A Basic Battery Management System Design with IoT Feature for LiFePO4 Batteries

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Abstract

The production of electricity with renewable resources has also necessitated the storage of energy. This need, which is satisfied by lead acid batteries, is now being replaced by lithium battery cells. But the necessity of monitoring and managing the lithium battery cells also lead to the design of battery management systems. In this study, firstly, battery management systems, general features and basic concepts were emphasized, and then a battery management system with passive balancing and IoT feature was designed on the purpose of controlling a 4 cell lithium iron phosphate battery pack. Laboratory and field tests of the designed equipment have been performed and it has been seen that the switching between the working modes, the charge-discharge control and the balancing feature have been successfully performed according to the obtained results.

1. Introduction

The increasing search of alternative energy sources, gives rise to usage of renewable energy sources such as solar power and wind power; however, it brings along the continuity issue on electrical power generation. Therefore the energy reproductivity creates a storage requirement and the developing battery technology becomes responsive by time [1,2].

The lead acid batteries which was seen as unmatchable for a long time, leave its place to lithium based batteries with higher energy density thanks to developing technology [2-5]. Because of lithuim based batteries' high temperature durability, higher cycle life and lower weight advantages, these types of batteries has a common usage area.

Lithium-based batteries can produce flammable gases or direct flame to cause fire if they are overcharged. In case of over discharge or over charge, they also lose capacity seriously [6]. Therefore, the charging and discharging of these types of batteries must be under strict control. To ensure this function, battery management systems are used. In addition to this basic function, some battery management systems also include some features such as cell balancing, charge and discharge current reading, SoC (state of charge), SoH (state of health) calculation [7-13].

In this study, a battery management system is designed to perform charge discharge control of a four cell LiFePO4 (Lithium ferrite phosphate) battery pack. This battery management system, which also includes passive balancing feature, transmits the measurements such as current, voltage and temperature to a remote server via GSM module. This allows the system to be remotely controlled and monitored. The battery management system and load control device were configured to operate a low power LED lighting system and laboratory and field tests were performed to collect data. The obtained data shows that the battery pack is kept in safe operating area and, the balancing function is performed successfully in addition to the charge discharge control.

2. Main Properties of the Battery Management Systems

2.1. Definition of the BMS

The term of battery management system (BMS) refers to a structure that allows a battery pack to be kept in a safe operating area; althought it has no specific definition. A relatively advanced battery management system is basically expected to provide the following functions [8]:

- Keeping the battery pack between certain voltage values, preventing overcharging and discharging
- To keep the battery pack within certain temperature limits and to intervene in the system to provide these limits when necessary
- Measuring and limiting the charge and discharge current
- Reducing voltage imbalances between cells to increase the effective use capacity of the battery pack
- Remaining Useful Life (RUL), State of Charge (SoC) and State of Health (SoH) estimation
- Equal aging of the battery pack and prolonging the service life of the cells
- Sending data to a remote server and receiving commands from the server

Safe operating area (SoA) can be considered as a concept that includes upper and lower voltage limits, temperature limits and current limits. Keeping the battery cells in this area is provided by the battery management system. It is a must to keep the battery pack in the SoA so that it can operate without being damaged [8].

The balancing function is also a prominent feature of the battery management system. A battery management system that provides a successful balancing will also enable the battery cells to be used more efficiently and for longer periods of time [9-17].

Some estimations of the battery pack need to be performed either by the battery management system directly or by the server. These include Remaining Useful Life (RUL), State of Charge (SoC) and State of Health (SoH) [18-21].

2.2. Basic Functions of a BMS

2.2.1 Voltage Measurement

The most important function of a lithium battery management system is to measure the voltages of all the cells and to terminate the charge and discharge directly or indirectly. The damage stemming from overcharging or discharging of any of the cells in the package, cause loss of capacity which affects the performance of the entire package; as a result, the amount of available capacity significantly reduces. If the designed system is only used to terminate the charge discharge operations and if this function is carried out from the voltage, reading of the voltages with a deviation of 100 mV is sufficient for the function to be performed. If a relationship between SoC and OCV (open circuit voltage) is asked for, a deviation of 50 mV is sufficient. When the battery pack is not fully cycled, a voltage reading of 1mV is required to calculate the SoC [8].

