Innovations for a Greener Tomorrow: Michigan Tech's E-Rush

Wade Roberts, Adrienne Piron, Terry Gregoricka, Justin Sliva, and Justin Stancy
Dr. Jason R. Blough
Michigan Technological University

ABSTRACT

The Michigan Technological University Clean Snowmobile Team is entering the 2014 Society of Automotive Engineers Clean Snowmobile Challenge with a redesigned 2010 Polaris Rush. The final product was re-engineered to be an electric powered, zero emissions snowmobile. This has been accomplished through the use of a Thunderstruck AC-20 motor, Curtis motor controller, CALB 70AH batteries and a Michigan Tech designed rear drive system. Areas considered while designing the snowmobile include range, weight, noise, towing capability and overall price.

INTRODUCTION

Global climate change and the effects of chemical emissions on the environment have attracted a great deal of attention in recent years and will continue to attract attention in the years to come. The environmental effects of emissions are being closely monitored at Summit Station located on the Greenland Ice Cap. The terrain of the Greenland Ice Cap however, is extremely sensitive. It quickly absorbs chemicals both produced naturally by the atmosphere and those which are byproducts of human activity. Due to the sensitive nature of this environment and the measurements being taken, a zero emissions vehicle is the only suitable replacement for travel on foot. Emissions output from conventional snowmobiles powered by two or four stroke internal combustion engines are enough to introduce detrimental noise, corrupting the measurements being taken at the Greenland Ice Caps.

In 2004 the Clean Snowmobile Challenge (CSC) added an additional event, the Zero Emissions (ZE) category. This category is designated to the design and production of an electric snowmobile. With recent advances in battery and motor technology the feasibility of a zero emissions snowmobile has greatly improved. This environmentally friendly source of transportation can make collecting data in more distant, sensitive locations such as the ice caps possible. This utilitarian use of zero emissions snowmobile was reflected in the design goals for Michigan Tech's ZE entry. The goals of the Michigan Tech ZE Team can be observed in Table 1.

Table 1. Michigan Tech's goals for 2014 CSC.

Category	2013 CSC Competition Best	MTU 2013 Achieved	MTU 2014 Goals
Range	8.1 Miles	DNF	15 Miles
Acceleration	16.1 s	DNF	15 s
Drawbar Pull	587 lbf	DNF	650 lbf
Weight	482 lbs	633 lbs	550 lbs
Noise	57 dB	DNF	50 dB
MSRP	$14.459.00	$16,042.00	$14,000.00

DESIGN STRATAGY

Scoring criteria for the Clean Snowmobile Zero Emissions Competition has been designed in parallel with the National Science Foundation's design goals. The 2014 competition marks the fourth year for Michigan Tech's CSC team building a zero emissions vehicle. Certain aspects were concentrated on, ensuring an effective re-design. These important aspects include; range, towing capacity, innovation and most importantly safety. Additional areas also taken into consideration were; weight, handling, acceleration, cost and durability.

CHASSIS SELECTION

The Michigan Tech Clean snowmobile team chose to continue using 2010 Polaris Rush chassis. This was done for a couple of reasons including; weight, handling, packaging, suspension and the E-Rush's unique rear drive system. Most importantly, build time would be significantly decreased, allowing more time for running and focus on other important aspects.

The rear suspension is easily adjustable by moving the operator's weight to different positions on the snowmobile. The Rush chassis comes stock with Walker Evans clicker shocks; the mono-shock in the rear has 19 different settings that it can easily be adjusted to accommodate any riders preferences. This adjustability allows easy compensation for the added weight of all of the electrical components. Another key feature of the Rush chassis is a large engine compartment, making packaging all of the necessary components relatively easy. Having a large engine bay also allows for easier maintenance completion to the snowmobile and electrical systems. Lastly, as mentioned in MSRP, the cost benefit to using the Rush was significant. Due to the availability of this chassis, a low cost is associated with it. The stock Polaris Rush used as the base platform for the E-Rush is shown in Figure 1.

Figure 1. Stock Polaris Rush used for the Michigan Tech E-Rush.

ELECTRICAL DESIGN

While designing the E-Rush, emphasis was placed on component location, weight distribution and cooling. These areas are directly connected to serviceability, handling and possible overheating of components. Based on these considerations it was decided that the tunnel would be the best place to mount the controller. This location would allow for easy access in case of a tractive system fault and sufficient cooling.

To make the E-Rush an all-in-one system, the charger is mounted directly above the controller within the same box as shown in Figure 2. Practicality of a snowmobile containing an onboard charging system is much greater since it is now possible to recharge the batteries at any location containing a 120 VAC supply.

Figure 1. Charger and controller mounting location.

Mounting the motor at the rear of the snowmobile not only made it easy to service but, also opened up a substantial amount of room under the hood for accumulator packaging. With ample space beneath the hood, the batteries were able to be cleanly housed in a single box, confining the high voltage (HV) as much as possible.

In addition to the high voltage accumulator, a separate 12 volt DC system was implemented. This was completed using a 96 volt DC to 12 volt DC converter. The 12 volt system is used to power accessories such as the headlight and taillight. A full system schematic is shown in Appendix A.

DC TO DC CONVERTER

The team has implemented a DC to DC converter for the 2014 competition, eliminating the need for an additional 12V charger. With only a high voltage charger required, the E-Rush has increased convenience. DC to DC switched-mode converters are electronic devices utilized whenever DC voltages are required to be changed efficiently. In many ways a DC to DC converter is similar to an AC transformer; where the DC output is stepped up or down to satisfy design needs.

While selecting a DC to DC converter, an important consideration was whether or not full dielectric isolation between the input and output was offered. Often times, non-isolation converters are used when voltages are required to be stepped up or down by a minimal ratio, 4:1 or lower generally. In addition, there are four main types of high efficiency (+80%) non-isolation converters; Buck, boost, buck-boost and charge pump converters.

It was determined that to maintain the goal of a safe to operate electric snowmobile, a device containing isolation was a must. This was decided based on the fact that the desired DC to DC conversion ratio is roughly 10:1. Additionally, the competition rules require full isolation between the high and low voltage systems. Transformers are the key component in isolated topologies. Transformers isolate the high and low voltage circuits by containing no direct internal electrical connections between the two circuits. The transformer also allows for an output higher or lower than the input, as long as the power in equals power out, for ideal analysis. The difference in these two voltages is adjusted by simply changing the turns ratio of the transformer's coils. With this isolation strategy, the individual sides can maintain different common (ground) points. With all of this information taken into account the Michigan Tech Clean Snowmobile Team purchased a Mean Well SD-150D-12, shown in Figure 3. This particular converter offers isolation up to 1500V, which is an order of magnitude higher than the nominal voltage of the battery pack designed. The SD-150D also offers a wide range of input voltages (72-144V).

Figure 3. SD-150D-12 DC to DC Converter.

Energy conservation is an important aspect to consider while assessing components to be purchased for the competition. The less energy dissipated in the form of heat, the longer the snowmobile will be able to run during the endurance competition. For the low voltage circuit configuration, consisting of head and tail lamps, relays, contactors and switches, this converter offers between 80-85% efficiency. At a total of 36 watts output to the 12V rail, 6.35 watts would be lost as heat through the DC to DC converter. This dissipation is minimal when compared to the 8 kWhr battery pack and 50HP motor.

