Design of a Marketable Electric Snowmobile without Sacrificing Performance

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ABSTRACT

The Clarkson University Electric Knights (CUEK) have developed a lightweight snowmobile based on the Ski Doo REV XP platform. This year's snowmobile should have a [32.18km (20 mi)] range under optimal conditions; resulting in a slight decrease from last year. CUEK has been building electric snowmobiles for participation in the SAE Zero Emissions Snowmobile Competition since 2007. Through seven years of experience, the team has challenged itself to come up with new ideas and improvements to the sled's functionality.

The new snowmobile is expected to have better handling, acceleration, aesthetics, and [electrical designs]. To do this, the team must utilize its knowledge to minimize the battery pack weight to balance the weight throughout the snowmobile while maintaining it as low to the snowmobile's frame, while retaining structural rigidity. By the design of the motor mount optimizing gear sizes, and [using a more efficient battery layout and wiring]. We were able to characterize the snowmobile to our desires.

The battery system consists of four MP310-049 Moxie+ Modules in series that each are comprised of 24 cells. These cells are divided into 12 groups of cell in series, where each group consists of two cells in parallel. Thus, the four modules provide 5.44 kWh of energy and up to 24.6 kW of continuous power at maximum voltage. They weigh a total of 64kg, which is significantly less than the cells used previous years. These batteries have excellent thermal capabilities, chemical stability and power to weight ratio. An Orion battery management system (BMS) monitors the cells for safety and performance reasons. It also monitors the temperatures of the cells. An Azure Dynamics motor controller is used to manage a highly efficient Azure Dynamics AC24 motor. The AC24 motor has a continuous torque of 31 Nm at 4000 RPM, which increases range over previous builds.

A two-stage gear reduction leads to an overall gear ratio of 3.2:1 with minimal loss in efficiency by custom tension, gears, and two Gates Carbon Polychain Belts.

INTRODUCTION

National parks and other pristine areas that are environmentally sensitive are in need of a mode of transport that is quiet, has zero impact on the environment, and can travel long ranges on a single charge while also towing equipment. The Greenland Ice Cap is such an area; absorbing chemicals in the atmosphere like a sponge. National Science and Forestry’s Summit Station is performing research on these chemicals that may be measured in only parts per billion. Thus, a mode of transport that has zero emissions has been sought after for many years. With the recent advancements in battery and motor technology, it is now possible to fill this niche.

System Overview

This electric snowmobile is designed with the intent of competing in the SAE Zero Emissions Snowmobile Challenge. The intention is to develop a snowmobile that can be used in areas of remote research testing locations such as Summit Station in Greenland for the National Science Foundation (NSF) research. The Greenland Ice Cap acts like a sponge, absorbing atmospheric chemicals produced naturally, or via anthropogenic activities. Many of these chemicals are also photoactive in the lower troposphere and even in the upper layers of the snow. Research at Summit Station seeks to understand the processes involved and how they might play into the global cycling of these agents. Some of the chemical constituents under study are measured in parts per billion. Emissions resulting from the burning of fossil fuels on site can hopelessly skew the research results. Due to the sensitive nature of much of the research conducted at Summit Station, NSF seeks to find a “zero-emissions” vehicle for transporting researchers and support staff to and from research sites.

The tractive system of this snowmobile utilizes four Li-Ion battery modules for energy storage. These batteries are monitored by a centralized BMS system during charge and discharge. The drive system of the snowmobile utilizes an inverter driven induction motor. A GLV or 12V relay system is used to control the electrical components of the snowmobile. Figure 1 shows a basic block diagram that illustrates the components and functionality of the tractive system.

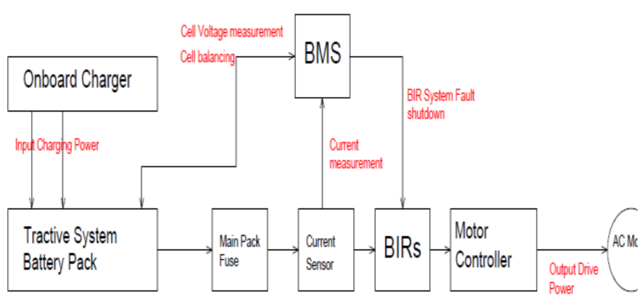

Figure 1 Tractive-System Block Diagram

Design Strategy

The 2011 snowmobile proved to be a great design. To build upon the successes of the 2011 snowmobile design, Clarkson Electric Knights decided to go with the REV XP snowmobile chassis from a 2012 Ski Doo MX Z Sport 600 ACE. This chassis is in the Ski Doo MX Z Sport with the Rotax 600 Carb engine has a dry weight of 190.5 kg (420 lbs.). A weight of which is a 24.9 kg (55 lbs.) drop in weight (previous sled’s dry weight was 215.7 kg (475 lbs.). The Rotax 600 Carb engine is similar to the engine in the stock Polaris, so comparing the weight of the two sleds this way better shows the difference is the frame weights.

