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Sampling based State of Health estimation methodology for Li-ion batteries

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HIGHLIGHTS

- A new circuit design has been presented for SoH estimation of the Li-ion batteries.
- The battery cells can be separated into two groups when SoH estimation is needed.
- Simple SoH estimation is performed using the test battery.
- The micro-chip performing the idea has been produced.
- Preliminary results of SoH estimation is very promising.

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ABSTRACT

Storage and management of energy is becoming a more and more important problem every day, especially for electric and hybrid vehicle applications. Li-ion battery is one of the most important technological alternatives for high capacity energy storage and related industrial applications. State of Health (SoH) of Li-ion batteries plays a critical role in their deployment from economic, safety, and availability aspects. Most, if not all, of the studies related to SoH estimation focus on the measurement of a new parameter/physical phenomena related to SoH, or development of new statistical/computational methods using several parameters. This paper presents a new approach for SoH estimation for Li-ion battery systems with multiple battery cells: The main idea is a new circuit topology which enables separation of battery cells into two groups, main and test batteries, whenever a SoH related measurement is to be conducted. All battery cells will be connected to the main battery during the normal mode of operation. When a measurement is needed for SoH estimation, some of the cells will be separated from the main battery, and SoH estimation related measurements will be performed on these units. Compared to classical SoH measurement methods which deal with whole battery system, the proposed method estimates the SoH of the system by separating a small but representative set of cells. While SoH measurements are conducted on these isolated cells, remaining cells in the main battery continue to function in normal mode, albeit in slightly reduced performance levels. Preliminary experimental results are quite promising, and validate the feasibility of the proposed approach. Technical details of the proposed circuit architecture are also summarized in the paper.

1. Introduction

Importance of portable energy storage technologies has been increasing dramatically in the last decades not only for low power applications such as cell phones but also for high power applications such as Electric Vehicles (EVs) and Unmanned Air Vehicles (UAVs). Li-ion batteries are one of the most popular alternatives for high capacity energy storage applications. As the number of cells increase, complexity of the battery management system (BMS), which is responsible for condition monitoring of individual cells, maintaining their operational limits, protecting them from out-of-tolerance conditions, cell voltage balancing, estimation of battery state of charge (SoC), State of Health (SoH),

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state of life (SoL), and optimum charging, does increase as well [1].

SoH of a battery system is a critical parameter for its effective usage throughout its life. Prediction of time to exhibit unsatisfactory performance levels can be estimated from SoH measurements [2]. Accurate real time estimation of SoH is crucial for reducing the through life ownership cost of the battery and increasing availability and safety of the overall battery system. In one hand, early disposal of the batteries increases the ownership cost of the batteries; on the other hand, unexpected failure of the battery leads to low availability, safety, and comfort. For example, the life cycle cost of a light armored vehicle will be reduced by 94.9 K $ if unnecessary battery replacement can be avoided [3]. We can also note two catastrophic battery failure examples: First, in 2000, landing gear of an aircraft did not work due to battery failure, which in turn led to crash of the aircraft [4]. Second, in 2006, Mars Global Surveyor has been lost in the space in due to a battery failure related problem [4].

The general definition of SoH is the ratio of the current energy storage capacity to the initial capacity. Even though internal resistance and self-discharge may affect the capacity this SoH definition will be used throughout this paper [5].

SoH estimation has been studied extensively in recent years. The basic approach in SoH estimation is the process of counting the discharged energy of a fully charged battery during a controlled constant load, which is known as the load test [6]. This approach requires a full discharge process under constant load just for the sake of SoH estimation. It is obvious that the time and labor required to apply this method is not very practical. This approach requires interrupting the normal operation of the battery system, and causes waste of significant amount of energy during tests. The main motivation of this paper is to find feasible alternatives to this problem. More precisely, to develop a system on which SoH can be estimated with minimum possible disturbance to the system, preferably without interrupting its normal mode of operation, and also with minimum possible energy consumption.

Another commonly used method for SoH estimation is measuring the charged and discharged energy during the normal usage of the battery, called Columb counting [7]. Even though this approach removes the impracticality of the load test, measurement errors may accumulate and lead to significant estimation errors [8]. Periodic calibration is needed to get accurate results [7], and researchers continue to work on several different improvements [9–11].

