Exploring the Potential Commercialization of Electric Snowmobile Technology Using Advanced Powertrain Modeling and Simulation

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ABSTRACT

This paper addresses the question: can an electric snowmobile be a cost effective solution for use as a utility snowmobile?

In addressing this question the performance limitations of current electric snowmobile prototypes are investigated and it is shown that, unless a huge leap is seen in current battery technology energy density, electric snowmobiles cannot perform on par with gasoline snowmobile on both range and performance simultaneously.

Despite this, electric snowmobiles do have a certain number of niche applications where they can be useful. This paper explores a few examples of these applications and shows that, using advanced powertrain modeling and simulation, an electric snowmobile design can be developed to be a cost effective solution for a given application.

INTRODUCTION

Worldwide, an extensive amount of research and development is being performed with the goal of reducing emissions and energy consumption associated with transportation. One of the areas receiving the most attention is the passenger car sector. This research brought to market the use of electronic fuel injection and catalytic converters. Both technologies have now been widely implemented in passenger cars for many years. This widespread implementation has yielded great improvements in emissions and energy consumption in passenger cars. Lately, the use of battery electric technology has been under strong investigation as a means of further improving passenger car emissions and energy consumption.

Snowmobiles have not received as much global research interest as passenger cars and it is only recently that snowmobile manufacturers started to implement 4-stroke engine technology and electronic fuel injection on multiple snowmobile models. As far as one can tell from the press releases, unlike the auto industry, none of the major snowmobile manufacturers has the use of electric technology as a means to improve snowmobiles on its agenda. While lower global research interest is possibly one of the factors in this reality, it most likely isn't the only one. The reality of consumer expectations on the performance and cost of snowmobiles, regardless of how extreme the terrain and conditions are, plays a significant role in this apparent lag in snowmobile technology when compared to passenger cars.

SNOWMOBILE DESCRIPTION - The definition of a snowmobile is fairly broad. It says that a snowmobile is "a motor vehicle with a revolving tread in the rear and steerable skis in the front, for traveling over snow”"/>.

The first attempts at building a vehicle that would move over snow on runners happened over 70 years ago. In 1935, a snowmobile was built with skis in front and a sprocket wheel and track system in back. It carried 12 people. Family doctors, veterinarians, ambulance and taxi drivers were first in line to purchase one[i]. Nowadays, most North Americans, when hearing the word "snowmobile", picture a small, open chassis, track propelled and ski steered vehicle, which can be straddled by a driver (and sometimes one or two passengers). Such a vehicle can be seen in Figure 1 below.

Figure 1: Snowmobile with Utility Cargo Box in the Rear

Today, the majority of snowmobiles in the world are manufactured by the four members of the International Snowmobile Manufacturer Association (ISMA): Arctic Cat, BRP, Polaris, Yamaha. These vehicles are powered by gasoline internal combustion engines. The engine's power is usually transferred to the track via a V-belt continuously variable transmission (CVT) and a step-down secondary ratio. The CVT, which also houses a centrifugal clutch, allows the snowmobile to seamlessly go from idling mode to various motoring ratio modes with nothing more than driver pressure on a handle bar mounted “throttle” lever.

Today’s snowmobiles are one of the simplest and fastest ways to transport people and cargo on snow covered ground and frozen bodies of water.

The following statistical information regarding the snowmobile industry comes from the ISMA’s online snowmobile fact book[ii]:

- In 2008 there were 163,753 snowmobiles sold worldwide; 79,552 were sold in the U.S. and 50,556 were sold in Canada. Worldwide sales have generally been declining since 1998 (257,936 units).
- There are approximately 1.62 million registered snowmobiles in the US and 708,490 registered snowmobiles in Canada.
- Approximately 80% of snowmobilers use their snowmobile for trail riding and touring on marked and groomed trails. 20% of snowmobilers use their snowmobile for work, ice fishing or transportation.
- Average snowmobilers ride their snowmobile 1674 km (1040 miles) per year. They average 22 days snowmobiling per year. (i.e. over 75km per day on average when calculated based on the above numbers)
- The average suggested retail price of a new snowmobile sold in North America in 2008 was $9,324.00.

