EVS26
Los Angeles, California, May 6-9, 2012

Electric Cars in Arctic Regions

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Abstract

Vehicles that do have the need for cabin heat like four-wheelers and snowmobiles are prime candidates for electric conversion. The University of Alaska Fairbanks' latest electric snowmobile has a 51.5 km (32 mi) range at 32 km/h (20 mi/h) under optimal snow conditions. A Ski-Doo Renegade Sport 550F (wet weight: 232 kg (512 lb)) was modified. The NetGain WarP 7 DC-series motor is connected directly to the sprocket shaft using a Gates Poly Chain. The accumulator is configured to support 177.6 V using 72 Turnigy 5 A•h lithium-ion polymer hybrid cells, which utilize a gel electrolyte. The battery box, containting the 7.992 kW•h accumulator, comes off as one piece. Innovation was a key design concept as the team developed the first electric snowmobile on the Ski-Doo RevXP Chassis. This was a difficult design challenge with its tight pyramidal frame; however the result is having one of the most efficient snowmobile chassis available, running on electric power. The design allowed for any part to be easily removed and replaced. The team developed a robust Battery Management System (BMS) based on the Peter Perkins open source work. This innovation consisted of modifying the programming for a user display that contains battery information, power monitoring and speed. Not content with current DC motor controllers the team utilized the Open ReVolt plans to come up with a reliable and safe unit. The 137 inch suspension was retained to allow for use of the GTX silent track technology and assist during the drawbar pull. Our innovations have kept our MSRP the lowest amongst the competition sleds. The snowmobile weighs a respectable 250 kg (550 lb) and has a top speed of 120 km/h (75 mi/h) and a noise level of less than 60 dB.
Keywords: Lithium Battery, Electric Snowmobile, Arctic Transportation

1 Introduction

The National Science Foundation (NSF) supports research in Polar Regions, which are extremely sensitive areas that are highly impacted by pollution. In 2005 the Clean Snowmobile challenge added the additional category: "Zero-Emissions" in order to promote the use of vehicles which would not contaminate the fragile environments in these regions [1]. Also, it was important to avoid contaminating samples taken from these areas, as engine fumes could adversely affect the samples. Our team was also motivated to design an affordable electric snowmobile due to local high energy costs in Alaska. Gasoline is a precious commodity in rural villages across the state, many of which are not connected to a road system. The price of a gallon of gasoline can be in the $ 10 range. Fuel is shipped to Alaskan villages in the summer by barge when the rivers and other shipping lanes are ice free. In some areas, fuel needs to be flown in, increasing the price even more [2]. The Nanook EV team has focused on finding transportation solutions for rural Alaska that can help reduce villagers' energy consumption, but still maintain their way of life. Electric vehicles have been a very promising solution when paired with locally generated renewable power. The team envisions clean, efficient electric vehicles used as primary local transportation, powered by renewable energy such as geothermal, wind and hydropower. These resources are abundant in rural Alaska but are currently under-utilized. Our snowmobile is designed for the most practicality and performance that an electric sled can offer. At the same time, we strove to demonstrate that electric vehicles can be a viable option for certain applications. To accomplish this, an “innovative, quicker, inexpensive” design philosophy was adopted. The goal was to produce a system that had impressive performance, while still being affordable and easily accessible to the general public. This is our fourth year in this competition, and we offer an improved vehicle that is light and comfortable for the rider, along with additional modifications to the original chassis, all while maintaining a clean, flexible, and aesthetically pleasing design. Snowmobiles are an indispensable means of winter transportation in rural Alaska. While these machines are primarily used for recreation in the rest of the country, here they are an important tool that makes life in remote villages possible. Snowmobiles are therefore an ideal candidate for electric conversion. The Nanook EV team has extensive experience in converting traditional vehicles to run on electric power. Members of the team have converted everything from cars and trucks to ATVs and lawn mowers [3].

2 Design Strategy

The main design strategy was to convert the snowmobile to be most successful at the competition. This year’s competition scoring is more in line with National Science Foundation (NSF) contractor desires. Currently, over 57% of the events relate directly to their needs to support arctic research. The restriction of the accumulator size is an interesting complexity, however, the 8 kW·h size has been successful in doing 14 mi runs in Greenland, and UWM did a successful 20 mi run last year. The acceleration event has been modified. We still needed a high power density battery for the straight-aways, which would benefit our machine on the objective handling track. We were unsuccessful in obtaining cutting-edge batteries that boasted mass energy density of over 300 W·h/kg. These include many lithium-ion based batteries using elements like sodium and silicon. We even sought some semiconductor batteries. What we settled on was an inexpensive pack of lithium cobalt ($LiCoO_2$), which fit in nicely with our light-weight chassis. This keeps our overall cost low for our final Manufacturer’s Suggested Retail Price (MSRP).

