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A Better Cold Weather Battery for Arctic Environments

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Abstract

Alternative energy sources such as solar and wind can generate power intermittently, and with the use of inexpensive, environmentally-safe batteries, such systems can achieve improved performance. These batteries also are designed for energy storage with excess diesel power generation during off-peak times, and could also supplement biomass, tidal and geothermal sources. Our approach focuses on developing a battery which (i) works in extreme environmental temperatures, as found in rural Alaska; (ii) is easily assembled from raw subcomponents to keep costs down (where local residents can do the manufacturing), allowing the collection and dismantling of used batteries for proper recycling; (iii) create a high power density battery for mobile requirements. Lithium iron phosphate ($LiFePO_4$) will be utilized for design, fabrication and testing of a known battery chemistry. We will focus on creating Zn_2SnO_4 powder and use prior knowledge to design and fabricate the novel cold-weather high-density battery, lithium zinc stannate (Li Zn_2SnO_4).

Keywords: Lithium Battery, Cold Temperature Battery, Battery Safety

1 Introduction

Inexpensive cold-weather batteries would be ideal for electric vehicles, remote off-grid housing, and remote sensor sites. Our intention is to start a process to wean consumers from using lead acid batteries. Improper disposal of these batteries is harmful to the environment. We will develop a replacement battery that is improved in every aspect of performance and create a distribution system to transport them where they are needed. Current battery technology for off-grid electrical use consists mainly of lead acid batteries. These batteries have a low energy mass density. They are also expensive and heavy, which makes them difficult to transport. Lead acid batteries exhibit poor cycle life of an average of 750 cycles.

Their performance is reduced in cold temperatures. Lead acid batteries are harmful to the environment if not disposed of correctly. Newer, larger format lithium-based batteries alleviate previous concerns. They are lighter and easier to transport. Cycle life is over 3,000 cycles. The materials used in lithium-ion batteries are environmentally benign. However, these batteries are still expensive and not well known. These newer batteries do exhibit a better cold temperature performance; however that leads to our innovation: we propose to develop an affordable cold temperature battery.

2 Justification and Need

Roads in Alaska connect only a small number of communities, and most villages are accessible only by boat or plane. This lack of infrastructure makes electrical transmission as difficult as transportation. Many rural villages depend primarily on diesel-run generators to provide their homes and businesses with electricity, and on fuel oil to generate heat. Diesel must be shipped in on barges or flown in on planes, and is normally purchased in bulk in the summer and stored in large tanks in the villages. It can only be shipped in the short summer when the waterways are not frozen. When the price of oil spikes, as it did in the summer of 2008, rural Alaska's reliance on diesel and fuel oil can be devastating to villagers. Alaska is abundant with various forms of renewable energy. Wind turbine generators have been proving themselves across Alaska from the Matsu Valley to the Eskimo village of Toksook Bay, located on the Bering Sea. Wind is a clean and plentiful source of energy in most areas of Alaska. Geothermal energy is one of the most sustainable and environmentally friendly energy resources that can be developed. Renewable resources such as wind, solar, and hydro are abundant at certain times and in some places, but they are not always available when and where they are needed. Switching to other generation sources may require additional energy sources and equipment when renewables become unavailable. Alternatives can take the form of storage or portable generation technology which can be used when required. For electrical systems, batteries are the most direct way to store electrical energy. Batteries are more appropriate for providing short term energy storage to allow a transition between a variable renewable energy source and a small generator. This is the case in the wind-diesel power system in Wales, AK or in smaller applications, such as home or small community systems. Several battery types can be considered for rural applications: (1) Lead-acid batteries are the most common batteries. Although batteries are highly reliable, they have a limited life, are heavy to ship, and contain toxic materials which usually require removal at the end of their useful life. (2) Lithium-ion batteries are an alternative to lead-acid batteries. They are more robust, with longer life in stationary applications. Although Li-ion batteries are considerably more expensive than lead acid batteries, this longer life expectancy and their usefulness in high power applications may make them less expensive on a life-cycle basis, particularly in rural Alaska where long operating life is beneficial.

Batteries are also important in the production of Electric Vehicles (EV). UAF has been offering a class which converts fuel powered vehicles to electric powered vehicles. The use of electric cars as a potential transportation method has become more popular worldwide. The environmental and health- related advantages of electric cars include: (1) the reduction of emissions of carbon dioxide, a greenhouse gas that contributes to global warming; (2) lessening cancer risk from exposure to toxic air contaminants such as benzene; and (3) reduction of oil consumption and dependence on imported oil. It is widely believed that the use of electric cars in cold regions may be more favorable compared to other regions, since more pollution particles are generated in winter due to inefficient combustion and the elongated warm-up period of the fossil fuel powered automobile.

