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Performance Evaluation of Lithium Polymer Batteries for Use in Electric Vehicles

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***Abstract*--The purpose of this paper is to investigate the performance of 100 A-h lithium polymer batteries to determine their suitability for use in battery powered electric vehicles (BPEVs). The performance includes: battery cell capacity evaluation, battery efficiency, temperature effects on the performance of the batteries, self discharge, fast chargeability, and realistic load test. These are important factors that determine this battery's suitability for BPEVs. The characteristics are conducted at four different temperatures to study the effect of seasonal changes in temperature. The tests show that the lithium batteries performed well during the evaluation at 0, +20, and +40 Degree Celsius (°C). Also it shows that the batteries can be fast charged. The battery voltage and temperature stayed with the limits during the realistic load test. More over the batteries exhibited very high energy efficiency and low self discharge rate.**

***Keywords*--Lithium Polymer Battery, Efficiency, Battery Temperature, Fast Chargeability, Realistic Load Test, Electric Vehicle.**

I. INTRODUCTION

The BPEVs is a vehicle that utilizes chemical energy stored in rechargeable batteries, and electric motors and controllers instead of internal combustion engines [1]. The BPEVs will be only as good as its battery. Plan to keep BPEVs for a long time and have as versatile BPEVs as possible, should get the absolutely best battery. The BPEVs were among the earliest automobiles. It produces no exhaust fumes, and minimal pollution if charged from most forms of renewable energy. The BPEVs have had issues with high battery costs, limited travel distance between battery recharging, charging time, and battery lifespan, which have limited widespread adoption. The future of the BPEVs depends primarily upon the cost and availability of batteries with high energy densities, power density, and long life. Lithium has the highest electrochemical potential as well as being one of the lightest elements, making it an excellent choice for use in an advanced battery [2]. The lithium polymer battery has been developed with high energy capacity, light weight, and high current capability, making it suitable for use in an electric vehicle [3]. The lithium polymer batteries have energy densities high enough to deliver range over 250 miles with single charge and recharge times comparable to conventional vehicles.

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Lab at University of Massachusetts Lowell

The Battery Evaluation Lab at the University of Massachusetts Lowell (UML) has three complete battery test systems. The systems are computer controlled and are designed to test batteries ranging from 0.1mV to 20 volts at 1mA to 320 amps. The current regulators are capable of current sinking or sourcing and can change from charge to discharge mode instantaneously [4]. The data acquisition and control systems provide current control and data acquisition including voltage, current, time, and temperature. Each tester is controlled via A/D and D/A interfaces. The Center for Electric cars & Energy Conversion at University of Massachusetts Lowell owns 10 BPEVs manufactured by Solectria. They are used for research.

II. CHARACTERISTICS

The lithium polymer battery cell investigated is nominally rated at 3.7 volts and 100 Ah. A power rating could not be ascertained. The battery measures 0.72cm thickness, 45.5cm width, and 32.5cm length for a volume of 1.065 liters. The battery has a mass of 2.7kg. This corresponds to a specific energy of 146 W-h/kg, and a rated energy density of 373 W-h/L. These ratings will be assessed and the power capacity will be established [5]. The battery life cycle is estimated by the manufacturer to be over 1200 cycles with 80% of depth of discharge. The lithium battery has a low self discharge rate of approximately 5% per month, compared with over 30% per month in nickel metal hydride battery, and 20% per month in nickel cadmium batteries. The picture of lithium polymer battery is shown in Fig.1.

Chemistry:

The lithium polymer battery makes use of lithium cobalt dioxide as the positive electrode and a highly crystallized specialty carbon at the negative electrode. Both reactions are mediated by electrolyte. Liquid electrolyte in lithium polymer battery consist of $LiPF_6$ (Lithium Hexafluorophosphate) and organic solvents.