Since the BMS requires an "always on" 12V source for data retention purposes, a 12V sealed lead acid battery will be mounted on the snowmobile as a precautionary measure. This battery will act as the power source when the machine is turned off or in the event of a DC to DC failure. As stated previously, the DC to DC will be used to recharge this source, acting much like an automobile alternator.

ACCUMULATOR SYSTEM

BATTERIES

For the 2014 competition 35 Lithium Iron Phosphate (LiFePO4) batteries were used to power the tractive system. Lithium Iron Phosphate cells were chosen for their stability characteristics. When compared to other batteries in the Lithium family, LiFePO4 is much safer to work with and less likely to have a thermal event. The exact cells used are Chinese Aviation Lithium Batteries (CALB) 3.2 volt, 70 Ah. All 35 cells are wired in series to allow for a total pack voltage of 114 volts, producing a combined pack energy of 8 kilowatt hours. It was decided to run a higher pack voltage than in past years to produce more power at the motor. Additionally, the short time discharge rating of these cells is 700 A, allowing the motor to draw the maximum current the Curtis controller can handle.

BATTERY MANAGEMENT SYSTEM

To manage the 35 LiFePO4 batteries, a Battery Management System (BMS) was a necessity. It was decided that the Orion BMS was most suitable for the Team's needs. Orion has one of the smartest BMS modules on the market and can monitor a wide range of cell parameters. For each cell the BMS monitors over-voltage, under-voltage, over-current and temperature to ensure proper operating conditions for the batteries. The BMS also monitors the total pack voltage and discharge current being drawn. If any of these conditions are out of the predetermined bounds, the BMS will produce a fault and interrupt power to the tractive system. Fault codes can be read through CANBUS communication, allowing for easy correction of any problems.

Another key aspect of the BMS is its ability to monitor and control the charging system. Charging will not be possible unless it is deemed safe to charge by the BMS. Once charging, the input current to the cells and each individual cell voltage is monitored. Through this process the BMS can level off the pack voltage so that all cells are at roughly the same state of charge upon completion. If an error is to occur while charging the BMS opens the Battery Interrupt Relays. In addition a signal is also sent to the charger, turning it off until charging is once again safe. A schematic of the BMS implementation can be seen in Figure 4.

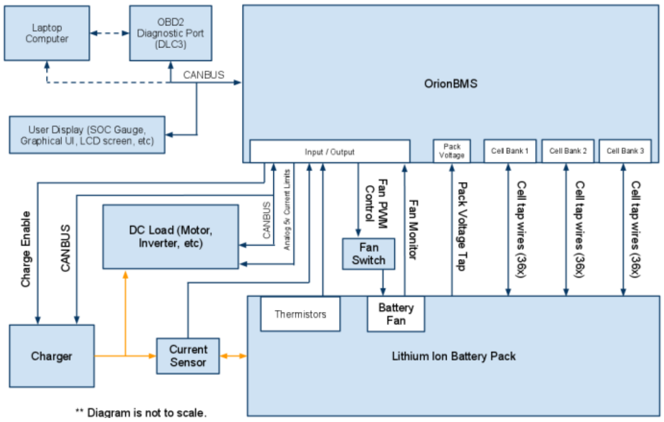

Figure 4. BMS general schematic.

BATTERY CONTAINMENT

Michigan Tech's E-Rush contains adequate space within the typical engine compartment to house the batteries. The basis for the battery containment was to package the batteries in a single container while maintaining a center of gravity similar to that of the original engine. To achieve this, the team designed a complex container capable of housing the 35 batteries and some associated components. The resulting design provides a container which tightly packages the batteries and fits securely within the bulkhead.

The box container was constructed of 1/8 inch 6061-T6 aluminum, making it structurally sound and water resistant. The container was modeled with UGNX 7.5 and Finite Element Analysis was performed using Abaqus 6.12 to determine its structural integrity. Boundary conditions, material properties, loads and a finite element mesh were applied to the design. The analysis was done with applied loads along various axes to determine if the box construction met competition standards. A deceleration of 10 g's was simulated in the vertical direction, while decelerations of 20 g's were simulated in the horizontal directions. The maximum stresses for each direction are shown in Table 2 below. The maximum stress would be encountered if a 20 g deceleration in the for/after direction occurred. Figure 5 through Figure 7 contain the Von Mises stress contour plots for the up/down, for/after, and side/side directions generated from the analysis of the container.

Table 2. Maximum Stresses in Battery Container Design.

Axis	Load (g's)	Force(lbs)	Max Stress (PSI)
Up/Down	10	2,138.6	12,000
For/After	20	4,277.2	37,710
Side/Side	20	4,277.2	37,150
Yield Strength of Aluminum 6061-T6 (psi)			40,000
Weight of Battery Container & Contents (lbs)			213.86

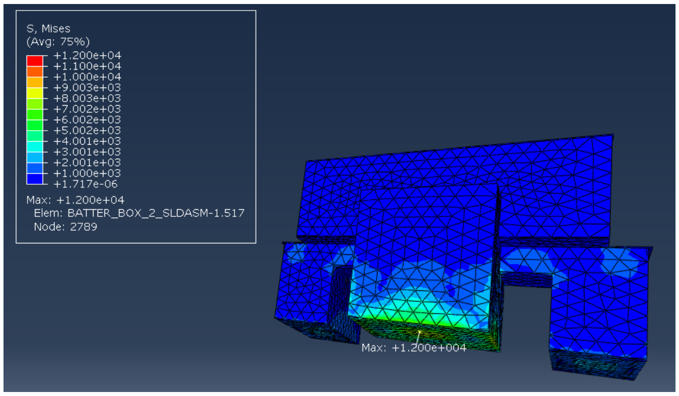

Figure 5. Von Mises Stresses caused by a 10 g vertical deceleration.

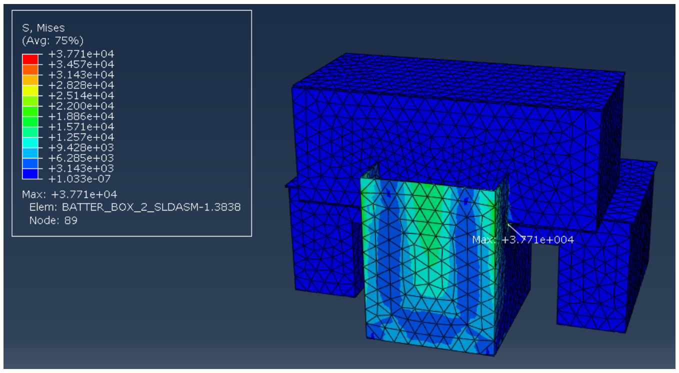

Figure 6. Von Mises Stresses caused by a 20 g deceleration in the For/After direction.

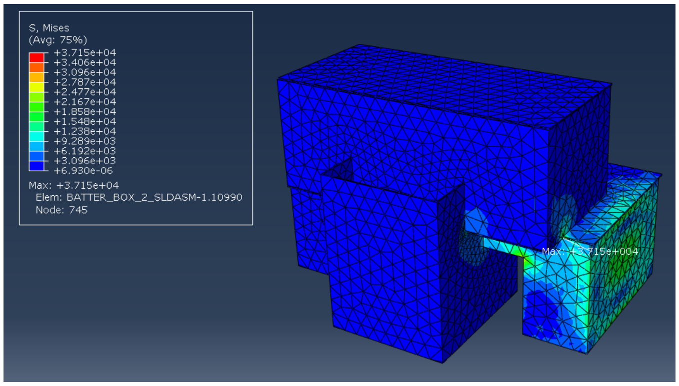

Figure 7. Von Mises Stresses caused by a 20 g Side/Side deceleration.