The snowmobile industry, like many other transportation industries, has, in recent years, been criticized for some of its perceived negative environmental impacts. Areas of criticism include:

- Noise
- Emissions
- Effects on wildlife
- Energy consumption
- Effects on snow, water and soil
- Effects on plants and crops

There is some debate between a number of organizations and individuals on many of these perceived issues. That being said, the current reality of some snowmobile applications has prompted some snowmobile users to look for a type of snowmobile not currently offered by the four members of the ISMA: an electric snowmobile.

One of the first to come forward was the scientific community who was looking for a zero-emissions on-snow utility vehicle to decrease contamination risk of samples taken in remote locations.

Following them, some snowmobile tour operators in both North America and Europe started to show interest in electric snowmobiles.

The North Americans saw a way for their customers to better appreciate the environment which they are visiting and thus they believed that the electric snowmobile could provide a plus value to their short range tours. The Europeans (currently located in the French Alps) saw a potential way to try and expand or simply keep their business in operation given the recent ban on snowmobiles in France.

Lastly, winter sports resort operators started to come forward in order to see if their operations could benefit from the use of electric snowmobiles. Two pilot projects (one in Quebec with Mont St-Sauveur International at its Mont St-Sauveur and Avila winter resort and one in France with Val d’Isere ski town while it was hosting the 2009 FIS World Alpine Ski Championships) have demonstrated that electric snowmobiles can better meet the needs of some winter resort applications than their gasoline snowmobile counterparts.

So, if there are applications out there where electric snowmobiles can shine, why are we not seeing more electric snowmobiles being used on a regular basis?

The answer is short: cost.

Electric snowmobiles can do wonderful things as prototypes… but when it comes time to move from the “prototype world” to the “real world”, the cost factor becomes a major obstacle.

Thus, one may ask: In the short term, is there a way for these other applications to benefit from electric snowmobiles at a viable cost? If so, how?

Dedicated mass production of electric snowmobiles to bring down the cost is very unlikely. Electric snowmobiles will for the foreseeable future be limited in how much range and power then can simultaneously offer when compared to what current user have become accustomed to. Thus it is unlikely that a single electric snowmobile model can meet the needs of enough applications to enable cost reduction via mass production.

Instead, this paper proposes that the custom design, using advanced computer modeling and simulation, of application specific powertrains to be retro fitted in currently mass produced snowmobile chassis, is the most promising way for these “pro-electric” applications to benefit from electric snowmobiles at a viable cost.

This paper is divided into three main sections:

The first section investigates the main physical and technological obstacles facing the design of an electric snowmobile.

The second section presents a pair potential commercial applications that are currently under study.

The third section discusses modifications that have been made in order to improve the viability of the electric snowmobile as a commercial product.

THE CHALLENGES OF MAKING (AND SELLING!) AN ELECTRIC SNOWMOBILE

Why is the design of a practical electric snowmobile such a challenge? Why can't electric snowmobiles aspire to replace the majority of current gasoline powered snowmobiles?

The short, two word, answer to the above questions is: **energy density**.

The more detailed answer is: because current energy storage systems (ex. batteries) have very low energy density when compared to currently permissible alternatives. (i.e. gasoline for snowmobiles in North America).

Let us look at electric and gasoline snowmobiles in more detail to see why energy density is a tremendous obstacle to overcome for electric snowmobiles and thus why it greatly limits the number of potential applications which could see their needs be fulfilled by electric snowmobiles.

ENERGY DENSITY - Using a value of 8760 Wh/l[iii] as the energy available in gasoline and looking at the size of the fuel tanks offered by the four main snowmobile manufacturers on one of their small utility snowmobile models, Table 1 shows that, on average, their utility snowmobiles carry 355,875 Wh of energy on-board.