Positive Electrode:

$$LiCoO_2 \leftrightarrow Li_{(1-x)}CoO_2 + xLi + xe^-$$

Negative Electrode:

$$C_n + xLi + xe^- \leftrightarrow C_nLi_x$$

Overall:

$$LiCoO_2 + C_n \leftrightarrow Li_{(1-x)}CoO_2 + C_nLi_x$$

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Figure 1. The picture of 100 A-h lithium polymer battery

III. BATTERY CYCLING TESTS

The batteries were subjected to constant current/constant voltage (CC/CV) cycle tests. Each cycle was repeated five times at -20°C, 0°C, +20°C, and +40°C. The two stage charge cycle is performed to fully charge the battery. The first stage of the charge cycle was constant current 50amps (C/2, C is charging rate) until the battery terminal voltage reached 4.2 Volts, which is the maximum voltage specified by the manufacturer. The second stage was constant voltage applied until the current dropped to the minimum charging current, which is 5 amps (C/20). The first stage of the discharge cycle was constant current 50 amps until the battery terminal voltage reached 2.7 Volts, which is the minimum voltage specified by the manufacturer. The second stage was constant voltage applied until the current dropped to the minimum discharging current, which is 5 amps. At a constant current discharge rate, the lithium polymer battery maintained a relatively flat voltage discharge profile with a steep decrease in the profile near the end of discharge. The battery discharge was stopped at 5 amps, which is minimum discharge current. The results of the cycling test are shown in Table 1and 2, and typical constant current and constant voltage characterization runs are shown in Fig. 2 through 5.

TABLE I.
CAPACITY AND EFFICIENCY OF BATTERY #1 AT VARIOUS TEMPERATUERS

Battery #1	Temperature	Charge	Discharge
A-h Capacity	-20ºC	69.266	63.767
	0ºC	90.171	91.062
	20ºC	98.292	99.148
	40ºC	99.671	100.412
W-h Capacity	-20ºC	286.665	198.541
	0ºC	366.431	316.552
	20ºC	393.143	386.570
	40ºC	393.892	376.832
A-h Efficiency	-20ºC	0.92	
	0ºC	1.00	
	20ºC	1.00	
	40ºC	1.00	
W-h Efficiency	-20ºC	0.69	
	0ºC	0.86	
	20ºC	0.97	
	40ºC	0.96	

TABLE II.
CAPACITY AND EFFICIENCY OF BATTERY #2 AT VARIOUS TEMPERATUERS

Battery #2	Temperature	Charge	Discharge
A-h Capacity	-20ºC	64.601	63.049
	0ºC	92.071	92.362
	20ºC	102.577	103.170
	40ºC	103.642	104.003
W-h Capacity	-20ºC	265.736	206.813
	0ºC	362.431	327.552
	20ºC	401.410	397.717
	40ºC	405.693	398.579
A-h Efficiency	-20ºC	0.92	
	0ºC	1.00	
	20ºC	1.00	
	40ºC	1.00	
W-h Efficiency	-20ºC	0.78	
	0ºC	0.90	
	20ºC	0.99	
	40ºC	0.98	