Figure 2 Snowmobile Chassis

In addition to a change in chassis, the 2015 Zero Emission (ZE) snowmobile design strategy had a primary focus on weight reduction this year as this can drastically impact the range of the vehicle. This approach included dropping weight where it was safe to do so such as the batteries which is this vehicle's primary source of weight. This is because a drop in weight means that motor will not have work as hard, thereby drawing less current from the pack, which results in a greater range as less power is being used to move the sled per unit distance. Therefore, lighter weight directly leads to a greater range with the same capacity battery pack.

An increase in reliability was another design goal. Concurrent with dropping weight, the 2015 ZE Snowmobile has only 4 commercially produced battery packs which results in less complexity of wiring and a less of a chance of cell failure. To avoid complications with the electric system, increase safety, prevent the need for repairs, and to lower the 2015 ZE snowmobile’s MSRP, the use of more simplified circuits and a centralize BMS was utilized in the 2015 design. The basic design strategy was to ‘keep everything simple” for safety and reliability.

Goals

The goal of the competition in Michigan is to determine whether an electric snowmobile can be adequately used in Greenland’s Summit Station by the NSF. Every event in the completion is important, but from the experience of the CUEK visiting Greenland, certain events stand out as more important. These events are the range event, the draw bar bull, acceleration plus load event, subjective handling, and cold start events. By performing well at these events, it leads to a snowmobile that can be very realistically used at Summit Station in Greenland and effectively aid in the research being performed there.

Table 1. The possible points that may be obtained for each event. [1]

Zero Emissions Class Events	Minimum points for minimum performance	Maximum Additional Points
Manufacturer's Suggested Retail Price (MSRP)	2.5	50
Oral Presentation	5	100
Weight	0	100
Range	5	100
Draw Bar Pull	5	100
Acceleration + Load Event	2.5	50
Objective Handling and Drivability	2.5	50

Table 1. Continued. The possible points that may be obtained for each event. [1]

Zero Emissions Class Events	Minimum points for minimum performance	Maximum Additional Points
Subjective Handling	2.5	50
Cold Start	2.5	50
Objective Noise	3.75	75
Subjective Noise		75
No-Maintenance Bonus		100
Engineering Design Paper	5	100
Static Display	0	50
Total	36.25	1050

When CUEK took the point weighting for the Clean Snowmobile Challenge events into consideration, it was decided that a focus of reliability, the range event and weight, design of the snowmobile, and the draw bar pull event.

The draw bar pull event is the event where a snowmobile must pull a progressive resistance in weight at four miles per hour until it can no longer proceed due to a lack of traction and/or power. During the event, the driver of the snowmobile is not permitted to bounce the snowmobile so as to gain traction for the sled. The maximum draw bar pull load is then measured and recorded. Points are determined by awarding the winner 100 points and then using a linear scale to determine the amount of points for each successive place.

For the range event, the judges set a speed limit of 20 mph that the snowmobile must travel on a closed test course at until it cannot move any farther. The team that travels the furthest receives 100 points. Based on a linear scale, teams who compete in the event will receive an appropriate score where the team that achieves the least amount of miles in range will be given a score of 5 points. 5 points will be given to team that achieves the minimum requirement of 500 feet. As for the weight event, each team's snowmobile will be set on scales during inspection to determine each sled's weight. The team with the lowest weight receives 100 points. Once again a linear scale will be employed.

Reliability was most important to CUEK this year. This is not only because reliability will aid in avoiding complications that have arisen in past years and that have then impeded on past performances. The other reason for reliability being a top goal is because there is a one hundred (100) point no-maintenance bonus. Any team that does not need to repair or service their sled during the completion will receive 100 points. Reliability in CUEK's design goals is important in considering the use of the Zero Emissions snowmobile. The snowmobile is meant to be used by researchers in remote areas where maintenance and repair will be scarce.

Good design is incredibly important in engineering. By considering the life cycle of the snowmobile in one's design, one not only develops a better snowmobile, but reduces costs in manufacturing. Thus, it leads to a lower MSRP. An excellent design also leads to less need in maintenance over the life of the produces and a greater level of reliability in the product. Good design is rewarded in the SAE clean snowmobile challenge in not only the events such as the range event and the draw bar pull event, but in the Design Paper and the Oral Presentation. In these events, a team can explain their thought process behind their product. These two events total 200 points, which should encourage teams to put time and effort in their design. CUEK noticed this and plan their work so that CUEK develops good designs.