Table 1: On-Board Energy of 2008 Model Year Gasoline Powered Utility Snowmobiles

Vehicle	Fuel Volume (l)	Energy On Board (Wh)
Arctic Cat Bear Cat 570	49.2	430,992
Polaris 340 LX	44.6	390,696
Ski-Doo Skandic Tundra	34	297,840
Yamaha Venture Multi-Purpose	36	315,360
Average	40.95	358,722

Using a mass of 0.73 kg/l [iv] as the specific mass of gasoline, the weight of the average 355,875 Wh of energy carried on-board those snowmobiles is 29.66kg.

In order to compare battery energy density with gasoline, Table 2 looks at the energy density of four of the main battery technologies mature enough for use in electric snowmobiles: lead acid (PbA), Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH), Lithium-Ion (Li-ion).

Table 2: Energy Density of Common Battery Technologies

Battery Technology	Gravimetric Energy Density (Wh/kg)	Volumetric Energy Density (Wh/l)
PbA	33.5	76.2
NiCd	54	95
NiMH	60	155
Li-ion	105	284

It is clear from Table 2 that none of the common battery technologies have energy densities approaching the 12,000Wh/kg and 8760Wh/l of gasoline. Nevertheless, in Table 3, all four battery technologies and gasoline are compared head-to-head on weight and volume basis in the case where they would be installed in a common utility snowmobile.

Table 3 answers the following three questions:

If one was to use a Ski-Doo Skandic Tundra snowmobile with 297,840Wh of energy on board (as seen in Table 1), for different energy carriers, what would be

- the energy carrier (EC) volume ?
- the energy carrier (EC) weight ?
- the ratio of energy carrier (EC) weight to vehicle dry weight?

Table 3: Head-to-Head Comparison of Raw Energy Density of Common Battery Technologies and Gasoline in a Snowmobile

Energy Carrier (EC)	Gasoline	Batteries			
		Li-ion	NiMH	NiCd	PbA
Vehicle	Ski-Doo Tundra				
Dry Weight	172 kg				
Energy On-Board	297,840 Wh				
EC Volume	34 (l)	1049 (l)	1292 (l)	3136 (l)	3910 (l)
EC Weight	24.8 (kg)	2837 (kg)	4965 (kg)	5516 (kg)	8892 (kg)
Ratio: EC Weight / Vehicle Dry Weight	0.144	16.5	28.9	32	51.7

As Table 2 has shown, the "raw" energy density of battery technologies is nowhere near the "raw" energy density of gasoline. Consequently, as shown in Table 3, unrealistically large amounts of batteries would have to be used to equate the on-board energy of a standard gasoline snowmobile.

Why is the term "raw" energy density being used?

The term “raw” energy density is used since the values in Table 2 only consider the energy density of the batteries themselves. For a more accurate comparison between the energy density of batteries and gasoline, one should also account for the weight and volume of the containment chamber or other means of holding the gasoline and batteries on board. To this, one must add the difference in weight and volume, of energy transfer systems (i.e. fuel pump and tube vs. battery management system and wires). Lastly, the reduction in battery energy density related to cold temperature and high discharge rates should be taken into account for a true comparison between battery technology and gasoline.

Taking all these factors into account can be termed the “net” energy density comparison. In general, the “net” energy density comparison will make the difference between the energy density of gasoline and battery technologies even greater than the “raw” energy density comparison.

In a best case scenario, (see Table 3), in order to have as much energy on-board an electric snowmobile as on a gasoline powered snowmobile, one would have to carry over 2800kg (6173lbs) of batteries. In a utility snowmobile such as Ski-Doo's Skandic Tundra weighting 172kg (379lbs) (dry weight)[v], this represents a “fuel” weight 16.5 times larger than the weight of the vehicle itself! Furthermore, unlike liquid fuels, the mass of the batteries will not diminish as energy is consumed. It is clear that such a vehicle to fuel weight ratio is not suitable for a snowmobile.