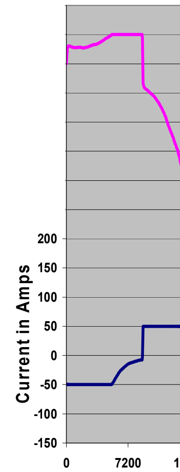

Figure 2. Cycling test battery #2 at -20°C

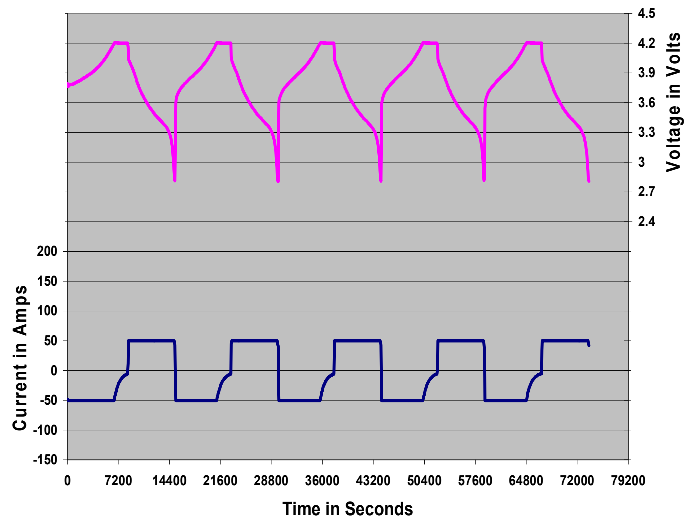

Figure 3. Cycling test battery #1 at 0°C

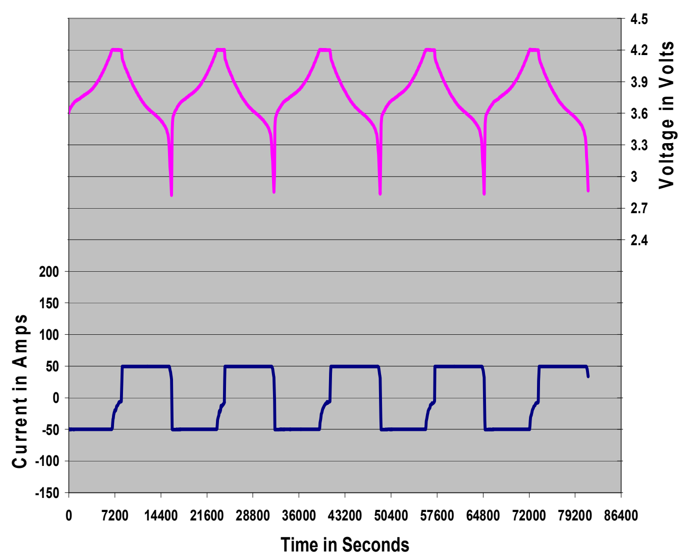

Figure 4. Cycling test battery #2 at +20°C

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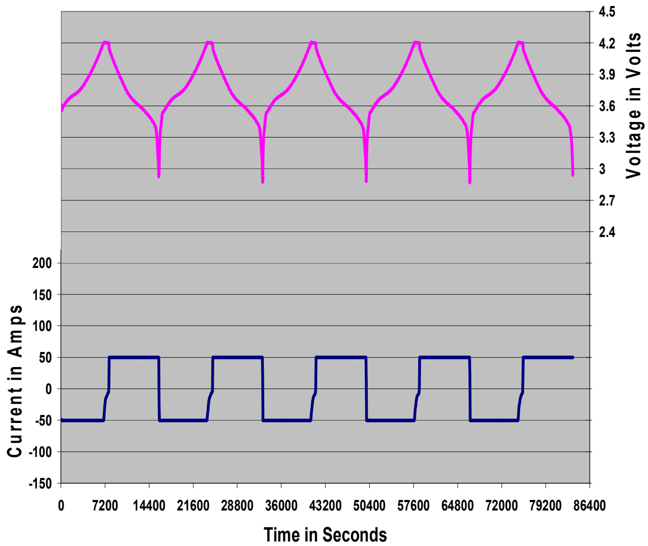

Figure 5. Cycling test battery #2 at +40°C

A. The Battery Efficiency

The energy efficiency of the lithium polymer battery at various temperatures is shown Table 1 and 2. The lithium polymer batteries have higher energy efficiency which is over 96% at between +20°C and +40ºC. This is a large improvement compared with lead acid, nickel metal hydride, and nickel cadmium batteries. These other batteries have energy efficiency between 80 to 85%. Better efficiency can be achieved by keeping the battery temperature between +20ºC and +40ºC. At lower ambient temperatures, the slight self-heating of the battery during discharge would have a beneficial effect on battery performance.

B. Analysis of Effect of Temperature

Monitoring the temperature of the battery during cycling test is important because the lithium polymer battery is dangerous if it is over-heated. The battery could be seriously damaged or catch fire. Sometimes temperature control is required. The graph in Fig. 6 and 7 show temperature and current during a representative cycle test. The ambient temperatures were set at 0ºC and +20ºC at the beginning of the cycling test. The graph show that the temperature was stable during the constant current charge, and the temperature was rose slightly during the constant current segment of the discharge. From Table 1 and 2 this battery works well above 0ºC. It does not need a cooler, because this battery does not have significant temperature rise during the cycling test at any temperatures between -20°C to +40ºC, but the battery needs a heater at low temperature because the battery loses efficiency and capacity at temperatures below 0ºC. The battery has less than 90% of energy efficiency and specific energy efficiency at below 0°C.