To attain sufficient range for an EV, emphasis is on energy storage capacity. Batteries generally available for traction applications consist of metals such as lead, nickel and lithium. Thomas Edison designed the first traction batteries using nickel iron (NiFe). His battery (and his electric car) was later replaced with lead acid batteries (PbA) in the early 20th century. The nickel battery has evolved to such variants as the nickel cadmium (NiCd) and nickel metal hydride (NiMH) battery. Using nickel was an improvement over lead, except for cost and safety to the end user. Both lead and nickel exhibit a poor mass energy density of under 75 W-h/kg. However, when using the lightest metal available, lithium batteries promised excellent mass energy density. At first, a non-rechargeable lithium battery was developed and dubbed "Lithium Metal". When the first lithium secondary cells were promoted, they were distinguished from non-rechargeable primary cells as "Lithium-Ion", or "Li-Ion." Today there are four types of lithium rechargeable batteries in production and available for resale: lithium cobalt (LiCoO2), lithium manganese (LiMn2O4), lithium nickel (LiNixMnyCozO2 also known as NMC Li-ion), and lithium iron phosphate (LiFePO4).

3 Research Objectives and Approach

The electrochemical features of Inverse spinel structure Zn_2SnO_4 crystals prepared by a solid state reaction have not been fully investigated in arctic regions. Initial studies show a higher mass energy density of 20 times greater than typical lithium-ion batteries. Even though the battery exhibits 1025 mA-h/g this reduces to a stable 689 mA-h/g within 50 recharge cycles. However, this feature has only been shown during ambient-temperature studies. This research is to fabricate the lithium zinc stannate battery and determine if it would be a viable candidate for extreme cold weather specifications. Many lithium-ion batteries use graphite for anode materials. Graphite electrodes have several disadvantages, which are: electrical disconnection, structural deformation and initial loss of capacity. This limits their further application in future high-energy-density battery systems possessing safety and rate performance.

The overarching goal of this project is determine the commercial use of this particular battery chemistry. However, several sub-goals can be achieved: a better understanding of this anode chemistry, and load testing at cold temperatures. As a kind of tin–zinc composite oxide, Zn_2SnO_4 is a very important material with high electron mobility, high electrical conductivity and low visible absorption. These properties allow this functional material to have a wide range of potential applications in advanced technologies including gas sensors, photoelectrochemical cells, and synergistic flame retardants. Zn_2SnO_4 was first prepared by Coffeen3 with the wet method. During the past few years, Zn_2SnO_4 has been successfully synthesized by various methods, such as the thermal evaporation sol–gel route, high-temperature calcinations, and the hydrothermal method, etc. The electrochemical features of Zn_2SnO_4 prepared by a solid state reaction at 800°C have rarely been studied. We have an opportunity to study this battery chemistry for use in an arctic environment.

In order to complete the experiment we need to manufacture some of the battery cells for testing purposes. Relying on previous research and additional thesis materials, we can make some in the laboratory. Using solid-state chemistry, there are four methods to produce powders: these are solid- state reaction, mechanochemical activation, carbothermal reduction and microwave processing. The compound Zn_2SnO_4 has good electrochemical properties when synthesized by a solid state reaction, which is convenient, low-cost and easily adapted to mass production. The battery will be made with existing equipment at UAF.

4 Battery Management System

Our battery project is very project oriented, doing as much as possible of the design, construction, and testing in-house. To this end, we are adapting our own version of a battery management system to handle this new battery. Electrically, much of the design is based on the work of Peter Perkins, who started his own BMS project in 2007. We have followed his work very closely, and have adapted his system to fit our new battery. Changes so far include software edits to handle the voltages associated with the new 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 and pack current, as well as pack temperature. 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 [Watt-hr]/mile, or as configured). 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.

Figure 1: Secondary boards monitor up to 16 cells each

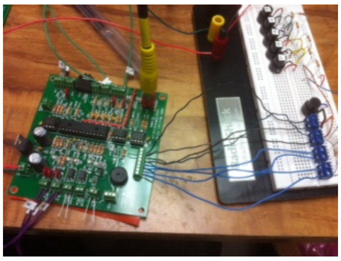

Figure 2: Master board accepts input from secondary boards, and performs calculations

Figure 3: Master unit displays battery pack and cell voltage information

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Authors

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.