It has been established that a large energy density difference between gasoline and battery technology exists and that, given this large difference, with current technology, it is impractical for one to have as much energy as a standard gasoline snowmobile on-board an electric snowmobile.

Next, we investigate if this energy density difference can be compensated by the difference in energy efficiency between gasoline powered technology and electrically powered technology.

ENERGY EFFICIENCY - To see if energy efficiency can offset the energy density difference between gasoline and batteries, we investigate a theoretical best case scenario for the battery technology. For this best case scenario the following steps and assumptions are used:

- Two identical snowmobiles with the same weight distribution and drive characteristics are used
- One is given 24.8 kg of gasoline, the other 24.8 kg of the best battery technology as listed in Table 2 (Li-ion)
- The amount of available energy on-board is calculated using “raw” energy density (Table 2)
- The electric snowmobile is assumed to have maximal theoretical efficiency. (i.e. All the energy in the battery is transferred to the ground without any losses).

Based on all of the above, the efficiency value of the gasoline snowmobile powertrain required for the gasoline snowmobile to have exactly the same performance as the electric snowmobile is calculated. Table 4 below summarizes this procedure and its result.

Table 4: Comparison of Required Theoretical Efficiencies for Equivalent Vehicle Performance

Energy Carrier (EC)	Gasoline	Batteries (Li-ion)
Vehicle	Ski-Doo Tundra	
Dry Weight	172 kg	
Energy Carrier Weight	24.8 kg	
Energy On-Board	297,840 Wh	2,604 Wh
Theoretical Efficiency for Equivalent Performances	0.87%	100%
Energy Used to Propel the Snowmobile	2,604 Wh	

Table 4 shows that even using “raw” energy density values and assuming a theoretical electric snowmobile drive system efficiency of 100%, the gasoline powered snowmobile’s drive system would only have to be less than 1% efficient for the two vehicles to be equal in terms of range and performance with the same mass of energy carrier (EC) on-board.

Calculations based on results from the SAE Clean Snowmobile Challenge results[vi] indicate that snowmobile engine efficiencies generally tend to range in between 17 and 24 % (depending on operating point) with some specific operating points on some specific engines sometimes achieving up to 28% efficiency.

It is clear from this exercise that electric snowmobiles cannot compete with gasoline snowmobiles on both range and performance simultaneously. The gap in energy density between battery technology and gasoline is so large that, even when using an ideal theoretical scenario when factoring in energy efficiency, one cannot fully compensate for this fundamental difference.

However, not all applications require all the range and performance modern gasoline utility snowmobiles can offer. Some applications require only a limited range and/or limited power.

Potentially, electric snowmobiles could be used in such applications. Also, some applications exclude the use of current gasoline snowmobiles since they cannot be used due to their exhaust emissions. In such cases, an electric snowmobile can be a very interesting solution.

OBSTACLE TO ELECTRIC SNOWMOBILE COMMERCIALIZATION - Is the energy density issue the main obstacle to the use of electric snowmobiles in day to day operations? Not exactly. Cost is the main issue.

There are a number of applications that could see their needs satisfied by snowmobiles with low energy density. However, based on our work with various commercial snowmobile operators (tour operators and winter sport resort operators), there are currently almost no applications where the snowmobile owners are willing to spend substantially more on an electric snowmobile than on a gasoline powered snowmobile to meet their needs.

The exact amount one might be willing to spend on an electric snowmobile varies a lot based on the application. For example, some tour operators have certain routes or packages on which they net much more profit then others. After discussing with them, without much surprise, these tour operators felt they were able to spend more on an electric snowmobile that could meet the needs of the product with the biggest profit margin than the product with a lower profit margin.

However, more than the cost of the electric snowmobile itself, what interests most owners is its cost relative to other alternatives. Once known, the relative costs can be weighted along with the advantages and disadvantages of each alternative to see which option they will choose. This is nothing new. The exact same decision process is currently happening within the gasoline snowmobile world when these operators are faced with the choice between 2-stroke vs. 4-stroke.

