E54

Design of a Marketable Electric Snowmobile without Sacrificing Performance

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ABSTRACT:

The Clarkson University Electric Knights (CUEK) have developed an electric snowmobile based on the 2016 Polaris Widetrak LX platform. This year's snowmobile should have a [32.2km (20 mi)] range under optimal conditions. CUEK has been building electric snowmobiles for participation in the SAE Zero Emissions Snowmobile Competition since 2007. Through nine years of experience, the team has challenged itself to come up with new ideas and improvements to the sled's functionality.

The new zero emission snowmobile will be more versatile and applicable for utility use, without sacrificing handling, comfort, or looks, based on the original stock design. To do this, the team must utilize its knowledge to minimize battery pack weight and balance the weight throughout the snowmobile, while minimizing extension from the frame and retaining structural rigidity. By designing a new motor mount, optimizing gear ratios, and using a more efficient battery layout, we were able to characterize the snowmobile to our desires.

The battery system consists of four MP310-049 Moxie+ Modules, two being in parallel and two in series. Each module is comprised of 24 cells. These cells are divided into 12 groups in series, where each group consists of two cells in parallel. As a result, the four modules provide a total of 5.44 kWh of energy and up to 24.6 kW of continuous power at maximum voltage. The cells weigh a total of 64kg, which is significantly less than the cells used previous years. The batteries have excellent thermal capabilities, chemical stability, and power to weight ratio. An Orion battery management system (BMS) monitors all four modules. The BMS also monitor the temperatures of the cells. A Curtis 1238 motor controller is used to manage an extremely efficient Curtis AC20 motor. The AC20 motor has a continuous torque of 72.5 ft lb at 4500 RPM.

A two stage gear reduction with a two speed transmission leads to an overall gear ratio of 3.4:1 in high gear, and 6.09:1 in low gear. There is minimal loss in efficiency through the use of custom tensioning, gears, and a Gates Carbon Polychain Belt.

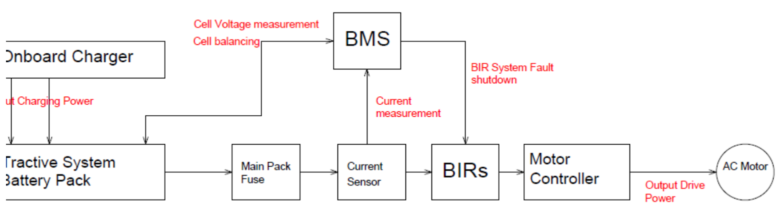
INTRODUCTION:

National parks and other pristine areas are environmentally sensitive and 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 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. 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. 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. 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. With the recent advancements in battery and motor technology, it is now possible to fill this niche.

System Overview:

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:



DESIGN STRATEGY:

The CUEK have chosen to reuse our 2016 Polaris Widetrak LX 550 as it will provide more room and a stronger suspension to house and support all aftermarket components necessary for the conversion from IC to electric. The standing weight of the stock Widetrak LX chassis is 320 kg (705 lbs). This is an increase from previous years which had a standing chassis weight of 190.5 kg (420 lbs). To account for this increase in weight, components will be positioned to give an even weight distribution to improve handling and balance. This will be accomplished by having the battery containers installed in the center of the chassis, as opposed to the rear most position on the snowmobile used in previous years.

One design goals for the 2017 CUEK was to improve the overall power of our vehicle, to compensate for the increase in weight, while remaining more efficient. To do this we will also be reusing the Curtis AC20 motor purchased last year. The Curtis AC20 is a 65 hp (48 kW) peak motor with continuous torque of 72.5 ft.lb at 4500 RPM. This motor is controlled by a Curtis 1238 controller that was also purchased last year with the motor.

This combination was chosen by the 2017 CUEK because it will result in a more powerful and efficient vehicle, meeting our goals.

An increase in reliability was another design goal. The 2017 ZE Snowmobile has only four commercially produced battery modules, which results in simpler wiring and a smaller chance of cell failure. To avoid unnecessary complications with the electric system, increase safety, prevent unnecessary maintenance, and to lower the 2016 ZE snowmobile's MSRP, the use of more simplified circuits and a centralize BMS became part of the 2015 design. The basic strategy used was to simplify as much as possible in order to guarantee our success, without compromising performance and safety.

Goals:

The goal of the SAE Clean Snowmobile Challenge is to determine whether an electric snowmobile can be adequately used in Greenland's Summit Station by the NSF. Every event in the competition is important, but from the experience of the CUEK visiting Greenland, certain events stand out as being more important. These events are the range event, the draw bar bull, acceleration plus load event, subjective handling, and cold start events. The events with the minimum and maximum point values can be seen in Table 1. By performing well at these events, it leads to a snowmobile that can be realistically used at Summit Station in Greenland and effectively aid in the research being performed there.

