collector end of the transistor to the other end. The transistor emitter was connected to ground, and the base to a resistor that in turn was connected to a microcontroller pin. This pin was then set to switch from low voltage to high, and the relay produced an audible click, indicating that the configuration worked.

Having an AC generator with DC battery and motor required the design teams to build some sort of conversion system. This design was tested by connecting the power supplies in parallel and attaching their combined output directly to the golf cart controller. The teams plugged the power supplies into a standard wall socket for initial testing. The teams activated the headlights and other minor electrical systems to ensure operation when operating from generator power. Following this successful test, the team pressed the accelerator pedal, causing the rear wheels to spin. The teams did this to confirm that the power supplies were sufficient to power the system. The teams performed this test again with the power supplies attached to the generator output instead of a wall socket, with successful results.

Following the successful testing of the power supplies, the ability of the system to change motor power sources was tested. The circuit shown in Figure 7 was wired into the vehicle. The vehicle was turned on using the batteries to power it. The power system relays were then activated, and the system successfully switched over to generator power, proving that the power circuit functioned as desired.

Chapter V: Project Schedule

At the start of the Fall 2015 semester, ECE Team 9 was an independent battery management system project. Within two weeks of the project start, however, the College of Engineering gave the team the opportunity to instead join ME Team 2, who were working on a related project with Cummins, Inc. From this point forth, both teams worked on the project sponsored by Cummins, Inc, developing schedules and plans together.

The design teams learned the full details of the desired end product during their first conference call with their sponsor, Dr. Michael Hays. Dr. Hays informed the design teams that the electric vehicle at the center of this project was in transit and would not arrive for at least two weeks. Dr. Hays also tasked the teams with increasing the operable range of the cart via the installation of a Cummins generator, and to make it function at -40˚C. This electric vehicle would serve as a model for a semi-truck with the 'hotel system of charging'.

The Fall 2015 semester saw most of the system planning accomplished. ECE Team 9 developed a Gantt chart, seen in Appendix C: Initial Gantt Chart. Since the first conference call, the design teams started generating ideas and conceptualizing the final design. Initially, the teams emphasized the need to make the vehicle work at the very low temperature they had been assigned, searching for methods to both achieve this and to test it. Achieving -40˚C throughout the entire vehicle and test it seemed difficult to achieve for several reasons. The teams would need to see what type of batteries were capable of working under this condition properly, and after identifying the right type of battery, they would need to determine whether the charger included in the cart would be able to charge it and whether it would work at such a low temperature. If not, the teams would need to replace the battery, the charger, or both. In addition, the design teams needed to determine how to test the entire system at -40˚C, given the difficulty of finding a large enough testing chamber for the vehicle or even just the major electrical components.

After performing battery research, the design teams were still on track with their initial schedule. Once the vehicle arrived, the design teams attempted to test the vehicle in its initial state. This effort was attempted so that its performance could later be compared against the performance of the final system. However, at this point, the teams discovered that the batteries provided with the cart had crystallized, making them unusable. The design teams informed their sponsor of this issue, as well as difficulty in finding affordable batteries capable of functioning at -40˚C. As a result, the teams' sponsor increased the temperature requirement from -40˚C to -29˚C, and the design teams abandoned the battery research and focused instead on finding a method to heat the batteries, which would be replacements of the original lead-acid types.

After finding a microcontroller that could function at low temperatures, the design teams acquired the microcontroller for the design in the Fall semester and accomplished most of its programming then. The design teams also evaluated the vehicle motor to determine the power it would require from the generator the design teams would attach. The design teams used this information to select a generator for the vehicle, choosing it so that it would be capable of supplying enough power to run all necessary systems while also fitting within the vehicle. The design teams informed the sponsor of their generator decision at the end of the Fall semester, and were informed it would arrive before the beginning of the Spring semester.

Unfortunately, the design teams faced a significant setback, as the generator arrived later than anticipated, two weeks after the start of the Spring semester. The design teams acquired the batteries one week later. With most of the major components acquired, the design teams placed the new batteries within the vehicle and again attempted to test it as it was for documentation purposes. The design teams attempted to charge the new batteries with the on-board charger, but doing so revealed that the charger was broken and in need of replacement. This caused another setback, as the teams then needed to wait for the ordered replacement charger to arrive before they could accomplish any kind of testing.

The design also learned at this time that the battery charger would not be able to function while the batteries were in use, as mentioned in Chapter III: Design of Major Components, leading the design teams to investigate the design of an AC to DC converter, an idea that had been considered but then abandoned during the Fall semester. As discussed in the same chapter, due partly to time constraints, the design teams chose to use commercial power supplies rather than a programmed rectifier circuit to accomplish the AC to DC conversion.

By the time the charger arrived, the design teams had most of the components tested and ready for installation into the final design. The design teams mounted and tested each component separately, ensuring that they functioned as intended. During final system testing, the design teams encountered an unexpected obstacle: when the design teams activated systems that used the batteries, the measured voltage across the battery terminals would drop significantly. This necessitated a change in the manner that the system measured state of charge, even though the original measurement system had been implemented at the sponsor's suggestion. Since this setback occurred so late in the Spring semester, the design teams have had little time to implement an adequate replacement; however, the design teams still expect to finish the project before 4/14/2016. Even so, the design will have room for improvement by future teams, as the 'switch' solution suggested by the sponsor prevents the system from being completely automatic, a stated goal of the project.

Even though the design teams encountered several setbacks, they successfully designed and tested most of the components. While the cold-temperature testing had to be cancelled due to time constraints, and the final design will be non-automatic, most of the items on the schedule were accomplished. The final Gantt chart used for the Spring semester, adjusted due to delays and reprioritizing during the project, can be seen in Appendix D: Final Gantt Chart.

Chapter VI: Budget

The final design teams' budget can be seen in Appendix E: Final Budget, showing the individual budgets of both ME Team 2 and ECE Team 9 and an itemized list of all components acquired with team funds. Four items are not included on the list: the GQ2800 generator, which was provided by the sponsor; the two Meanwell RSP-1500-48 power supplies, which was also provided by the sponsor; and a seventh 8V battery (purchased when one of the original six purchased in the Spring semester broke), which was provided by the ECE department directly.

Despite a promising starting budget of $2700 ($2000 provided by the sponsor, Dr. Michael Hays, plus $70 provided by the ECE department), the design teams needed to spend most of it simply replacing broken components. In total, the design teams needed to spend just over $1411, approximately 52% of their budget, to replace the six broken 8V batteries and the broken battery charger. The full budget breakdown can be seen as a pie chart in Figure 11.

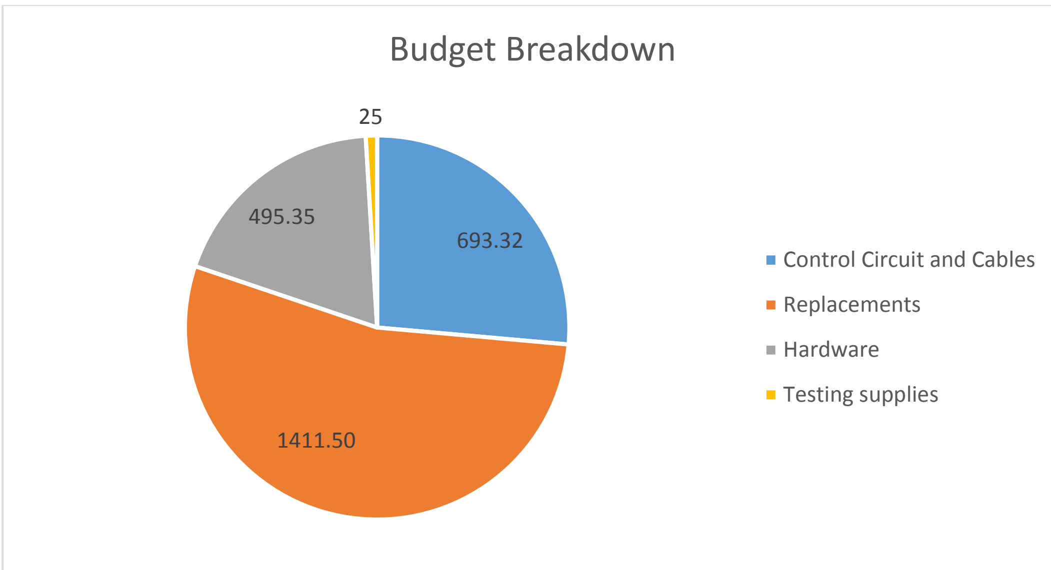


Figure 11: Budget Pie Chart

The majority of the remaining budget was spent on components for the control circuit, accounting for 26% of the overall budget: relays, diodes, cabling, terminals and connectors, transistors, in addition to two microcontrollers (since one broke during development). Another 18% was spent on hardware for installation, such as the generator's propane tank and fitting, labor for parts, nuts, oil, screws, angle bars, washers, bolts, and hinges. Approximately 1% of the budget was spent on testing supplies, namely a thermometer and prototyping board. This left the design teams with just under $75, or 3%, of their original budget unspent.

At the onset of the design project, the design teams did not expect to spend the entirety of the allocated project budget, expecting instead to use only between $1500 to $2000, with the remaining money acting as a safety fund in case of emergency purchases. If it weren't for the need to replace the original batteries and charger, the team would have been in this range. In this situation the team would have spent $1214 on the same items mentioned in Appendix E: Final Budget, plus $610 for the power supplies and $169 for the seventh battery, totaling $1991, leaving them with over $700 unspent. The massive $1411 spent replacing broken parts, however, made a great difference in the team's final budget.

Chapter VII: Conclusion

As mentioned in Chapter I: Introduction, the end product accomplishes almost all of the goals that the design teams and sponsor set, despite multiple setbacks and budget concerns. The design teams successfully planned, designed, and implemented a 'hotel system of charging' prototype within an electric vehicle, attaching a generator to it and controlling it via microcontroller as part of a battery management system.

The design teams selected a generator based on size and power output, and designed dependent systems for heating the batteries, charging them, powering the motor from the generator, and switching between circuits. The battery heating is accomplished via heating pads that activate to warm the batteries to a safe temperature while the vehicle is in use, extending the operable temperature range of the design. When the battery state of charge runs low, the user may activate the generator to recharge them, allowing for continued operation beyond what would normally be achievable. The design teams added power supplies to the design to allow the generator to drive the vehicle, and designed and implemented an intricate system of cabling and microcontroller-driven relays to ensure only the appropriate systems would activate when called upon, and to isolate the batteries from the motor when the generator is active.

All of the systems in the electric vehicle are tested and functional, save for the state of charge determination, and the vehicle is capable of running using either the batteries or the generator. The teams will install a manual switch in the design for a user to activate the generator when battery charging is needed, a decision informed by the on-board state of charge indicator. If the teams had more time available to them, they would attempt to design around the issue, but with the end of the semester arriving, implementing an appropriate state of charge estimation is a task left to future design teams.

Due to time considerations, the teams also had to abandon much of their planned cold-temperature testing, another task left to future teams. The control system as a whole needs to be tested in a controlled low-temperature environment, as does the entire vehicle.

In spite of this, the design teams are satisfied with the work they could accomplish. Save for fully automating the design, the design teams accomplished all of their design objectives. The design teams invite the College of Engineering to continue their project with future senior design teams, expanding their design in additional directions, using their accomplished work as a base.

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[2] Senyshyn, A.; Mühlbauer, M.J.; Dolotko, O.; Ehrenberg, H.; "Low-temperature performance of Li-ion batteries: The behavior of lithiated graphite", *Journal of Power Sources*, Volume 282, Pages 235-240, 15 May 2015, ISSN 0378-7753, http://dx.doi.org/10.1016/j.jpowsour.2015.02.008. (http://www.sciencedirect.com/science/article/pii/S0378775315002311)

[3] Linden, D.; Reddy, T.B. (2002). *Handbook of Batteries* (3rd ed.). New York, NY: McGraw-Hill, Inc.

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Appendix A: Major Components

Link to Electric Vehicle Maintenance Manual

http://www.mobiletomberlin.net/downloads/Consumer%20Information/E-Merge%20Service%20Manual%202010-2011-1.pdf

Current Microcontroller Code

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x20,16,2);

const int HP_pin = 13;          //pin for heating pad relay
const int CH_pin = 12;          //pin for charger relay
const int GEN1_pin = 11;        //pin for generator on relay
const int GEN2_pin = 10;        //pin for generator off relay
const int PS1_pin = 9;          //pin for power source relay 1
const int PS2_pin = 7;          //pin for power source relay 2

const int V_pin = A0;           //voltage pin
const int T_pin = A1;           //temperature pin
const int I_pin = A2;           //current pin

volatile int GENSET = 0;        //generator state 0:off 1:on
int HP = 0;                     //heating pad state 0:off 1:on
int CH = 0;                     //charger state 0:off 1:on

volatile int useron = 0;

int state = 1;                  //state of system

const float T_low = 0;
const float T_fine = 20;
const float T_high = 50;

const float V100 = 52.0;        //V_m = 4.33;
const float V_charge = 50.0;    //V_m = 4.08;

//current below which charger is done charging
const float I_stop = 0.5;

int N = 30;                     //input sample size

/*****************************************/
void setup()
{
        Serial.begin(9600);

        //intilize lcd
        lcd.init();
        lcd.backlight();

        //Set all digital pins as outputs set to low
        for (int j = 0; j < 14; j++)
```

```
	{
		if ((j ==2)||(j == 3))
		{
		pinMode(j,INPUT);
		}
		else
		{
		pinMode(j,OUTPUT);
		digitalWrite(j,LOW);
		}
		delay(5);
	}

	//declare pin inputs
	pinMode(V_pin,INPUT);
	pinMode(T_pin,INPUT);
	pinMode(I_pin,INPUT);

	attachInterrupt(0, userstartup, FALLING);
	//attachInterrupt(1, usershutdown, FALLING);

	delay(2000);
}

void loop()
{
	int V_m_dig = 0;		//measured digital battery voltage
	int V_m_sum = 0;		//sum digital battery voltage

	int T_batt_dig = 0;		//measured digital temperature
	int T_batt_sum = 0;		//sum digital temperature

	int I_ch_dig = 0;		//measured digital current
	int I_ch_sum = 0;		//sum digital current

	//initialize sensor input variables
	float T_batt = 0.0;
	float V_batt = 0.0;
	float I_ch = 0.0;

	const float R1 = 1200000.0;
	const float R2 = 92300;

		for (int i = 0; i < N; i++)
		{
		//sensor inputs into A/D pins
		V_m_dig = analogRead(V_pin);
		delay(5);
		T_batt_dig = analogRead(T_pin);
		delay(5);
		I_ch_dig = analogRead(I_pin);
		delay(5);

		//calculate sum of inputs
		V_m_sum += V_m_dig;
```

```
        T_batt_sum += T_batt_dig;
        I_ch_sum += I_ch_dig;
        }

        //calculate averaged digital values
        V_m_dig = V_m_sum/N;
        T_batt_dig = T_batt_sum/N;
        I_ch_dig = I_ch_sum/N - 504;

        V_batt = V_m_dig*(5.0/1023.0)*((R1+R2)/R2);        //raw measured voltage (V)
        T_batt = (100.0*(T_batt_dig*(5.0/1023.0)) - 50.0)/15.0;
        I_ch = I_ch_dig*(5000.0/1023.0)/40.0;

        if (I_ch<0)
        {
        I_ch = 5;
        }

    lcd.setCursor(0,0);
    lcd.print("V: ");
    lcd.print(V_batt);
    lcd.setCursor(9,0);
    lcd.print("T: ");
    lcd.print(T_batt);
    lcd.setCursor(0,1);
    lcd.print("I: ");
    lcd.print(I_ch);

//***********************************************
switch (state)
{
    case 1:
        lcd.setCursor(9,1);
        lcd.print("State 1");
        delay(100);

        //if generator on change power source and turn off
        if (GENSET == 1)
        {
            if (HP == 1)
            {
            HPcontrol(0);
            }
            else
            {
            CHcontrol(0);
            }
            delay(1000);    //delay to allow steady state formation
            powerBATT();    //switch to battery power
            delay(1000);    //delay to allow steady state formation
            genstop();      //turn off generator
        }
        /****************************************************/
        //change states based on sensor inputs
        if (T_batt < T_low)
```

```
                {
                state = 2;
                }
                else if ((T_batt > T_low)&&(useron == 1)) //&&(V_batt < V_charge)
                {
                state = 3;
                }
                break;
/*************************************************************/
        case 2:
                lcd.setCursor(9,1);
                lcd.print("State 2");
                delay(100);

                //if generator off turn on
                if (GENSET == 0)
                {
                genstart();
                delay(5000);            //delay until generator fully operational
                powerGEN();             //switch to generator power
                delay(5000);            //delay until returned to steady state
                HPcontrol(1);           //turn heating pad on
                }
                else
                {
                        if (CH == 1)
                        {
                        CHcontrol(0); //cut power to charger
                        delay(5000); //delay until returned to steady state
                        }
                HPcontrol(1); //power heating pad
                }
                /****************************************************/
                //change states based on sensor inputs
                if ((T_batt > T_low)&&(V_batt < V_charge))
                {
                state = 3;
                }
                else if (T_batt > T_fine)
                {
                state = 1;
                }
                break;
/*************************************************************/
        case 3:
                lcd.setCursor(9,1);
                lcd.print("State 3");
                delay(100);