So when will these commercial snowmobile operators start to not only pick between "2-stroke vs. 4-stroke" but rather "2-stroke vs. 4-stroke vs. electric"?

Believe it or not, the first steps of this process have already started in Western Canada, Eastern Canada and in Europe.

Based on our conversations with commercial snowmobile operators, figuring out the relative cost between gasoline snowmobile is mostly based on the vehicle price tag. Some look at the fuel savings and in some cases a more thorough investigation might include cost of oil and/or coolant as well as specific maintenance cost related to a specific engine. However, in many cases the decisions are mainly made on upfront price tag and perceived advantages vs. disadvantages of the different gasoline powered options.

Adding the electric snowmobile to the list of possible options to pick from brings up 2 major questions which the commercial snowmobile operator needs an answer to before he can take an informed decision:

1. Can an electric snowmobile meet the needs of my application without too much of a compromise on vehicle weight (and thus still handle like a "snowmobile")?
2. At what cost can an electric snowmobile meet the needs of my application?

Given that there are currently no worldwide electric snowmobile distribution networks with a wide range of available models, being able to answer these 2 questions rapidly and precisely, without actually designing, building and testing a complete electric snowmobile prototype to answer it, is crucial. Otherwise simply the cost of answering these 2 questions would scare away potentially interested operators.

Advanced powertrain modeling and simulation is now an established tool for automotive product development, and has already been shown to be an effective means of answering these important questions relating to electric snowmobiles[vii]. While it is important to take into account the effect of varying driving conditions associated with off-road vehicles, simulations can be run based on information specific to a certain customer's application in order to develop an electric snowmobile design that is optimized for that role. The following section briefly outlines a few of the opportunities for small-scale electric snowmobile commercialization that McGill is currently exploring.

OPPORTUNITIES FOR COMMERCIALIZATION

Having been a key player in electric snowmobile development for a number of years, the McGill Electric Snowmobile Team has established a number of contacts with potential electric snowmobile operators. With a strong background in electric snowmobile modeling and simulation, it has been possible to give these potential operators a clear idea of what exactly would be involved in a switch to electric snowmobiles and a clear understanding of the limits of the current technology. While many have realized that it is unlikely that entire fleets of snowmobiles will easily be swapped with zero-emissions replacements, it is quite feasible to adapt operations in such a way that at least a portion of an operator's snowmobiles can run on electricity.

WHISTLER BLACKCOMB CHILDREN'S LEARNING CENTRE - Whistler Blackcomb, by many measures the largest ski resort in North America, operates the Children's Learning Centre (CLC) on Whistler Mountain where skiing lessons are offered to children of all ages. The smallest children are transported to and from the CLC on a sled towed by a snowmobile. The snowmobile picks the children up at a gondola mid-station and transports them 100 meters across snow to the CLC, with a total sled weight of approximately 800lbs. On busy days there can be as many as 15 loads of children. The children must then be returned to the Gondola at the end of the day. The CLC's snowmobile is also used to transport equipment to and from the school. Currently, the needs of the CLC are satisfied by a dedicated gas powered snowmobile.

This is an excellent opportunity for an electric snowmobile. The driving distances are very limited, and the snowmobile always stays within a small area where electricity is readily available. In order to satisfy the needs of the CLC, an electric snowmobile would not require a large capacity battery pack, and therefore the cost of such a snowmobile could be kept very reasonable. Furthermore, the sensitive aspect of vehicle exhaust while towing young children behind the snowmobile adds extra value to the zero-emissions nature of an electric snowmobile.

McGill had a chance to test the most recent electric snowmobile prototype in this role during February of 2010:

Figure 2: Electric snowmobile towing children to ski lessons on Whistler Mountain.

