BATTERY MANAGEMENT SYSTEMS FOR ELECTRIC VEHICLE APPLICATIONS

AYMAN S. ELWER (1)   SAMY M. GHANIA (2)   NAGAT M. K. A. GAWAD (3)
(1) Electronics Research Institute – Cairo- Egypt   (2) Shoubra Faculty of Engineering – Cairo- Egypt
(3)   Shoubra Faculty of Engineering – Cairo- Egypt

Abstract:

Battery Management Systems (BMS) are used in many industrial and commercial systems to make the battery operation more efficient and for the estimation to keep the battery state, as long as possible, away from destructive state, to increase battery life time. For this purpose, many monitoring techniques are used to monitor the battery state of charge, temperature and current. In the current paper, the monitoring system for battery powered Electric Vehicles (EV) has been implemented and tested. This system evaluates and displays the battery temperature, charging/discharging current and State Of Charge (SOC) for the considered model battery. For monitoring purpose, digital and analog sensors with microcontrollers are used. The battery information and the obtained results explaining the main characteristics of the system are presented by photographs and some experimental results are given by the LCD screen.

Keywords: Battery management systems, Electric vehicles, Monitoring techniques, microcontroller and State of charge.

1- INTRODUCTION

A Battery management system (BMS) consists of software and hardware, designed to increase the discharge cycle of the battery to maximize the battery lifetime [1]. To explain the battery management systems (BMS), there are two variables that should be considered. The first variable is the battery State Of Charge (SOC) which refers to the amount of charge presented in a battery in a charge or discharge cycle. The second variable is the Battery State Of Health (SOH) which represents the performance of the battery compared to its past and expected future.

As shown in Figure 1, the basic BMS consists of three main building blocks which are, the Battery Monitoring Unit (BMU), the Battery Control Unit (BCU) and the CAN bus vehicle communication network. Also, it is clear that, BMS building blocks interface with the rest of the vehicle energy management systems. While, the other configurations are embedded with distributed BMS in the battery cell to the cell interconnections.

In practice, the BMS may also be coupled to other vehicle systems which communicate with the BMS via the CAN bus such as the Thermal Management System or to anti theft devices which disable the battery. Also, there are monitoring system and programming data logging using an RS232 / RS485 serial buses.

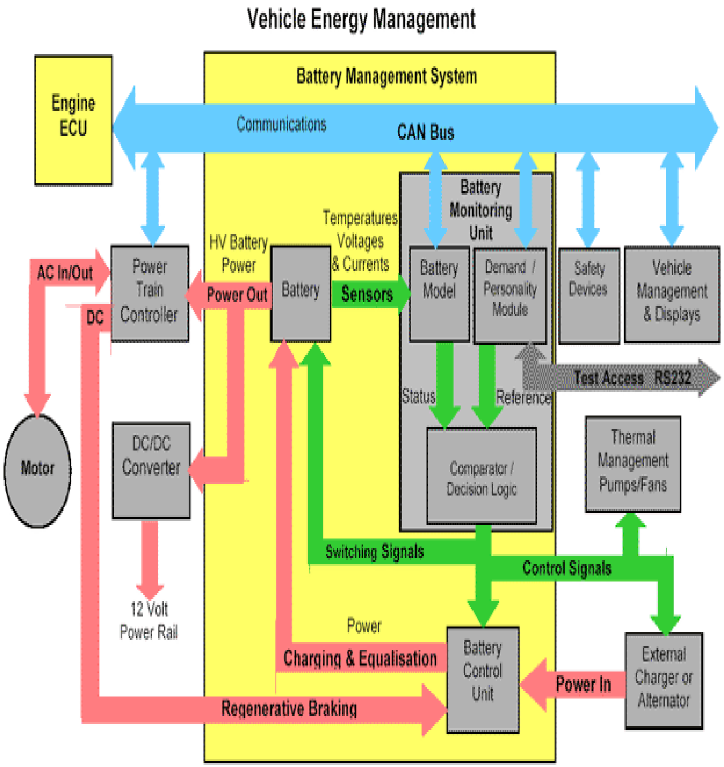


Figure 1: Vehicle Energy management

2-SOC DETERMINATION

A good SOC calculation provides many advantages for EV such as; longer battery life, better battery performance and failure warning of the battery pack. The residual battery

capacity can be determined by measurement of the density of chemical components of the battery; however it is not a practical solution [2]. Accordingly, various methods have been proposed based on battery voltage and current measurement [3]. Most of these methods ignore the temperature effect in calculation of the battery SOC.
The SOC should be determined accurately, especially for electrical vehicles applications to predict the travel / remaining distance of the vehicle. There are three basic interrogation methods existing for determining the SOC of a battery. The first method is the Coulomb counting, the second one is the voltage delay and the third one is the impedance methods. Other methods, such as measuring electrolyte specific gravity are not practical for implementation in an electric vehicle fuel gauge/battery management system.