Our primary goal was to boast our innovations for this project. We had incentive to keep the modification as simple as possible while using available and affordable parts. The parts needed to be low cost yet durable. Emphasis was added on using the best and least expensive parts to make our motor controller, BMS and other key components. This not only would keep the MSRP low, but allow repeatability and ease for a pre-fabricated kit to be manufactured, so other users could enjoy and benefit from the use of an electric snowmobile. Although electric sleds have been emphasized in past competitions as tools for research purposes, our sled would also be ideal for the general public. Uses could include transportation to work in rural areas, checking trap-lines, subsistence hunting and fishing, and grooming ski and dog sled trails. We wanted a snowmobile that riders would want to use. Consumers are mostly interested in cost and range, and we feel we have achieved a snowmobile that meets those criteria.

Historically, it is interesting to note that dog mushing had been a common transportation choice in Alaska until the mid-1970s. Dog teams were used by the Postal Service in remote villages until the 1960s. The U.S. Army (Figure 1) and the National Park Service maintained sled dog teams for rescue missions or patrolling in remote areas. Denali National Park still employs a dog team today since motorized vehicles are not allowed in certain areas of the Park. With the advent of the snowmobile, Alaskans and other northern locals became enamored with this new machine; however, travel could be dangerous if the snowmobile broke down or ran out of fuel. An electric snowmobile offers a few different options. While the batteries may run out, the machine probably is not too far away from help. Also, the snowmobile could be equipped with an on-board emergency generator to provide enough power to limp home. But perhaps the most exciting option would be for the machine to carry either a hydro or wind turbine that could be setup when the snowmobile was stationary. The use of portable solar panels was also considered, but solar is not a viable option for several reasons. Arctic regions enjoy little sunlight in the winter, and current solar panel technology is very inefficient and would require a trailer that is 12 m (40 ft) long to accommodate the number of panels required.

3 Battery Management System

We adapted our own version of a battery management system. There are many systems commercially available, but none of them offered the compact size, affordable price, or flexibility that our design criteria demanded. Some available BMS systems and their price per cell are shown in the Figure 1. Electrically, much of our design is based on the work of Peter Perkins, who started his own BMS project in 2007.

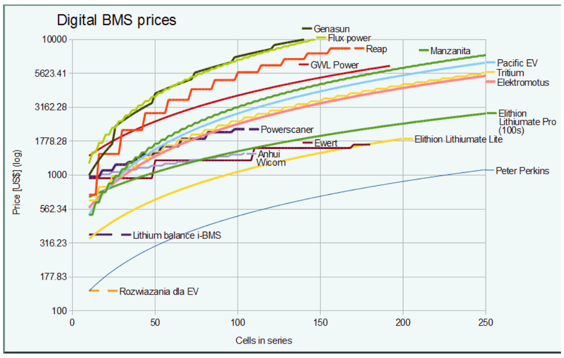

Figure 1: Cost comparison chart of commonly available BMS systems

We have followed his work very closely, and have adapted his system to fit our battery. Changes to the original design include software edits to handle the voltages associated with different battery chemistry, as well as modifying the temperature monitoring and current sensing routines. Future changes will likely involve cell board layout, adapting a surface mount design instead of the current through-hole design. This will allow many more cell monitors to fit on the same board in a much smaller area.

Presently, the BMS monitors cell voltage, pack current, pack temperature, and vehicle speed. It uses this information to display total pack voltage on screen, along with highest and lowest cell voltage (and their cell numbers.) It also tracks and displays total current in and out of the pack, and uses this to display pack state of charge (SOC). Additionally, the BMS displays instantaneous power being supplied by the battery, as well as instantaneous energy use per distance (in units of [W•h]/mile). In addition to monitoring pack condition and displaying relevant information, the BMS is also able to control basic vehicle functions. During charging, individual cell voltage is monitored, and throttles the charger back to a trickle charge state so that cells can top balance. The BMS cell boards are capable of balancing at 500 mA per cell. When all cells have reached the balancing phase, the charger is shut down completely.

During discharge (while the machine is in use) the BMS monitors cell voltage and watches for a low voltage condition on any cell. When the first cell reaches a low voltage condition, the BMS will throttle the controller back. This alerts the driver that the pack is almost empty and needs to return to a charging station immediately, allowing the vehicle to be driven to a safe location in "limp"-mode. However, if any battery cell goes under a pre-set "absolute minimum" voltage, the controller is shut down completely in order to keep from damaging the battery by over-discharging it. In daily use the battery should never be discharged to absolute minimum, but if it does happen, the BMS will ensure that catastrophic damage does not occur. Additionally, this same shut-down procedure is enacted if pack temperature ever goes over a set max temp, such as if the battery were being worked too hard for too long. Because the shutdown procedure consists of opening the main contactors, this will also prevent the pack from overheating in the event of a short circuit or overcharging situation.