The electric snowmobile performed perfectly in this application. With a maximum traveling distance of at most 4km in the morning and the same in the afternoon with time for a full recharge in between. This is a very low-speed application where acceleration must be gentle to ensure a smooth ride for the children onboard the sled.

This is a perfect example of an application where there is little need for batteries of the highest energy density possible. A battery pack with less than 2kWh of energy would be sufficient for the distances involved, and cheaper, heavier batteries would only improve the snowmobile's traction - a crucial characteristic while towing, as has been seen in previous SAE CSC events.

The operators of the CLC are enthusiastic about the idea of switching over to an electric snowmobile designed specifically for their operations, and discussions are ongoing.

CANADIAN SNOWMOBILE ADVENTURES - Canadian Snowmobile Adventures (CSA), one of Canada's largest all season motorized tour operators, located in Whistler B.C., offers their clients the opportunity to travel through the wilderness in the Whistler region by snowmobile, with packages for riders of all skill levels. CSA was one of the first snowmobile operators to express interest in incorporating electric snowmobiles into their business, having worked with the McGill Electric Snowmobile Team for a number of years.

CSA has made it clear over the years that despite the best of intentions, the company simply could not afford electric snowmobiles equipped with $9000 battery packs. Running and maintenance costs of an electric snowmobile should be lower, but while the customer experience would be greatly enhanced by a clean and quiet snowmobile, the added initial cost of such a sled would leave CSA with an overall loss which could not be justified.

It would instead be necessary to explorer possibilities designed around a snowmobile with a lower cost battery. By focusing on a tour that would emphasize the appreciation of the natural surroundings rather than the loud and thrilling performance of a gas powered snowmobile, CSA could develop a product that would appeal to a wide range of people who might otherwise shun the idea of riding a snowmobile.

Testing conducted last year and presented in McGill 2009 SAE CSC Design Paper showed that a return trip on CSA's Fitsimmons Creek trail consumed less than 2kWh of energy. While this trip on it's own is a relatively short journey, CSA could incorporate a second activity into an electric snowmobile tour that would simultaneously increase the value of such a tour to it's customers while allowing the opportunity to recharge the snowmobile batteries. CSA is currently looking into a combined Electric Snowmobile and Snowshoeing Tour. Customers would travel by electric snowmobile to a forested area appropriate for snowshoeing, park the snowmobiles at a location with access to the electrical grid, and enjoy the forest on snowshoes for an hour while the snowmobiles are recharged. Allowing the snowmobiles to recharge half-way through the trip could effectively cut the required battery pack size and cost in half. Meanwhile, customers enjoy a longer trip with added variety, and with a strong focus on enjoying nature with as little disruption as possible to the wildlife.

ADDRESSING THE CHALLENGES FOR COMMERCIALIZATION

For the SAE CSC 2010, McGill will be showcasing an electric snowmobile platform that it feels is ready to meet the needs of certain commercial applications. Compared to its 2009 competition entry, the 2010 sled presents anumber of significant modifications. While these modifications may not necessarily improve McGill's performance at the SAE CSC, the team feels that the changes increase the viability of the electric snowmobile as an actual affordable product given the right application. The primary modifications are a new brushless motor system, and a new battery chemistry that sacrifices energy density somewhat for a drastically reduced cost compared to lithium-ion.

BATTERIES - The disparity between the energy density of gasoline and even the best batteries means that an electric snowmobile can by no means compete with a conventional snowmobile in terms of range. As such, it is necessary to focus specifically on applications that do not require the snowmobile to travel long distances. The case for an electric snowmobile gets stronger as the range requirements, and hence battery cost, are reduced. It makes little sense to blindly squeeze as many batteries on board a snowmobile as possible, unless the application truly demands it. Instead, it becomes more interesting to focus on roles for an electric snowmobile where the demands on the battery pack are lower, allowing the use of a much cheaper battery pack and therefore greatly increasing the affordability of the snowmobile.