SAFETY PRECAUTIONS

Since the E-Rush has a fully charged accumulator voltage of 114V, it is considered high voltage. Extra precautions were taken to ensure this high voltage system of the E-Rush was as safe as possible. Being that the accumulator contains the highest voltage, increased emphasis was placed on the battery storage container. A great deal of thought went into a structural design that would restrict any potential interaction between the operator and the high voltage. With the storage container fabricated out of aluminum, a non conductive linear was required. Nomex was chosen as this liner due to its fire resistant and electrically insulating properties. In addition to the Nomex, a thin layer of polycarbonate was used. The polycarbonate is not only an additional insulator but protects the Nomex from wearing through in the event of batteries shifting. As discussed in sections prior, the decision to use LiFePO4 batteries was made with these safety concerns in mind. Any high voltage that enters or leaves the storage container is sealed in nonmetallic, liquid tight, orange conduit. The conduit not only prohibits human contact but also maintains the wire's integrity.

The other main area of concern was the controller. Being connected to the accumulator and motor, the controller contains both high voltage DC and AC. One of the main issues with the controller is many of its inputs, such as the menu push button mounted on the dash reference the high voltage system. Per competition rules, no high voltage is allowed at the dash. To comply, a relay was utilized to restrict this high voltage to the controller box. The relay coil is powered by 12V connected to the push button on the dash and has the capability of switching up to 125 VDC. Although these wires are only signal wires and carry very few amps, precaution had to be taken.

In addition to the steps taken to isolate the high voltage system from the operator, a Bender GFCI IR155-3204 was installed to monitor the chassis potential. This device continually monitors to ensure that the high voltage is not grounded to the chassis. If for any reason there is high voltage at the chassis the Bender opens the shutdown circuit stalling the snowmobile. In this event an LED is illuminated on the dash warning the operator. This fault must be reset manually at the Bender, ensuring that the problem is corrected before further operation.

SPEED CONTROL

To control the motor, a Curtis 1238-7501 motor controller was utilized as displayed in Figure 8. This controller has the ability to monitor the tractive system state, ensuring safe operation. If a fault is detected the high voltage to the tractive system is interrupted by opening a contactor. Another reason for this controller selection is its ability to directly invert the Direct Current (DC) from the accumulator to Alternating Current (AC) required to power the three phase motor. The adequate control over all ranges of speed and torque also played a role in deciding to use this particular controller.

Through the use of a Curtis Spyglass 840 located on the dash, various controller parameters and state are made visible to the operator. A pushbutton allows the rider to scroll through the display screens and monitor the system's states of charge, current, accumulator voltage, vehicle speed, motor temp and RPMs. It is also possible to define many parameters within the controller allowing for maximum efficiency and power to be obtained.

Figure 8. Curtis 1238 mounted in snowmobile.

HIGH VOLTAGE FUSING

Per competition rules, various fusing techniques are required based on the battery pack configuration. Since all batteries are wired in series for the 2014 competition, only a single fuse was required. The fuse must be rated for the pack voltage and continuous ampere rating of the wire used within the pack to complete connections between cells. Zero gauge wire, with a continuous amp rating of 250A was used to make these connections. Since the controller has the capability to draw up to 650A, a Bussman Slow blow fuse was utilized. This particular fuse has a continuous rating of 250A, complying with the rules. However, being a slow blow fuse over-current can be achieved for a period of time without the fuse blowing. This property allows for max draw and power to the motor.

Master Switch Relocation

The master switch originaly located underneath the hood of the snowmoible was moved to the rear end in compliance of the rules. This allows for eaiser access to the switch in the event of a failure of the electrical system. The measuring points for the electrical system were included in this relocation and can be seen in Figures 9 and 10 below. The pelican box used for this relocation is both water proof and shock resistant. The manufactured lid on the box allows for the banana jacks to be easily accessable in a measuring situation.

Figure 9.
Mater Switch Relocation

Figure 10.
Measuring Point access

SYSTEM CHARGING

To recharge the accumulator the Michigan Tech ZE sled contains an onboard charging system, as previously stated. The charger selected is a 1 kW delta-q, qui-q charger, pictured in Figure 11. This charger was chosen for its size and adaptability. A notable characteristic of this particular charger is that it is completely sealed, which is very important when being mounted on a snowmobile. It is also very simple to change the charging algorithm, adapting to any desired pack configuration and voltage. Unlike many other chargers available, the qui-q can be programmed to charge a wide range of battery types. To charge the system all that is required is plugging the snowmobile into a 120VAC outlet.

The enable relay of the charging system is controlled by the BMS. This relay is spliced into the chargers signal wire attached to the negative pole of the battery pack. Upon applying 120 VAC to the snowmobile, a signal is sent to the BMS verifying it safe charging conditions. If determined by the BMS it is safe to charge, the relay spliced into the charger's signal wire closes, allowing charging to commence. If any issues are sensed while charging the relay is opened, signaling the charger to shut off.

Figure 11. Delta-q Qui-q Charger.

POWER TRANSMISSION

The Michigan Tech E-Rush uses an innovative rear drive system, which was a first for the Clean Snowmobile Challenge. To accommodate this, the driveshaft was relocated from the front of the skid to the rear where the idler shaft normally is located. This modification greatly increases the driveline efficiency by pulling the track directly down the rails. This allows for the portion of the track that is "slack", or not under tension, making changes in direction around idler pulleys rather than having the high tension section making these same directional changes. Another advantage to the rear drive system is the fact that the entire chain case can be eliminated. This allows for a notable weight reduction in the front of the snowmobile, as well as the great losses associated with the chain case. While eliminating the chain case is excellent for weight savings, it creates the need to move the brake. This will be further discussed in the Brake Relocation section.

The driveshaft used in the rear of the snowmobile had to be custom made in order to function properly in this location. To achieve this, a piece of hexagonal steel stock was used, creating a press fit with the drivers commonly used in the snowmobile industry. Both ends of this stock were turned down to a one-inch diameter and mounted on pillow block bearings, which were the bolted to the rails of the rear suspension. The size of the bearings used were based on a bearing rating equation, Equation 1, which calculates hours of life taking into account rated load, actual load, operating RPM, bearing quality and a life adjustment factor. This equation is based on L_{10} life which means 90 percent of a group of bearings will survive for the calculated number of hours if mounted, maintained and operated according to the parameters used to calculate the given life.

$$L_{10}=\left[\frac{Radial\ Rating\ (lb)}{Radial\ Load\ (lb)}\right]^3 * \frac{B}{Operating\ rpm} * Life\ Adjustment\ Factor \qquad (1)$$

Bearing life was calculated using the radial load rating of a flange mounted bearing, 3,147 pounds, a worst case anticipated radial load value of a quarter the final weight of the snowmobile, 150 lbs, a constant B value chosen by the ISO bearing certification method and an average operating speed of 1,027 RPM, 27.5 mph. Since the bearings will be subject to cold temperatures, moisture, salt, dirt and other contaminants, the life adjustment factor was one half. Completing the calculation yielded a bearing life of 75,000 hours. With an average speed of 27.5 mph, well over 10,000 miles, the average life expectancy is roughly the same as that of a stock internal combustion snowmobile. The bearings were left significantly oversized for two reasons. Being more robust, bearings provide increased reliability, as well as the one inch inside diameter of the bearings works well when machining one inch hex for the drive shaft. If rear drive is standardized, using the same parts will create an advantageous manufacturing situation.