INNOVATION AND PAST WORK

A key point in the design this year was incorporating new ideas, change established norms, and introduce a new electric snowmobile that is not only functional, but ascetically appears close to stock. In the drive to drop weight, a motor mount was designed that weighs less than 15 lbs. Where it was safe and convenient, aluminum gears were utilized in place of stock iron or steel. The only material added to the sled was material deemed necessary for rigidity and safety under the worst conditions.

Though the University of Alaska at Fairbanks has used the Rev XP chassis before for conversion to a ZE Snowmobile, The Clarkson ZE snowmobile has a more even weight distribution and differs in almost every other aspect. The use of two stage gear reduction that was optimized with consideration of space restrictions greatly increases our efficiency and is new to this chassis. Another goal with gearing was to design the gears so that transmission of energy through the drive-train would be efficient and lead to a higher acceleration. A larger torque at the gear connected to the track is desired so that improved performance can be seen in the draw bar pull. The 2014 snowmobile by CUEK is innovation in its simplicity with reliability at the top.

Previous Work

Over the last seven years, the Electric Knights have worked to convert an internal combustion (IC) snowmobile to a fully electric utility snowmobile. This past year, safer, more reliable and more energy dense batteries were chosen to power the snowmobile; an improvement over the LiPo4 cells used in previous versions of the snowmobile. These batteries needed to meet specifications for output current, voltage, and operate in conditions required by competition and the NSF. An energy density that is as high as possible is desirable so that the cells supply as much energy as possible at a lower cell weight. A high power density or volume power density is also desirable. This is because if each cell has a higher power density, less space will be taken up by each cell, and thus when constrained in a specific space, there will be more energy in the constrained space. With a high energy density and high power density, it is possible to get the power needed to complete the events that require the snowmobile to run under a load. With more power the events such as the Draw Bar Pull as well as the Range event are accomplished more easily.

As the main power system involves a large quantity of cells, it is essential to use a Battery Management System to normalize the system. The centralized BMS equalizes each individual pack as well as preventing any pack from sinking below the minimum operating voltage. By protecting the batteries from falling lower than its minimum voltage, no one battery will cause the entire battery system to perform inadequately or fail. Included within the BMS is the capability to sense variables of each battery pack to allow the user to monitor the system. A close watch of the temperature, voltage and current output of the batteries can be used to keep the snowmobile operating safely. For example high temperatures, currents or drops in voltage are all indications that the snowmobile needs to be serviced.

Balancing the speed and torque applied to the track is also necessary to increase the snowmobile's performance when towing a load. The use of a more efficient motor controller allows more power to pass from the main battery system to the motor increasing both speed and torque and the range of the snowmobile. Secondly, the gear ratio can be adjusted. Speed and torque are inversely related with this adjustment; in other words an increase in speed leads to a reduction in torque and vice versa. With somewhat less emphasis on acceleration and the event requiring the snowmobile to tow 500 pounds for 500 feet, more torque is needed. While taking into account that the events are still time based, ratios for gears still need to be able to provide the torque needed, at the same time moving at a reasonable speed.

Another improvement made to the conversion was the elimination of the oil-filled chain drive system that is found stock on the IC Snowmobile. Instead a belt driven drive system was implemented. Use of a belt driven system, instead of the chain drive makes the snowmobile substantially quieter. Not only does switching to this system help with the noise event, but in fact it played an important part in helping with the handling of the snowmobile. In the process of switching to a belt driven system, the placement of the motor was altered. The motor was moved to a position lower than it was in previous years allowing a more desirable center of gravity for the snowmobile, improving handling. Through past years at the Clean Snowmobile Challenge the weight of the snowmobile has varied due to changes in the design. To help improve performance, the team sought to reduce weight where possible on new and existing components on the snowmobile. With a lower weight, less energy will be needed in the snowmobile, thus giving it a larger range.

Finally, a reasonable cost is desirable, and since cost effectiveness is one of the main goals, there was a very large portion of time spent researching the least expensive parts that would not sacrifice the safety or overall performance of the snowmobile. Reliability is also very important to CUEK, so careful planning and design when into BMS choices, battery cell choices, and mechanical designs.