Table 1:

Zero Emissions Class Event	**Minimum Points for Minimum Performance**	**Maximum Points for Relative Performance in Event**
Engineering Design Paper	5	100
Manufacturer's Suggested Retail Price (MSRP)	2.5	20
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
Subjective Handling	2.5	50
Cold Start	2.5	50
Static Display	0	50
Objective Noise	3.75	75
Subjective Noise		75
No-Maintenance Bonus		100

When CUEK took the point weighting for the Clean Snowmobile Challenge events into consideration, it was decided that the focus of the design would be on the range, drawbar pull, weight of the snowmobile and design.

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 until it cannot move. 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 mileage in range will be given a score of 5 points. 5 points will be given to any 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 implemented.

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 and lessons learned from last year into our chassis for an electric snowmobile that is not only functional, but ascetically appears close to stock. In opposition to previous years, all original body panels and seats will remain in stock locations and minimal components will be added to the exterior of the vehicle. The motor and motor controller incorporated into the design that will be powered by previously used $LiFePO_4$ modules. This will improve the range, power, and efficiency of the vehicle.

Over the last eight years, the Electric Knights have worked to convert internal combustion (IC) snowmobiles to fully electric utility snowmobiles. Three years ago, safer, more reliable and more energy dense battery modules were purchased and are still used to power the snowmobile; an improvement over the $LiPO_4$ 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 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. 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 lithium ion cells, it is essential to use a battery management system to normalize the system. The centralized BMS balances each individual cell and prevents them from sinking below the minimum operating voltage. By protecting the cells from falling lower than its minimum voltage, no one battery will cause the entire battery system to perform inadequately or fail. Included in 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 the other way around. 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.

Use of a belt driven system makes the snowmobile run quietly. 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. 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 in 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 handle bars, and a tractive system master switch (TSMS). Automated shutdown circuits include the IMD, BMS, acceleration lever position sensor (ALPS), and brake plausibility detector (BPD) fault sensing circuitry. If the shutdown circuit is opened by any of the automated faults, the tractive system remains disabled. All these systems will remain in fault state until the appropriate reset switch is hit. The driver cannot reach the reset switches, so they can only be reset manually 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 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 open 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 relay is latching, and is reset by a button on 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 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 opens 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 high voltage indicator circuit controls the vehicle energized light. The circuit turn on the VE LED whenever there is over 40V DC outside of the battery box and on the motor controller.

The tractive system battery box and tractive system circuit design incorporates a maintenance disconnect and a High Voltage Disconnect (HVD). The HVD will disconnect the positive most leads of the battery pack to the BIR. The HVD also has a low voltage interlock that disables 12v power to the motor controller and BIRs that will shut down the sled.

A "ready to drive" sound is activated when the high voltage indicator circuit senses there is high voltage present at the motor controller. The ready to drive sound is necessary, because it alerts people nearby that the sled is energized. A warning is needed because electric vehicles can be operational without any evidence to the people surrounding it.

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 not 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: (BMS)

CUEK will be utilizing the Orion BMS Lithium Ion Battery Management System purchased two years ago. The Orion BMS was suggested as a good fit by Enerdel. It's a very detailed system as far as user preferences and interface goes. The user can view and control the important information about the pack, such as temperatures measurements, state of charge measurements, voltage limits, and current limits. This unit will monitor all four modules. 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 and Extension are 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. Both the BMS and the Extension have charge and discharge digital on/off enable signals that are wired in series, so that both systems must signal on for charge or discharge to occur.

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

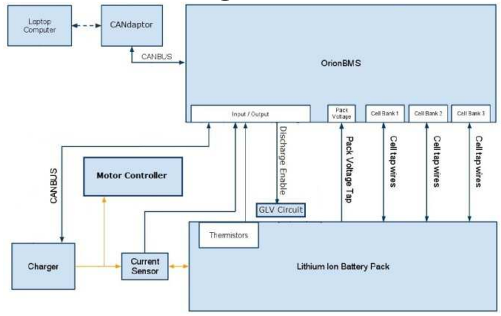
The BMS operates on both analog and CAN bus controls. The BMS controls the on board tractive system charger via CAN bus controls. The BMS has the ability to shut off the charger if any cell reaches its maximum voltage. The charger automatically deactivates if CAN bus communication with the BMS is lost. 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 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. 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 enable outputs are turned off. The failsafe condition resets when the power is cycled.

Figure 2:

Figure 3:



MOTOR CONTROLLER:

CUEK chose the Curtis 1238 motor controller to regulate the Curtis AC20 motor. It is a variable frequency induction motor drive. This controller was chosen based on power and efficiency specs, as well as its compatibility with our design. 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 are 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 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 pre-charge procedure and the throttle is released to close the contactor.

The motor controller is powered on when the key is turned to the on position. Once the key is turned to crank the motor controller will receive a start signal and it will start is pre-charge cycle. The motor controller controls the positive BIR and the pre-charge relay so there is no high voltage present outside the battery box when the motor controller is powered off. A discharge circuit is controlled by the auxiliary contactor on the positive BIR to discharge the internal capacitors in the motor controller. As soon as the controller is powered off, the discharge circuit is enabled to discharge the controller so there is zero voltage present outside of the motor controller.

