Journal of Power Sources 196 (2011) 458–464

Contents lists available at ScienceDirect

Journal of Power Sources

journal homepage: www.elsevier.com/locate/jpowsour

Modularized battery management for large lithium ion cells☆

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ARTICLE INFO

Article history:
Received 26 January 2010
Received in revised form 8 April 2010
Accepted 18 April 2010
Available online 28 April 2010

Keywords:
Battery management system
Equalization
Lithium ion battery

ABSTRACT

A modular electronic battery management system (BMS) is described along with important features for protecting and optimizing the performance of large lithium ion (LiIon) battery packs. Of particular interest is the use of a much improved cell equalization system that can increase or decrease individual cell voltages. Experimental results are included for a pack of six series connected 60 Ah (amp-hour) LiIon cells.

1. Introduction

The high energy density of lithium ion (LiIon) has made it the battery of choice in applications ranging from cell phones and laptops to large electric vehicles. Low power LiIon batteries typically consist of packs with a few small cells, but high power applications require packs that may have upwards of 80–120 large cells connected in series. When properly managed, these cells provide excellent service, but caution is required because even slight misuse can cause the cells to ignite. As might be expected, proper cell management becomes more of a design challenge as the size of the pack increases.

To provide safe operation and optimum performance, these large LiIon packs must be supervised by an electronic battery management system (BMS) that monitors and services each of the individual cells. At a minimum, a typical BMS must provide the following functions:

- Measure various temperatures throughout the pack.
- Measure the battery current.
- Measure each cell voltage.
- Adjust the charge on the cells so that they all remain close to the same voltage (equalization).

Temperature and current measurements are fairly simple and can be implemented with a wide variety of sensors. Cell voltage measurements are more complex since the series connected cells are at different voltage reference levels, and each measurement must be transferred to a common level. Equalization is probably the most challenging of these basic functions, and a wide variety of methods have been proposed [1–16,18]. This process is required because maximum charge is limited by the highest cell voltage, and maximum discharge is limited by the lowest. Because of the volatility of LiIon, each cell must be equalized individually, i.e., the pack cannot be trickle charged like a lead acid battery since even a slight overcharge on any cell can create a serious fire hazard.

To obtain good accuracy at a reasonable cost, one cell voltage measurement technique is to use a transconductance circuit to produce a current signal proportional to the cell voltage, and then change back to a voltage at the common reference level. A description of such a circuit will be provided later.

Although there are a wide variety of proposed equalizers (EQUs), the most common technique is the dissipation method such as in [9,16]. Dissipation, or D type, EQUs simply connect a small resistor across each cell until it discharges to the same value as the lowest cell voltage in the pack. Although simple to implement, D type EQUs are inefficient and can be very slow when equalizing higher capacity cells, e.g., 60 Ah cells. Charge transfer, or C type, methods also have been developed [1–5,9–12,15,18], but these systems are more complex and do not seem to have been widely implemented.

A relatively simple, yet very effective technique is to use a relay circuit [6–8,13,14] that provides both charge and discharge capability for the individual cells, i.e., a C/D type. Since it only processes the deviant cells, this system can provide a much higher equalization current and therefore is both fast and efficient. Miniature sealed

☆ This paper was submitted to the Special Issue "Batteries for Automotive Applications".

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0378-7753/$ – see front matter
doi:10.1016/j.jpowsour.2010.04.055

relays can be used for accessing the cells, and some of these devices are quite small, as shown by the 5 A/30 Vdc relay in Fig. 6. Since the relays in this system only switch under no load, their reliability is quite high, and can easily exceed 5,000,000 lifetime operations [17]. This far exceeds the expected number of lifetime operations in EQU applications since the time between relay operations typically varies between 10s of seconds to several minutes.

Details of an experimental BMS with a C/D EQU are included along with comparisons with a D type EQU for a LiIon pack containing 6 series connected 60 Ah LiIon cells. The test results for these two systems show improvements in equalization time by factors ranging from 2× to 15× for the C/D EQU, depending on the type of imbalances in the cells. It is also shown that these factors of improvement will tend to increase in proportion to the number of series cells in the pack. This 6 cell system is similar to earlier versions that have been implemented successfully in much larger systems, one of which was for an autonomous underwater vehicle which contained 80 series connected cells in each of 5 battery packs [13].

