Development of a Simple Battery Management System for Cell Balancing

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Abstract. As the use of Lithium Ion (Li-Ion) battery is increasing, proper means of increasing the life cycle and reliability of the battery should be adopted. A discussion on the precautions to be carried out while integrating Li-Ion batteries are discussed. A Battery Management System (BMS) is developed to address the unbalance State of Charge (SoC) issue that arise in the battery pack. The proposed algorithm is simulated in MATLAB Simulink. The battery pack used in this simulation is inspired from Tesla. This paper can be used as a tutorial or as a reference for anyone getting started with Li-Ion batteries or battery management systems.

1. Introduction

With increase in Global warming and different types of pollutions because of increase in emission of carbon di oxide from factories, (ICE) Internal combustion engine vehicles, and also due to the rapid depletion of crude and fossil fuels a new source of energy must be sought for. This need for an alternate source of energy has led to the development of battery-based energy systems. These types of energy systems, are gaining much interest among researchers and thus paving way to the development of (EV) Electric Vehicles [1].

One of the most commonly preferred on board source of energy to power these applications is the Lithium-ion batteries (Li-ion). Over the due course of time, the Li-ion batteries have gained popularity in the global market because of their a) high energy density, b) well versed technology, c) desirable characteristics, d) no memory effect and d) least self-discharge rate [2]. Due to these characteristics, the Li-ion batteries are employed as either primary or secondary source in several electrical based energy applications [3], [4]. Though the Li-ion batteries have a lot of desirable features, they are quite intolerable when it comes to discrepancies in design and implantation such an a) over voltage, b) high temperature, c) over current or power, d) thermal runway etc., [5], [6]. Currently, many research works are being carried in the developing the chemical and physical characteristics of the Li-ion batteries both in terms of cost and performance in order to achieve maximum potential out of these batteries. Some of the most advanced and important ones among them are safely charging and discharging the batteries under safe State of Charge (SoC) values [7].

With Li-ion batteries becoming more and more popular for electric based applications, a need for a Battery Management System (BMS) arises to improve the performance, life span and safety of the battery to a much greater extent. A BMS is nothing but a protective circuit or a system or a module that controls the overall battery parameters, such as safe operating voltage, current, temperature, power etc., along with providing and monitoring real time data about fault diagnosis, amount of charge available, charge stabilization etc., [8], [9]. This paper discusses about the Li-Ion battery source and its
wide application, issues arise due to integrating Li-Ion cells as battery pack, safety precautions while dealing with the battery pack, cell balancing strategies, BMS and its algorithm. Simulation of BMS system for the Li-Ion battery pack. A three cell and a five-cell battery pack model are tested for the proposed algorithm.

2. Lithium-Ion Batteries

The Li-ion batteries are an unmatchable choice when it comes to battery-based energy applications because of their high energy density and other such superior characteristics. They are being used in electric vehicles, portable tools, power electronics and so on. The Li-ion battery pack is nothing but a combination of individual lithium-ion cells connected in series formation in order to increase the voltage or in terms of parallel formation in order to increase the current or sometimes in combination of both to achieve higher ampere hour rating. Lots of cells can be included into a battery module, based on the voltage parameter required. For example, a Tesla car with an overall battery pack voltage of 85kWh has around 7104 cells. In basic terms a Li-ion cell individually consists of two electrodes namely a cathode and an anode, immersed in an electrolytic liquid or membrane in some cases, based on the type of cell and chemistry involved [10]. Right from the commercialization of the Li-ion batteries by Sony, the Li-ion batteries have gained a wide popularity in the global market [11], [12]. Now a question may arise what is so special about Lithium-ion batteries? The main features of the Li-ion batteries include less toxicity, longevity in terms of capacity and charge / discharge cycles, usability within a wide range of temperatures and environments etc., [13]. But, just like a coin has two sides, the Li-ion batteries also have two sides i.e. the positive and negative traits. The positive traits include the high energy and power density as already discussed above. But, the negative traits include mainly the cost and the protective systems that are needed for safe charging and discharging of the Lithium-Ion Batteries [14]. While the Lithium and Nickel batteries were used in secondary systems of energy storage systems [15], learning about their wonderful utility, we started utilizing them as primary sources at present. There are a variety of materials used in the building of Li-ion batteries, often the cathode materials of these batteries include, amalgams of the oxides of Lithium metals, some of them consist, manganese (LMO), cobalt (LCO), combinations having a blend of aluminium such as LiNiCoAlO$_2$ [16]. Now we can make it clear that the High energy and power densities of the Lithium-ion batteries are because of the utilization of Lightweight materials and high potential electrochemicals in the construction of the batteries, thereby giving rise to voltages of 3.2 – 3.8V. In present days, extensive research works are being carried out on Li-ion batteries, to improve their performance in terms of power, energy and in terms of operating voltages too, as result of which, the operating voltages of up to 4.7 – 4.8 V have been achieved [17].