4 Motor Controller

The open source motor controller is the heart of the machine. Without the proper controller, the snow machine would have poor performance and render the machine unpractical. The choice of going with the open source motor controller was made for cost and the ability to redesign and modify the controller as required. The open source motor controller project, known as the ReVolt controller [4], got its start in electric car conversions. It was designed to be a low-cost high-performance alternative to existing expensive "dumb" controllers. Most DC motor controllers available in the $ 1 500 category were just very simple analog switching circuits that would take a throttle signal and create a torque command proportionally to drive the traction motor. Torque control was chosen because this is the form of control that a normal combustion engine uses.

Some of the flaws of these controllers are their switching frequency. At high temperature or low duty cycles (small amounts of throttle) the controllers would drop from a switching frequency of 15 kHz to 1 kHz. This would create less heat in power stages due to the smaller amount of transitions of the switching devices per second. The downside to this "feature" is it causes an audible wine in the motor when in this mode. While some people like this to make the vehicle more noticeable to pedestrians, one of the coolest things of an electric vehicle is it can move with almost zero noise. For this reason, the ReVolt controller was design to run at 16 khz. The Revolt controller never changes out of this switching frequency, but instead limits power output if the controller in 8 steps starting at 75 ºC and full shutdown at 95 ºC. As the controller cools down, output will be restored using the same 8 steps but inverted.

The Revolt controller possesses microprocessor control, communication port and extensive safety features. The Atmega168 microprocessor chosen was based on cost, performance, and programming simplicity. This is one of the many AVR based microprocessors. It was set up to run at 16 MHz allowing the 15.625 kHz Pulse Width Modulated (PWM) output frequency as well as 16 kHz interrupt clock running inside the chip to keep functions happening at specific, time sensitive intervals. The communication port is a standard RS-232 protocol running at 19200 baud 8,N,1 allowing devices that supports the RS-232 protocol to talk to the controller. The software runs with a real time data stream that outputs all the values the controller is reading from external sensors and it is internally generated at a user defined interval from 1 ms to 9999 s intervals. Also, all the throttle adjustment and trip point settings, and current limit settings are available through this interface.

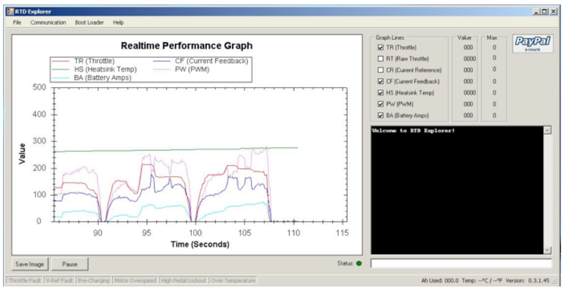

Figure 2: RTD Explorer provides many features for the open source ReVolt Controller

Because of the processing power extensive safety features were developed. A major feature is the ability to check multiple inputs for out of range and strange anomalies. In such a case the power stage would be shut down so nothing bad could happen. These inputs include throttle value checking, current sensor value checking and under voltage lockout protection. If any of these values output out of range, the controller will fault and shut down. The current sensor being the most important sensor in the controller, it is treated with more diligence. When the controller is powered up, there is a small delay for the output of the current sensor to stabilize, and then a reading is taken. Since the sensor is designed to output 2.5 V at 0 A, if this first reading is outside this range, the controller will fault immediately. Without a working current sensor, there is no way for the controller to regulate power from the batteries to the motor, thus making the vehicle unsafe to operate. Since the controller is a torque controlled, and torque is proportional to the amount of current being fed into the motor, without a way to measure current, there is no way to control torque. If the current sensor breaks during operation or becomes disconnected, the software will sense this and shut down the output.

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Author

Michael Golub has converted over 15 gasoline and/or diesel vehicles to run exclusively on electric power. He has driven his battery-powered 4x4 pickup truck in Interior Alaska at temperatures as cold as -30 degrees C. (-22°F). He recently led the UAF electric snowmobile team to win a best design award at the 2011 SAE Clean Snowmobile Challenge. Mr. Golub believes that electric cars would be ideal for most consumers, and that the conversion process of older vehicles is viable. He currently teaches the ES166 Electric Car Conversion course at UAF. Mr. Golub has a BS in Mechanical Engineering degree from UAF. He is currently a graduate student working on an interdisciplinary graduate degree. He also has a BS in Liberal Arts from Excelsior College, and an MFA in Television Production from Brooklyn College. He and his wife, Janice, live in North Pole, Alaska with several rescued and retired sled dogs.