However, there are some major differences between the present C/D EQU and that described in [13]. First, this new system uses simplified relay logic that has fewer contacts per cell and simpler relays. Second, the new EQU uses charge/discharge devices can be turned off briefly while the cell voltages are measured. This allows the EQU and the measurement circuit to share the same set of sensing lines, whereas the system in [13] required two separate sets of lines. This provides a major reduction in the size of the wiring harness. Third, since the small cell charger in the old EQU is operating while the voltage measurements are performed, EMI from this charger can increase the measurement error. In the new system, this EMI is not present since the cell charger is turned off while the measurements are taken. Of course the cost of a C/D type is probably higher than a D type, but the total system cost increase is slight and not an issue for applications that require higher performance.

This present study also provides data that compares the performance of the C/D EQU to the more conventional D type. Ref. [13] was only intended as a brief introductory paper, and no C/D vs. D type comparisons were presented since a D type for the same size battery pack was not available.

2. Battery management system (BMS) modularization

To increase reliability and decrease the length and bulk of the wiring harness between the cells and the BMS, a large battery pack is usually divided into separate sets of cells. This type of BMS includes a Local control module for each set, and a Central control module to coordinate the Locals via a serial data link such as CAN (controller area network). The block diagram for a typical system is shown in Fig. 1, which is similar to those presented earlier in [6,8,9].

Each of the Locals, L1–L4, in Fig. 1 consists of two parts, an electronic control unit (ECU) and an equalizer (EQU). Each ECU contains a microcontroller to perform at least the following functions:

- Communicate with the Central.
- Perform temperature and cell voltage measurements.
- Direct the EQU to equalize a specific cell(s).
- Perform safety checks and operations.

The EQU merely implements the ECU equalization instructions, i.e., it applies a supplemental charge (boost) or discharge (buck) to the specified cell.

The Central in Fig. 1 also contains a microcontroller that communicates with the Locals and processes the data they send. The Central has complete control of the pack since it contains the temperature and voltage data from all of the Locals. As a safety precaution, it also controls the 12 Vdc power to the Locals. This is necessary since the Local EQUs have the ability to boost or buck the cells. In the event of a Local malfunction, the Central can disable the 12 Vdc source to insure that no unmonitored boost or buck can

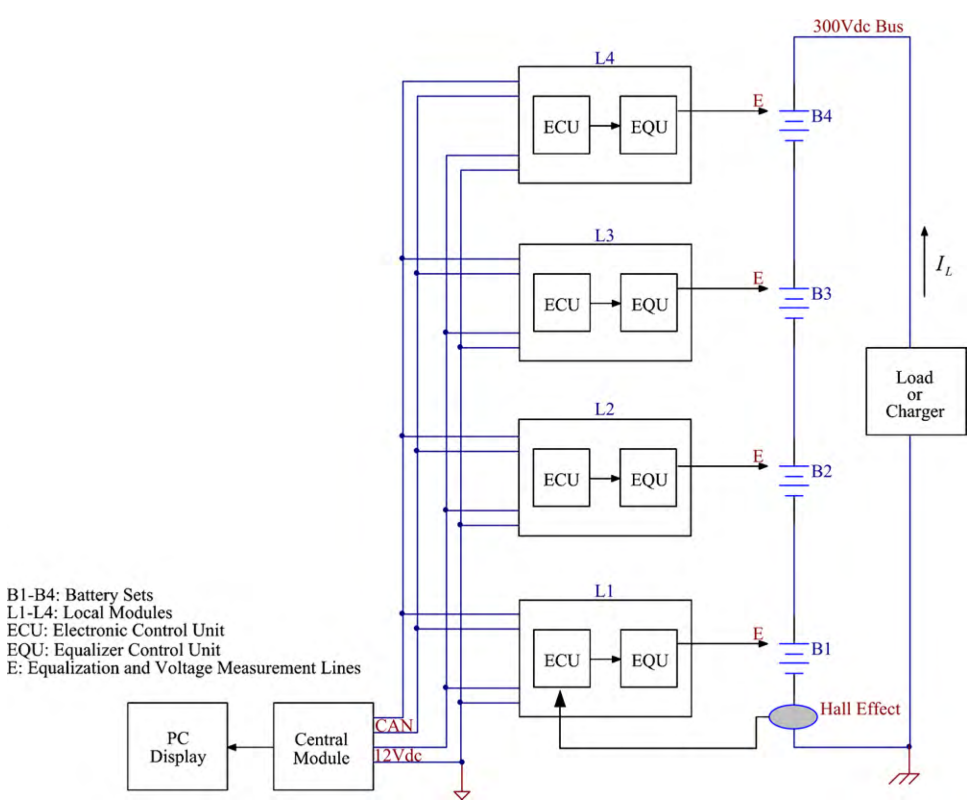

Fig. 1. Modularized battery stack and BMS with four locals of 20 cells each.