The coulomb counting method is the most widely used technique for battery fuel gauging in EVs. This method is reasonably accurate when SOC estimates are compensated for temperature and discharge rate variations. However, coulomb counting provides no diagnostic capability, which can be used to determine the state of health (SOH) of batteries.

The voltage delay method is commonly used to perform battery tests outside a vehicle. In this case, the battery is subjected to a transient load discharge and the voltage response of the battery monitored. The voltage recovery transient is then used to characterize the SOC of the battery. This technique is again limited in its ability to be implemented as an in-vehicle battery SOC/SOH instrument.

The impedance method uses a current/voltage excitation waveform to a battery and the monitoring of the battery's voltage/current response. In Electrochemical Impedance spectroscopy (EIS), the applied signal is small amplitude, ac waveform, so that the battery system is perturbed about its equilibrium condition.

The frequency of the excitation waveform may be swept over a wide frequency range and the resultant battery response can be used to determine an equivalent circuit model of the battery and correlated with battery SOC. Table 1 summarizes the different techniques used for SOC determination and its advantages and drawbacks.

Due to the modern advances in microcontroller, a battery having a degree of logic via microcontroller unit (MCU) is called Smart Battery [4]. The Smart Battery has many advantages such as; acquisition signal recognition, reporting battery voltage and reporting charging/discharging current to refine and calculate data to the main applications. Also, the dangerous states such as; too high charge/discharge currents can be reported to predict, automatically, the dangerous situations and to make the cell balancing. The task reporting battery voltage ensures that only the correct type of battery is used.

Reporting refine/calculate to the vehicle applications include the voltage and charging/discharging. Battery remaining life is based on the battery parameters such as voltage, discharge current and the battery charging/discharging characteristic which are stored in the MCU data memory. Figure 2 shows the associated MCU requirements.

Table 1: Summarize the different methods for SOC determination.

Technique	Application field	Advantages	Drawbacks
Discharge Test	Used for capacity Determination at the beginning of life	Easy and accurate; Independent of SOH	Offline, time intensive, modifies the battery state, loss of energy
Coulomb Counting	All battery systems, most applications	Accurate if enough re-calibration points are available and with good current measurements	Sensitive to parasite reactions; needs regular re-calibrations points
OCV	Lead,Lithium,Zn/Br	Online,cheap,OCV prediction	Needs long rest time (current=0)
EMF	Lead, Lithium	Online,cheap,EMF prediction	Needs long rest time (current=0)
Linear model	Lead photovoltaic	Online, easy	Needs reference data for fitting parameters
Impedance spectroscopy	All systems	Gives information about SOH and quality	Temperature sensitive, cost intensive
DC internal resistance	Lead,Ni/Cd	Gives information about SOH, possibility of online measurements	Good accuracy, but only for a short time interval
Artifical neural networks	All battery systems	Online	Needs training data of a similar battery, expensive to implement
Fuzzy logic	All battery systems	Online	Ask memory in real-word application
Kalman filters	All battery systems,PV,dynamic application	Online, dynamics	Difficult to implement the filtering algorithm that considers all features as, e.g nonnormalities and nonlinearities

The proposed approach that has been developed, is the determination of SOC, its temperature and charging/discharging current by directly modeling the impedance response at a few discrete frequencies (using a fuzzy logic methodology), without the intermediate step of extracting equivalent circuit models for the batteries. Impedance measurements have the distinct advantage of being rich with information related to the state-of-health of the battery and can therefore, be useful in battery management systems for battery diagnostic purposes.