                //if generator off turn on
                if (GENSET == 0)
                {
                genstart();
                delay(5000);            //delay until generator fully operational
                powerGEN();             //switch to generator power
```

```
		delay(5000);		//delay until returned to steady state
		CHcontrol(1);		//turn charger on
		delay(10000);
		}

		//If generator and heating pad on turn off heating pad and turn on charger
		if ((CH == 0)&&(HP == 1))
		{
		HPcontrol(0);		//cut power to heating pad
		delay(5000);		//delay until returned to steady state
		CHcontrol(1);		//power charger
		delay(10000);
		}

		/****************************************************/
		//change states based on sensor inputs
		if ((I_ch < I_stop)&&(T_batt > T_low)&&(V_batt >= V100))
		{
		state = 1;
		}

		if (T_batt < T_low)
		{
		state = 2;
		}

		if (T_batt > T_high)
		{
		state = 4;
		}

		break;
/****************************************************************/
	case 4:
		lcd.setCursor(9,1);
		lcd.print("State 4");
		delay(100);
		if (CH == 1)
		{
		CHcontrol(0); //stop charging batteries
		}
		/****************************************************/
		if (T_batt <= T_fine)
		{
		state = 3;
		}
		break;
}
}

//generator start up function
void genstart()
{
	delay(1000);
	digitalWrite(GEN1_pin,HIGH);
```

```
	delay(5000);
	digitalWrite(GEN1_pin,LOW);
	GENSET = 1;
}

//generator shut down function
void genstop()
{
	digitalWrite(GEN2_pin,HIGH);
	delay(2000);
	digitalWrite(GEN2_pin,LOW);
	GENSET = 0;
}

//Generator power source relay control function
void powerGEN()
{
	digitalWrite(PS1_pin,HIGH);
	digitalWrite(PS2_pin,HIGH);
}

//Battery power source relay control function
void powerBATT()
{
	digitalWrite(PS1_pin,LOW);
	digitalWrite(PS2_pin,LOW);
}

//Heating pad control function
void HPcontrol(int value)
{
	//cut power to heating pad
	if (value == 0)
	{
	digitalWrite(HP_pin,LOW);
	HP = 0;
	}
	//power heating pads
	else if (value == 1)
	{
	digitalWrite(HP_pin,HIGH);
	HP = 1;
	}
	delay(5000);
}

void CHcontrol(int value)
{
	//cut power to charger
	if (value == 0)
	{
		digitalWrite(CH_pin,LOW);
		CH = 0;
	}
	//power charger
```