To accommodate the bearings at the rear of the snowmobile it was necessary to enlarge a portion of the rails, allowing the one-inch shaft to pass through. The rear portion of the 0.1875-inch rail was removed from the stock suspension and then replaced with a thicker and larger square area portion of 0.25-inch aluminum, providing more area for the flange of the bearings as well as help with the added stress introduced by the drive components. A 1.125-inch slot was then created in the rail, allowing for a 0.0625-inch clearance on each side of the 1.00-inch outside diameter driveshaft. Bushings were created to ride in the slots created, making it possible to easily tension the track in a similar manner as a standard snowmobile. Shown below in Figure 12 is a diagram of the back part of the E-Rush skid.

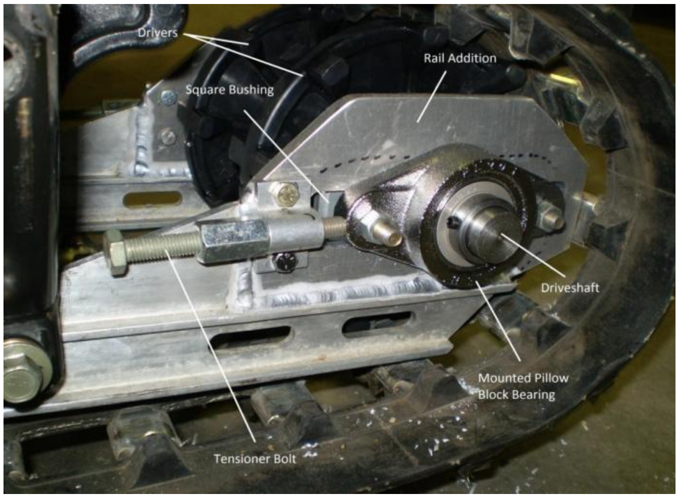

Figure 12. Michigan Tech ZE rear drive system.

MOTOR MOUNT

The E-Rush utilizes an innovative rear drive system to propel it through the snow as briefly discussed previously. Due to this innovative drive system, a custom mounting system was also required. The mount was designed to move with the rear suspension, causing the chain tension to remain constant no matter the position of the suspension. Making a mount that could withstand the AC-20's 53 lbs and a torque of 75 ft-lbs were the first design constraints. Using these constraints as a basis for the stress analysis on the motor mount, several different designs were modeled in Unigraphics. After each design was modeled, the fabrication time, complexity and cost to produce each design was determined. The top two designs were then imported to the Finite Element Analysis (FEA) program called Abaqus as is shown in Figure 13.

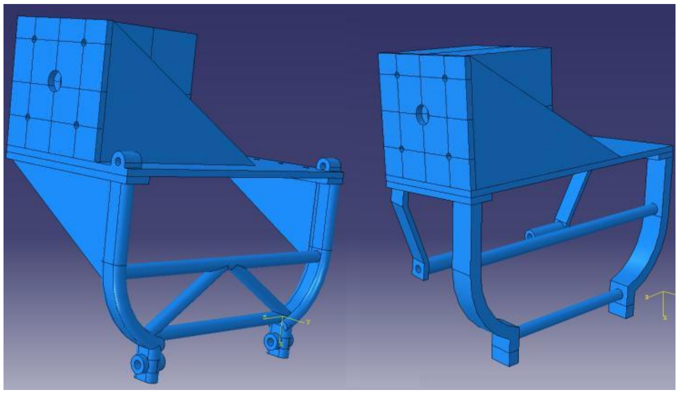

Figure 13. Two design concepts for the E-Rush motor mount.

The material properties, loads, boundary conditions and a finite element mesh were applied to both concepts. The output from this analysis showed where the high stress areas in each design were and areas prone to potential failure. From this analysis the final design was chosen. Von Mises Stresses determined by Abaqus for the final design is shown in Figure 14. The mount was then made lighter based on the Abaqus output by switching portions of the design from steel to aluminum while still maintaining enough strength to firmly secure the motor in place. These alterations led to a very important weight saving technique that was found by effectively using the FEA software. Table 3 shows the three best designs that were modeled and analyzed.

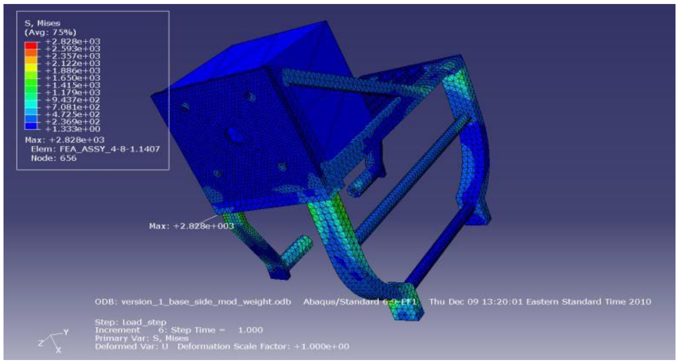

Figure 14. Von Mises Stress Plot from Abaqus of final design.

Table 3. Maximum stresses seen per design with Factor of Safety and weight.

Design	Max Stress (psi)	Max Displacement (in)	Yield Stress (psi)	Factor of Safety	Weight
1	3,106	0.01136	36,000	11.5	48
2	2,726	0.00164	36,000	13.2	36
2 Aluminum	2,828	0.00187	36,000	12.7	26

BRAKE RELOCATION

Relocating the brake on the E-Rush was necessary to both eliminate the chain case and also enhanced performance. The braking efficiency and power increases while the weight of the snowmobile is decreased.

On a typical IC snowmobile the brake is located on the driveshaft under the hood. This is because while using a gas engine plenty of room is left for all of the brake components and other components associated with an IC engine. In the case of the E-Rush, most of the available space is taken up with electrical components required to propel the snowmobile. Moving the brake to the rear of the skid is also beneficial because drivers in the front and rear of the suspension are no longer necessary. The drivers in the front could be replaced with a standard set of idler wheels, greatly reducing the amount of rolling resistance in the skid. The brake setup was mounted on the same side as the drive sprocket for the simple reason that everything fit without having to extend the axel. Extending the axel would have been time consuming and labor intensive.

Calculations were necessary while in the design phase to ensure the relocation was compliant with the competition rules. First of all, it was necessary to make sure there was no more than a 15 percent reduction in the breaking surface area and the rotor was no smaller than 7-inches. The rotor used on the rear of the E-Rush was from a Polaris FST. In order to fit the rotor inside the track it was turned down to 7-inches. By using the FST rotor the breaking area was actually increased, eliminating the concern of removing too much of the braking surface. Equation 2 through Equation 11 show all supporting calculations.