2.2.2. Temperature Measurement

Temperature measurement is generally not a necessity. When the thermal runaway situation occurs, it is not possible to intervene immediately in the system [8]. However, the temperature measurement may be useful in determining defective conditions because of the production process faults. At the same time, temperature measurement is effective when the SoC, SoH values are also determined. Especially in battery packs designed for use in electric vehicles, temperature measurement is of significantly important in terms of thermal management and troubleshooting [22].

2.2.3. Current Measurement

In some lithium-based battery cell types (for example LiFePO4) the voltage at SoC values between 40% and 90% forms a relatively flat plateau ("Fig. 1".) [23]. To eliminate this disadvantage coulomb counting method is used. When the battery pack is fully charged, SoC is set to 100% and then the current is measured during charging and discharging to update this value. There are also studies to correct this value with temperature and voltage measurements.

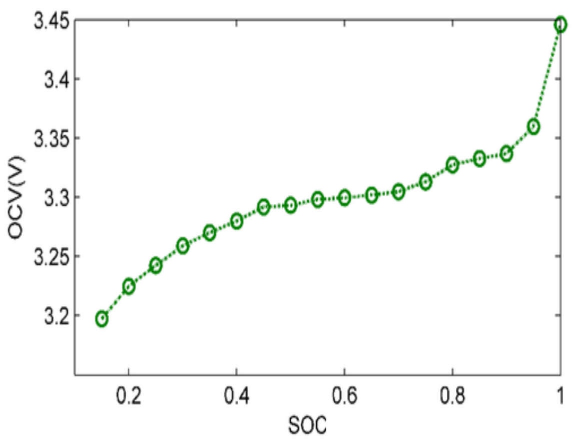

Fig. 1. OCV-SoC curve of a LiFePO4 battery cell

In addition to all these functions, the functions such as communication and data logging are also available in battery management systems. But they are complementary features that support basic functions.

2.3. Battery Balancing: Why and How?

Voltage imbalances that occur during charging and discharging of series-connected lithium-based battery cells cause battery pack to be ineffective. Battery management systems may also include the ability to balance in order to remove the differences in charge rates between cells due to imperfections from the chemical structure and electrical properties [8,15]. Passive and active balancing methods eliminate this problem and increase the performance of the battery pack and the amount of available capacity available [7-17].

The methods used in passive balancing are relatively simple and low-cost. The general purpose here is by discharging the battery cell with a charge rate above the average with the aim of approximating its charge rate to the average value. This method, which is generally implemented by means of a resistor switching, is often preferred because of its ease of implementation and low costs.

Active balancing methods have been developed to eliminate the loss and efficiency disadvantage created by passive balancing. This includes techniques such as transferring energy from the high capacity cell to the low capacity cell or from the entire battery pack to the lowest capacity cell or separately charging the cell with low capacity (low voltage) [14-16]. They are used less than the passive balancing technique because they are relatively complex and costly. But nowadays there is an increasing trend in this direction.

Passive balancing is often preferred because of its low cost and ease of application where the efficiency is not critical. Using the passive balancing technique, a 1% balancing can be achieved within one hour for a 10mA per Ah discharged battery cell [8]. When this balancing technique is concerned, the relationship between actual capacity after balancing, *acab*, and initial capacity before balancing, *icbb*, is as below:

$$acab[Ah] = icbb\ [Ah] - 10\ [mA/Ah] \times time\ [hour] \qquad (1)$$

Active balancing is usually preferred in situations where the high capacity battery is used and efficiency is important. It is also preferable that active balancing techniques should be applied to medium and big battery packs which are required to be charged quickly at the same time. With the reduction of electronic component costs and the importance of efficiency improvements efforts, the number of structures that are used active balancing is increasing.

2.4. SoH and RUL Estimation

SoH and RUL values are two important determinations of battery packs. Based on these values, it is possible to estimate the life expectancy of the battery pack and the cell failures. Depending on this, the battery cell to be replaced can be determined and the life of the battery pack can be extended.