```
	else if (value == 1)
	{
	digitalWrite(CH_pin,HIGH);
	CH = 1;
	}
}

void userstartup()
{
	if (state != 1)
	{

	}
	else
	{
	useron = 1;
	}
}
```

Generator Data Sheet

Specification sheet

Cummins **Onan**

RV generator set Quiet Gasoline™ Series RV QG 2800

Features and benefits

- Microprocessor control with diagnostics and lightweight, compact design.
- Gasoline or LP fueled.
- Quietest generator sets of their size.
- Easy maintenance with single-side service.
- Completely enclosed with muffler, quick and easy to install.
- 3-year limited warranty.
- Low fuel consumption.

Weight, size and sound level

Weight: 125 lbs (57 kg)

Size: Length 22 in (560 mm), width 16.3 in (415 mm), height 12.8 in (325 mm)

Sound: 70 dB(A) readings at 10 ft (3 m) half load

- Meets National Park Service sound level requirements (60 dB(A) @ 50 ft) for use in national parks.
- Typical installation will further reduce sound level.

Models and ratings

Model	Fuel	Hz	RPM	Watts	Voltage	Amps	Phase	Circuit breaker
2.8HGJBB-1120A	Gasoline	60	3600	2800	120	23.3	1	25A
2.8HGJBB-1124A	Gasoline	60	3600	2800	100	28	1	30A
2.3HGJBB-1122A	Gasoline	50	3000	2300	230	10	1	10A
2.5HGJBB-1121A	LP vapor	60	3600	2500	120	20.8	1	21A
2.3HGJBB-1123A	LPvapor	50	3000	2000	230	10	1	10A

Ambient conditions for rated power output with muffler and RV enclosure, per ISO 8528-1:
- Temperature: 77° F (25° C)
- Altitude: 500 ft (152.4 m), (99 kPa dry)

Typical power output change based on ambient conditions:
- Temperature: Power output decreases 1% for every 10° F (5.5° C) increase
- Altitude: Power output decreases 3.5% for every 1000 ft (305 m) increase

Ratings represent minimums. Actual peak performance may be significantly higher (between 5-7%) based on installation and operating conditions.

Operating temperature range

	Low	High
Gasoline	-20° F (-29° C)	120° F (49° C)
LP	0° F (-18° C)	120° F (49° C)

- Depends upon LP tank capacity, surface area and butane content of LPG.

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Standard features

- Cummins Onan sound-attenuating enclosure
- Focalized mounting system with vibration isolators
- Cross-flow cooling
- Sheet steel drip controlling base
- Enclosed muffler
- Integral USDA Forest Service approved spark arrestor muffler
- Adjustable mechanical governor
- Automatic choke
- Overhead cam
- Single-side service
- Low oil level shutdown
- Electric fuel pump (gasoline); electric solenoid (LP)
- Mounted control panel
- Sealed remote start connector
- Electric start
- Fused DC circuits to protect set wiring and remote control wiring
- Magnetic circuit breaker
- 50 in (1.3 m) generator set output leads
- Solid-state ignition
- Standard onboard diagnostic capability

Engine details

Model: EX 21

Design: 4-cycle, single cylinder, OHC

Displacement: 13.2 in^3 (217 cm^3)

Compression ratio: 8.5:1

Power: 7.0 bhp (max) at 3600 r/min

Cooling: Pressurized air

Cooling air volume: Includes engine cooling air volume
60 Hz: 300 ft^3/m (8.5 m^3/min) at 3600 r/min
50 Hz: 250 ft^3/m (7.1 m^3/min) at 3000 r/min

Fuel system: (Gasoline) electric fuel pump, fuel lift 3 ft (914 mm); (LP) electric fuel solenoid; automatic choke

Combustion air:
60 Hz: 12.5 ft^3/m (0.35 m^3/min) at 3600 r/min
50 Hz: 10.4 ft^3/m (0.3 m^3/min) at 3000 r/min

Ignition system: Breakerless, electronic

Starting system: Remote, 12 V, 3-wire negative ground; start-stop rocker switch on control; connector for remote start cable

Lubrication: Splash lubrication

Oil capacity: 0.6 qt (0.63 L)

Cylinder crankcase: Alloy aluminum with iron cylinder liner cast into the block

Oil base: Aluminum

Cylinder head: Alloy aluminum, removable

Average fuel consumption

Gasoline	No load	Half load	Full load
60 Hz	0.2 Gal/h (0.8 L/h)	0.4 Gal/h (1.3 L/h)	0.5 Gal/h (1.7 L/h)
50	0.2 Gal/h (0.6 L/h)	0.3 Gal/h (1.1 L/h)	0.4 Gal/h (1.4 L/h)
LPG	**No load**	**Half load**	**Full load**
60 Hz	0.3 Gal/h (1.2 lb/h) 0.6 kg/h	0.4 Gal/h (1.6 lb/h) 0.7 kg/h	0.6 Gal/h (2.3 lb/h) 1.0 kg/h
50 Hz	0.2 Gal/h (1.0 lb/h) 0.4 kg/h	0.3 Gal/h (1.3 lb/h) 0.6 kg/h	0.4 Gal/h (1.8 lb/h) 0.8 kg/h

Alternator details

Design: Cummins 2-pole revolving field, self-excited, electronically regulated, 1 phase, direct drive

Insulation system and temperature rise: Class H insulation system meets ANSI/RVIA EGS-1 standards and CSA TIL RV-06 temperature requirements

Cooling: Direct drive centrifugal blower

Rotor: Laminated electrical steel assembly press-fitted to shaft, balanced, heavy insulated copper wire windings, copper damper circuit for excellent waveform

Stator: Laminated electrical steel assembly; heavy insulated copper wire windings

Voltage regulator: Electronic

DC brushes: Electrographite

Generator set performance

Air conditioner operation:
2.8kW generator set will start and run one 13500 Btu high efficiency air conditioner(15.5 Amps or less) plus 600 watt base load with an additional 300 watts of power available.
2.5kW generator set will start and run one 13500 Btu high efficiency air conditioner (15.5 Amps or less) plus a 600 watt base load with no additional watts of power available.
2.3kW generator set will start and run one 7800 Btu high efficiency air conditioner(5.5 Amps or less) plus 600 watt base load with an additional 100 watts of power available.

Voltage regulation: Exceeds requirements of ANSI/RVIA EGS-1 ±10%

Frequency regulation: Exceeds requirements of ANSI/RVIA EGS-1 ± 5%

Note: See your Cummins Onan distributor or certified Cummins Onan service dealer for a listing of approved air conditioners.

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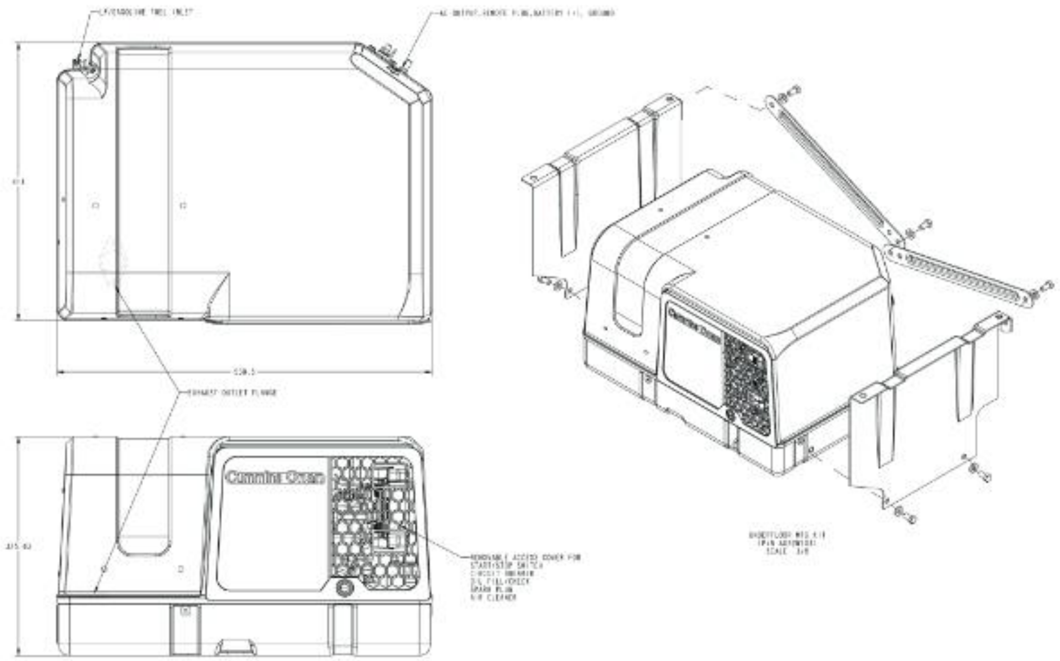
Basic dimensions

Dimensions in (mm)



Note: This outline drawing is provided for general reference only and is not intended for design or installation. For more information see Operation and Installation manuals or obtain drawing and wiring diagram from your distributor/dealer.

Accessories

- Exhaust kit elbow 90 degree (P/N A041H694)
- Exhaust kit downtube (P/N A041L816)
- Display shell gasoline (P/N A041Y359)
- Display shell LP (P/N A041Y361)
- Under floor mounting kit (P/N A042W103)
- Retro adapter from KV (P/N A043F935)
- Remote start/stop rocker switch (P/N 300-5331)
- Remote control with start/stop switch and running time meter (P/N 300-5332)
- Remote control with start/stop switch and DC voltmeter (P/N 300-5333)
- High altitude kit A042V579
- Remote control plug and wire harness 10 ft (P/N 338-3489-01), 30 ft (P/N 338-3489-02)
- Battery, 12 V, 360 cold cranking amps at 0° F (-18° C)
- Energy Command 30 auto generator start (P/N 018-02030)
- Energy Command 20 remote start/stop with diagnostics (P/N 018-02020)
- Energy Command 30W wireless auto generator start (P/N 018-03000)
- Energy Command Y harness (P/N 044-00087)

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Testing for RV application

- Tested at extremes of temperature -20 °F (-29 °C) to 120 °F (49 °C) for starting and operation
- Tested with RV loads, air conditioners, microwaves, converter, TVs, VCRs
- Tested installed; Cummins owned RVs used for product development testing
- Tested in high humidity conditions
- Tested in salt spray conditions
- Tested in heavy airborne dust conditions
- Field test program
- 60 Hz (120 V only) models listed by SGS United States Testing Company, Inc. per ANSI/RVIA EGS-1 and CSA-certified per Std. 100 Motors and Generators and TIL RV-06.
- This generator set was designed and manufactured in facilities certified to ISO 9001
- 60 Hz models meet applicable U.S. EPA and California emissions standards
- 50 Hz models are CE certified

Warranty policy

This limited warranty covers virtually everything except routine maintenance for the first two years you own your RV generator set, and covers parts and labor on major power train and generator set parts during the third year. In addition, it also includes a free 90-day adjustment policy, which provides that Cummins Inc. will make minor adjustments during the first three months you own it - free of charge! Please note: This 3-year limited warranty applies to RV generator sets used in RV applications only, and does not apply to RV generator sets used in commercial mobile applications.

WARNING:

Do not use this generator set on a boat. Such use may violate U.S. Coast Guard regulations, and can result in severe personal injury or death from fire, explosion, electrocution, or carbon monoxide poisoning.

WARNING:

Back feed to a utility system can cause electrocution and/or property damage. Do not connect to any building electrical except through an approved device or after building main breaker is open.

After sale support

Complete line of parts and accessories
Cummins Inc offers replacement and tune-up parts, accessories, oil and maintenance chemicals - all specially designed to help keep your Cummins Onan generator set running at peak performance. Cummins Inc. also provides genuine Onan Green Label Parts™ that exactly match generator set specifications and will help maximize power output and extend the life of your generator set.

Largest distributor/dealer support network
Cummins Onan generator sets are supported by the largest and best trained worldwide certified distributor/dealer network in the industry. This network of knowledgeable Cummins Onan distributor/dealers will help you select and install the right generator set and accessories to meet the requirements of your specific application. This same network offers a complete selection of commonly used generator set maintenance parts, accessories and products plus manuals and specification sheets. Plus, they can answer your questions regarding proper operation, maintenance schedules and more.

Manuals: Operation and installation manuals ship with the generator set. To obtain additional copies or other manuals for this model, see your Cummins Onan distributor/dealer and request the following manual numbers: Operation (A031C171), Installation (A031C172), Parts (A035B506), Service (A031C173).

To easily locate the nearest Cummins Onan distributor/dealer in your area, or for more information, contact us at 1-800-888-6626 (or 763-574-5000), or visit www.cumminsonan.com.

Contact your distributor/dealer for more information.

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NAS-5501c-EN (1/13)

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Battery Charger Data Sheet

QuiQ™ *HF/PFC Battery Charger*

Product Manual for:
QuiQ 912-24xx / 36xx / 48xx / 72xx

delta-q TECHNOLOGIES
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www.delta-q.com

SAVE THESE IMPORTANT SAFETY INSTRUCTIONS

This manual contains important safety, operating, and installation instructions – read before using charger.

Battery Safety Information

Warning: Use charger only on battery systems with an algorithm selected that is appropriate to the specific battery type. Other usage may cause personal injury and damage. Lead acid batteries may generate explosive hydrogen gas during normal operation. Keep sparks, flames, and smoking materials away from batteries. Provide adequate ventilation during charging. Never charge a frozen battery. Study all battery manufacturers' specific precautions such as recommended rates of charge and removing or not removing cell caps while charging.

Electrical Safety Information

Danger: Risk of electric shock. Connect charger power cord to an outlet that has been properly installed and grounded in accordance with all local codes and ordinances. A grounded outlet is required to reduce risk of electric shock – do not use ground adapters or modify plug. Do not touch uninsulated portion of output connector or uninsulated battery terminal. Disconnect the AC supply before making or breaking the connections to the battery while charging. Do not open or disassemble charger. Do not operate charger if the AC supply cord is damaged or if the charger has received a sharp blow, been dropped, or otherwise damaged in any way – refer all repair work to qualified personnel. Not for use by children.

INFORMATIONS IMPORTANTES DE SÉCURITÉ

Conserver ces instructions. Ce manuel contient des instructions importantes concernant la sécurité et le fonctionnement.

Information de Sécurité de la Batterie

Attention: Utiliser seulement sur les batteries 72V avec un algorithme approprié au type spécifique de batterie – voire le manuel. D´autres types de batteries pourraient éclater et causer des blessures ou dommages. Les batteries peuvent produire des gaz explosives en service normal. Ne jamais fumer près de la batterie et éviter toute étincelle ou flame nue à proximité de ces derniers. Fournisser la bonne ventilation lors du chargement. Ne jamais charger une batterie gelée. Prendre connaissance des mesures de précaution spécifiées par le fabricant de la batterie, p. ex., vérifier s´il faut enlever les bouchons des cellules lors du chargement de la batterie, et les taux de chargement recommandés.