Stock braking area:

$$rcle\ Area = \frac{\pi}{4}(8in^2 - 4.1875in^2) = 36.49\ in^2 \qquad (2)$$

$$Hole\ Area = (72\ Holes)\frac{\pi}{4}(0.325in^2) = 5.97\ in^2 \qquad (3)$$

$$Triangle\ Area = (12\ Triangles)(1.95in)(0.45in)\left(\frac{1}{2}\right) = 5.265\ in^2 \qquad (4)$$

$$Total\ Area = \quad rcle\ Area - Hole\ Area - Triangle\ Area = 25.26in^2 \qquad (5)$$

Stock average pad braking area:

$$\frac{Solid\ Area - (Hole\ Area + Tr\quad ngle\ Area)}{Solid\ Area} = 0.6921 \qquad (6)$$

$$ad\ Area = (1.55in)(0.8786in) + (0.575in)(0.8786in) = 0.5052\ in^2 \quad (7)$$

$$Aver\ \ ge\ Pad\ Braking\ Area = (0.5052in^2)(0.6921) = 0.3496\ in^2 \quad (8)$$

New braking area:

$$Total\ Area = \left(\frac{\pi}{4}\right)(7\ n^2 - 4in^2) = 25.92in^2 \quad (9)$$

New average pad braking area:

$$ad\ Area = (1.55in)(0.8786in) + (0.575in)(0.8786in) = 0.5052\ in^2 \quad (10)$$

Percent increase in average pad braking area:

Percent increase in average pad braking area: $\frac{0.5052in^2}{0.3496in^2}(100\%) = 144.51\%$ (11)

As the calculations show the total rotor surface area was increased by 0.66 square inches and the brake pad surface area was increases by 44.5%. These calculations show the new, lighter and more efficient brake design will have plenty of stopping power for the E-Rush. Final design and implementation can be seen in Figure 15.

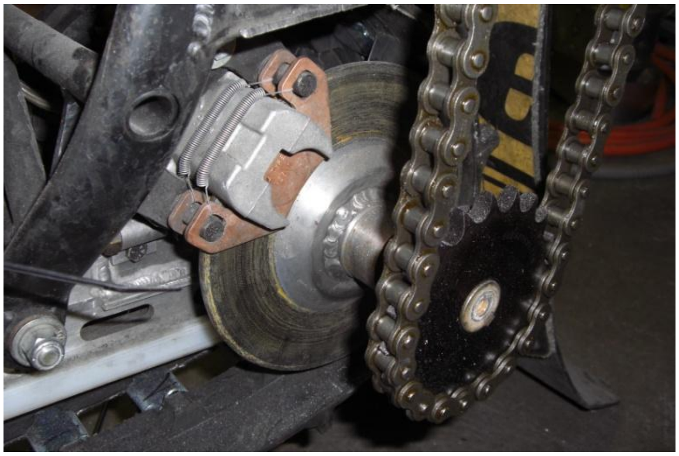

Figure 15. New brake position in E-Rush.

WEIGHT

Weight is an important aspect when designing any snowmobile. The weight and component placement can drastically alter the handling and performance on snow. Bare, the Rush chassis weighs in at 271 lbs. This is a low starting weight and is a great advantage for an electric snowmobile due to all of the added weight coinciding with all of the electrical components. Each battery chosen weighs 5.51 lbs, generating a total pack weight of 192.85 lbs. The Aluminum storage container which houses the batteries contributes approximately another 25 lbs to the snowmobiles weight. Additionally, the motor and controller used weigh 53 lbs and 12 lbs respectively. All of these weights take away from the handling of the E-Rush; however, proper placement of the weight can minimize the overall effect. The final design weight of the snowmobile is expected to be less than 600 lbs.

Michigan Tech was very aware of weight while going through the design and building phases, which is how the team planned to achieve this goal. The original gas tank was used as a mold to create a carbon fiber shell, leading to a significant decrease in weight and increased storage. This storage is a great place to mount electrical components because of the shelter created by the carbon fiber shell. With the batteries and most electrical components placed in the engine compartment of the E-Rush and the motor mounted on the rear, similar weight distribution as a stock Rush is achieved. These efforts greatly increased performance and handling.

RANGE

One of the largest concerns with not only Zero Emission snowmobiles, but electric vehicles in general is the range of travel possible on a single charge. The importance of this characteristic is obvious in the Clean Snowmobile Competition with the amount of points allotted to this area of scoring. This being said, importance was placed on this property, influencing many design decisions. It was this thought that lead to the decision of utilizing LiFePO4 batteries in conjunction with the Curtis controller and AC-20 motor. These components were selected because they are purposefully packaged together. The synergy between these three major components allows for the achievement of the maximum range possible. As stated previously, several mechanical aspects of the snowmobile were also modified, reducing mechanical losses. Once again, the primary modification implemented to increase mechanical efficiency was the rear drive implementation. Weight reduction was the final design parameter used to increase the range. The lighter the snowmobile the less energy required to move it. This characteristic strongly influenced the chassis selection.

DRAW BAR PULL

In order to meet the needs of scientists at Summit Station the snowmobile must be able to tow the experiment equipment to the test site each day. For this reason, one of the judged areas at competition is draw bar pull and therefore was a necessary design consideration. In addition to choosing the AC-20 high torque electric motor other factors were considered with regard to the towing capacity. Motor relocation to the rear of the snowmobile increased the weight above the track, directly affecting the traction of the snowmobile. Maximum traction for this event was achieved through the use of a pre -studded Camoplast Ice Attak track. This particular track is designed for the best possible traction on ice and hard pack by molding the studs directly into the tips of the track lugs. Draw bar pull force on the E-Rush was calculated using Equation 12 and Equation 13 below.

$$\mathrm{DP} = \frac{TxR}{r - RR} \quad (4) \qquad 12)$$

$$\mathrm{RR} = \frac{GVW * R}{1000} \quad (5) \qquad 13)$$

DP- Drawbar Pull (lbs)
T- Torque of motor (in-lbs)
R- Gear Reduction
r- Radius of drive wheel (in)
RR- Rolling Resistance (lbs)
GVW- Gross Vehicle Weight (lbs)
R- Rolling resistance of the surface (lbs)

The first equation (12) was used to calculate the rolling resistance of the snowmobile. A surface rolling resistance (R) of 37 pounds, selected from a table containing data for various materials, was used to complete this calculation. With the rolling resistance calculated (RR), the second equation (13) could be completed. This equation is generally used to calculate the drawbar pull of vehicles such as trucks or trains; however, Michigan Tech has applied the same equation to achieve an estimation of the E-Rush's pulling power. The values inputted into the equation were 105 lbs for torque, 24.05 lbs for rolling resistance, gear reduction of 2 and 3.5 inches for the radius of the drive wheel, leading to an estimated drawbar pull of 695 lbs.

MSRP

In order for this competition to really help students' experience real world engineering, cost has to be a factor at competition. It is hard to keep the cost of electrical components such as the motor, controller and batteries. High cost is mostly due to the fact that this technology is still relatively new and in high demand. A large amount of care was taken when selecting the components to build the Michigan Tech Zero Emissions Snowmobile. The team started off on a good foot by using a Polaris Rush for the chassis which is a common snowmobile now days and is also very fun and easy to ride. The team was also able to easily produce many of the custom parts at a very low cost and in a manner that would be easily repeatable for large quantity production. For the 2014 competition, a manufacturers selected retail price (MSRP) of $16,041.47 was calculated, which is notably less than previous years. This was accomplished through constant awareness of price when selecting materials to use when fabricating different parts of the snowmobile. However, this MSRP is still higher than standard Internal Combustion snowmobiles MSRP due to the high demand of the snowmobile and the technology involved.

SAFETY, PERFORMANCE AND RELIABILITY

Several key aspects where kept in mind throughout the design of the E-Rush. Key aspects included but were not limited to safety, manufacturability, reliability and serviceability. Safety of the E-Rush was improved through the relocation of the braking system. By positioning the braking system directly on the drive axel at the rear of the snowmobile, it cannot be affected by drive train failures such as a chain breaking. Relocating the brake also increased the amount of brake surface area, therefore increasing stopping power. Another notable improvement is the decrease in noise produced. This reduction in noise increases rider awareness and safety allowing increased ease when listening for issues with the drive train.