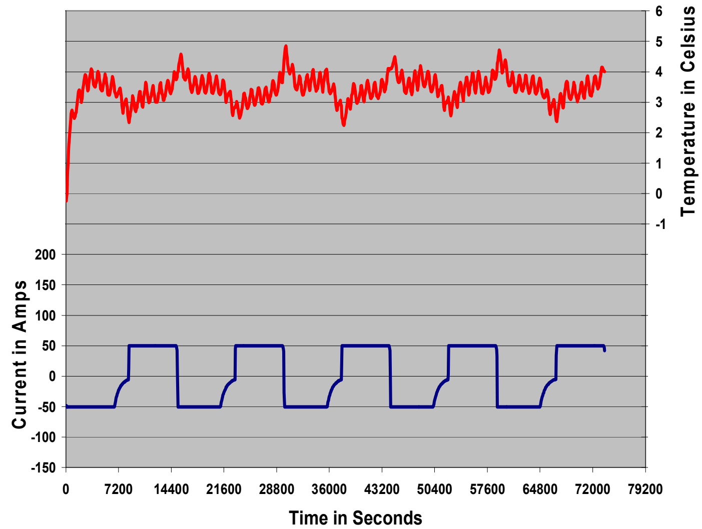

Figure 6. Battery #1 case temperature during cycling test at 0°C

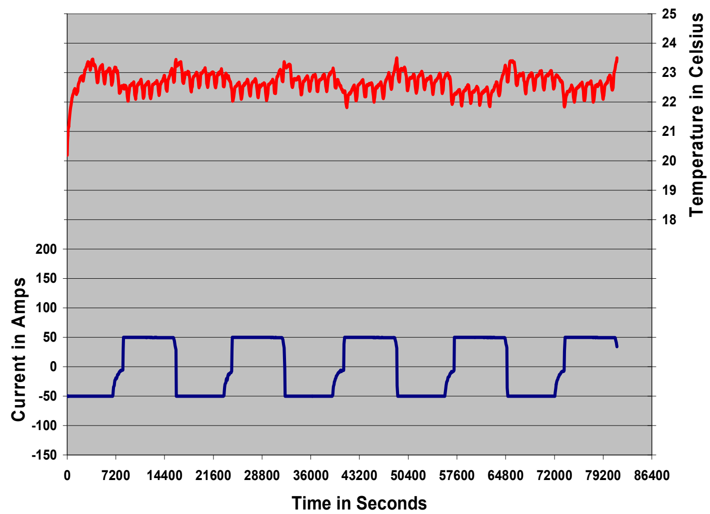

Figure 7. Battery #2 case temperature during cycling test at +20°C

C. Battery Self Discharge

The batteries were tested for self discharge. The tests were done over 10 times under the same conditions. It was fully charged at the beginning of the test. When it was fully charged, the batteries capacity was 98 A-h and 102 A-h. It was set aside for a month in an open circuit condition at +20°C. It was then fully discharged. When it was fully discharged, it has capacity of 94 A-h and 99 A-h. It shows that the lithium polymer battery has less than 5% per month self discharge.

D. Fast Chargeability

The charging of the lithium polymer battery in these tests were done using constant current (CC) followed by constant voltage (CV) methods (CCCV). The ambient air temperatures for the tests were -20°C, 0.0°C, and +20°C. The charging current was 100 amps (1C), 200 amps (2C), 300 amps (3C), and 320 amps (3.2C). The 3.2C rate was used because it is presently the maximum rate of the battery tester at UML. All charging cycles were followed by discharging at 100 amps

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using a Taper method to determine the actual charge absorbed by the battery during fast charge.

The fast charging cycles with 3C at ambient temperature +20°C is shown in Fig. 8. Battery case temperature for the 2C at +20°C is plotted in Fig. 9. The profiles of the charging current, battery voltage, battery case temperature at different ambient temperature were recorded during the test. The time needed for a battery to be charged to 80% of capacity and fully charged was recorded.

The first step of the fast charging test was cycling test to verify its capacity. The battery had average 100Ah during 5 cycling test at +20°C. During the fast charging procedures, the battery accepted given high current until the voltage reached the maximum voltage (4.2 volts). The current was reduced in a controlled fashion so as to maintain 4.2 volts. The charging was stopped when the charging current had fallen to C/20 (5 amps). The charging time (to 80% of capacity and to full charge) and battery case temperatures with different charging currents are shown in TABLE 3.