Information de Sécurité Électrique

Danger: Risque de chocs électriques. Ne pas toucher les parties non isolées du connecteur de sortie ou les bornes non isolées de la batterie. Toujours connecter le chargeur à une prise de courant mise à la terre. Ne pas ouvrir ni desassembler le chargeur – referer toute reparations aux personnes qualifiés. Pas à l´usage des enfants.

Operating Instructions

1. Always use a grounded outlet. When using an extension cord, avoid excessive voltage drops by using a grounded 3-wire 12 AWG cord.
2. The charger will automatically turn on and go through a short LED indicator self-test (Models 912-xx0x will flash all LED's in an up-down sequence and Models 912-xx1x will alternatively flash its LED RED-GREEN) for two seconds. If the charger is connected to battery pack, a trickle current will be applied until a minimum voltage is reached. If the charger is used in an off-board application and the charger is waiting to be plugged into a battery pack, the charging algorithm number will be displayed for 11 seconds (see "Check / Change Charging Algorithm") before ultimately displaying an under-voltage fault (fault disappears when plugged into battery pack).
3. Once a minimum battery voltage is detected, the charger will enter the bulk charging constant-current stage. Models 912-xx0x will display the current to the battery on the bargraph and Model 912-xx1x will flash its LED GREEN off more than on to indicate <80% charge status. The length of charge time will vary by how large and how depleted the battery pack is, the input voltage (the higher, the better), and ambient temperatures (the lower, the better). If the input AC voltage is low (below 104VAC), then the charging power will be reduced to avoid high input currents (Models 912-xx0x 'AC' LED and Models 912-xx1x single LED both flash YELLOW). If the ambient temperature is too high, then the charging power will also be reduced to maintain a maximum internal temperature (Models 912-xx0x bargraph flashes and Models 912-xx1x single LED flashes YELLOW).
4. When the battery is at approximately 80% state of charge, the bulk stage has completed and an >80% charge indication is given (Models 912-xx0x turn on the '80%' LED and Models 912-xx1x will flash its LED GREEN on more than off). In the next phase known as the absorption or constant-voltage phase, the last 20% of charge is then returned to the battery. The charging could be terminated at this point if the vehicle requires immediate usage, however, it is highly recommended to wait until 100% charge indication is given to ensure maximum battery capacity and life.
5. A low current "finish-charge" phase is next applied to return and maintain maximum battery capacity (Models 912-xx0x will flash the '100%' LED).
6. When Models 912-xx0x '100%' LED or Models 912-xx1x single LED is continuously GREEN, the batteries are completely charged. The charger may now be unplugged from AC power (always pull on plug and not cord to reduce risk of damage to the cord). If left plugged in, the charger will automatically restart a complete charge cycle if the battery pack voltage drops below a minimum voltage or 30 days has elapsed.
7. If a fault occurred anytime during charging, a fault indication is given by flashing RED with a code corresponding to the error. There are several possible conditions that generate errors. Some errors are serious and require human intervention to first resolve the problem and then to reset the charger by interrupting AC power for at least 15 seconds. Others may be simply transient and will automatically recover when the fault condition is eliminated. To indicate which error occurred, a fault indication will flash RED a number of times, pause, and then repeat.
   [1 FLASH] Battery Voltage High: auto-recover
   [2 FLASH] Battery Voltage Low: auto-recover
   [3 FLASH] Charge Timeout: the charge did not complete in the allowed time. This may indicate a problem with the battery pack (voltage not attaining the required level), or that the charger output was reduced due to high ambient temperatures.
   [4 FLASH] Check Battery: the battery pack could not be trickle charged up to the minimum level required for the charge to be started. This may indicate that one or more cells in the battery pack are shorted or damaged.
   [5 FLASH] Over-Temperature: auto-recover. Charger has shutdown due to high internal temperature which typically indicates there is not sufficient airflow for cooling – see Installation Instructions 1). Charger will restart and charge to completion if temperature comes within accepted limits.
   [6 FLASH] QuiQ Fault: an internal fault has been detected. If Fault 6 is again displayed after interrupting AC power for at least 15 seconds, the charger must be brought to a qualified service depot.

Maintenance Instructions

1. For flooded lead-acid batteries, regularly check water levels of each battery cell after charging and add distilled water as required to level specified by battery manufacturer. Follow the maintenance and safety instructions recommended by the battery manufacturer.
2. Make sure charger connections to battery terminals are tight and clean.
3. Do not expose charger to oil, dirt, mud or to direct heavy water spraying when cleaning vehicle.

See flip side for **Product Specifications** and **Installation Instructions** for qualified personnel.

Specifications

DC Output – see Operating Instructions

QuiQ Model: 912-	24xx	36xx	48xx	72xx
Voltage-nom (V)	24	36	48	72
Voltage-max (V)	33.6	50.4	67.2	100
Current-max (A)	25	21	18	12
Battery Type	Specific to selected algorithm			
Reverse Polarity	Electronic protection – auto-reset			
Short Circuit	Electronic current limit			

AC Input

All models	
Voltage-max (Vrms)	85 – 265
Frequency (Hz)	45 - 65
Current-max (Arms)	12A @ 104VAC (reduced 20%<104V)
Current – nominal (Arms)	10A @ 120VAC / 5A @ 230VAC
AC Power Factor	>0.98 at nominal input current

Operation

Charger Model: 912-	xx0x (10 LED)	xx1x (1 LED)
AC ON	Solid YELLOW	LED Active
AC LOW	Flash YELLOW	Flash YELLOW
Thermal Cutback	Flash Bargraph	Flash YELLOW
<80% Charge Indicator	-	Short Flash GREEN
>80% Charge Indicator	Solid YELLOW	Long Flash GREEN
100% Charge Indicator	Solid GREEN	Solid GREEN
Fault Indicator	Flash RED	Flash RED
DC Ammeter	LED Bargraph	-
Bat Temp Compensation	Automatic	Optional
Maintenance Mode	Auto-restart if V<2.1Vpc or 30 days elapse	

Mechanical

All models	
Dimensions	28.0 x 24.5 x 11.0 cm (11 x 9.7 x 4.3")
Weight	<5 kg (<11 lbs) w/ standard output cord
Environmental	Enclosure: IP46
Operating Temperature	-30°C to +50°C (-22°F to 122°F), derated above 30°C, below 0°C
Storage Temperature	-40°C to +70°C (-40°F to 158°F)
AC input connector	IEC320/C14 (require ≥1.8m localized cord)
DC output connector	OEM specific w/ 12AWG wire

Regulatory

Safety	
EN 60335-1/2-29	Safety of Appliances/ Battery Chargers
UL2202	EV Charging System Equipment
UL1564 2nd Edition	Industrial Battery Charger
CSA-C22.2 No. 107.2	Battery Chargers- Industrial
Emissions	
FCC Part 15/ICES 003	Unintentional Radiators Class A
EN 55011	Radio disturbance characteristics (Class A)
EN 61000-3-2	Limits for harmonic current emissions
EN 61000-3-3	Limits of voltage fluctuations and flicker
Immunity	
EN 61000-4-2	Electrostatic discharge immunity
EN 61000-4-3	Radiated, radio-frequency, EMF immunity
EN 61000-4-4	Electrical fast transient/burst immunity
EN 61000-4-5	Surge immunity
EN 61000-4-6	Conducted Immunity
EN 61000-4-11	Voltage variations immunity

Installation Instructions

WARNING: The output of chargers with greater than 48V may pose an energy and/or shock hazard under normal use. These units must be installed in the host equipment in such a manner that the output cable and battery connections are only accessible with the use of a tool by qualified personnel.

1) Determine Mounting Location:

While its sealed nature allows the charger to be mounted virtually anywhere, the choice of mounting location and orientation is extremely important. For optimum performance and shortest charge times, mount the charger in an area with adequate ventilation. The charger should also be mounted in an area that will be relatively free of oil, dirt, mud, or dust since accumulations within the fins of the charger will reduce their heat-dissipating qualities. Optimal cooling also occurs when the charger is mounted on a horizontal surface with the fins vertical. More airflow from below the charger will help cool the fins, so mounting above open areas or areas with cut-outs for airflow is desirable. Contact Delta-Q for information on other mounting orientations. As the charger may get hot in operation, the charger must be installed such that risk of contact by people is reduced. The charger's AC plug must be located at least 18" above the floor/ ground surface and the status display must be visible to the user.

2) Mounting Procedure:

Mount the charger by the mounting plate using appropriate fasteners (i.e. 1/4" or M6 with locking hardware). For UL2202 compliance, a 12AWG green bonding wire with ring terminals must be attached from the bonding stud located on the front of the charger (identified by ⏚) to the vehicle frame. The vehicle connection must be made using corrosion resistant hardware (e.g., a #10 stainless steel machine screw with at least two threads of engagement and, if required, a paint piercing washer).

3) DC Battery Connection Procedure:

a) The green wire outputs battery voltage when the charger is not plugged into AC to provide an interlock function – see Fig. 1. **If used, a user-supplied 1A fast-blow external fuse must be installed inline to prevent damage. Shorting or drawing more than 1A may damage charger and void the warranty.**

b) Securely fasten the black ring terminal from the charger to the negative terminal ("-", "NEG", NEGATIVE") of the battery pack.

c) Check that the correct charge algorithm is being used – refer to section 4). Securely fasten the red ring terminal to the positive terminal ("+", "POS", "POSITIVE") of the battery pack.

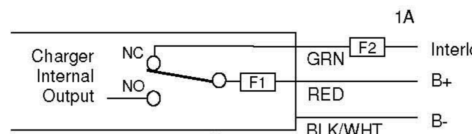

Figure 1

4) Check / Change Charging Algorithm:

The charger comes pre-loaded with algorithms for batteries as detailed in Table 1. If your specific battery model is not listed, please contact Delta-Q.

Each time AC power is applied with the battery pack NOT connected, the charger enters an algorithm select/display mode for approximately 11 seconds. During this time, the current Algorithm # is indicated on the '80%' LED (Models 912-xx0x) or on the single LED (Models 912-xx1x). A single digit Algorithm # is indicated by the number of blinks separated by a pause. A two digit Algorithm # is indicated by the number of blinks for the first digit followed by a short pause, then the number of blinks for the second digit followed by a longer pause.

To check / change the charging algorithm:

a) Disconnect the charger positive connector from battery pack. Apply AC power and after the LED test, the Algorithm # will display for 11 seconds.

b) To change algorithm, touch positive connector during the 11 second display period to the battery pack's positive terminal for 3 seconds and then remove – the Algorithm # will advance after 3 seconds. Repeat until desired Algorithm # is displayed. A 30 second timeout is extended for every increment. Incrementing beyond the last Algorithm moves back to the first Algorithm. After desired Algorithm # is displayed, touch the charger connector to the battery positive until the output relay is heard to click (~10 seconds) – algorithm is now in permanent memory.

c) Remove AC power from the charger and reconnect the charger positive connector to the battery pack. It is highly recommended to check a newly changed algorithm by repeating step 4) above.

Alg #	Battery Type
43	Discover AGM
27	Crown CR-325
21	Exide Flooded
12	Exide/Sonnenschein Gel
7	J305 DV/DT CP
6	DEKA 8G31 Gel
5	Trojan 30/31XHS
4	US Battery USB2200
3	T105 DV/DT CP
1	Trojan T105

Table 1.

Product warranty is two years - please contact dealer of original equipment for warranty service.

Note: This is a Class A product. In a domestic environment this product may cause radio interference, in which case the user may be required to take adequate measures.