Safety Systems

The snowmobile has four shutdown switches, including a key switch, a tether, a kill switch on the handlebars, and a tractive system master switch (TSMS). Automated shutdown circuits include the IMD and BMS fault sensing circuitry. If the IMD opens the shutdown circuit, the tractive system remains disabled. Because the IMD Reset Switch cannot be reached by the driver, the IMD can only be reset manually reset by first dismounting the snowmobile. If the shutdown circuit is opened by BMS, the tractive system remains disabled until the BMS deems it safe to discharge the tractive system batteries again. A Bender A-Isometer IR155-3204 is used for the IMD. The HV sense wires for the IMD are connected before and after the BIRs so that a fault is still detected even when the BIRs are open. The HV sense wires for the IMD are appropriately fused for the battery pack voltage and current draw of the IMD's high voltage measurement points. The relay that is actuated by the IMD and used to close the BIRs in the event that a fault is detected is controlled through a bipolar junction transistor. This design is based off a recommendation by the manufacturer and is intended to avoid sourcing current above the IMD's status output maximum current by directly driving a relay. The IMD is always powered on even when the key is off. The IMD relay is latching, and is reset by a button under the hood. The IMD maintains the normally open switch of DPDT IMD Fault in the closed position under normal operation when no ground fault is detected. The IMD Fault relay controls 12v power to the BMS, motor controller, and BIRs so that in the event of a ground fault detection, the IMD Fault relay will shut down the BMS and motor controller and open the BIRs. BMS receives a 12V input from the Ignition Crank relay signaling it to switch from sleep mode to ready mode. The Ignition Crank relay is wired to latch closed when the ignition button is pressed. The BMS operates the BMS Discharge Enable relay that controls 12v power to the motor controller and BIRs so that when the BMS is inactive or detecting an error, it closes the relay and disconnects the motor controller and the BIRs from 12v power which effectively disconnecting the motor controller and motor form the tractive system. This relay is driven by the BMS's discharge enable signal, which is activated when the BMS is ready to allow discharging of the tractive system. As part of the snowmobile onboard charging system, the Charge Enable key signals BMS to enter charging mode and powers the AVC2 board to allow for charging with J1772 EV ports. This switch is also used to select charge modes.

A vehicle energized light is a green LED mounted on the dashboard panel. The vehicle energized light is controlled with an auxiliary relay on one of the battery isolation relay. This auxiliary relay is actuated when the high voltage relay in closed and activates the vehicle energized light when tractive system circuit is live and there is high voltage outside the battery container.

The tractive system battery box and tractive system circuit design incorporates a single connector that acts as both a high voltage disconnect and a maintenance disconnect. Two Anderson Power Products SBX350 disconnects are used for the maintenance disconnect/high voltage disconnect connectors. One end of the connector pair is secured to side wall of the battery box while the other is attached to a rod that protrudes outside the battery box and is terminated in a T-style handle. A positive locking feature is provided by a pin that goes through the T-style disconnect handle and a short length of tube that extends outside battery box. The removal is tool-less. Additionally, the connectors utilize last mate/first break auxiliary contacts that activate the shutdown circuit and close the battery isolation relays.

A “ready to drive” sound is activated when the BMS deems it allowable that the load can discharge the battery. It is controlled by the discharge enable output of the BMS, which also closes the BIRs and powers the motor controller through a relay. The discharge enable output is read by an Arduino Uno microcontroller that then signals a buzzer to output sound for two seconds. This is necessary, because it alerts people and animals nearby. A warning is needed, because electric vehicles can travel both quickly and quietly, with an inherent warning.

Two normally open, hermetically sealed contactors are used as BIRs. They are placed at both the positive-most and negative-most poles of the tractive system batteries before the conductors exit the battery box. The BIRs open and close according to the BMS discharge enable output. The BIRs are actuated by both the IMD and BMS relays so that if there is a fault in the IMD or BMS, the BIRs will open. The current supplied to the BIRs is connected in series with all of the safety shutdown switches, including the start key, tether, shutdown button, and TSMS.

Battery Management system

CUEK spent some time looking at different BMS systems to regulate our pack. The BMS system utilized is the Orion BMS Lithium Ion Battery Management System. as it was suggested as a good fit by Enerdel. it’s a very detailed system as far as user preferences and interface goes. You can view and control the important information about your pack, such as temperatures measurements, state of charge measurements, voltage limits, and current limits. This is a centralized system where the wiring and control is direct and simple, which increases safety and reliability.

The primary functions of the BMS are to monitor the cell voltages and temperatures, to balance the cells during charge and discharge, and to keep track of the state of charge of the pack. As a centralized system, the BMS monitors voltage through individual fused leads to each group of parallel cells. Thus, there are 52 cell voltage tap leads. These leads are protected by fuses, as suggested by Orion. The BMS also has a built in temperature sensing ability that monitors the tractive system cells.

The ready power source of the BMS is connected to 12V power whenever the BMS should be active for normal use. The charge power source of the BMS should be connected to 12V power source to signal to the BMS that it should enter charging mode. The discharge enable signal is an open drain digital on/off signal used to signal to the load that the load can discharge the batteries.

The BMS operates a normally open relay so that when the BMS disables its discharge enable output due to a critical voltage, current, or temperature reading, the relay is de-energized and opens. This disconnects the GLV power from the motor controller and the BIRs.