While the McGill Electric Snowmobile Team has made use of both lithium-ion and lead-acid battery packs over the past few years, recently an opportunity has risen to explore the use of a new battery chemistry that can offer an interesting compromise between battery size and cost. Nickel Zinc (NiZn) batteries offer an energy density on par with NiMH batteries at a much lower cost than the top of the line lithium-ion batteries favoured by most ZE CSC contestants. For some potential electric snowmobile customers, such a battery might meet the optimal balance between cost and performance.

McGill's entry for SAE CSC 2009 used a lithium-ion battery pack valued at $9000, %60 of the total vehicle cost. This battery pack holds 3.2kWh of energy which is enough to propel the snowmobile approximately 10km, while keeping the weight of the snowmobile down to approximately 500lbs. While maximum range at a minimum weight might be important for many roles, the added cost of such a battery is extremely hard for any operator to justify. By comparison, the NiZn battery pack under study at McGill will cary 2.3kWh of energy while adding approximately 30lbs to the total vehicle weight. Clearly the range of such a snowmobile will be reduced and the acceleration and handling will be impacted slightly by the added weight, but with a total battery cost of only $1100, the electric snowmobile suddenly becomes a more attractive proposition for those who can accept these performance limitations. Clearly, the two snowmobile operators discussed in the previous section could satisfy their needs with a battery of this capacity.

The design of the McGill Electric Snowmobile platform allows for an easy transition from one type of battery to another, allowing the adaptability required for custom designs for specific applications.

MOTOR - The change to a new motor was driven by the desire to reduce running costs of the snowmobile, while simultaneously increasing the user friendliness of the vehicle. Since 2007, McGill's electric snowmobiles have all employed permanent magnet, brushed DC motors. While these motors have offered excellent power density at a low price, brushed motors subtract from the "maintenance-free" aspect often touted as an advantage of electric vehicles. Motor brushes need to be inspected on a regular basis and replaced multiple times during the life of a vehicle, a job that can be difficult without removing the motor from a vehicle depending on the layout of the powertrain.

Wearing of motor brushes also introduces a safety concern as was seen by McGill during the 2009 SAE CSC. Carbon dust from the brushes can collect inside a brushed motor, eventually leading to a slight connection between the high voltage circuit and the body of the motor and hence the vehicle chassis. All SAE competition electric vehicles are equipped with a ground fault circuit interrupter that would detect such problems and cut off power to the vehicle, so while there is no real danger to the driver with such a system in place, the carbon dust leads to an element of unreliability with such motors.

Switching to a brushless motor would therefore reduce the maintenance costs of an electric snowmobile, while also improving it's safety and reliability. McGill selected a three phase AC induction system with a peak power output of 18kW and peak torque of 35Nm at 0rpm and a maximum speed of 7500rpm.

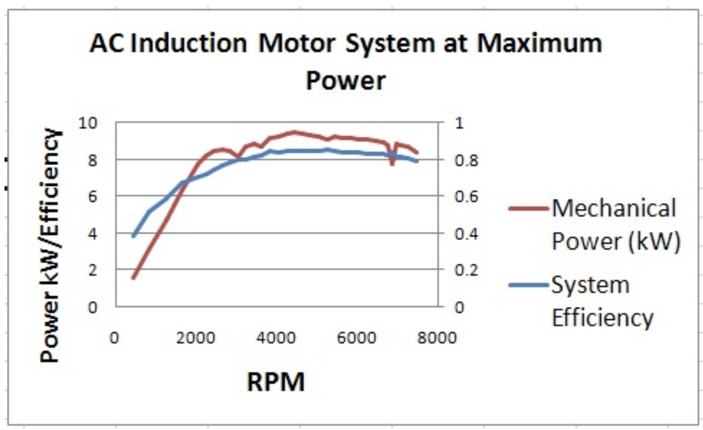

Figure 3: Results from dynamometer testing of the AC Induction Motor System

Dynamometer testing showed that this motor could exceed the current limits of the batteries used by the McGill Electric Snowmobile Team. It was therefore necessary to implement a Power LImiting Map to avoid damaging the batteries, which resulted in a peak power output of approximately 9.5kW at 4500rpm, while maintaining the peak torque of 35Nm. The AC motor controller and motor maintain an overall system efficiency of over 80% over a wide range of rpm at maximum power output. Furthermore, the strong low-end torque coupled with a high maximum motor speed allows the snowmobile to use a 98% efficient fixed belt drive rather than a CVT as was necessary with previous motor systems, improving overall vehicle efficiency as well as reducing vehicle noise levels.