POWER IN MOTION

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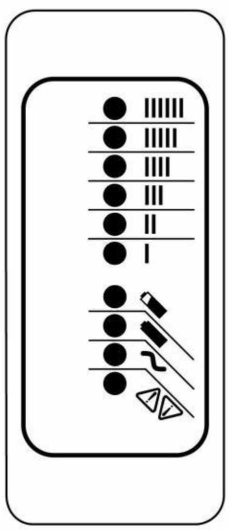
QuiQ Charger Troubleshooting Guide

Delta-Q's QuiQ charger is designed for a long, trouble-free service life. Occasionally, the user may encounter abnormal operation which can usually be corrected by following the procedures in this guide.

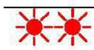
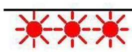
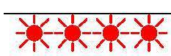
Indications on the Charger 10-LED Display

LED indications following "Power-On Self Test":

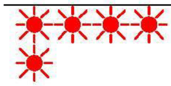


Ammeter (Amber)	IIIIII IIIII IIII III II I	**Solid:**	Displays approximate scale of current output during bulk phase. Also indicates algorithm #1-6 for 11 seconds if no battery is connected.
		Flashing:	High internal charger temperature. Current output reduced. • Provide better airflow to the charger. • Try to move the charger to a cooler location. • Confirm that dirt or mud is not blocking the cooling fins of the charger. Clean the charger. Rinse charger with low pressure hose if required. Do not use high pressure. Do not use a pressure washer.
80% Charge (Amber)		**Solid:**	Bulk charge phase complete, 80% charged. In Absorption phase.
		Flashing:	With no battery connected, indicates algorithm # selected by number of flashes.
100% Charge (Green)		**Solid:**	Charging complete. Charger in Maintenance Mode.
		Flashing:	Absorption phase complete. In Finish phase
AC On (Amber)		**Solid:**	AC Power good
		Flashing:	Low AC Voltage, check voltage and extension cord length (max 100', 12-AWG or 50' 14-AWG).
Fault (Red)		**Flashing:**	Charger error. Check code and refer to troubleshooting guide below.

Fault Indications:

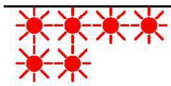
Fault LED Flashes (Red)	Explanation and Solution
	High Battery Voltage Detected • Check that the battery charger voltage is consistent with the battery pack voltage. The first two digits of the four digit model name indicate the battery voltage the charger supports. • Check for wiring errors. • High battery voltage could also occur if there is another source charging the battery. Disconnect any other sources during charging. • If this problem does not clear after the battery voltage is confirmed to be less than 2.4V per cell, return the charger for service. • This fault will automatically clear and the charger will restart charging when this problem is removed.
	Low Battery Voltage Detected • Check the battery and connections to the battery. • Check the nominal battery voltage. The first two digits of the four digit model name indicate the battery voltage the charger supports. Confirm that a nominal battery voltage is the same as the charger voltage. • If this problem does not clear after the battery voltage is confirmed to be higher than 1V per cell and all connections are good, return the charger for service. • This fault will clear automatically when the low battery voltage problem is rectified.
	Charge Timeout - Indicates the battery failed to charge within the allowed time. This could occur if the battery is of larger capacity than the algorithm is intended for. In unusual cases it could mean charger output is reduced due to high ambient temperature. It can also occur if the battery is damaged, old, or in poor condition. • Check the battery for damage such as shorted cells and insufficient water. Try the charger on a good battery. • If the same fault occurs on a good battery, check the connections on the battery and connection to AC power, and AC voltage. • Confirm that the nominal battery pack voltage is the same as the battery charger voltage. • If a charger displays this fault on a battery pack, and the pack is of questionable status, reset the charger by disconnecting AC power for 30 seconds, and then reconnect the AC to start a new charge cycle. After a few charge cycles this problem could stop occurring as the pack "recovers." • This fault must be cleared manually by unplugging the AC, waiting 30 seconds and reconnecting the ac power.
	Check Battery - This fault indicates the battery pack could not be trickle charged up to the minimum level required for the normal charge cycle to be started. • Check that none of the battery pack connections between modules are reversed or incorrectly connected. • Check that one or more cells in the battery are not shorted. • Confirm that the nominal battery pack voltage is the same as the battery charger voltage.

- Try the charger on a good battery.
- If this fault occurs the battery pack is likely in poor condition. Try to recover the pack with a charger that can charge the individual cells – such as an automotive charger. Be sure to set this charger to the appropriate voltage – 6V per 6V battery, 12V per 12V string/battery.



Over-Temperature: This fault indicates the charger has become too hot during operation. This extra fault indication (as opposed to the flashing ammeter described above), indicates an even higher temperature was reached inside the charger. Though not damaging to the charger, charge time will be extended significantly

- This fault indication will not clear automatically, but the charger will restart charging automatically when the temperature drops. The fault indication must be cleared manually by unplugging the AC power, waiting 30 seconds and reconnecting the AC.
- If possible, install the charger in a cooler location or increase cooling air flow to the cooling fins.
- Confirm that dirt or mud is not blocking the cooling fins of the charger. If required, clean the charger by rinsing it with a low pressure hose. Do not use high pressure. Do not use a pressure washer.



QuiQ Internal Fault: This fault indicates that the batteries will not accept charge current, or an internal fault has been detected in the charger. This fault will nearly always be set within the first 30 seconds of operation. If it occurs after the charger has started charging normally, be sure to make a note of it.

- Try to clear the fault by unplugging AC power, waiting 30 seconds and reconnecting the AC.
- Check all battery connections. Look for a high resistance connection. The most likely reason for this fault is a fault in the battery such as a bad battery connection, an open cell, or insufficient water.
- This fault will occur if an internal fuse inside the charger blows. If the green wire is shorted to ground even momentarily this fuse will blow. To check the fuse, measure with an ohmmeter between the green and red wires with the AC disconnected. If a short circuit is not measured, the fuse has blown. Return unit to a service depot to have this fuse replaced.
- For software revision 0.81 or older, this fault may indicate that the input or output voltage went out of range. Check input and output connections before returning the unit to a service depot. Charger may need to be brought to a service depot to have its software upgraded. Refer to the lower right hand corner on the back of the Product Manual to determine the software revision.
- If this fault occurs after battery charging has started, confirm that AC power was not interrupted and that all battery connections are good.
- If all battery connections are good, an internal fault has been detected and the charger must be brought to a qualified service depot.

Other Indications:

Indication	Explanation and Solution
AC On LED Lit, Charger won't start charging.	Charger has detected a condition that does not allow it to charge

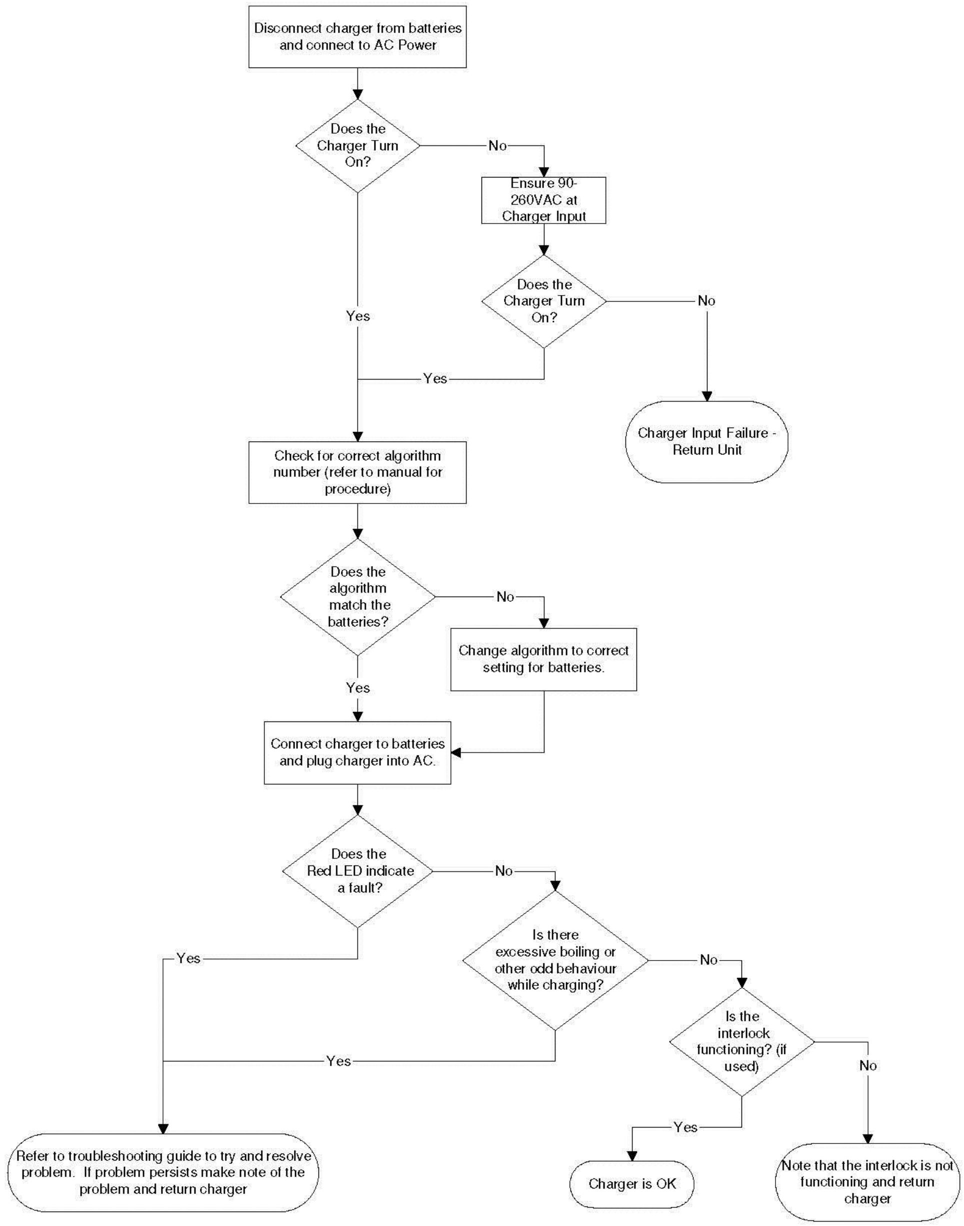
	• Confirm battery connections are good. • The nominal voltage for a lead acid battery is 2 V per cell. For example, a 48V battery will have 48/2 = 24 cells. • If the battery voltage is greater than 2.5V per cell, the charger will not start charging. • If the battery voltage is less than 0.5V per cell, the charger will not start. • For software revisions 0.81 or lower, the charger will not start charging if the battery voltage is less than 1V per cell. Refer to the lower right hand corner of the back of the Product Manual to determine the software revision. • Check for any fault codes that might be set and refer to the descriptions above. • A fully charged battery will draw very little current, but will not show 100% charged immediately. The charger will change to Absorption mode in under 5 minutes once the conditions for the end of bulk charge have been met. The 80% LED will illuminate at this time. During the final phase of charging, the battery will only accept a very small current – the charger is unable to accelerate this portion of the charge cycle without damaging the battery.
Excessive Battery Watering or Strong Sulphur (Rotten Egg) Smell	Overcharging or high battery temperature. These symptoms are unlikely to be caused by too high a charge current since the maximum charge current of the charger will be small compared to even a moderately sized battery pack. The most likely cause for this problem is incorrect charge algorithm setting and/or high ambient temperatures. • Confirm that the battery pack is not too small – usually > 50Ah. • Confirm that the nominal battery voltage matches the charger output voltage. • Confirm the correct battery charge algorithm. If the battery pack is new, the algorithm will need to be changed if the pack is not the same as the old one. Refer to the Product Manual for instructions on how to determine and change the battery charge algorithm. • If the output voltage of the charger seems excessive, return the charger for service. Contact Delta-Q to get the expected battery voltage settings for the charger in question. Be sure to have the charger's serial number and charge algorithm setting available when calling.
Difficulty Changing the Default Battery Charge Algorithm	The mode to change the battery charge algorithm can only be selected during the first 10 seconds of operation. Refer to the Product Manual for instructions. If the 10 second window is missed, cycle AC power by unplugging the charger, waiting 30 seconds, and reconnecting AC power. To extend Battery Charge Algorithm Change Mode by 30 seconds (120 seconds on newer models), connect the charger output to a good battery for approximately 1 second and then disconnect the battery again.

General Troubleshooting

Should the condition of a charger be in doubt, the flow chart on the next page should be followed to check the charger's operating condition.

19Aprr07 chui@delta-q.com

Delta-Q Technologies
QuiQ Charger Troubleshooting Flow Chart



Power Supply Data Sheet

SAGER POWER SYSTEMS

MEAN WELL
RSP-1500 SERIES
1500 Watt Enclosed with Fan Power Supply

Measures: 10.95 x 5.00 x 3.29"

■ Features :
- Universal AC input/Full range
- ZVS new technology
- AC input active surge current limiting
- High efficiency up to 91%
- Built-in active PFC function,PF>0.95
- Protections: Short circuit / Overload / Over voltage / Over temperature
- Forced air cooling by built-in DC ball bearing fan
- Output voltage can be trimmed between 70~100% of the rated output voltage
- High power density 8.3W/inch^3
- Current sharing up to 6000W(3+1)
- Alarm signal output
- Built-in 12V/0.1A auxiliary output for remote control
- Built-in remote ON-OFF control
- Built-in remote sense function
- 5 years warranty

CB CE

SPECIFICATION

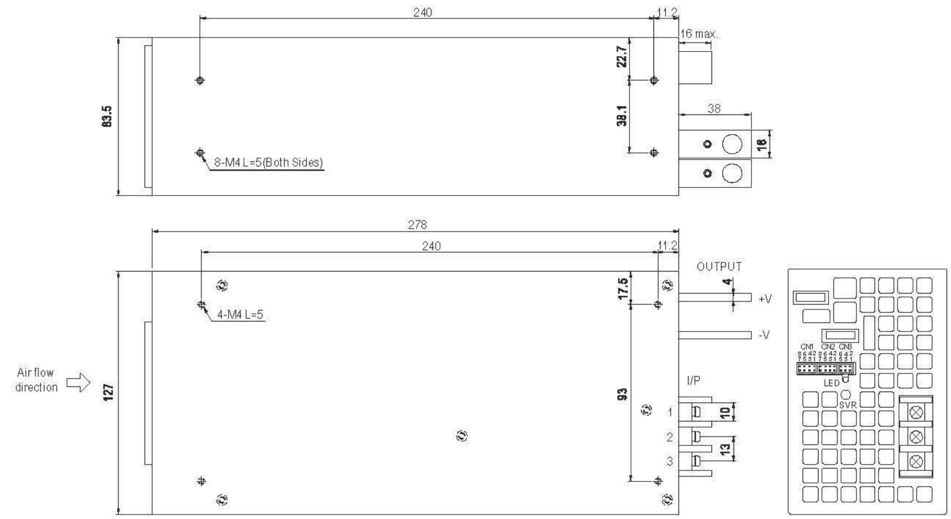
MODEL		RSP-1500-5	RSP-1500-12	RSP-1500-15	RSP-1500-24	RSP-1500-27	RSP-1500-48
OUTPUT	DC VOLTAGE	5V	12V	15V	24V	27V	48V
	RATED CURRENT	240A	125A	100A	63A	56A	32A
	CURRENT RANGE	0 ~ 240A	0 ~ 125A	0 ~ 100A	0 ~ 63A	0 ~ 56A	0 ~ 32A
	RATED POWER	1200W	1500W	1500W	1512W	1512W	1536W
	RIPPLE & NOISE (max.) Note.2	150mVp-p	150mVp-p	150mVp-p	150mVp-p	150mVp-p	200mVp-p
	VOLTAGE ADJ. RANGE	4.5 ~ 5.5V	10 ~ 13.5V	13.5 ~ 16.5V	20 ~ 26.4V	24 ~ 30V	43 ~ 56V
	VOLTAGE TOLERANCE Note.3	±2.0%	±1.0%	±1.0%	±1.0%	±1.0%	±1.0%
	LINE REGULATION	±0.5%	±0.5%	±0.5%	±0.5%	±0.5%	±0.5%
	LOAD REGULATION	±2.0%	±0.5%	±0.5%	±0.5%	±0.5%	±0.5%
	SETUP, RISE TIME	1500ms, 100ms at full load					
	HOLD UP TIME (Typ.)	10ms at full load		14ms at full load		16ms at full load	
INPUT	VOLTAGE RANGE	90 ~ 264VAC 127 ~ 370VDC					
	FREQUENCY RANGE	47 ~ 63Hz					
	POWER FACTOR (Typ.)	0.95/230VAC 0.98/115VAC at full load					
	EFFICIENCY (Typ.)	80%	87%	87%	90%	90%	91%
	AC CURRENT (Typ.)	17A/115VAC 8A/230VAC					
	INRUSH CURRENT (Typ.)	30A/115VAC 60A/230VAC					
	LEAKAGE CURRENT	<2.0mA / 240VAC					
PROTECTION	OVERLOAD Note.5	105 ~135% rated output power					
		Protection type : Constant current limiting unit will shut down o/p voltage after 5sec. Re-power on to recover					