TABLE III.
CHARGING TIME AND RANGE OF BATTERY TEMPERATURE WITH SET AMBIENT TEMPERATURE -20°C, 0°C, AND +20°C

Ambient Temp (°C)	Charging Rate	Time to Reach 80% of Capacity (Minutes)	Time to Fully Charge (Minutes)	Case Temp Range (°C)
-20	1C	49	74	-20 to -12
	2C	25	41	-20 to -1
	3C	Could not charge		
	4C			
0.0	1C	48	76	0 to 7
	2C	24	44	0 to 11
	3C	17	35	0 to 22
	4C	16	32	0 to 23
+20	1C	48	78	20 to 22
	2C	24	47	20 to 27
	3C	16	36	20 to 36
	4C	15	35	20 to 38

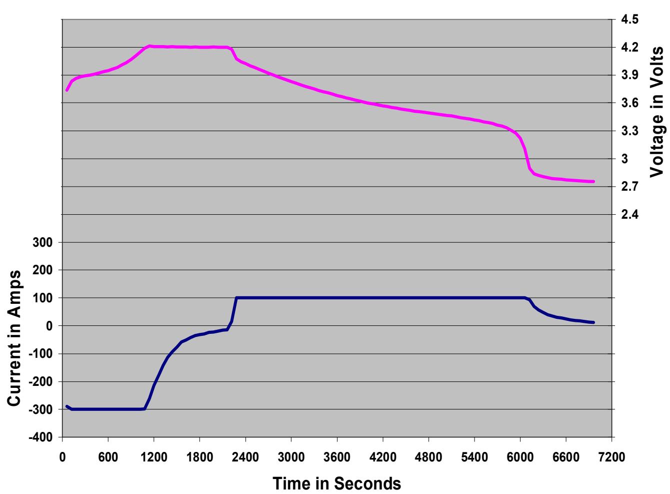

Figure 8. Fast charging test with 3C at +20°C (Battery #2)

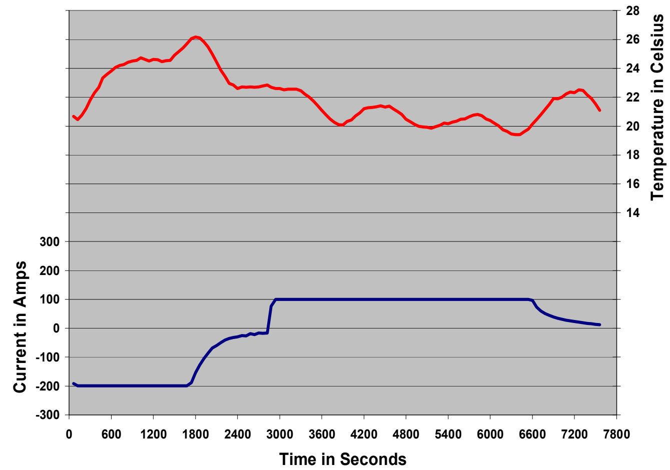

Figure 9. Battery #1 case temperature during the test with 2C at +20°C

E. Realistic Load Test

The realistic BPEVs simulations subject the battery to the same source and sink currents as those in the actual road drive test. The currents used in the realistic load test are derived from real time current data that was taken from an electric vehicle using an on board data acquisition system designed at University of Massachusetts Lowell (UML). The electric vehicle was driven on a typical commute while the battery current as well as other data was recorded at one second intervals. The batteries were tested at four different ambient temperatures, namely -20˚C, 0˚C, +20˚C, and +40˚C. The realistic load test used boundary conditions between 2.7 volts to 4.2 volts which is a normal charging and discharging single Lithium Polymer Batteries [6]. After the realistic load test, any residual charge in the cell was drawn off to determine how much energy was actually used during the simulated commute. Plots of the experimental test data for the test taken at +20˚C presented in Fig. 10. The battery case temperature at ambient temperatures +20˚C is shown in Fig. 11. The battery voltage and case temperature were stable at ambient temperature above 0˚C during the realistic portion. The batteries performed well at the higher temperatures. The realistic load test at an ambient temperature -20˚C was stopped in the middle of the testing because the battery voltage rose over the maximum voltage during high current charging. The battery will need to be heated for the BPEVs to work well when the ambient temperature is below 0˚C. The voltage moved over a wider range than at higher temperatures because voltage drops increased due to increased series impedance.