The BMS operates on both analog and CAN bus controls. The BMS controls the on board tractive system charger via CAN bus controls. The BMS has the ability to shut off the charger if any cell reaches its maximum voltage. The charger automatically deactivates if CAN bus communication with the BMS is lost. State of charge monitoring is achieved with a Hall

Effect current sensor that measures all current flow into and out of the pack, as well as with the cell voltage tap leads.

The BMS is fully programmable. All tractive system battery and charger specifications are uploaded to the BMS to ensure proper handling of both components. If a violation to an operation parameter continues after a specified duration of time that is the responsibility of the motor controller or charger, the BMS disables its discharge enable output and charge enable output. This opens the BIRs and shuts down the charging circuit, respectively. The BMS does not shut down the snowmobile completely. It only shuts down the tractive system when necessary.

The BMS has a charge and discharge limit enforcement fault mode. The limit enforcement faults are caused when charge or discharge current either exceeds the limit set by the BMS or continues after the digital on/off outputs are turned off. For example, if the BMS has set a discharge current limit (DCL) of 50 amps and the BMS measures 100 amps for an amount of time exceeding the limit in the profile, it will set the discharge limit enforcement fault, because more current is being drawn than is allowed. The same fault will get set if the BMS turns off the discharge enable output and any current is discharged after the set amount of time passes. Charge limit enforcement corresponds to charge current; discharge limit enforcement corresponds to discharge current. This error can be falsely triggered if the current sensor polarity is backwards. When this error is triggered, the BMS is put into a failsafe mode and all charge/discharge/charger enable outputs are turned off. The failsafe condition resets when the power is cycled.

Figure 3: Orion BMS

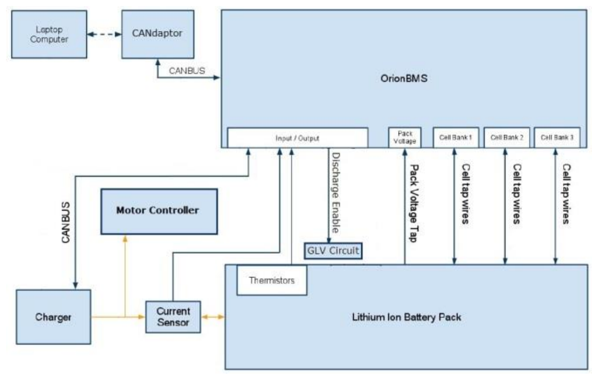

Figure 4: Wiring Diagram for Orion BMS

MOTOR CONTROLLER

CUEK chose the Azure Dynamics motor controller to regulate our AC-24 motor. It is a variable frequency induction motor drive. We chose this controller based upon its past successes in our previous work. It is very configurable by the user to optimize individual settings and requirements.

The direction of the motor is determined by the motor controller via a three position rocker switch mounted on the dashboard of the snowmobile. The rocker switch pulls either of the motor controller directional inputs (forward or reverse) to ground potential. The motor controller defaults to neutral mode when neither is pulled to ground. The motor controller has a configurable variable that helps prevent the rider from accidently switching from one drive direction to the other. “EEXInterlockSpeedHigh” is the speed above which shifting drives is disabled. This is set to 0 rpm, which means that if the motor is spinning in one direction (forward or reverse) and the rocker switch is switched to neutral or the other direction, the motor controller will immediately enter neutral drive mode. It will remain in neutral mode until the motor stops spinning and the throttle is released. The motor controller does not leave neutral mode whenever the throttle is pressed. The position of the directional switch does not matter. However, once the motor stops spinning and throttle is released, it will enter the drive direction mode determined by the rocker switch. Therefore, the snowmobile has to be immobile in order for the rider to change the drive direction. The motor controller also does not close its contactor if the throttle is pressed during start up. It waits until it completes its precharge procedure and the throttle is released to close the contactor.

The DMOC 445 motor controller has a built-in pre-charge circuit, which is controlled automatically by internal circuitry. In order for the pre-charge circuit to function correctly, the battery should not be disconnected and reconnected to the motor controller while the motor controller remains powered on, since the pre-charge contactor may remain closed. The shutdown circuit is configured so that the motor controller is powered off whenever the BIRs are opened. Through a relay, the BMS discharge enable output closes the BIRs and powers the motor controller. This ensures that the tractive system batteries are connected to the motor controller before the motor controller is powered on and therefore before it begins its pre-charge cycle. This relay only turns off when the shutdown circuit is opened, or the BMS discharge enable is turned off. Therefore, if the motor controller is shut down during pre-charge, high voltage power is inherently disconnected from the pre-charge circuitry. Discharge circuitry is not needed for this snowmobile design. There is no high voltage present outside the motor controller when the motor controller is powered off. The motor controller has a built-in discharge circuit for the internal capacitors. The discharge time of the internal capacitors is unknown. As soon as the controller is powered off, contactors within the unit are opened so that zero voltage is present outside of the motor controller. Thus, it is impossible to determine the discharge time of the capacitors without opening the unit, which is not recommended by the manufacturers.