For a battery cell which has lower SoH the internal resistance is relatively high. This situation causes the battery quickly reach the overvoltage protection limit during charging, and will quickly reach the undervoltage protection limit during discharging. In this case the amount of available capacity will be significantly reduced [23].

Calculation of the SoH value is generally carried out in two main ways. The first of these is the comparison of the nominal internal resistance, R_{nom}, value with the actual internal resistance value, R_{act}, of the cell. Accordingly, the SoH value of the battery cell, which has higher internal resistance than the others, can be determined relatively [8,21].

$$SOH = 100 \times (1 - R_{nom} / R_{act}) \quad (2)$$

In the second way, the nominal capacity, *Cnom*, is compared to the actual capacity *Cact*. The SoH value of the battery cell, which has low capacity compared to the nominal capacity, is considered to low [8,21].

$$SOH = 100 \times (1 - C_{nom} / C_{act}) \quad (3)$$

But also one of the easiest approach to estimate SoH is using number of cycles [8]:

$$SOH = 100 \times (1 - \text{Cycle Number} / \text{Nominal Cycle}) \quad (4)$$

Today, different approaches and algorithms are extensively studied in order to determine SoH value with higher performance [21].

The concept of RUL is generally a term associated with SoH, but it also describes how much longer the battery pack can be used. A total evaluation with maintenance costs, usable capacity, fault possibilities ensures that the RUL value is determined [19,20].

3. Experimental Work

In this study, 4 pouch type LiFePO4 battery cells with 10 Ah capacity connected in series are used. The passive balancing technique is used to balance this battery pack with a nominal package voltage of 12.8 V. The balancing current is set to be approximately 360mA. This indicates that a 3% balancing will occur within an hour. The battery pack is protected from overvoltage by reading the cell voltages to be charged by the PV panel and MPPT equipment via the battery management system and disabling the charge relay. At the same time, the charge and discharge currents were also read separately. SoC value can be calculated by coulomb counting. A simplified block diagram of the designed system is shown in "Fig. 2".

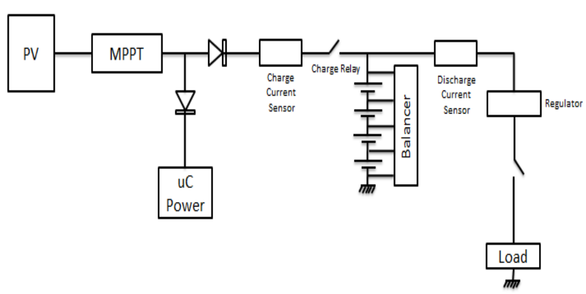

Fig. 2. Basic block diagram of designed system

The control of the system is based on the cell voltages. The control parameters of the system are also shown in "Table 1".

Table 1. Control parameters of BMS

Maximum Cell Voltage	Minimum Cell Voltage	Voltage Difference for Balancing
3.70 V	2.80 V	100 mV

The system communicated with a GSM module over the TTL-UART line and transmitted data (voltage, temperature, current, SoC and operating status) to the remote server. At the same time, a command infrastructure has been developed that will cut off charging and discharging from the remote server when needed. This function also adds IoT feature to the system.

The designed battery management system is controlled by a 8-bit microprocessor. The voltages of the battery cells are read through the 10-bit ADC module, which is embedded in the microprocessor. The temperature sensors are read in the same way and data are obtained for the corrections that can be made further depending on the cell temperatures. The embedded system realized for this purpose is shown in "Fig. 3".

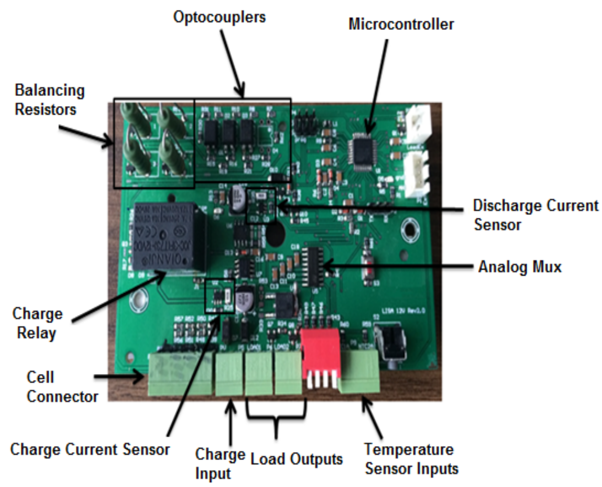

Fig. 3. Designed embedded system

The operation of the system is set to 5 modes. These are charge state, relaxation state, balancing state, discharge state and critical state, respectively. The details of the transition between modes are as follows:

Charging State: If the input voltage is higher than the desired value and the cell voltages are below the upper voltage limit, the system is in the state. If one of the cells reaches the upper voltage limit (3.70 V), the charging process is terminated and the state is relaxed.

Relaxation Status: The status after the battery pack is recharged. In this case, current draw from the battery pack is kept minimal. This is a 10-minute process in small capacity battery packs (<60 Ah) to balance the chemical reactions in the cells.

Balancing Condition: If the difference between battery voltages after relaxation is above 100mV, the cell with high voltage is subjected to balancing for 10 minutes.

Discharge Status: The system is energized from the battery pack when the input voltage drops to a level that can not charge the battery pack. The load outputs are activated either by the timer or by the input voltage depending on the input voltage and the output is energized. When one of the cells in the battery pack drops to the asked minimum cell voltage level (2.80 V), the load output is turned off and the system is switched to the critical state.

Critical State: The load outputs are completely turned off. And the self power consumption is the lowest. The system remains in this state until the input voltage reaches the level at which the circuit will feed.

The data that the battery management system has been sent to the remote server, gives the information about the availibility of the system and evaluate the balancing function. This IoT feature also gives an ability to control load output and charge process. All the working modes are optional in manual mode and they can be selected from the remote server by the user.

The obtained data for the balancing function is shown in "Fig. 4".

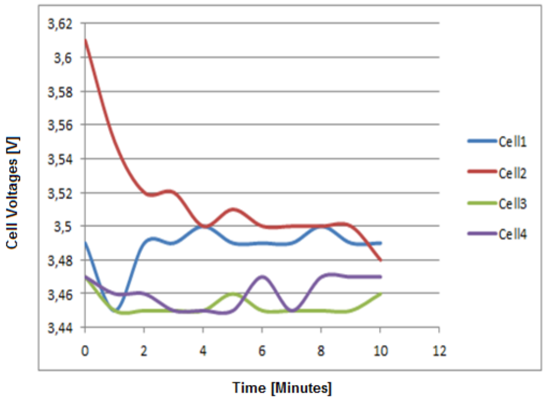

Fig. 4. Cell voltages during balance state

4. Results and Discussion

The actual hardware was tested in the laboratory and also on the field and the tests give similar results in both cases.

During the tests it was seen that the charging and discharging operations were interrupted when the specified limits were reached, and the transitions between working states were managed successfully. It has also been observed that data can be transmitted to remote server periodically. It has been observed that the IoT feature contributes greatly to the system's remote monitoring and control. Thus, it is possible to make some determinations (system malfunction, changing the failed cell, etc.) about the system from the center with no need to be located in the field. It is also important that remote control of charging and discharging operations allows the system to switch on and off in certain situations.

The balancing function has also been successful. After 10 minutes of operation, the voltage difference between the cell with the highest voltage and the cell with the lowest voltage was found to be around 20 mV.

As for the SoC value, it is determined that coulomb counting method is relatively inaccurate. Supporting this method with temperature measurement and voltage measurement has been achieved, if necessary, by using some advanced adaptive and hybrid methods (neural network, support vector machine etc.).

It is also noteworthy that the voltage-based passive balancing structure balances the cells in terms of voltage but reduces the total efficiency of the system due to lost heat. When it is evaluated from the point of view of cost, this method, which is logical, is required to leave its place to active balancing methods when it is evaluated in terms of efficiency.

As a consequence, lithium-based batteries are expected to be a serious alternative to lead acid batteries today, as renewable resources and energy storage technologies are becoming more widespread. Correspondingly, it is a fact that the battery management system researches whether academic or commercial will increase.

5. References

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