	OVER VOLTAGE	5.75 ~ 6.75V	13.8 ~ 16.8V	17 ~ 20.5V	27.6 ~ 32.4V	31 ~ 36.5V	57.6 ~ 67.2V
		Protection type : Shut down o/p voltage, re-power on to recover					
	OVER TEMPERATURE	Shut down o/p voltage, recovers automatically after temperature goes down					
FUNCTION	AUXILIARY POWER(AUX)	12V@0.1A(Only for Remote ON/OFF control)					
	REMOTE ON/OFF CONTROL	Please see the Function Manual					
	ALARM SIGNAL OUTPUT	Please see the Function Manual					
	OUTPUT VOLTAGE TRIM	Please see the Function Manual					
	CURRENT SHARING	Please see the Function Manual					
ENVIRONMENT	WORKING TEMP.	-20 ~ +70℃ (Refer to "Derating Curve")					
	WORKING HUMIDITY	20 ~ 90% RH non-condensing					
	STORAGE TEMP., HUMIDITY	-40 ~ +85℃, 10 ~ 95% RH					
	TEMP. COEFFICIENT	±0.05%/℃ (0 ~ 50℃)					
	VIBRATION	10 ~ 500Hz, 2G 10min./1cycle, 60min. each along X, Y, Z axes					
SAFETY & EMC (Note 4)	SAFETY STANDARDS	UL60950-1, TUV EN60950-1 approved					
	WITHSTAND VOLTAGE	I/P-O/P:3KVAC I/P-FG:2KVAC O/P-FG:0.5KVAC					
	ISOLATION RESISTANCE	I/P-O/P, I/P-FG, O/P-FG:100M Ohms / 500VDC / 25℃/ 70% RH					
	EMC EMISSION	Compliance to EN55022 (CISPR22), EN61000-3-2,-3					
	EMC IMMUNITY	Compliance to EN61000-4-2,3,4,5,6,8,11, EN55024, light industry level, criteria A					
OTHERS	MTBF	62.6K hrs min. MIL-HDBK-217F (25℃)					
	DIMENSION	278*127*83.5mm (L*W*H)					
	PACKING	3.0Kg; 4pcs/13Kg/1.19CUFT					
NOTE	1. All parameters NOT specially mentioned are measured at 230VAC input, rated load and 25℃ of ambient temperature. 2. Ripple & noise are measured at 20MHz of bandwidth by using a 12" twisted pair-wire terminated with a 0.1uf & 47uf parallel capacitor. 3. Tolerance : includes set up tolerance, line regulation and load regulation. 4. The power supply is considered a component which will be installed into a final equipment. The final equipment must be re-confirmed that it still meets EMC directives. For guidance on how to perform these EMC tests, please refer to "EMI testing of component power supplies." (as available on http://www.meanwell.com) 5. Derating may be needed under low input voltages. Please check the derating curve for more details.						

File Name:RSP-1500-SPEC 2013-11-01

MEAN WELL
RSP-1500 SERIES
1500 Watt Enclosed with Fan Power Supply
Measures: 10.95 x 5.00 x 3.29"

■ Mechanical Specification

Case No.943A Unit:mm



AC Input Terminal Pin No. Assignment

Pin No.	Assignment
1	FG ⏚
2	AC/N
3	AC/L

Control Pin No. Assignment(CN1,CN2) : HRS DF11-8DP-2DS or equivalent

Pin No.	Assignment	Pin No.	Assignment	Mating Housing	Terminal
1	RCG	4	TRIM	HRS DF11-8DS or equivalent	HRS DF11-**SC or equivalent
2	RC2	6	LS(Current Share)		
3,5,7	-S	8	+S		

RCG: Remote ON/OFF Ground
RC2: Remote ON/OFF
-S : -Remote Sensing
TRIM: Adjustment of Output Voltage
LS: Load Share
+S: +Remote Sensing

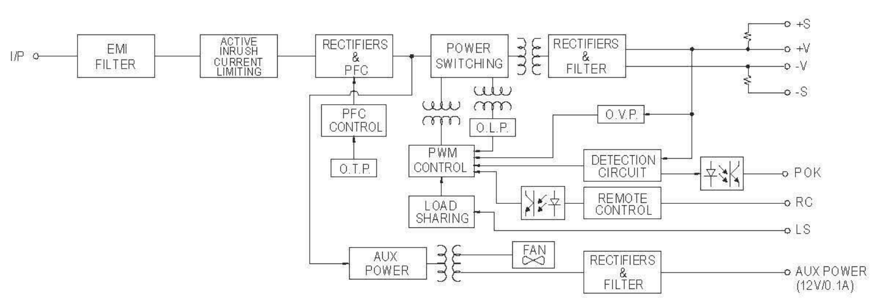
Control Pin No. Assignment(CN3) : HRS DF11-6DP-2DS or equivalent

Pin No.	Assignment	Pin No.	Assignment	Mating Housing	Terminal
1	P OK GND	4	AUXG	HRS DF11-6DS or equivalent	HRS DF11-**SC or equivalent
2	POK	5	RC1		
3	RCG	6	AUX		

P OK GND: Power OK Ground
P OK: Power OK Signal
RCG: Remote ON/OFF Ground
AUXG: Auxiliary Ground
RC1: Remote ON/OFF
AUX: Auxiliary Output

■ Block Diagram

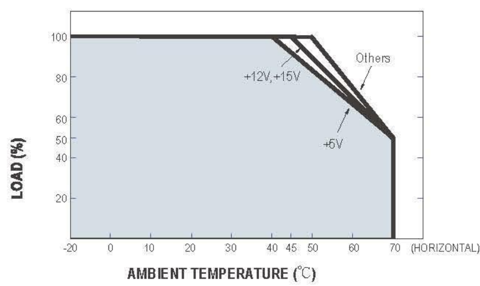
PFC fosc : 70KHz
PWM fosc : 100KHz



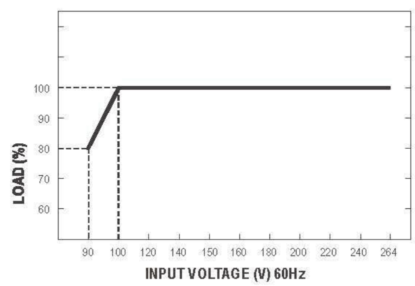
File Name:RSP-1500-SPEC 2013-11-01

MEAN WELL
RSP-1500 SERIES
1500 Watt Enclosed with Fan Power Supply
Measures: 10.95 x 5.00 x 3.29"

■ Derating Curve



■ Static Characteristics



■ Function Manual

1.Remote ON/OFF

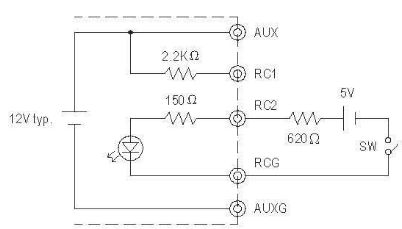
(1)Remote ON/OFF control becomes available by applying voltage in CN1 & CN2 & CN3
(2)Table 1.1 shows the specification of Remote ON/OFF function
(3)Fig.1.2 shows the example to connect Remote ON/OFF control function

Table 1.1 Specification of Remote ON/OFF

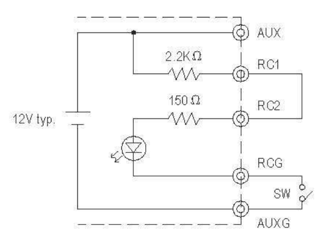
Connection Method		Fig. 1.2(A)	Fig. 1.2(B)	Fig. 1.2(C)
SW Logic	Output on	SW Open	SW Open	SW Close
	Output off	SW Close	SW Close	SW Open

Fig.1.2 Examples of connecting remote ON/OFF

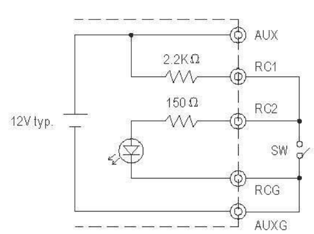
(A)Using external voltage source



(B)Using internal 12V auxiliary output



(C)Using internal 12V auxiliary output



File Name:RSP-1500-SPEC 2013-11-01

MEAN WELL
RSP-1500 SERIES
1500 Watt Enclosed with Fan Power Supply
Measures: 10.95 x 5.00 x 3.29"

2.Alarm Signal Output

(1)Alarm signal is sent out through "P OK" & "P OK GND" pins
(2)An external voltage source is required for this function. The maximum applied voltage is 50V and the maximum sink current is 10mA
(3)Table 2.1 explain the alarm function built-in the power supply

Function	Description	Output of alarm(P OK)
P OK	The signal is "Low" when the power supply is above 65% of the rated output voltage-Power OK	Low (0.5V max at 10mA)
	The signal turns to be "High" when the power supply is under 65% of the rated output voltage-Power Fail	High or open (External applied voltage 10mA max.)

Table 2.1 Explanation of alarm

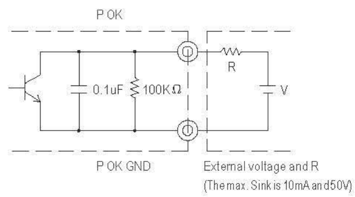


Fig. 2.2 Internal circuit of P OK (Open collector method)

3.Output Voltage TRIM

(1)Adjustment of output voltage is possible between 70~100% (Typ.) of the rated output which is shown in Fig. 3.1
(2)Connecting a resistor externally between TRIM and-S on CN1 or CN2 that is shown in Fig. 3.2.
(3)+S & +V, -S & -V also need to be connected on CN1 or CN2.

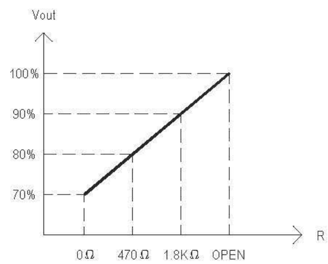


Fig. 3.1 External Resistor (Typical)

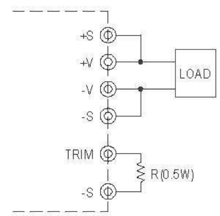
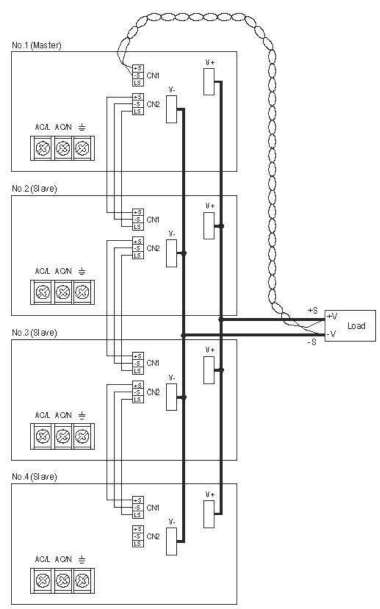


Fig. 3.2 Output voltage trimming

4.Current Sharing

(1)Parallel operation is available by connecting the units shown as below (+S,-S and LS are connected mutually in parallel):
(2)The voltage difference among each output should be minimized that less than 0.2V is required
(3)The total output current must not exceed the value determined by the following equation (Output current at parallel operation)=(The rated current per unit)×(Number of unit)×0.9
(4) In parallel operation 4 units is the maximum, please consult the manufacture for other applications
(5) When remote sensing is used in parallel operation, the sensing wire must be connected only to the master unit



File Name:RSP-1500-SPEC 2013-11-01

Generator Battery Data

SPECIFICATIONS	
Pulse (5-second) Hot Cranking Amps (PHCA)	1200
Cold Cranking Amps (CCA)	540
20Hr Nominal Capacity (Ah)	42
Reserve Capacity Minutes	78
Dimensions L x W x H (in)	7.87 x 6.66 x 6.80
Metric Dimensions L x W x H (mm)	199.9 x 169.1 x 172.7
Weight (lbs)	38.2
Weight (kg)	17.4

Main Battery Data Sheet

US 8VGCE XC2, US 8VGC XC2, US 8VGCHC XC2

DATA SHEET Deep Cycle 8 -Volt

Application: Wherever Deep Cycle 8-volt batteries are needed.

Dimensions: 10-1/4 (260)L x 7-1/8 (181)W x 11-1/4 (286)H

Type: Flooded Lead Acid (FLA) non-sealed.

Case material: Polypropylene / Heat Sealed

US 8VGCE XC2, US 8VGC XC2, US 8VGCHC XC2 - SPECIFICATIONS

BCI Group Size	Model	1-hr Rate	2-hr Rate	5-hr Rate	6-hr Rate	10-hr Rate	20-hr Rate	48-hr Rate	72-hr Rate	100-hr Rate	Voltage	Standard Terminal Type	AMP HOURS (20 HR. RATE)	MINUTES @ 75 AMPS	MINUTES @ 56 AMPS	MINUTES @ 25 AMPS	Length	Width	Height	wet Weight Lbs (kg)
GC8	US 8VGCE XC2	75	84	97	100	108	121	128	132	135	8	UTL	121	60	90	222	10-1/4 (260)	7-1/8 (181)	11-1/4 (286)	55 (24.7)
GC8	US 8VGC XC2	105	118	138	142	153	170	180	185	189	8	UTL	170	90	128	337				64 (29.2)
GC8	US 8VGCHC XC2	109	124	147	152	164	183	194	199	203	8	UTL	183	95	136	365				67 (30.4)

TERMINAL OPTIONS:

VENT CAP OPTIONS:

CHARGING INSTRUCTIONS:

Following is the charging recommendation and charging profile using 2 stage chargers for US Battery deep cycle products. *Equalization and float charge modes are not considered to be one of the stages in a charging profile.

1. **Bulk Charge** — Constant current @~10% of C/20 Ah in amps to 2.45+/-0.05 volts per cell (e.g. 7.35 volts +/-0.15 volts per 6 volt battery)
2. **Absorption Charge** — Constant voltage (2.45+/-0.05 vpc) to 3% of C/20 Ah in amps then hold for 2-3 hours and terminate charge. Charge termination can be by maximum time (2-4 hr) or dV/dt (4 mv/cell per hour)

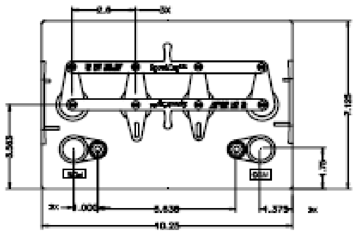
- (Optional Float Charge) — Constant voltage 2.17 vpc (6.51 volts per 6 volt battery) for unlimited time
- Equalization Charge — Constant voltage (2.55+/-0.05 vpc) extended for 1-3 hours after normal charge cycle (repeat every 30 days)

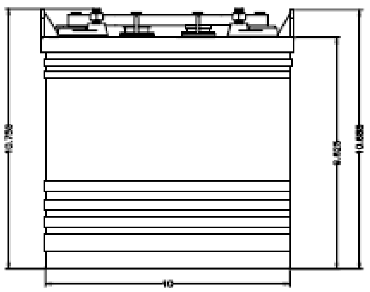
Notes: Charge time from full discharge is 9-12 hours.
Absorption charge time is determined by the battery but will usually be ~3 hours at 2.45 volts per cell.
Float time is unlimited at 2.17 volts per cell.
Specific gravity at full charge is 1.270 minimum

Battery temperature adjustment: reduce the voltage by 0.028 Volts per cell for every 10°F above 80°F, increase by the same amount for temperatures below 80°F.

Deep cycle batteries need to be equalized periodically. Equalizing is an extended, low current charge performed after the normal charge cycle. This extra charge helps keep all cells in balance. Actively used batteries should be equalized once per month. Manually timed chargers should have the charge time extended approximately 3 hours. Automatically controlled chargers should be unplugged and reconnected after completing a charge.

For more information or questions, please visit **WWW.USBATTERY.COM**





US 8VGCE XC2, US 8VGC XC2, US 8VGCHC XC2

DATA SHEET Deep Cycle 8 -Volt

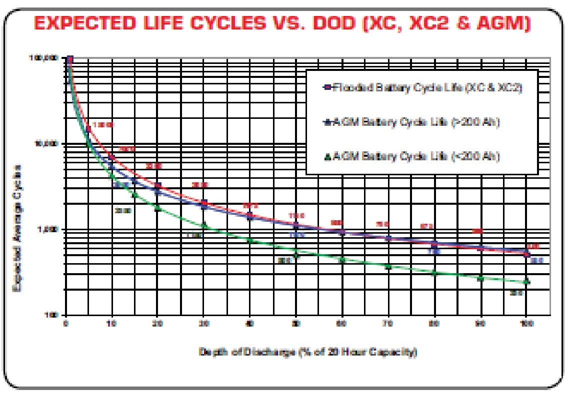
U.S. Battery Recommended Terminal Torque and Connection Hardware

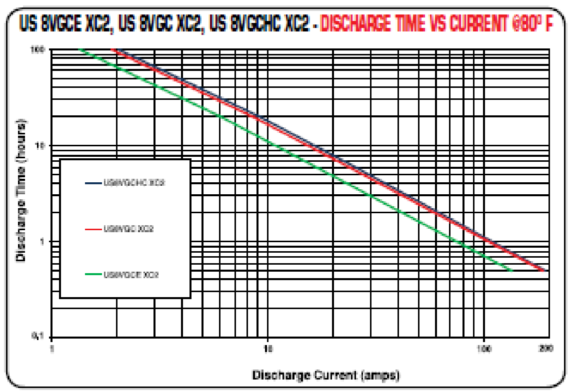
U.S. Battery Terminal Type	Recommended Torque (in-lb)	Recommended Torque (ft-lb)	Recommended Connection Hardware
UTL	95-105	7.9-8.8	[1]SS Hexnut with Lock Washer
UT	95-105	7.9-8.8	[1]SS Hexnut with Lock Washer
Flat Block	95-105	7.9-8.8	[1]SS Hexnut with Lock Washer
Dual	95-105	7.9-8.8	[1&5]SS Hexnut with Lock Washer
DC Marine	95-105	7.9-8.8	[2]SS Hexnut with Lock Washer
Off-Set "S"	100-120	8.3-10	[3]Zn or SS Bolt w/Hexnut & Lock Washer
Flag	100-120	8.3-10	[4]Zn or SS Bolt w/Hexnut & Lock Washer
Large "L"	100-120	8.3-10.0	[4]Zn or SS Bolt w/Hexnut & Lock Washer
Small "L"	100-120	8.3-10.0	[4]Zn or SS Bolt w/Hexnut & Lock Washer
Bus Lug	120-180	10.0-15.0	[5]SS Hexnut with Lock Washer
SAE	50-70	4.2-5.8	[6]No Hardware Supplied

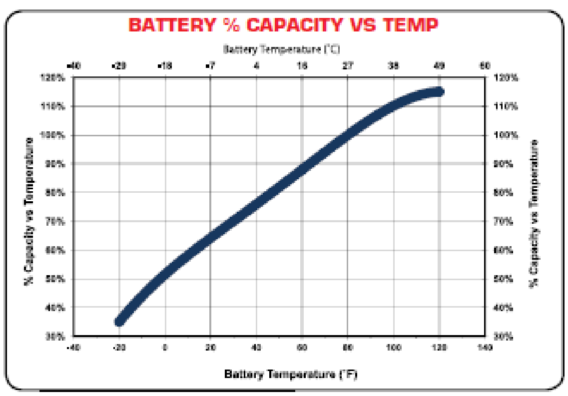
Proper connection is to position a lock washer between the nut and the connector (never between the connector and lead terminal) and apply the recommended torque or enough torque to completely compress the lock washer without deforming the lead terminal.

[1]Stainless Steel Hexnut with Stainless Steel Split-Ring Lock Washer (5/16" Positive & Negative)
[2]Stainless Steel Hexnut with Stainless Steel Split-Ring Lock Washer (3/8" Positive & 5/16" Negative)
[3]Square-Head, SS or Zinc-Plated Bolt with SS or Zinc-Plated Hexnut & Split-Ring Lock Washer
[4]Square-Head or Hex-Head, SS or Zinc-Plated Bolt with SS or Zinc-Plated Hexnut & Split-Ring Lock Washer
[5]Stainless Steel Hexnut with SS Split-Ring Lock Washer (1/2" Positive or 3/8" Positive & 3/8" Negative)
[6]No Hardware Supplied - Application Uses SAE Clamp for Positive & Negative Tapered Post

Note: The use of flanged nuts and other types of nuts with captive washers or other hardware not listed above is not recommended by US Battery and their use may void the battery warranty.







U.S. Battery Operating Temperature Guidelines

For charging, we recommend staying within 0°F to120°F (-18 to 49°C) to avoid charging frozen batteries at low temperature or going into thermal runaway at high temperature.

For discharging, we recommend -20°F to 120°F (-29 to 49°C). Batteries discharged at temperatures below 32°F (0°C) should be re-charged immediately to avoid freezing.

Batteries discharged at temperatures above 120°F (49°C) should be allowed to cool before recharging.

Extreme temperatures can substantially effect battery performance and charging. Cold reduces battery capacity and retards charging. Heat increases water usage and can result in overcharging. Very high temperatures can cause "thermal run-away" which may lead to an explosion or fire. If extreme temperature is an unavoidable part of an application, consult a battery/charger specialist about ways to deal with the problem.

Data references within this publication are nominal and should not be considered or construed as maximum or minimum values for specifications or for final design. Data for this product type and model may vary from what is shown in this publication, and U.S. Battery Mfg., Co. makes No warranties, expressed or implied based on the data within this publication.