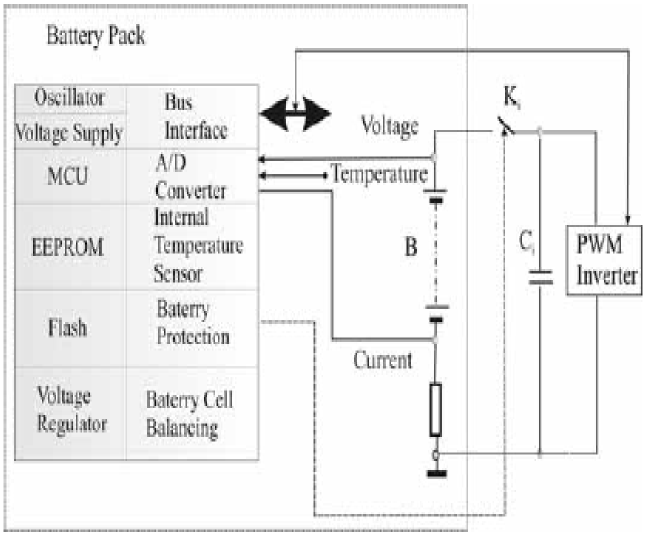


Figure 2: The associated MCU requirements.

3-BATTERY SOC MODELING

The SOC normally refers to the rated capacity of a new cell. It is not the fully charged capacity of the cell when it was last charged (i.e. the current charge-discharge cycle). This is because the cell capacity gradually reduces as the cell ages and it is also affected by temperature and discharge rate. At the end of the cell's life its actual capacity will be approaching only 80% of its rated capacity and in this case, even if the cell were fully charged, its SOC would only be 80%. This difference is important if the user is depending on the SOC estimation as he would in a real gas gauge application in a car. These ageing and environmental factors must therefore be taken into account if an accurate estimate is required. If the SOC reference was defined as; the current fully charged capacity of the cell, then the adjustment factors would have to be applied to the rated capacity to determine the new reference capacity.

In this case, a fully charged cell would have an SOC of 100%, but it would only have a capacity of 80% of a new cell. For cell balancing applications, it is only necessary to know the SOC of any cell relative to the other cells in the battery chain. Since all the cells will have been subject to the same influences during their lifetime, the ageing and environmental adjustments, which apply equally to all cells, can be ignored for this purpose.

Based on the Peukert equation, the discharge current of a battery decreases with increasing the discharge time [5].

$$I^n * T_i = const \tag{1}$$

Where:

I: The discharge current (Amp.).

n: The battery constant (n=1.35 for typical lead-acid batteries).

T_i: The time to discharge at current I (Sec.).

The Peukert relationship can be written to relate the discharge current at one discharge rate to another combination of current and discharge rate as:

$$C_1 = C_2 * \left(\frac{I_2}{I_1} \right)^{(n-1)} \tag{2}$$

Where :

C_1, C_2: The discharge rates at different discharge rate states.

I_1, I_2: The currents at the two different discharge rate states.

The Battery state of charge (SOC) at a constant discharge rate is given as:

$$SOC = 1 - \left(\frac{I * Time}{C} \right) \tag{3}$$

For non-constant discharge rates, the current and discharge rate (C_1 and I_1) should be previously known. Given the current at the present time step I_2, the corresponding discharge rate is calculated using equation for C_1 and plugged into a incremental form of equation for SOC. The incremental change in the battery ΔSOC can be given as:

$$\Delta SOC = I_2 \left[\frac{\Delta t / 3600}{C_1 * \left(\frac{I_2}{I_1} \right)^{(n-1)}} \right] \tag{4}$$

For the battery operating range used in Hybrid Electric Vehicle (HEV), determining the SOC of the battery is the second major function of the BMS. The SOC is needed not only for providing the fuel gauge indication, but also to check for uniform charge in all of the battery cells in order to verify that individual cells do not become overstressed. The SOC indication is also used to determine the end of the charging and discharging cycles. Over-charging and over-discharging are two of the prime causes of battery failure and the BMS must maintain the cells within the desired operating limits. Hybrid vehicle batteries require both high power charge capabilities for regenerative braking and high power discharge capabilities for launch assist or boost. For this reason, their batteries must be maintained at a SOC that can discharge the required power but still have enough headroom to accept the necessary regenerative power without risking overcharging the cells.

To fully charge the HEV battery for cell balancing, as shown in Figure 3, would diminish charge acceptance capability for regenerative braking and hence braking efficiency. The lower limit is set to optimize fuel economy and also to prevent over discharge which could shorten the life of the battery. Accurate SOC information is therefore needed for HEV to keep the battery operating within the required safe limits.