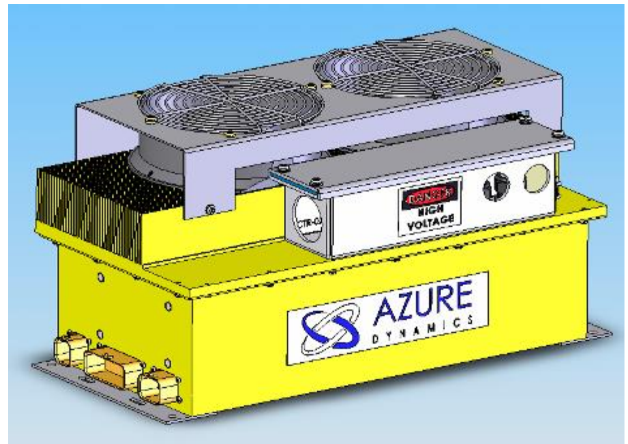

Figure 5: Azure Dynamics DMOC 445 Motor Controller

Dimensions	450.1mm x 237.3mm x 231.1mm (mating plugs not connected)	
Weight	14.7kg	
Min. Nominal Battery Voltage	120VDC	
Max. Nominal Battery Voltage	312VDC	
Min. Operational Voltage	100VDC	
Max. Operational Voltage	400VDC	
Unit Peak Efficiency	97%	
Min. /Max. Operating Ambient Temperature	40°C to 75°C	
Max. Motor Current	280A rms	
Peak Power	78kW @ 312V	
Continuous Power	38kW @ 312V	
Max. Voltage “On Charge”	450VDC	
Minimal Auxiliary Supply Input Voltage	11 VDC	12 VDC
Maximal Auxiliary Supply Input Voltage	15 VDC	30 VDC

Figure 6: Specifications on Motor Control

FUSING

From a safety standpoint fusing in the battery pack is vital. In the event of failure fuses will protect both the pack and the user from harm. Since this pack is built from modules designed for this application many of the requirements for fusing were avoided.

Fusing was still required in the cell taps for the battery management system. These fuses were wired into the existing wiring harness using clip in fuse holders so that fuses could easily be inspected in the case of an over current event. By fusing in this fashion, the BMS and the batteries are both protected.

The tractive pack is also fused by a full power rated fuse as another layer of protection. The main fuse of the tractive system protects the system from overcurrent conditions. The charger fuses protect the charger from overcurrent at its input. While the charger output fuse protects the battery pack from overcurrent from the charger. The BMS voltage tap fuses protect the BMS unit from overcurrent from cell voltage measuring points. The GLV circuit fuse protects the components that comprise the 12V circuit from overcurrent conditions from the 12V battery. The GLV input that supplies power 12V power to the motor controller is fused per manufacture recommendations. Finally, the IMD HV lead fuses provide additional protection to the devices built in protection for the IMD's high voltage sensing terminals.

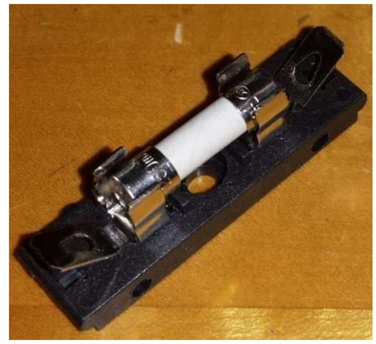

Figure 7: Fuses

BATTERIES OVERVIEW

For this build CUEK considered several options to build our pack out of. We needed a battery that could output a lot of power, provide the best resistance to the negative effects of cold, have a high energy density and most importantly be safe. In the past we have run K2 Energy 26650P cells, which are a high output $LiFePO_4$ cell in a cylindrical case, similar to a long 'c-cell'. We have been very happy with these cells but wanted to consider other types of cells. After much research, comparison of data sheets and discharge curves, we determined that the Enerdel MP310-049 Moxie+ battery modules were the best option; the real advantage to these batteries is their power to weight ratio. Also by using these modules it simplifies the wiring on our end and increase reliability. The tractive system battery pack is constructed of four of these Enerdel Li-Ion batteries wired in series. These modules came preassembled from Enerdel in a 12s2p configuration. Thus, putting these modules in series gives a configuration of 48s2p. Each series connection is monitored by the Orion centralized BMS. Each BMS cell voltage tap lead is fused with a 1A limit, as recommended by Orion. Thermistor temperature sensors are distributed throughout the pack to measure the temperature of 48 cells, using 24 thermistors. The power from the pack runs through welding cable rated at 600V and 260A. However, a maintenance plug, that can be disconnected by hand when working inside the battery box, separates the three nodes connecting the four modules. Fire resistant Makrolon® LF separates each battery module to keep the rated energy levels below 6MJ, since each module is rated at 1.36kWh, or 4.896MJ.