Figure 4:
Curtis 1238

Figure 5:
Curtis AC20

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 is still required in the cell taps for the battery management system. These fuses are wired into fuse blocks with connecters on either side made for easy plug in and unplug installation and removal. 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.

Batteries Overview:

For this build CUEK considered several options to build the pack out of. A battery was needed 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 K2 Energy 26650P cells have been used, which are a high output $LiFePO_4$ cell in a cylindrical case, similar to a long 'c-cell'. These cells have worked well, but other types needed to be considered. After much research, comparison of data sheets and discharge curves, it was determined that the Enerdel MP310-049 Moxie+ battery modules were the best option with the real advantage being their power to weight ratio. Also by using these modules it simplifies the wiring and increases reliability. The tractive system battery pack is constructed of four Enerdel Li-Ion batteries wired with two in series and two in parallel. These modules came preassembled from Enerdel in a 12s2p configuration. Thus, putting these modules in series gives a configuration of 24s4p. 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 380A. However, a maintenance plug, that can be disconnected by hand when working inside the battery box, separates the parallel connections connecting the four modules. Fire resistant Makrolon® GP separates each battery module to keep the rated energy levels below 6MJ, since each module is rated at 1.36kWh, or 4.896MJ.

Figure 6:
Single Module Specifications

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 7:
Cell Cycle

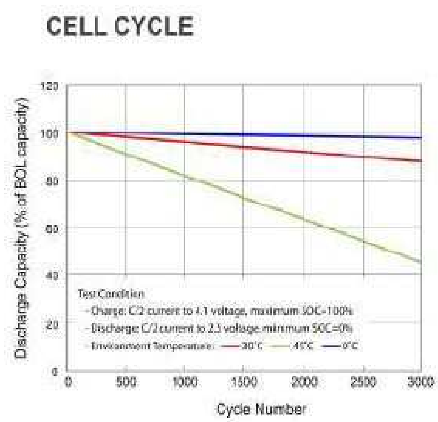
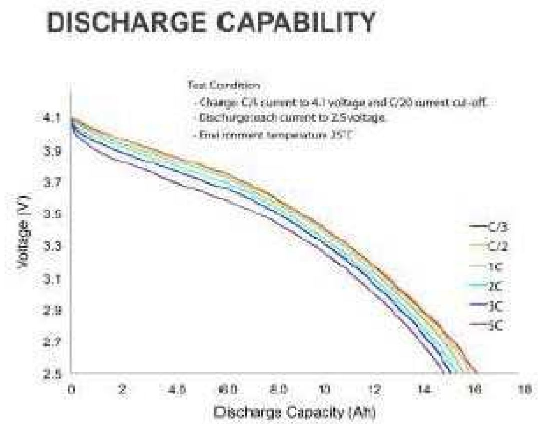


Figure 8:
Discharge Characteristics



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 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 function in the extreme cold that the snowmobile will experience during normal operation. Another great feature of this charger is that the Orion BMS is designed specifically to communicate with chargers like 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 either charger or both chargers together. 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.

Figure 9:
Charger

Drive Train:

CUEK's 2017 Snowmobile is zero emissions by its ability to run on only $LiFePO_4$ batteries. This makes the gasoline engine superfluous and so it is removed. Removed along with the engine was the continuously variable transmission (CVT), fuel tank, muffler, and other associated parts. In place of these parts, a Curtis AC20 motor and Curtis 1238 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 positive transfer belts that have teeth that fit into sprockets of matching tooth pitch. They require little tension and typically replace chains in designs. Timing belts also have no need for an oil bath unlike chains.

Timing belts are also very efficient in transfer of motion as they have no slippage when under correct tension. 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.

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. CUEK have chosen to have two gear ratio combinations that can be change for different applications. This, along with our two-speed transmission results in four gear ratios. Our overall gear ratios range from 3.4:1 in high gear, to 6.09:1 in low gear.

Summary/Conclusion:

Our design of this snowmobile is expected to be a significant improvement over previous years. This year's design will prove to be more reliable and suitable for its intended application, without sacrificing general operation procedures, comfort and looks, from the original IC model. The CUEK zero emission snowmobile will have a safer and more efficient design than previous years. With the main battery pack moved to the center of the chassis handling and comfort of the ride will be improved. Using the more efficient motor and motor controller set up will improve our range. Switching to a larger chassis snowmobile will increase our weight, decreasing handling slightly, causing only a slight decrease in performance from previous years in that area. However, the larger chassis will allow for a more versatile and utility applications that will meet the needs of our intended consumer, resulting in an overall improvement and a more desirable design.

RPM	Rotations Per Minute

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Definitions/Abbreviations

CUEK	Clarkson University Electric Knights
IC	Internal Combustion
BMS	Battery Management System
TSMS	Tractive System Master Switch
IMD	Isolation Monitoring Device
BIR	Battery Isolation Relay
DCL	Discharge Current Limit
CAN	Controller Area Network
GLV	Grounded Low Voltage
CVT	Continuously Variable Transmission