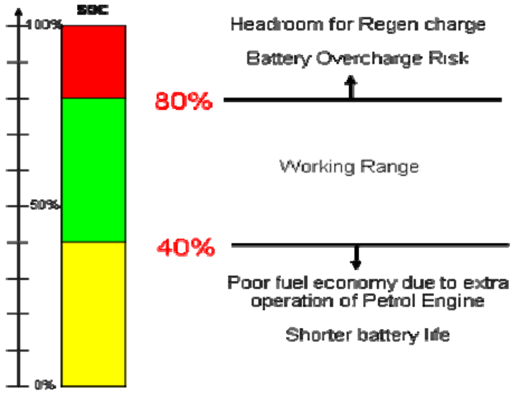


Figure 3: HEV battery operating ranges

A battery model applying the above equations and with using Matlab software is achieved to estimate the Battery SOC, and the result of SOC during both charging and discharging is as shown in Figure 4.

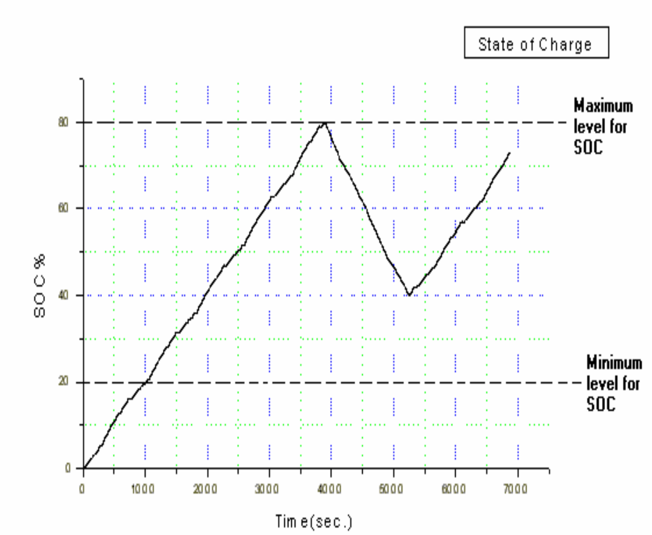


Figure (4): SOC for typical lead acid battery

4-EXPERIMENT SYSTEM

The battery pack used in this study is considered the main power source for a prototype model, which is based on re-engineering of ICE SUZUKI car. The battery pack consists of 6 modules of 12 V traction lead acid batteries connecting in series to supply the main traction DC motors of 75 V and 9 hp. Figure 5 shows the combination of the battery pack for the prototype model of EV. Firstly, to perform the SOC experimentation, two batteries of 12 V are used. Secondly, the developed system is applied for whole battery pack in the EV prototype.

Figure 5: Battery pack above the experimental prototype model.

4.1 DESIGNED SYSTEM AND RESULTS

For monitoring the battery SOC, a hardware system is designed using implementation of a microcontroller built with a flash memory. Figure 6 shows the processor unit utilized for SOC estimation. The used CPU is a microchip Atmel 89C51. The battery charging/discharging current is determined by using a LA255-S Hall Effect current sensor manufactured by LEM Corporation as shown in Figure 7. The battery terminal voltage is simply measured by a resistive voltage divider. According to the manufacture recommendation, a K-type thermocouple along with AD595 thermocouple signal conditioner is employed.

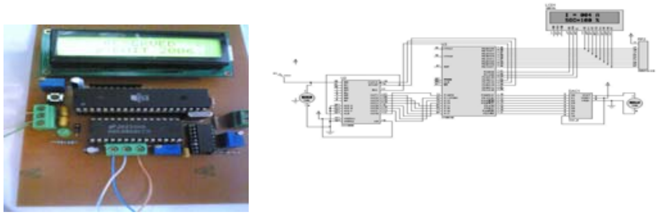


Figure 6: Picture of the SOC indicator and its wiring diagram.