Product Specifications:			
Cell Configuration	12S-2P	Max Cont. Discharge	125 A
Modules per System	N/A	Max Pulse Discharge	480 A (10 seconds)
Cells per Module	24	Max Cont. Charge	125 A
Total Cell Quantity	24	Max Regen. Current	320 A (10 seconds)
Max Voltage	49.2 V	Dimensions	199 x 170 x 269 mm
Min Voltage	30 V	Mass	16 kg
Rated Capacity	31 Ah	Heating/Cooling	Passive or Forced Air Thermal Management
Rated Energy	1.36 kWh		

Figure 8: Single Module Specifications

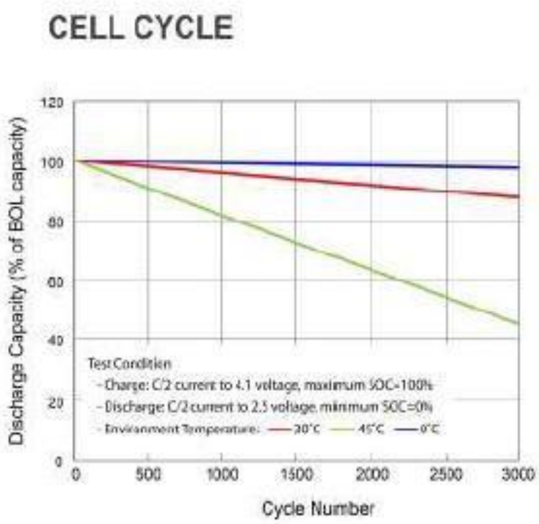

Figure 9: Cell Cycle

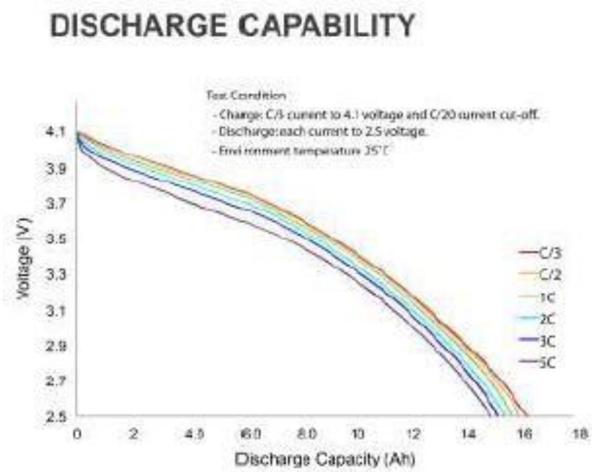

Figure 10: Discharge Characteristics

Figure 11: Charger

CHARGER

CUEK chose the ELTEK EV PowerCharger 220/3000 HE IP67 G2, as suggested by the battery manufacturer, Enerdel. This charger was chosen, as it is highly efficient under normal operation conditions. Another great feature of this charger is it can be installed in the snowmobile, which will allow the user to charge the snowmobile anywhere there is a standard outlet or EV port. This charger is liquid cooled to prevent overheating. The charger outputs a maximum of 3000 watts, which allows the user to charge the vehicle relatively quickly. This charger is also rated to functioning in the extreme cold that the snowmobile will experience during normal operation. Another great feature of this charger Orion BMS is designed specifically to communicate with certain chargers such as this one. All tractive system battery and charger specifications are uploaded to the BMS to ensure proper control of the charger. The BMS has full control over the current output from the charger.

The snowmobile's onboard charging system is capable of charging off a 120V NEMA 5 receptacle. Circuitry is provided to also allow charging from J1772 electric vehicle charging stations. A female J1772 with a locking cover is used as the input to the charger. A NEMA 5 to J1772 adapter is stored onboard the snowmobile. The AVC2 circuit board provides the circuitry required for a J1772 electric vehicle charging station to recognize the charger and allow charging.

A second onboard charger allows for charging of the snowmobile's GLV or 12V battery. A keyed selector switch is mounted on snowmobile's dashboard and used to enable both chargers or each charger individually for charging. The switch is also responsible for signaling the BMS to enter charging mode thereby activating the tractive system battery charger. Additionally, the switch provides a safety interlock for the charging system by closing the BIRs and de-energizing the motor controller. This ensures that there is no high voltage is present outside the battery and high voltage containers during charging.