1675 Sampson Avenue
Corona, CA 92879
(800) 695-0945

1895 Tobacco Road
Augusta, GA 30906
(800) 522-0945

717 North Belair Rd.
Evans, GA 30809
(888) 811-0945

For more information or questions, please visit **WWW.USBATTERY.COM**

Appendix B: Test Plan Documentation

Temperature Sensor Tests

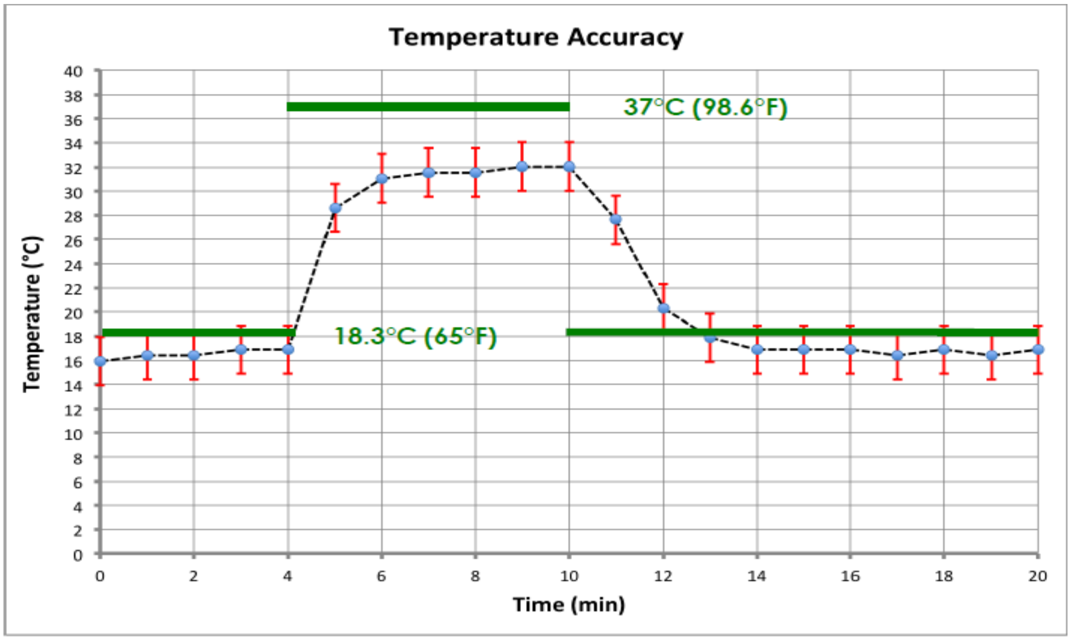


Figure 12: Temperature Sensor Testing - High Range

Figure 12 shows that at a temperature of 18.3°C, the temperature sensors worked within their acceptable range, but at higher temperatures, the temperature readings were significantly lower than the expected values.

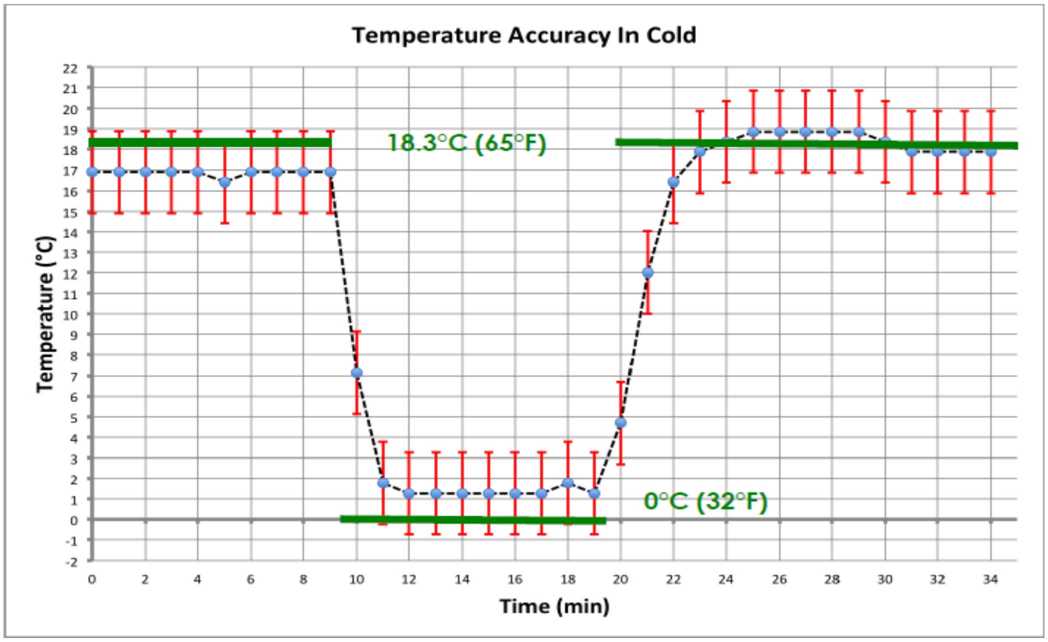


Figure 13: Temperature Sensor Testing - Low Range

Figure 13 again shows that at 18.3°C, the temperature sensor worked as expected, and when the temperature was brought down to 0°C, the temperature sensor reading was still within the acceptable range.

Current Sensor Tests

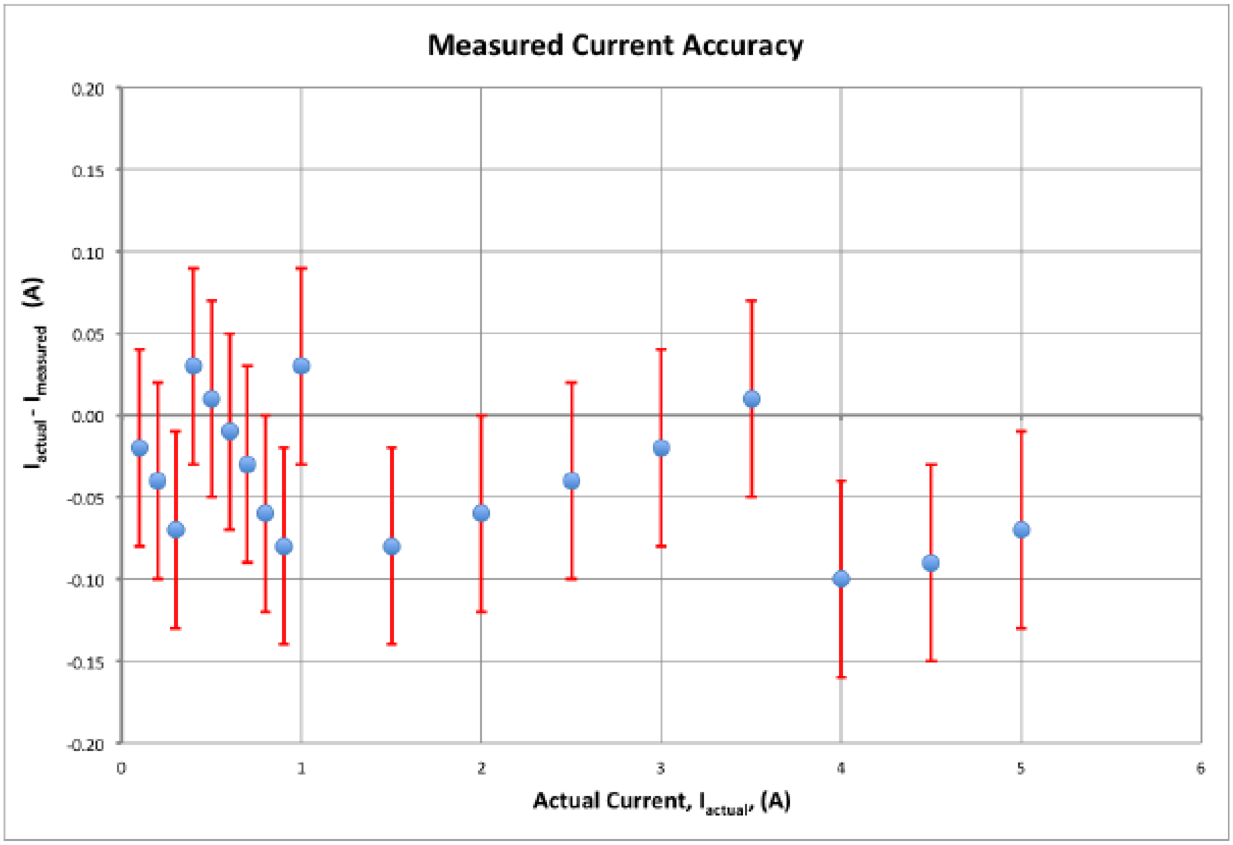


Figure 14: Current Sensor Testing

Figure 14 shows that the measured current from the current sensor was largely accurate within ±100mA. This acceptable for this design, since the currents that need to be measured for the design to work are one to two orders of magnitude larger.

Voltage Sensor Tests

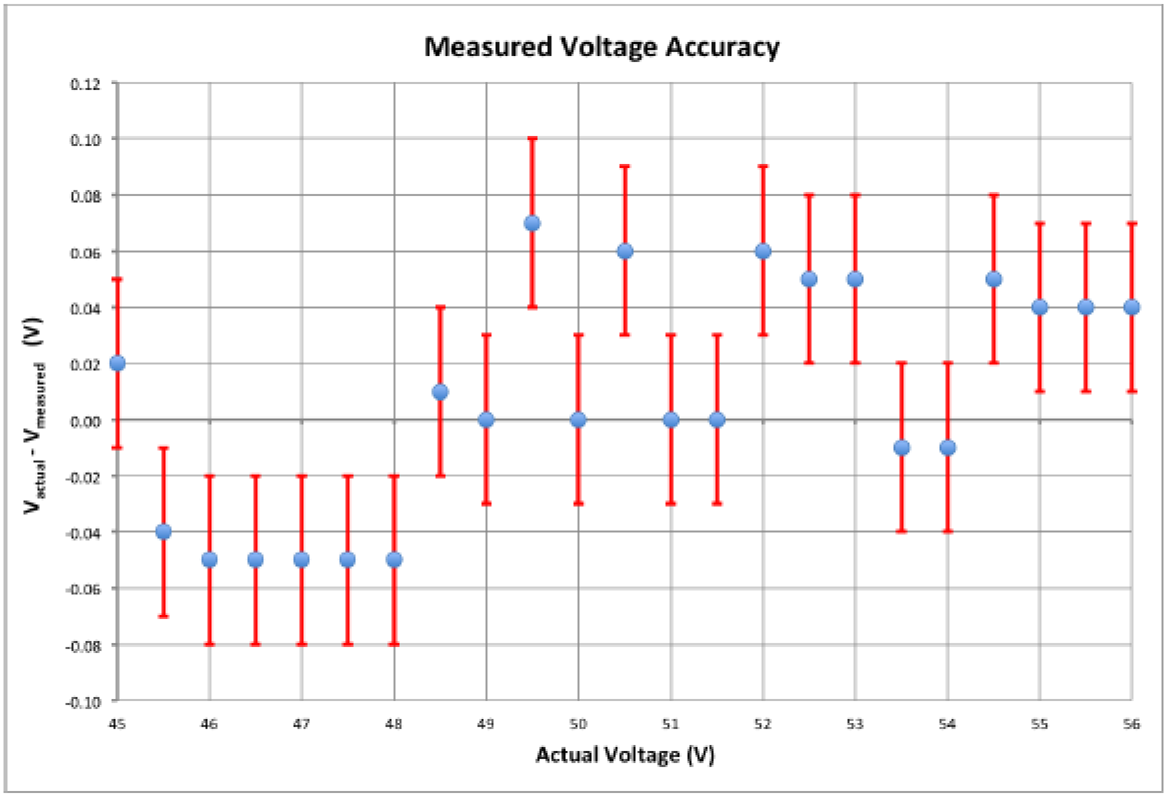
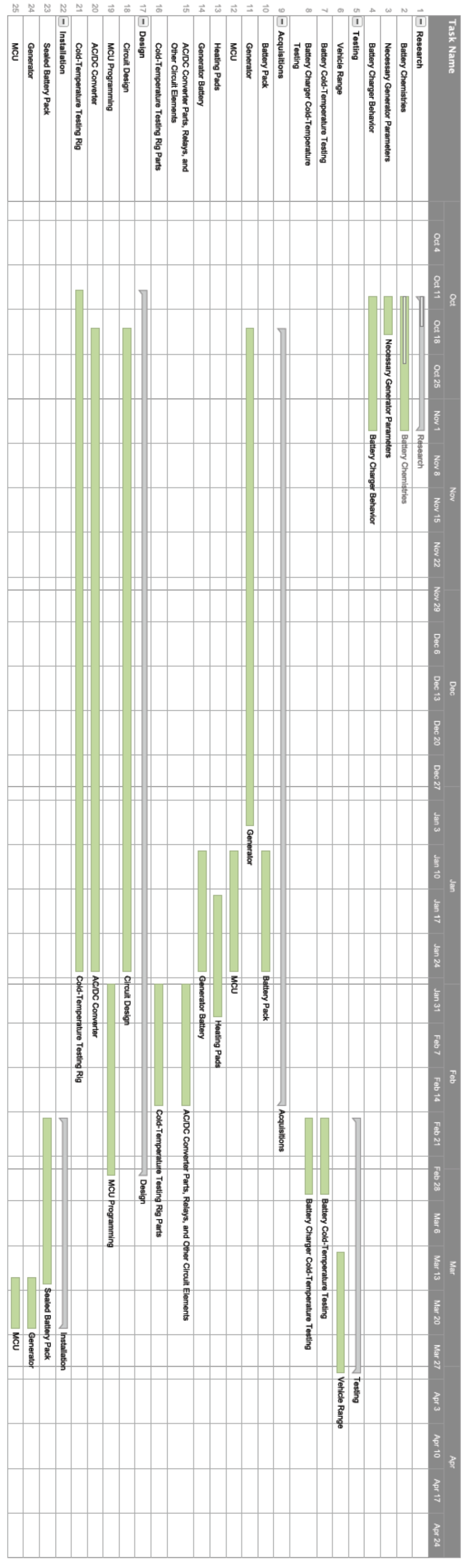


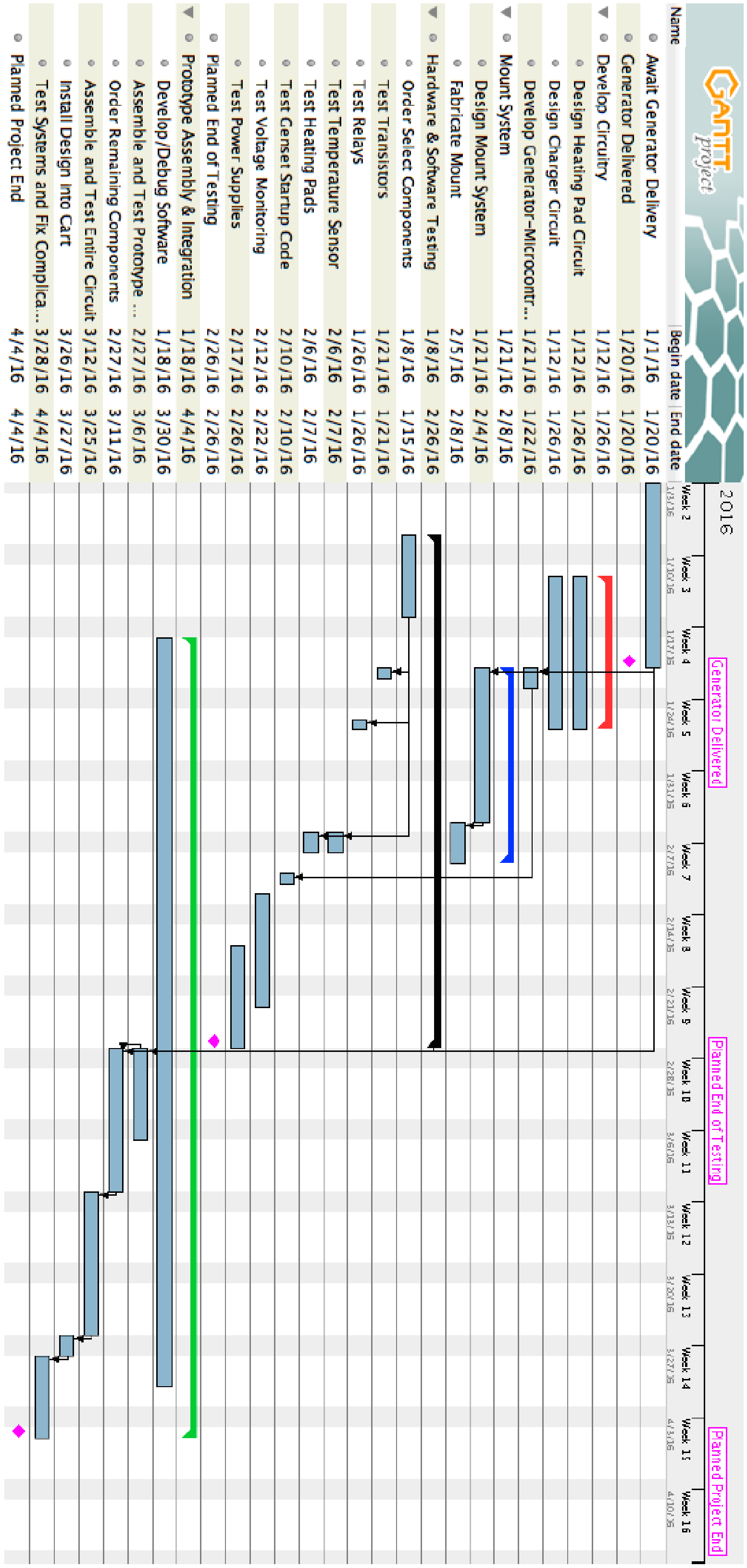
Figure 15: Voltage Sensor Testing

Figure 15 shows that the measured voltage from the voltage divider circuit are largely accurate, varying only by ±0.07V. This error is very well within the teams' error tolerance, indicating that the voltage divider works as intended.

Appendix C: Initial Gantt Chart



Appendix D: Final Gantt Chart



Appendix E: Final Budget

KEY
Control circuit and cables
Replacements
Hardware
Testing Supplies

ME Budget			2000	EE Budget			700
List of Parts Ordered	Unit Price	Quantity	Total	List of Parts Ordered	Unit Price	Quantity	Total
Rugged Circuit Microcontroller	49.95	1	53.94	8V Batteries	169	3	507
12 V 30A Relay	6.55	2	13.1	Control cables and ring connectors			83
12 V regulator	4.25	1	4.25	Hex bolt	0.11	8	0.88
8V lead acid batteries	169	3	507	Hex nut	0.06	10	0.6
12 V battery	209.95	1	209.95	Lock washer	0.15	10	1.5
Solenoid 200 amp relay	64.99	2	129.98	Screws	0.48	2	0.96
Heating Pads	62.99	3	188.97	4M lock washer	0.56	2	1.12
1/8x 2x2 Angle Bar		2	24.05	hex bolt	0.65	2	1.3
1/8x 1 1/4 x 1 1/4 Angle Bar		1	9.56	lock washer	1.18	3	3.54
Labor			18.75	heat shrink			1.97
Propane Tank / fitting		1	55.45	4mm hex nut	0.5	3	1.5
LP Hose	26.87	1	26.87	3m lock washer			0.48
Delta Q Charger	396	1	396	Hinge			2.47
drill bit and bolts			22	12 V voltage regulator	7.95	2	15.9

50 amp current sensor	14.55	1	14.55
iic lcd 1602 display	9.9	1	9.9
Arduino	24.95	1	24.95
Thermometer			19
200mA Fuse	0.32	15	4.8
75A Diodes	5	6	30
1A Fuse	0.32	4	1.28
300 V Fuse Block	3.86	3	11.58
6A Fuse	0.71	2	1.42
20A 12V Relay	5.1	2	10.2
Drill bit and star socket			13.96
5/16 Stainless Steal Nuts			3.26
Cut-off Wheel and Brass fittings			19.66
Battery Cables			30.08
Sand Paper	2		2
cut off wheels	8		8
black zip ties	2		2
Motor Oil	4.29		4.29
Terminal blocks, screw terminals, pin headers			45.57
3-D printed parts			30
Sub total			**1930.08**
Budget			**69.92**

IC pos VR 12V, 1A	4.25	1	4.25
Protoboard	5.95	1	5.95
Wire Nut	2.15	1	2.15
Hook up wire 600V 16AWG	8.95	1	8.95
Female terminal	2.49	1	2.49
Female terminal	2.74	1	2.74
Ring terminal	2.49	1	2.49
Toggle switch	5.27	1	5.27
T-NPN	2.66	5	13.3
Power cable 6 bulk	4.95	1	4.95
0.250 male tab 15 pak	2.49	1	2.49
Florida Pollutant fee	1.5	1	1.5
Sub total			**662.43**
Budget			**37.57**

Battery Management System User Guide

Senior Design Team 9

Fall 2015 – Spring 2016

Department of Electrical and Computer Engineering

FAMU-FSU College of Engineering

Contents

Executive Summary

This senior design project was a joint effort between Team 9 of the Electrical and Computer Engineering Department (formerly Team 11) and Team 2 of the Mechanical Engineering Department at the FAMU-FSU College of Engineering. The main goal of the project was to modify a Tomberlin E-Merge Series electric vehicle to extend its temperature operability range and to give it the ability to recharge while operating. At the time of writing, the final product is not completed; this operation manual is written for the vehicle in its current state, but also includes references to the ideal method of operation.

The basic operation of the vehicle is simple, differing little from the operation of the original electric vehicle. Once the microcontroller switches are activated (described in the 'setup' section), operation is a simple matter of inserting and turning the key, removing the parking brake, and driving it like any other vehicle using the steering wheel, acceleration and brake pedals, and light control sticks, among other peripherals. Ideally, all of the systems added by the design teams would be automated, with the user having no need to activate the mounted generator or heating pads manually. However, an issue with acquiring information pertaining to the battery pack's state of charge (SoC) means that the system as it is currently designed cannot operate in this manner.

To operate the vehicle in its current form, assuming ideal conditions (batteries charged, temperature acceptable), the user must keep track of the battery SoC indicator on the vehicle dashboard. Once the user notices that the battery SoC is low, or if the ambient temperature falls out of the intended range, the user should stop the vehicle and flip the generator control switch. This will activate the generator to run the motor and activate either the charger or the heating pads or neither, depending on the detected state.

The built-in speed controller ensures that the user drives at a safe speed while running off of battery power. However, if the accelerator pedal is pressed down too quickly, the motor will stall, so the user should take care to ease the pedal down. The vehicle should never be operated indoors, as the propane generator, when active, will exhaust carbon monoxide. Additional safety precautions are listed in the 'operation' section.

When not in use, the vehicle batteries may be recharged from a wall outlet, as in the original vehicle. This is accomplished by unplugging the battery charger from its base and using a standard AC power cable (the same type used to power personal computers) to plug it into a wall socket or extension cord.

Relevant images for the operation and setup of the vehicle are found in their relevant sections.

Components

The following is a list of all major components used in the project.

Generator

The generator used in the vehicle is a Cummins GQ-2800 series generator, model number 2.3HGJBB-1121A. The information in Table 3 is found in its specification sheet, available from Cummins. These ratings are for ambient conditions of 77°F at an altitude of 500 ft. Power output decreases 1% for every 10°F temperature increase, and decreases 3.5% for every 1000 ft altitude increase. Its temperature operating range is from 0°F to 120°F. Its position in the project vehicle is demonstrated in Figure 16.

Table 3: Generator Specifications

Fuel	Hz	RPM	Watts	Voltage	Amps	Phase	Circuit Breaker
Liquid Propane Vapor	60	3600	2500	120	20.8	1	21A

Figure 16: Generator

Generator Battery

The battery used to start the generator and power the microcontroller is an ODYSSEY Auto/LTV 12V Battery, Model PC1200MJT. It is capable of providing 1200 Hot Cranking Amps (in a 5 second pulse) and 540 Cold Cranking Amps, and has a 20 hour nominal capacity of 42 Amp-hours. The location of this battery in the vehicle is highlighted below in Figure 17.

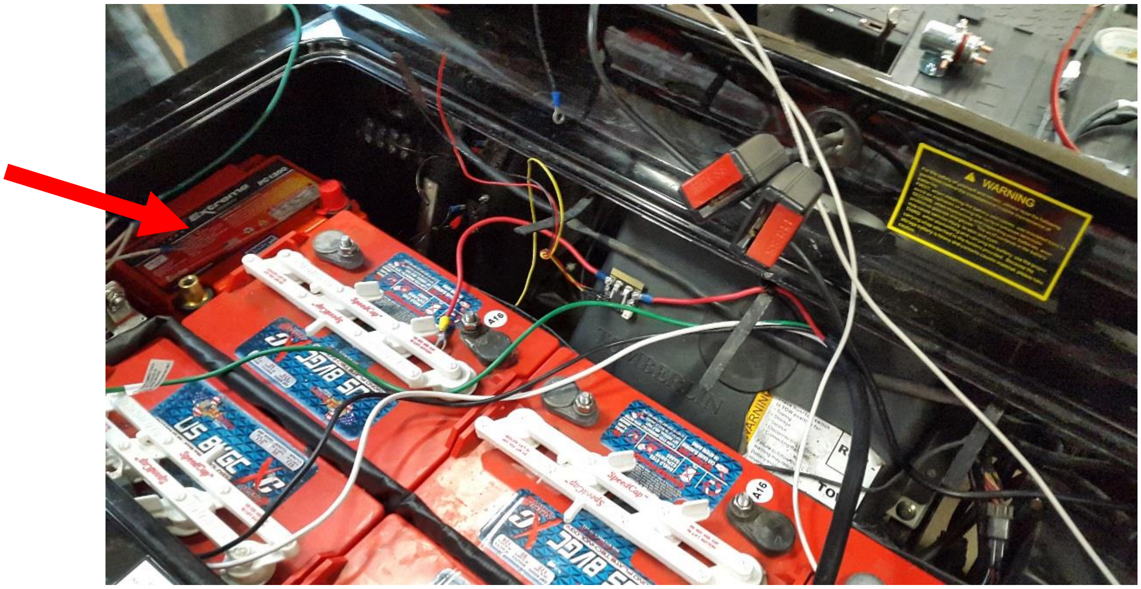


Figure 17: Generator/Microcontroller Battery

Main Batteries

The main batteries used to power the electric vehicle are US 8VGC XC2 deep-cycle batteries. The vehicle uses six such 8V batteries in series, obtaining an overall voltage of 48V. Each battery has a 20-hour rate of 170AH. These batteries can be recharged with the on-board charger. Figure 18 shows all six batteries in the vehicle, with the two terminals that sport all of the vehicle connections highlighted.

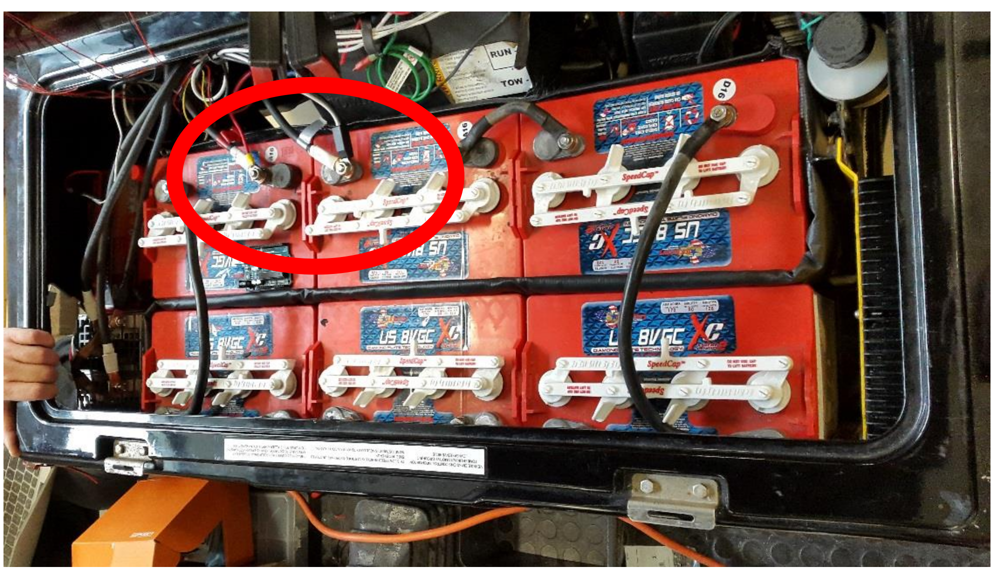


Figure 18: Main Batteries (Two Main Terminals Highlighted)

Microcontroller

The microcontroller used in this project is a Ruggeduino ET. This component is critically important to the project, as it executes all of the code to set the relays and switches for the activation of the generator, charger, and heating pads. The microcontroller will be mounted on top of the generator battery, encased in a small plastic container to insulate it from environmental hazard and protect it from physical shock.

Battery Charger

The battery charger used in the project is a copy of the one that was installed in the vehicle upon arrival, a delta-q QuiQ HFIPFC battery charger. The battery charger functions by first running a self-test, and then detecting the battery voltage. When the batteries are below 80% SoC, the charger will operate in constant-current mode; after the batteries have reached 80% SoC, the charger will operate in constant-voltage mode. The charger has an LED display that is visible from outside the vehicle. The LEDs display whether the charger is working, whether the battery is above 80% SoC, and whether a fault has been detected, in which case a red LED blinks. The charger stop charging the batteries once the pack has reached a full state of charge. Its position in the vehicle is demonstrated in Figure 19.

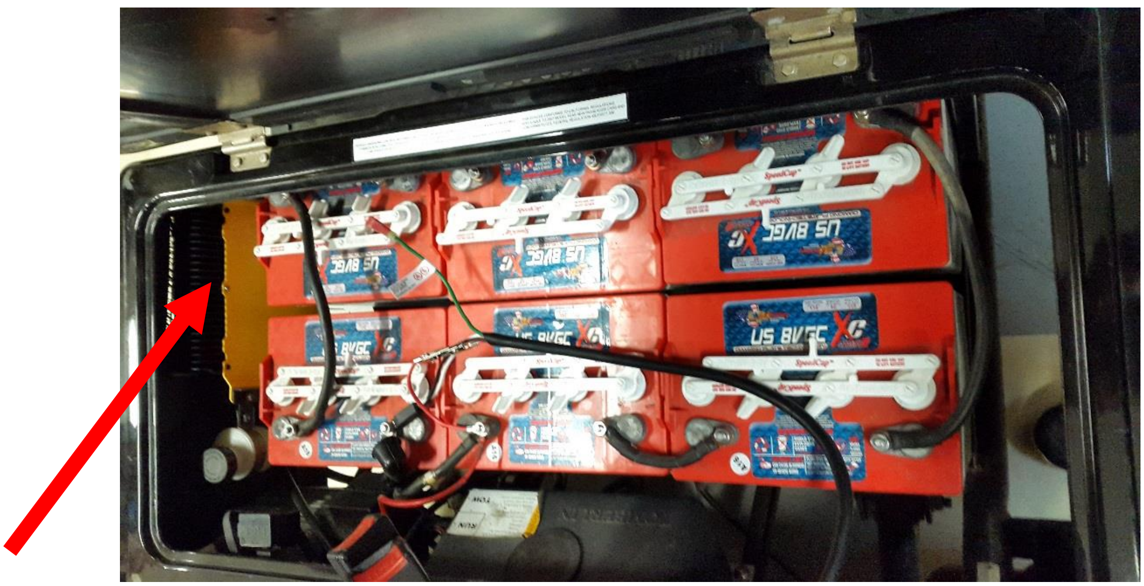


Figure 19: Battery Charger

Heating Pads

The devices used to heat the batteries during cold-temperature operation are a pair of Temro Zerostart 280-0071 Battery Warmers. They are programmed to activate when the microcontroller detects that the ambient temperature has dropped below 32°F.The heating pads are stacked vertically one on top of the other, and encircle the six batteries.

Power Supplies

The vehicle uses two AC to DC power supplies working in parallel to convert the generator's AC output to a DC output that the motor can use. The two power supplies are Mean Well RSP-1500-48 components, chosen specifically because they are designed to be capable of working together in parallel. With the two power supplies, the DC motor can receive 48V and up to 52A (the maximum possible generator power output), although this current value will be smaller when the charger or heating pads are also active. The location of the power supplies in the vehicle is shown in Figure 20.

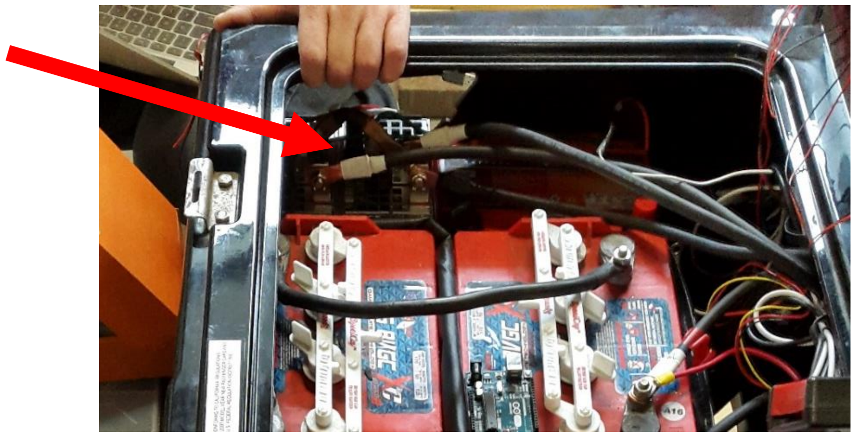


Figure 20: AC to DC Power Supplies

Relays

There are six relays in the vehicles. The two large relays (Amtek 200A SPDT relays) each control one terminal of the motor system control, and switch between providing the motor with current drawn from the batteries or current drawn from the power supplies. Two other relays, mounted on the generator casing, control the activation and deactivation of the generator. The two final relays (30A SPST A/C relays) are mounted on the right rear wheel well; one controls the battery charger activation, and the other controls the heating pad activation. Figure 21 shows the two motor relays (left side) and the buses they are connected to (right side).

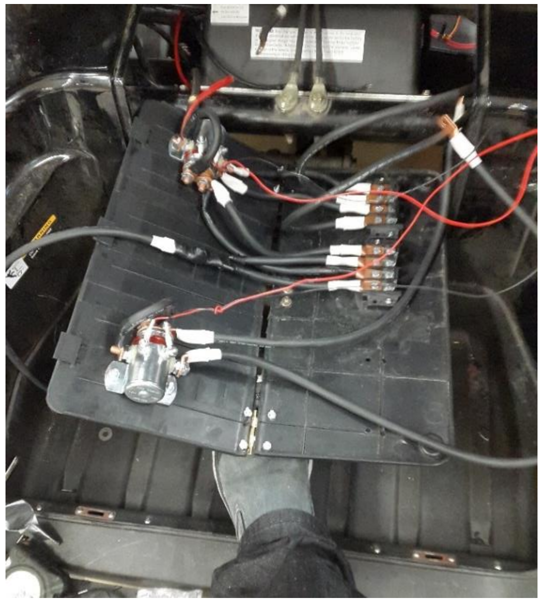


Figure 21: Motor Relays

Setup

In order to run the vehicle, the user must first remove the main bench. Once removed, the user should flip up the two switches located on the side of the built-in vehicle microcontroller box (location highlighted in Figure 22); this activates the on-board microcontroller, allowing the vehicle to be activated. Note that when not in use, these switches should be left off (flipped down) so as not to drain the batteries. If the batteries had been left to charge prior to use, the cord running from the charger to the wall outlet should be unplugged, and the cord used for normal operation should be plugged back into the charger.

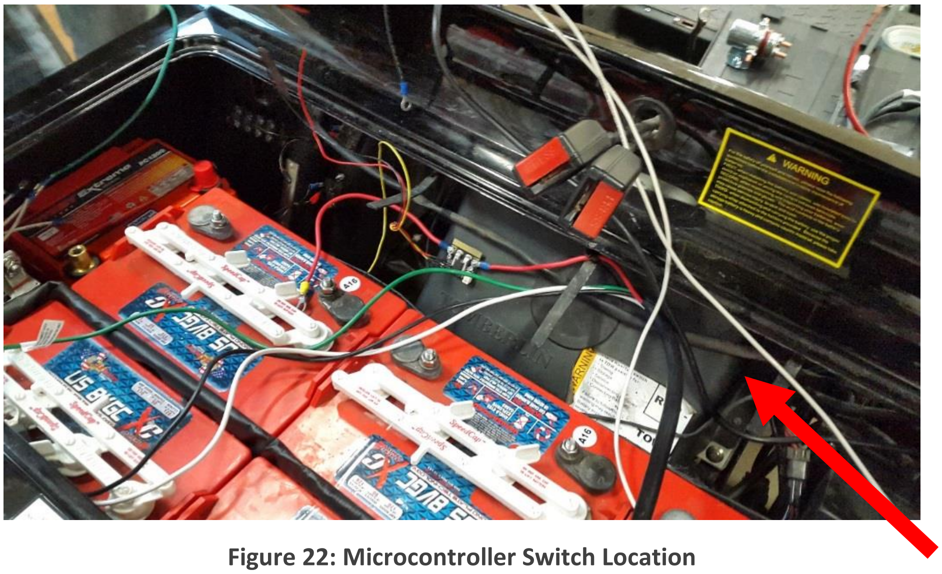


Figure 22: Microcontroller Switch Location