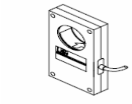


Figure 7: The used current sensor

A microcontroller, in which the SOC algorithm is stored, determines the SOC of the battery system based on the measured signals by the current sensor. Two types of memories are needed. First, the read-only memory (ROM) from which the amount of self discharge as a function of *T* and the discharging efficiency as a function of *I* and *T* are read and when the SOC algorithm is based on EMF measurements, the EMF–SOC relationship can be stored in ROM together with other battery specific data. Second, the random access memory (RAM) is used to store the history of use, such as the number of charge/discharge cycles, which can be used to update the maximum battery capacity. The simple flowchart of the developed algorithm is shown in Figure 8.

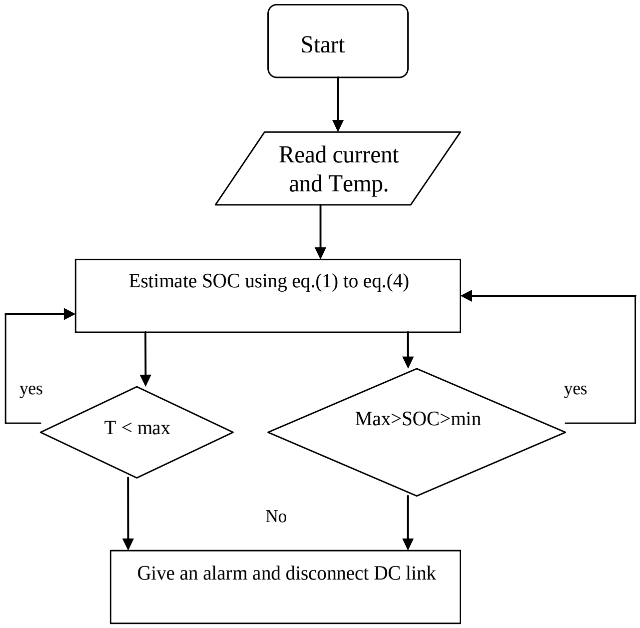
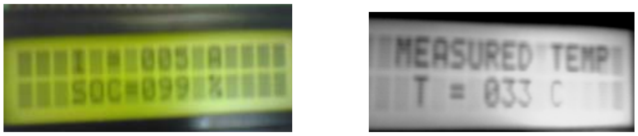


Figure 8: The flow chart for the developed Algorithm.

Each part of this system (software algorithm or hardware device) will influence the final accuracy in the SOC indication, as if there is inaccuracy in the *V*, *T* and *I* measurements this will give an inaccuracy in the final SOC. An important role must be recorded also to the calibration of the SOC as if the SOC algorithm is based on current measurement and integration the obtained error caused by the current measurement inaccuracy will accumulate over time.

The system is put together, as shown in Figure 9, with loading the motor by light load that draws a constant current of about 5 Ampere (by lifting the rear axel of the car from the ground)) and using one battery pack to test our model. And the data of the drawn current from the battery and its temperature are stored for a period of three hours at reporting data at each half hour. A captured photo results of SOC and temperature are shown in Figure 10 and these results are not drawn later for the purpose of comparison symmetrically between the no-loading and loading conditions.

Figure 9: Practical Setup for measuring Temp. And SOC



(a) (b)

Figure 10: Captures of SOC and temperature reading by LCD at no-loading conditions.

Figure 11 presents the variation of the SOC at different times for a period of three hours. It can be noticed that the SOC varies from about 100% to about 70 % for a period of three hours. Figure 12 presents the variation of the battery temperature at different times for a period of three hours. It can be noticed that the battery temperature increased by about 20 % from its initial temperature during the discharging cycle.