High regard was given to the manufacturability of the E-Rush during the design process. Systems such as the rear drive are constructed of readily available parts, requiring minimal modifications to operate properly. This was completed in an attempt to minimize additional machining process, lowering not only build time, but cost as well. Pillow block bearings utilized in the rear drive system require minimal machining on one end to interface with the track tensioning system. Additionally, only simple machining processes to a standard one inch piece of hexagonal stock are needed to create the rear driveshaft which is already compatible with stock snowmobile drivers. This focus on design for manufacturability allows for relatively easy integration of a zero emission option on existing snowmobile platforms.

Reliability and serviceability of the E-Rush are a must since the Clean Snowmobile Competition Zero Emissions category is based on utility for scientific advancement in harsh environments. Reliability was achieved through the use of oversized grease-able bearings. For the extreme cold and wet environment in which the snowmobile will be operating, proper lubrication is vital for long life and smooth operation of any rotating assembly. That being said, the design of the E-Rush was kept as simple as possible, minimizing the number of moving parts to simplify operation and maintenance. The rear drive design is a perfect example of this approach. This configuration allows for a single transmission between the motor and the drive shaft, eliminating many moving parts associated with clutches and chain cases. Along with design simplification the rear drive is also easily serviced requiring no specialty tools, continuing with the design goal of serviceability. The is completly isolated from the high voltage system either by conduit or voltage resistant material known as nomenx. The master key relocation and isolation circuit from the motor controler exhibit this shown in the schematic in appendix a.

SUMMARY

The Michigan Tech E-Rush snowmobile is a purpose built snowmobile designed as an effective mode of transportation on the Greenland Ice Cap. A vehicle such as this is in demand because emissions from a standard internal combustion engine can have a large affect on the validity of the tests being completed. Prominent goals of this snowmobile design include safe maximization of range the E-Rush can travel on a single charge while maintaining a thrilling experience. For many of the modifications made, performance was the large driver behind the change. The E-Rush continues to be a very innovative snowmobile using the rear drive system in order to maximize efficiency and reduce the overall weight of the snowmobile.

The electrical design behind the snowmobile had the same drivers as the mechanical design, safely maximize the range. This was accomplished utilizing the Thunderstruck AC-20 motor with the Curtis 1238 motor controller. This combination has the potential to exceed the expectations and capabilities associated with an all electric snowmobile. Putting the great mechanical aspect of the E-Rush chassis with the well designed electrical system, Michigan Tech has created a practical solution to an ongoing problem.

REFERENCES

1. EV Source, "CALB Power Inc." Accessed February 13, 2013. http://www.evsource.com/datasheets/BatteryData/CALB_SE70AHA.pdf.
2. Curtis Instruments, "AC Motor Controllers." Accessed February 17, 2014. http://curtisinstruments.com/?fuseaction=cProducts.dspPrdspProductCat&catID=8.
3. ThunderStruck Motors - Electric Vehicles, Electric Vehicle Accessories and Components. Web. 1 Sept. 2010. http://www.thunderstruck-ev.com/
4. Tory, Baughan, Bons Ross, Nasca Lauren, and et al. "Energizing the Future: Rear Drive E-Rush." working paper., Michigan Technological University, 2012. http://www.mtukrc.org/download/mtu/mtu_ze_design_papap_2012.pdf.
5. "HowStuffWorks "Calculating Drawbar Pull"" Howstuffworks "Auto " Web. 22 Feb. 2012. http://auto.howstuffworks.com/auto-parts/towing/equipment/tow-bars/drawbar-pull1.htm

CONTACT INFORMATION

Dr. Jason R. Blough is an Associate Professor in the Department of Mechanical Engineering at Michigan Technological University and the faculty advisor for both the Michigan Tech Clean Snowmobile Team and the SAE Student Chapter at Michigan Tech.

ME-EM Department
Michigan Technological University
1400 Towndend Dr.
Houghton, MI 49931
Phone: (906) 487-1020
Email: jrblough@mtu.edu

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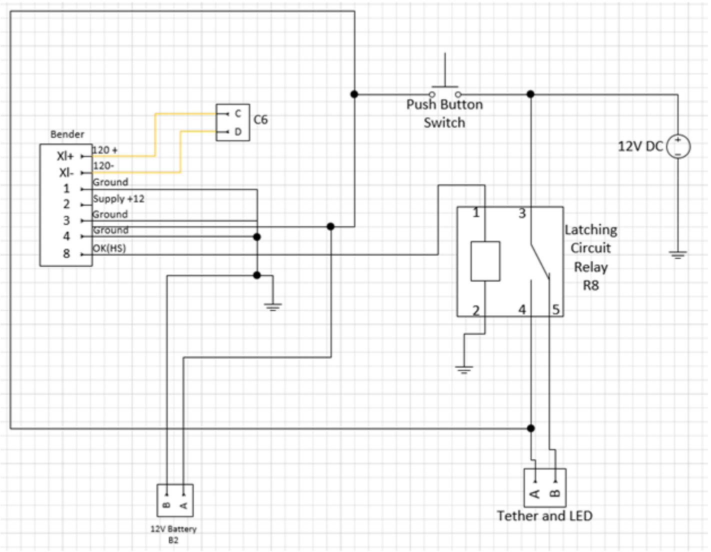
- CATERPILLER
- CHRYSLER LLC
- CUMMINS
- DENSO NORTH AMERICA FOUNDATION
- FORD MOTOR COMPANY FUND
- GM CORPORATE HEADQUARTERS
- PI INNOVO
- JOHN DEERE FOUNDATION
- MITSUBISHI ELECTRIC AUTO AMERICA
- OSHKOSH CORPORATION
- HMK
- VCONVERTERS
- M&M SHOP & STAFF
- HAYES
- TEAMTECH
- SPD

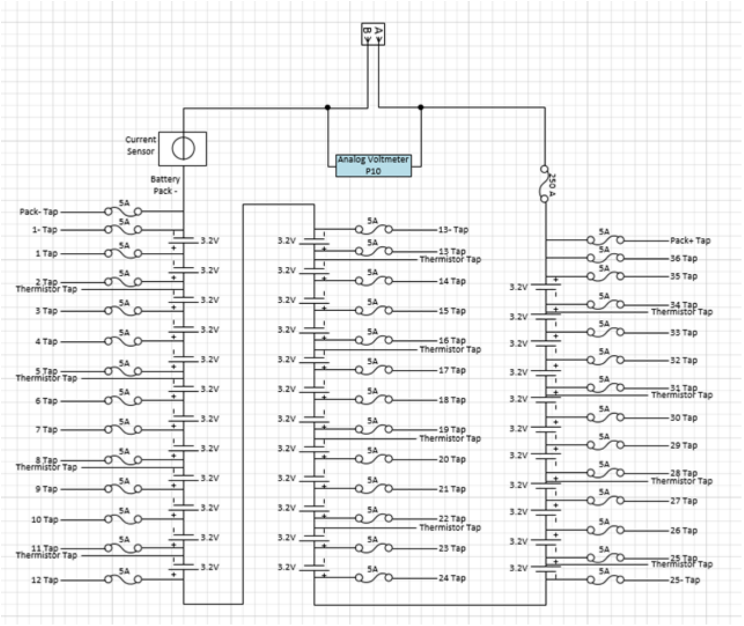
DEFINITIONS/ABBREVIATIONS

MTU	Michigan Technological University
ZE	Zero Emissions
IC	Internal Combustion
CALB	Chinese Aviation Lithium Batteries
CSC	Clean Snowmobile Competition
AC	alternating current
DC	direct current
HV	high voltage
LV	low voltage