Once the switches are activated, the user may replace the seating bench. The user should then insert the key into the key slot and turn it fully clockwise to activate the motor. The user should then look at the battery SoC monitor on the dashboard (near the key slot), as well as the status display (example output shown in Figure 23). If the SoC indicator shows a state of charge of at least one half, and if the temperature is between 0 and 49, then the user does not need to activate the generator, and may proceed with operating the vehicle. Otherwise, if the SoC level is low or if the temperature is outside the range of 0 to 49, then the user should flip the generator switch, which will cause the generator to activate within a few seconds and power the appropriate system. This procedure should only be performed when the vehicle is stopped.

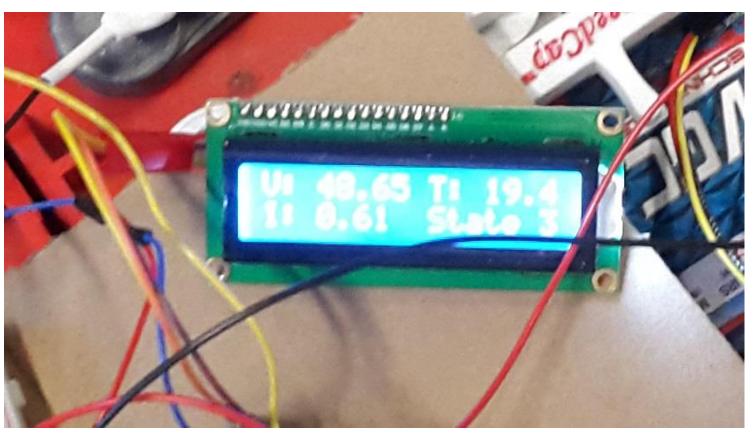


Figure 23: Status Display Example Readout

Once the system within the operable temperature range and the battery charger current is 0A or close to 0A, it is safe for the user to deactivate the generator. As before, the user should first let the vehicle come to a complete stop before switching power supply.

It is possible to charge the batteries while the vehicle is not in use, as briefly mentioned earlier. The battery charger's input cable can be disconnected from the base of the charger, which is accessible through the front panel without need of removing the seating bench. The user may then connect a typical personal computer power cable to connect the charger to an electrical outlet, activating the charger and allowing it to recharge the batteries.

In the ideal finished product, such manual activation of the generator would be unneeded, and the microcontroller would have the capability of knowing when to run the vehicle off of the main batteries. Due to an unexpected error in the manner in which the microcontroller detects the state of charge, the microcontroller will always think that the batteries are in need of charging, even if their state of charge is acceptable. This means that the vehicle will never run off of the batteries if the microcontroller has sole control over the generator activation. With too little time left to complete the project, it will likely be the case that the vehicle will not operate in the ideal scenario by the final deadline.

Safety Precautions

Before beginning operation, the user should ensure that no wires have gotten loose. While all wires have been securely crimped, some may eventually loosen over time. This may cause potential issues with proper operation of the vehicle, as well as potential shock hazards due to the high voltages and currents present in the vehicle. As a corollary to this potential hazard, users should always wear insulated gloves when handling the wiring or batteries in the vehicle to reduce the risk of shock.

Users should avoid touching any battery terminals directly, and should also avoid touching any of the wires found in the vehicle. Not only do the larger gauge wires present significant shock hazards (handling currents of up to 52A), but some of the smaller wires are potentially easy to dislodge and will likely cause the portions of the design to fail if disconnected, as they carry control signals to and from the Ruggeduino.

This vehicle is not meant for on-the-road driving. Test driving should only take place in closed courses. The user should always use the parking brake when the vehicle is not in use. If the vehicle needs to be jacked up, the user should avoid placing additional weight on the frame, and should also place weights such as concrete blocks before the front wheels to ensure the vehicle does not roll away in the event that the jack comes off.

If any future design teams wish to remove, replace, or add components to the project, they should be cautious to follow the wiring diagrams found in the main report to ensure that no short circuits are accidentally created, adversely impacting operation and introducing shock hazards.

For additional mechanical safety precautions, please refer to the operation manual written and submitted by Mechanical Engineering Team 2.

Operation

Once the vehicle has been set up for operation, as described in the previous section, operating the vehicle does not require any additional special instructions. As mentioned above, if running the vehicle off of battery power, the user should keep track of the battery SoC using the built-in display, and should also keep track of the ambient temperature. If SoC drops below one-half, or if the temperature exceeds 49°C or falls below 0°C, the user should stop the vehicle and power the generator as described earlier. If the ambient temperature later returns within operational range, the user should stop the vehicle and disconnect the generator as described above. If the batteries need to be charged during vehicle operation, it is likely that they will need to stay disconnected from the motor for at least two hours as long as the vehicle is running in order to regain a significant amount of charge. Users should check the battery SoC every 45 to 60 minutes to check whether the battery SoC has risen enough for them to be used as the main power source.

Figure 24 shows the main interactive features found the in the vehicle cabin. The circled items, from left to right, show the location of the turning signal stick, the headlight pull-button, the battery state of charge indicator, the forward/reverse control, and the key slot. The left pedal controls the brakes and the right pedal controls the acceleration of the vehicle. The small console at the top of the dashboard displays the current speed, as well as which lights are currently active. The wiper control is located near the ceiling on the driver side.

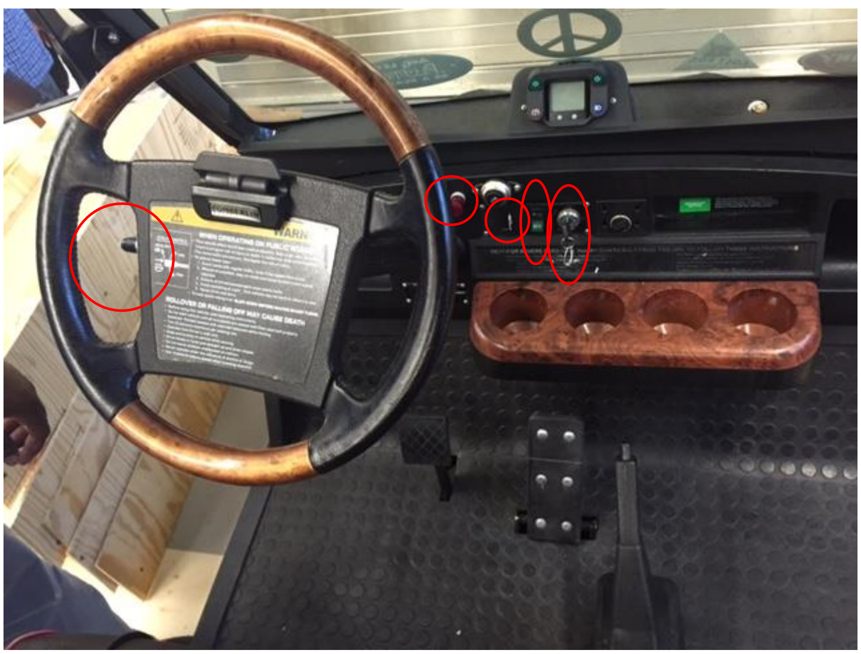


Figure 24: Vehicle Dashboard

It is advised that the user refrain from pushing down quickly on the accelerator, or to push the accelerator to its absolute limit. This will likely cause the motor to stall, requiring the user to come to a stop before it can recover. When running off generator power, it would ideally be impossible for the user to achieve high speeds while the electronic systems are activated. However, the user should nevertheless avoid driving at speeds above 10 mph to ensure that the electronic systems operate close to full efficiency. This vehicle should not be operated in traffic or anywhere other than a closed course.

When the user is finished using the vehicle, he or she should flip the microcontroller switches (shown in Figure 22) to the 'off' position to prevent unnecessary battery discharge. It is also possible to charge the batteries at this point, as mentioned in the Setup section above.

Operational Hazards and Concerns

As described in the Safety Precautions section above, there exists a significant risk of electrical shock if a user touches any of the batteries, the power supplies, the relays, or the microcontroller while the vehicle is active. Under no circumstances should users attempt to make or break connections while the system is powered. Doing so risks creating dangerous arcs and damaging the components in the vehicle. While all or nearly all of the wires in the vehicle have been secured with electrical tape or heat shrink, most of the connections are necessarily bare; for this reason, it is highly recommended that users wear insulated hand protection before attempting to perform any electrical diagnostics, even when the system is not active. If a battery needs to be replaced, it is of utmost importance that the user make every effort to ensure that both terminals are connected appropriately to the previous and subsequent battery. If the battery being replaced is one of the two that sport all of the exterior connections, users should always keep track of which wires go to which terminal. The batteries represent the easiest and most dangerous way of causing personal injury and system damage, as miswiring can cause high-current arcs between terminals, which can lead to injury as well as burn damage to adjacent systems or wires, in addition to reducing the batteries' lives.

As with any electrical system, any replacement batteries for the system should always be of the same type and model as the other batteries in the pack. The user should not replace an individual battery in the pack with one of a different model, as it may cause discharge imbalances and charging issues.

Most of the electrical systems are located in such a way that they should not be adversely affected by outside whether or debris. One important exception is the power supplies. The power supplies are positioned in such a way that it is possible for small stray debris to fall into their casing. Metal debris that fall into the power supplies may introduce short-circuits or otherwise damage the components, reducing the life of the vehicle. For this reason, it is important that the user endeavor to keep debris from entering the main compartment beneath the main seating bench. Other components (namely the main batteries, generator battery, and heating pads) should also be kept free of debris that could introduce faults or other undesired operation. All components –batteries, power supplies, relays, heating pads– should be regularly dusted to prevent material degradation and the likelihood of short-circuits due to outdoor moisture.

For additional operational hazards and concerns pertaining to mechanical systems, please refer to the operation manual written and submitted by Mechanical Engineering Team 2.

Troubleshooting

For all mechanical troubleshooting, please refer to the operation manual written and submitted by Mechanical Engineering Team 2.

Table 4 below is a list of the most common anticipated problems that a user may encounter while operating or expanding upon the design.

Table 4: Troubleshooting

Problem	Solution(s)
While operating, the SoC indicator may show that the batteries are at an adequate state of charge to run the vehicle, but the generator keeps activating and deactivating.	The batteries have sufficient state of charge to power the motor, but the microcontroller is incorrectly reading them as needing to be charged. Stop the vehicle and deactivate the generator as described in the Setup section.
The charger indicates that the battery pack state of charge is full, but the measured voltages across each battery are not equal.	This may happen when an old battery is replaced with a new, uncharged one. Allow the entire battery pack to discharge, and then attempt to charge it with the charger plugged into a wall outlet.
The vehicle won't start.	Ensure that the microcontroller switches (shown in Figure 22) have been switched to the 'on' position.
	Check the battery pack voltage. If below 47V, it needs to be recharged.
	Check the connections leading from the battery terminals to the 200A relays to the motor and replace any damaged components.
The generator won't start when it needs to.	Ensure the generator activation switch is the 'on' position.
	Ensure the generator and microcontroller are connected to the generator battery.
	Check whether the propane tank needs to be refilled or replaced. Also check whether the propane tank is connected to the generator.
	Check whether the control wires leading to and from the generator relays need replacement.
The generator starts, but the electronic systems won't come online.	Check whether the generator output power cable is plugged into the socket leading to the power distribution bus (Figure 25).
The charger won't start during operation.	Ensure that the input power cable (accessed from the front panel) has been reconnected to the power distribution bus after the charger was used from a wall outlet.

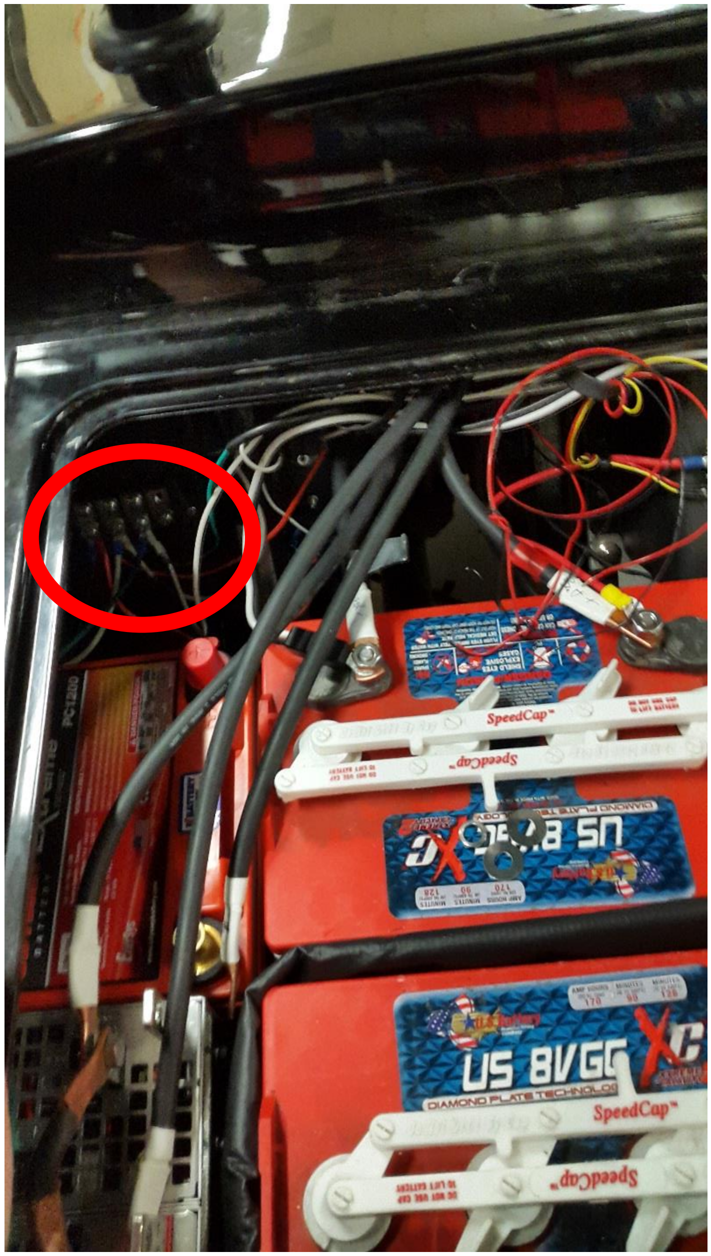


Figure 25: Power Distribution Bus to AC Systems

Appendix: Relevant Information

Please refer to Appendix A: Major Components in the final report for the manuals of most of the system components.

Link to generator manual:
https://powersuite.cummins.com/PS5/PS5Content/SiteContent/en/Binary_Asset/pdf/Consumer/specsheets/NAS-5501-EN-Final.pdf

Link to battery charger manual:

http://www.manualslib.com/manual/627404/Delta-Q-Quiq-912-24xx.html#manual

Electric vehicle maintenance manual:

http://www.mobiletomberlin.net/downloads/Consumer%20Information/E-Merge%20Service%20Manual%202010-2011-1.pdf

Generator battery product page:

http://www.odysseybatteries.com/batteries/pc1200lmjt.htm

Main battery product page:

http://usbattery.com/wp-content/uploads/2015/12/usb_8VGC_group_data_sheet_2015_web.pdf

Power supply product page:

http://www.mouser.com/ProductDetail/Mean-Well/RSP-1500-48/?qs=Xb8IjHhkxj6G63vKryxy8A%3D%3D

Heating pad product page:

http://www.amazon.com/Zerostart-280-0063-Blanket-Battery-Heater/dp/B002UNASS4