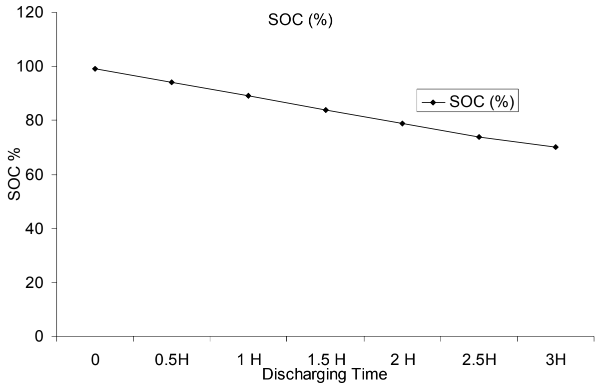


Figure 11: Variation of the battery SOC during the discharging time

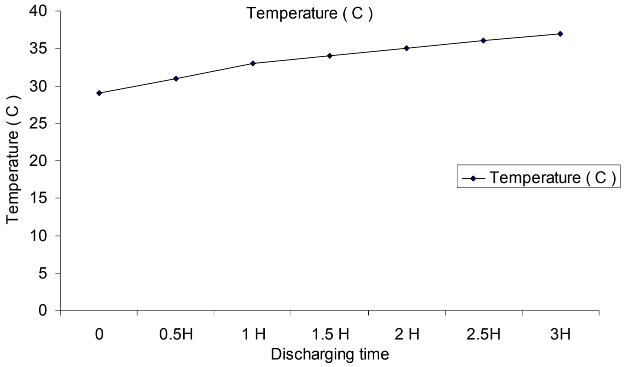


Figure 12: Variation of the battery temperature during the discharging time

The rear axel wheels are braked to make the motor draw its rated current and with connecting the whole 6 battery packs and the SOC and temperature are reported for a period of 3 hours. Figure 13 presents the variation of the SOC at different times for a period of three hours. It can be noticed that the SOC varies from about 100% to about 40% for a period of three hours.

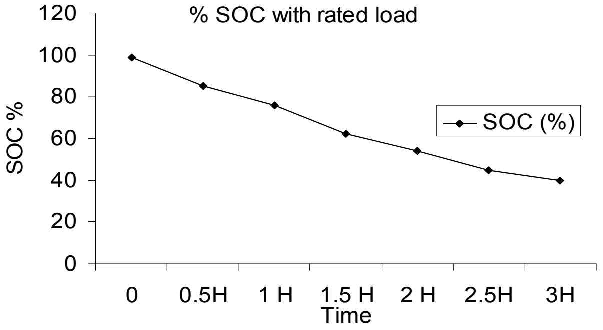


Figure 13: Variation of the battery SOC during the discharging time with rated current**.**

Figure 14 presents the variation of the battery temperature at different times for a period of three hours. It can be noticed that the battery temperature increased by about 110 % from its initial temperature during the discharging cycle.

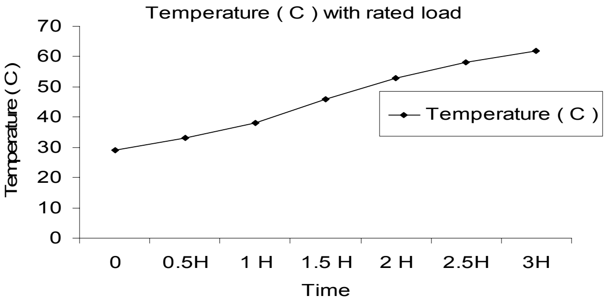


Figure 14: Variation of the battery Temperature during the discharging time with rated current

5. CONCLUSIONS

A simulated model for the applied battery using Matlab Software, is achieved to determine the SOC which is the major function of Battery Management System and the model gives a good result during both charging and discharging cycles. Also, a very simple and cheap experimental circuit applying MCU is designed to estimate the SOC and measure temperature of the battery the designed circuit gives a good estimation of SOC and an alarm is obtained when SOC exceeds the minimum or the maximum limits, also, an alarm is obtained if the temperature exceeds the maximum set point, and these alarms are protecting the battery to increase its life time.

6. REFERENCES

[1] John Chatzakis, Kostas Kalaitzakis, Nicholas C. Voulgaris and Stefanos N. Manias, "Designing a New Generalized Battery Management System", IEEE Trans. On I.E., VOL. 50, NO. 5, Oct. 2003.

[2] R. Weiss et.al., "Battery SOC determination in photovoltaic system", J. *Electrochemical society: electrochemical science* & *technology,* Vol-129 No. 9, September 1982, pp. 1928-1933.

[3] Caumont O., Le Moigne P., Muneret, X. Lenain P., Rombaut C., "An optimized State of Charge Algorithm for Lead Acid battery in Electric Vehicle", pp. 93-96, *EVS* 1999.

[4] Z. M. Salameh M. A. Casacca, W. A. Lynch, "A Mathematical Model for Lead Acid Battery", *IEEE Trans. On Energy Conversion* Vol-7, pp.93-96, March, 1992.

[5] Kiessling, R., “A battery model for monitoring of and corrective action on lead-acid EV batteries”, Battery Conference on Applications and Advances, Proceedings of the Ninth Annual Meeting, Long Beach, CA, USA January 11-13, 1994.