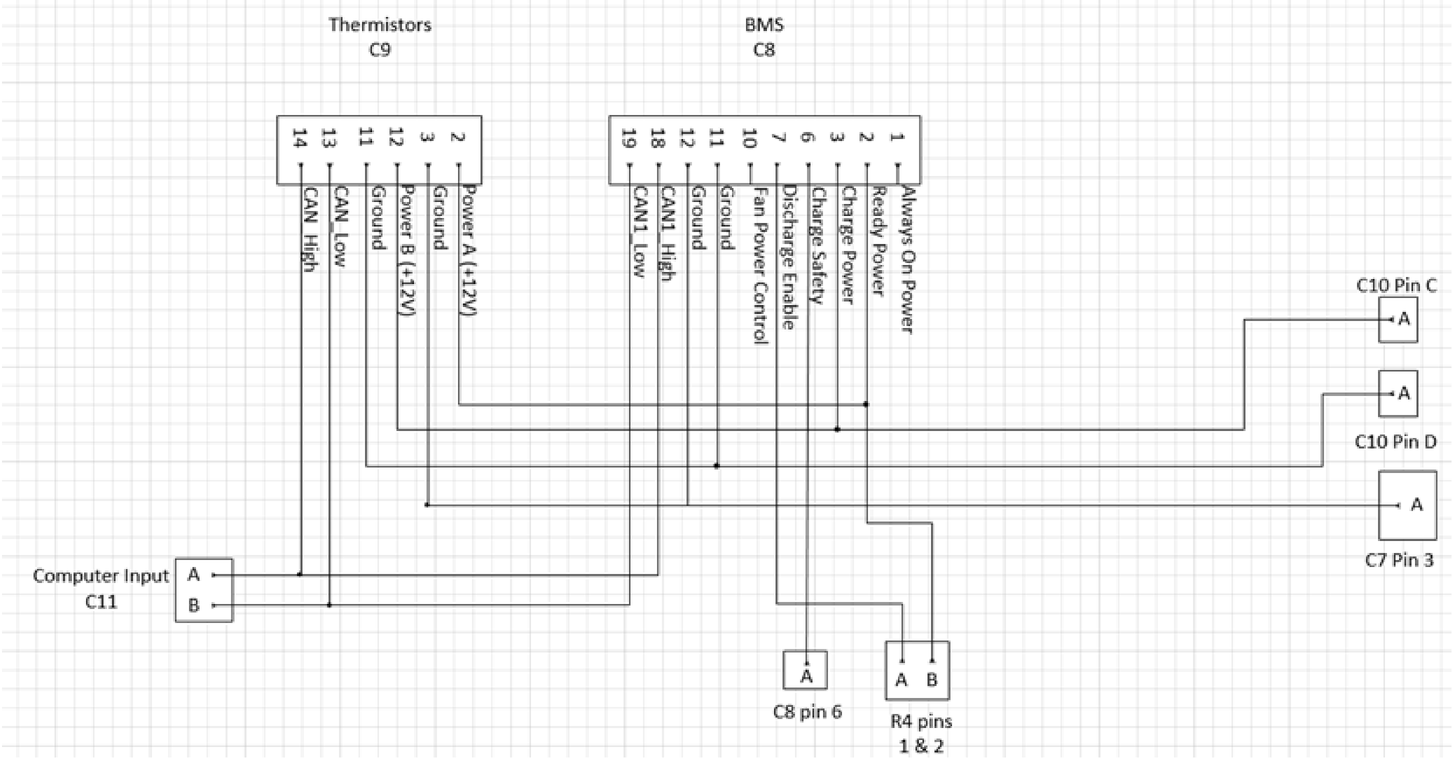
APPENDIX A



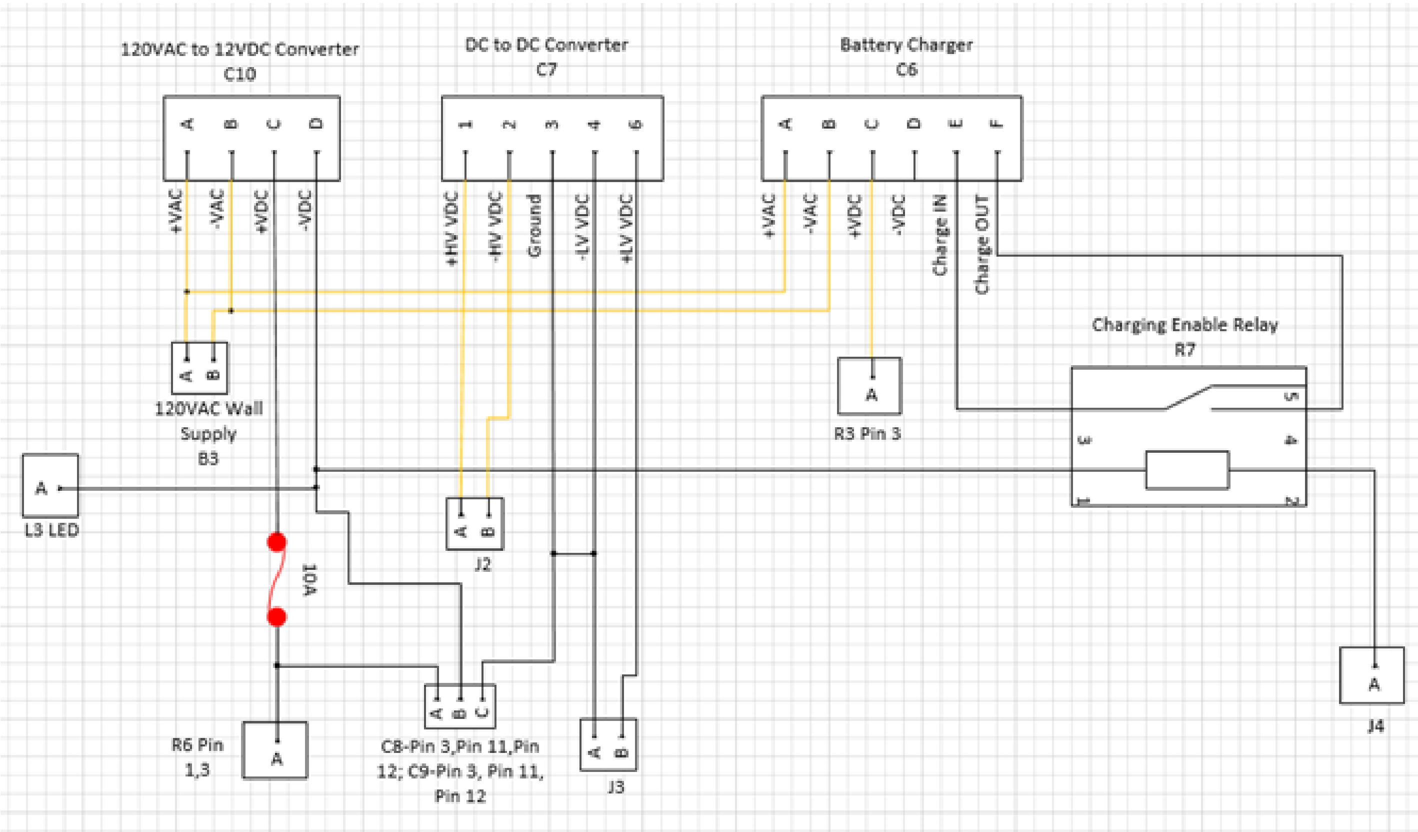
1: Latching Circuit



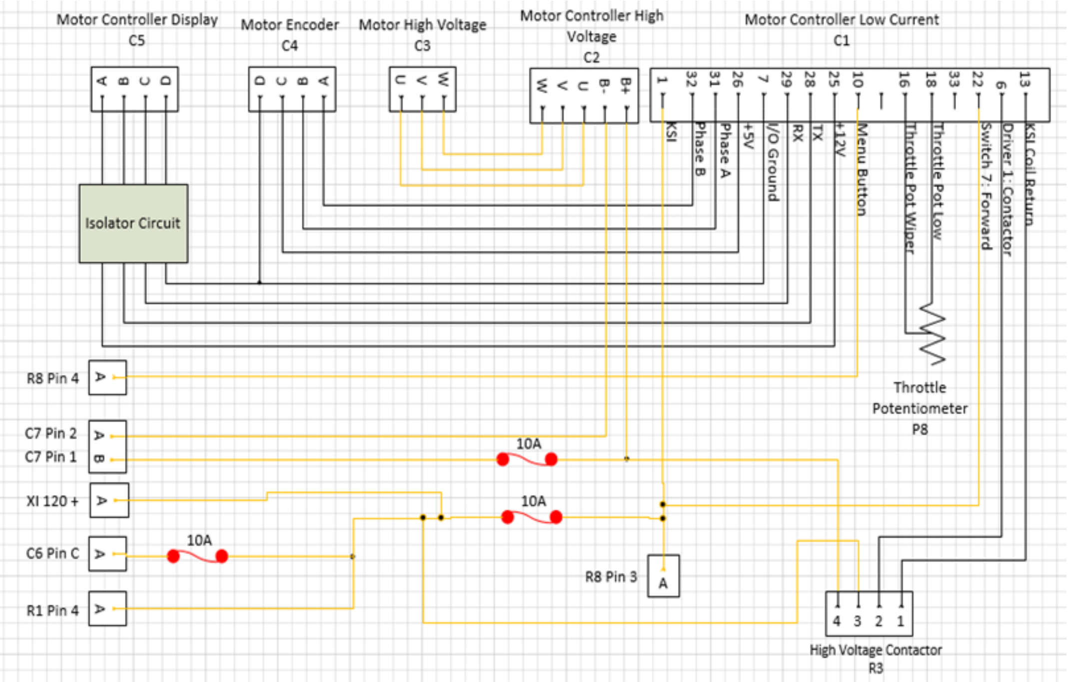
2. Batteries



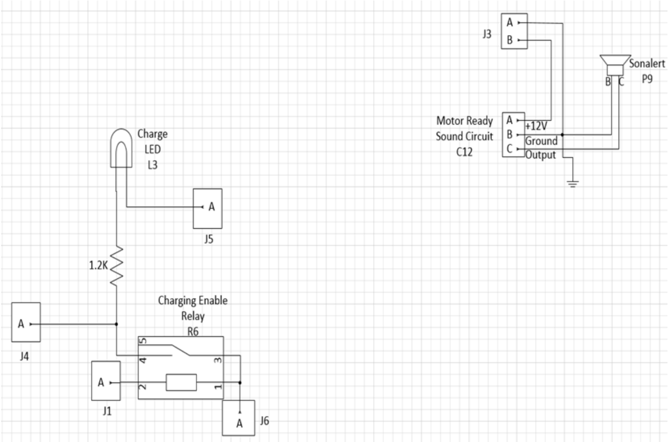
3. Thermistors and BMS