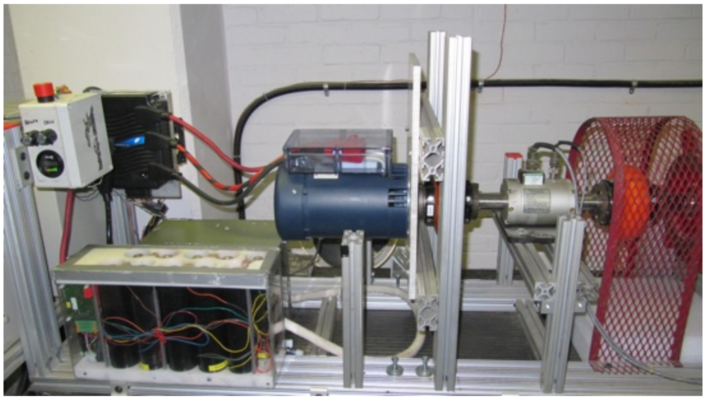

Figure 4: AC Induction Motor System mounted on electric dynamometer

The motor controller itself presents interesting features for commercial applications. It is highly programmable with a number of customizable options, such as a speed limiting function. It also allows the snowmobile to electronically switch into reverse gear - greatly improving handling of the snowmobile in tight spaces. Finally, the motor system also allows for regenerative braking, which can be extremely beneficial in mountain applications where it can simulate engine braking, essential to maintaining control on steep descents.

Overall, this new motor system adds approximately 1000$ to the cost of the electric snowmobile compared to last year's simpler DC motor system. However, this new system renders the powertrain truly maintenance free, allowing operators to save significantly on running costs. Furthermore, the added features of the motor controller mentioned above increase the value to the operator.

CONCLUSION

This paper has investigated the question: can an electric snowmobile be a cost effective solution for use as a utility snowmobile?

The proposed answer is yes. However in order for this to be true, an electric snowmobile must be properly sized for the target application.

Electric snowmobile will by no means take over the snowmobile world given the difference in energy density between gasoline and batteries. Nevertheless, McGill University has demonstrated with different successful projects that in applications where limited range and/or power is required, a electric snowmobile can potentially be successfully implemented.

In order to be a viable product, the end users must be willing to purchase electric snowmobiles at a price higher than the manufacturer's production cost. Unfortunately, mass production of electric snowmobiles is unlikely due to the relatively low number of suitable applications. Thus, other means of improving the end user's perceived cost/benefit ratio for electric snowmobiles must be investigated. It was proposed that electric snowmobile powertrain modeling and simulation can potentially improve the end user's perceived cost/benefit ratio in two ways:

1. By determining if an electric snowmobile design can perform adequately on a given duty cycle, thus ensuring the end users that the snowmobile will meet their needs without need for potentially expensive on-site trials

2. By being used as a tool to custom design electric snowmobiles for specific applications in order to limit costs associated with expensive energy storage and powertrain components.

Following earlier successes with electric snowmobile modeling and simulation, an easily configurable platform was conceived which can easily accept a number of powertrain configuration thus enabling the rapid implementation of an electric snowmobile in a given application.

Future work is currently being focused on further improving the use of advanced vehicle modeling and simulation for electric snowmobile commercialization. A number of North American and European partners have shown interest in using this approach in order to improve the services offered by their business via the use of electric snowmobiles.

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