DRIVE TRAIN

CUEK's 2013 Snowmobile is zero emissions by its ability to run on only LiPO batteries. This makes the gasoline engine superfluous and so it is removed. Removed along with the engine is the continuously variable transmission (CVT), fuel tank, muffler, and other associated parts. In place of these parts, a Azure Dynamics AC24 Motor and DMOC445 Motor controller were added. Though a CVT is very efficient by automatically adjusting to the necessary gear ratio, the CVT becomes unnecessary when an electric motor is added. Gearing however, is still an essential part of the design so that the power from the motor can be transmitted efficiently and in the desired manner. A light weight and efficient way of transmitting power is through the use of a belt. Belts are lightweight and usually have a high efficiency value. After doing research on what is available, CUEK decided the best choice for the drive train was to use a Gates Poly Chain GT Carbon belt. In choosing what belt would be best for CUEK's snowmobile, consideration was made towards efficiency, loudness of the belt while in use, cost, and ease of use.

Timing belts or synchronous belts are a positive transfer belt that has teeth that fit into sprockets of matching tooth pitch. They require little tensioning and typically replace chains in designs. Timing belts also have no need for an oil bath unlike chains.

Table 2. Comparison of Belt.

Belt	Efficiency [%]	Loudness [dB]	Cost	Ease of Use
V-belt	90-95	<60 dB	low	simple
Timing	98	73 dB	moderate	simple

Timing belts are also very efficient in transfer of motion as they have no slippage when under correct tensioning. Disadvantages in using a timing belt are inability to use a clutch and cost. When using a timing belt, special sprockets must be used and the belts themselves are usually more expensive. In designing a zero emissions snowmobile, a clutch is not needed as the motor controller can modify the RPM.

Vee belts (also known as V-belt) is the basic belt in power transmission. They have little to no slippage or misalignment. They typically have long life spans though they can lose up to 5% efficiency over a belts life [2]. V-Belts can withstand high speeds and large loads. They typically require larger pulleys since they have a large thickness. A wider width would not fit in the area constraints of the Rev XP chassis, so a timing belt would not work in this application. [3] As can be seen in Table 2, Timing belts have a greater efficiency.[2] For this reason and for the other benefits of choosing timing belts, such as its long life and reliability (no slippage even over time), a timing belt was chosen over the V-Belt.

Gear choice is very important in designing the drive train. Different gears can withstand different rotations per minute (RPM), have different weights; have a direct effect on power transfer and torque. Maximum speed and acceleration are determined by the gearing. As for gears, CUEK chose to use C3 PowerSports 63-tooth sprocket gear in the bottom of the chain case and their 30 tooth sprocket at the top of the chain case. On the top of the motor side (on the jack shaft) is a 45 tooth gear from Gates. On the motor's shaft of the same side is a 30 tooth gear was custom made motion systems. All the gears have a 8mm pitch. Both belts connecting the gears are Gates Poly Chain GT Carbon synchronous belts in the two stage gear reduction.

The 2013 snowmobile has an overall gear ratio of 3.15:1. This was found through the following equation:

$$\frac{N_4}{N_3}\frac{N_2}{N_1} = \frac{45}{30}\frac{63}{30} = 3.15$$

In CUEK's history, gear ratio has not been constant. In 2008 a gear ratio of 5:1 where 80 Nm of torque at 4000 RPM was outputted. During the draw bar pull, the sled lost traction due to too much instant torque. In 2009, the gear ratio for the drive train was 2.5:1. This led to a 5kg loss in weight and the ability to perform in the draw bar pull. Greater torque was desired in the 2010 build so the gear ratio was increased to 4:1 leading to a total torque of 360 Nm. The ratio of 4:1permitted the snowmobile to pull 737 lbs. before losing traction.

SUMMARY/CONCLUSIONS

Our design of this snowmobile is expected to be a significant improvement over previous years.

snowmobiles as far as a reliability and durability standpoint. The only decrease in expected performance is a slight decrease in the range test. This is due to CUEK using a battery pack that has less capacity than last year. This was a result of attempting to increase the safety of the snowmobile and to simplify the design of the high volt system. The snowmobile is expected to be more than 100lbs

lighter than the previous snowmobile. This will result in a much better handling snowmobile that should closer to the factory snowmobile's handling characteristics. The weight will also be as low to the chassis as possible which results in the lowest center of gravity possible with the chosen battery modules.

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DefinitionS/AbbreviationS

CUEK	Clarkson University Electric Knights
BMS	Battery Management System
test vector	do not capitalize term unless an acronym or proper noun