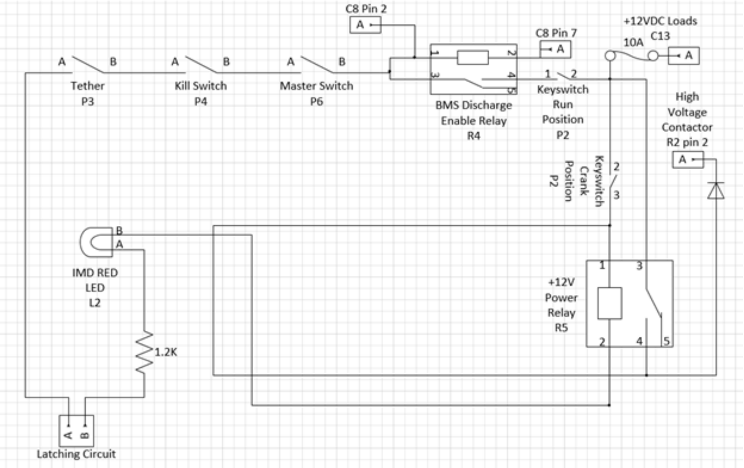
4. Converts and Chargers



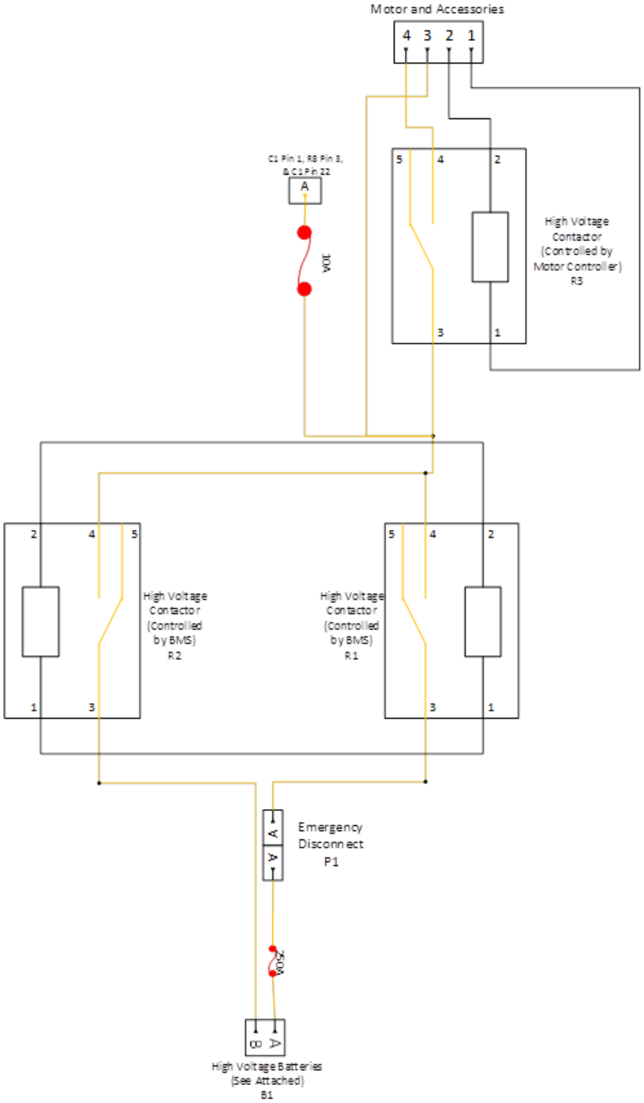
5.Motors and Accessories



6. Sound Ready Circuit



8. Teather, Kill Switch, and Master Switch



9. Contactors