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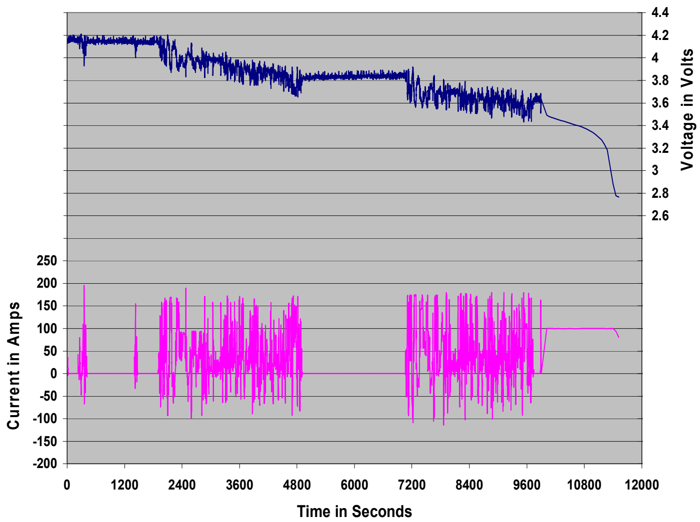

Figure 10. Battery #2 realistic load cycling at +20˚C

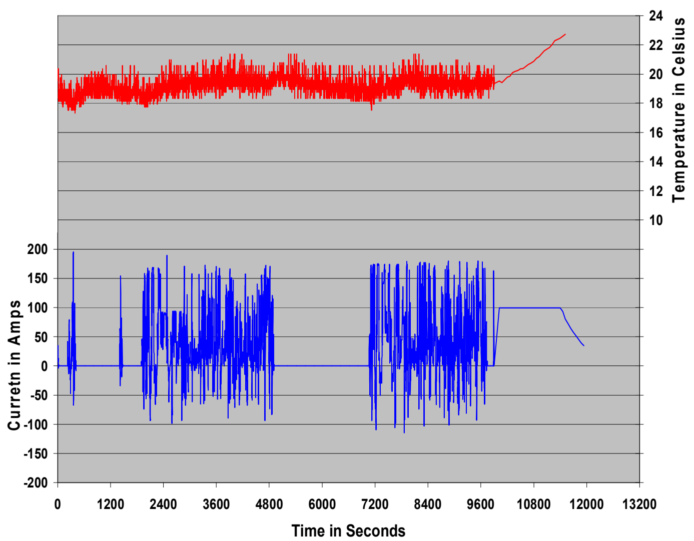

Figure 11. Battery #1 case temperature at +20.0˚C

III. Conclusion

From this data, this battery is suitable for electric cars. It has a very high energy density. This battery can work over a wide temperature range. However, while the research shows that it does not need cooling during summer, but will need heating at temperatures below freezing. The battery has high efficiency over a wide temperature range. The battery has low self discharge and can be charged quickly. Lithium Polymer batteries come close to satisfying the USABC long term goal criteria for electric vehicle batteries by providing high energy density and its fast chargeability.

V. Further Research

The next step is to install lithium polymer battery packs in real electric vehicles and to assess their service characteristics and to develop a battery management system for optimal performance.

References

[1] http://en.wikipedia.org/wiki/Battery_electric_vehicle
[2] M. J. Riezenman, "The Search for Better Batteries," IEEE Spectrum, v. 32, pp. 51-56, May 1995.
[3] A. Davis, "Synergetic Lithium-Ion Battery Pack Performance Evaluation," MS. Eng. Dissertation, Dept. Electrical and Computing Eng., Univ. Massachusetts, Lowell, 1996.
[4] W. A. Lynch, Ziyad M. Salameh, "Electrical Component Model for a Nickel-Cadmium Electric Vehicle Traction Battery", IEEE Annual Vehicular Technology Conference. Toronto, Canada. July 4-9, 2006.
[5] F. P. Tredeau, "Characterization of Nickel-Zinc Battery," MS. Eng. Dissertation, Dept. Electrical and Computing Eng., Univ. Massachusetts, Lowell, 2003.
[6] William A. Lynch, "Nickel Cadmium Battery Evaluation, Modeling, and Application in an Electric Vehicle," D. Eng. Dissertation, Dept. Electrical and Computing Eng., Univ. Massachusetts, Lowell, 1997.

Biographies

Bong Gon Kim received his B.S. M.S. from University of Massachusetts, Lowell in 2002 and 2004 respectively. He is currently working on a doctoral degree at University of Massachusetts, Lowell. He is a life time member of Eta Capa Nu. His areas of interest are fuel cells, battery evaluation, electric cars, and power electronics.

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