Another approach for SoH estimation is to utilize the look-up tables prepared by the battery manufacturer, and utilize the relationship between the open circuit voltage (OCV) and the SoC. These tables might be used to estimate the SoH indirectly. However, its accuracy is not quite high since the environmental conditions for OCV/SoC tables may not be the same as the actual usage environment of the battery [12]. Furthermore, this technique requires very high accuracy OCV measurements, causing this method to be not so practical as well [13].

Temperature is an important parameter, and is used for SoH estimation together with other parameters [14]. Internal resistance of the battery, which is difficult to measure directly, is another parameter closely related to the SoH. Various different battery models can be used to estimate the internal resistance of a battery. There are basically two types of battery models: circuit and electrochemical models. Electrochemical models are good for design of electro–chemical interactions within electrodes and electrolyte, however it is difficult to build and time consuming [5,15]. There are several circuit models such as Thevenin, Randles, and Lumped Parameter battery models [5,16]. Even though these models may estimate the internal impedance, these estimations are not often sufficient to obtain the SoH accurately.

Electrochemical impedance spectroscopy (EIS) is a special technique to understand the effects of chemical reactions in the battery, which cannot be measured through simple sensors. It is shown that there exist a close relationship between SoH and EIS measurements at specific frequencies [17]. However, EIS measurement is a difficult and expensive process requiring special tools and equipment [7]. The size and the cost of the required equipments make EIS measurements not very practical, especially for online applications. For example, it may not be feasible to install an EIS system on an electric/hybrid vehicle for SoH measurement.

As seen from the discussions given above, measurement of a single parameter is not sufficient for effective SoH estimation. Thus, alternative complex statistical and/or computational methods based on various different parameter measurements, have been presented in the literature. For example, fuzzy logic, artificial neural networks, support vector machines, relevance vector machines, Kalman filters, and particle filters are some of the tools used for SoH estimation [7].

All of the studies mentioned above focus either on identification of a new measurement parameter or development of new statistical/computational methods for SoH estimation.

In this paper, a completely different approach to SoH estimation is presented. The proposed approach does not require interrupting the whole battery system for SoH measurement, instead it is based on separating a small but representative set of cells from the main system. While SoH measurement is performed on these isolated cells, remaining cells in the main battery system can continue to provide energy to outside, or can be charged all together. The model presented in this paper has a pending patent application.

This paper is organized as follows. In Section 2, the circuit model which can separate the battery cells into two groups is presented. In Section 3, we present results of various tests performed on the Li-ion batteries using a custom made microcontroller board, and professional battery test equipment. Finally, in Section 4 some concluding remarks are made.

2. Methodology

The proposed battery system is composed of parallel connection of several (Nc) column systems, where each column system is series connection of several (Nr) battery cells. Total number of battery cells should be selected according to design requirements of the main battery system. Fig. 1 displays "+" and "−" terminals of the main battery system used for charge, discharge, and possibly for parameter measurement of the whole battery system.

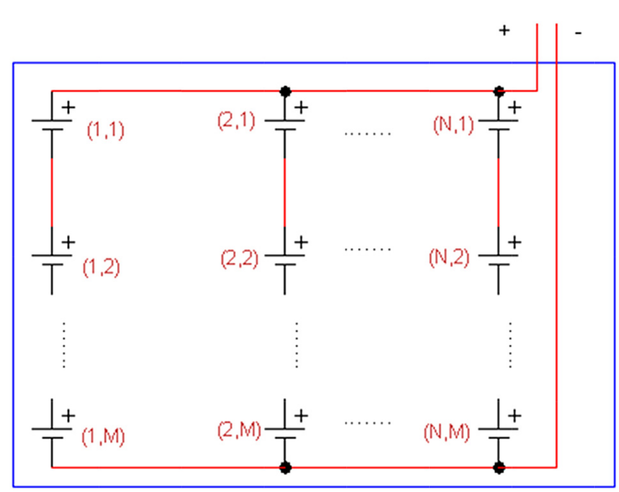

Fig. 1. Traditional battery system with single charge–discharge structure.