3. Safety and Precautions

Though Li-ion batteries have a lot of desirable characteristics, they are quite unforgiving when it comes to mishandling, error in designing and short circuits. The short circuit causes the current to flow in an unintended path thereby causing explosion, fires and even death. Hence, few safety measures need to be followed, they are as follows:

- At all times safety gear such as glasses, insulation gloves and aprons should be worn in the environment where works on Li-ion batteries are being carried out.
- Due concentration must be given while handling Li-ion batteries and chit chatting unnecessarily in the work place must be avoided.
- Never keep any metal tools just above the battery pack, because if the tool accidentally happens to fall on the battery and connects the battery terminals it could cause fatal short circuits.
- During designing proper calculations must be carried out in order to avoid mismatch of cells, over voltage / currents which could lead to thermal runaway.
- Battery packs should never be forced in to housings which are smaller in size comparing to the battery packs as these could result in cell deformations causing, cell venting, internal short circuits etc.,
While measuring the Open Circuit Voltage (OCV), if the value comes to 0.0 V it could mean that either the fuse is blown or the cell has been completely discharged [18]. In the event of any signs of explosion such as flares, smokes, sparks etc., rush to the nearest exit. In case of unavoidable fires, never use water as the fire resulting will be an electrical and fire hence dry chemical extinguishers loaded with potassium bicarbonate or monoammonium phosphate must be used to put off the flames. Never ever mix Old and new cells together as they could have different levels of (SoCs) State of charges and could result in a mismatch hence a separate log should be maintained about the cells. In order to check the life of a cells, charge the cells and after one hour of resting the cell, measure the voltage of the cell. If the voltage shows out to be 4.2 V then the cells are good in condition to be used. Though this is a basic method, it can used in general and not to be relied up on all times. The cells and battery packs should be stored in a safe and closed environment under nominal temperature conditions. Suitable battery management systems with temperature, voltage and current sensors should be employed in any battery based energy applications as this could not only boost the performance of the batteries but also can prevent fatalities due to poor handling of the batteries.

4. Cell Balancing

Cell mismatch or cell imbalance is one of the important phenomena that leads to the reduction in battery life of Li-ion batteries when using multiple cells together as described earlier for the meeting the power requirement of an application. It also leads to the reduction in battery performance and reduces its State of Health (SoH) [18]. Researches stated that in a string of series connected cells, the cell with the least SoH level, dominated the entire string of cells thereby causing safety issues and thermal runaway while the battery pack was discharged below its limit [19], [20]. In order to overcome such discrepancies that deter the overall performance of the cells and the battery pack as a whole, cell balancing techniques need to be used. The cell balancing techniques are of two types namely:

- Active cell balancing and
- Passive cell balancing

4.1. Active cell balancing

In general active cell balancing is a method in which, the cells are maintained in uniform charge levels, with the help of electronic storage elements such as capacitors, inductors etc., in which these elements distribute the charge from highly charged cells to the cells with lower charge, this operation takes place until the charge in all the cells become uniform [21]. The active cell balancing technique is of two types namely:

- Capacitor based active cell balancing
- Inductor and transformer based active cell balancing.

4.2. Passive cell balancing

Passive cell balancing technique employs the idea of using a venting or balancing resistor to vent out or discharge the extra charge in the highly charged cells and thereby balancing the entire string voltage by making the charge in the highest charged cell to the lowest cell voltage potential finally creating a balance in the entire string voltage. The passive cell balancing technique is of two types namely:

- Fixed shunt resistor method
- Switching shunt resistor method
4.2.1. **Fixed shunt resistor method.** In this method of passive cell balancing technique, a fixed resistor is placed in parallel across each series connected cells based on the current to balance the cells. Since this method of passive cell balancing employs a simple circuit and very few components, the cost is very less. However, it has a disadvantage of heat dissipation through the cells during the cell balancing operation, where the excess energy is lost or vented out or discharged [22].

4.2.2. **Switching shunt resistor method.** employs resistors connected in parallel across each series connected cells, by means of a relay or semiconductor switch. In this method the imbalance in voltage can be sensed and based on that the cell balancing operation can be carried out accordingly. This method is of two types namely the continuous mode in which the semiconductor switches are controlled simultaneously. Whereas, in the other mode known as the sensing mode, the cell balance operation is carried out once an imbalance in voltage is detected by the sensor module which decides the resistor to be shunted [22].

5. **Battery Management System**

A (BMS) Battery Management System is a very crucial part in any battery-based energy applications especially in (EV) Electric Vehicles. The main need for the BMS is to protect the battery pack from discrepancies in voltage/current/power etc., along with collecting and providing real-time log data on the battery conditions such as SoC, Temperature and so on. These parameters are very important when it comes to boosting the overall performance and efficiency of the battery packs. The main architecture of the Battery Management System can be split into two parts namely the Hardware and the Software parts. The Hardware part aims at various types of sensors such as voltage, current, power, temperature sensors etc., these sensors need to have a high sampling rates in order to provide the values with precisely and with least errors. Whereas, the software part aims at the GUI through which the user can easily monitor battery parameters and the program codes which limit the hardware in terms of suitable values or parameters under within which the battery and the sensors are supposed to function [23].

Following are the features of a BMS:

- The BMS should prevent the voltage of the cells from exceeding the prescribe voltage value by limiting or blocking the charging current.
- It should also maintain the temperature of the batteries by ensuring proper cooling through cooling mechanisms such as current limiting during charging or using physical coolant liquids or gases to remove the heat from the battery pack.
- The BMS should ensure proper cell balancing by monitoring the SOH and SOC levels in the cells because failing to do so can affect the entire performance and the charging and discharging characteristics of the battery as a whole.
- The BMS should trigger alarms in case of any abnormalities with respect to the cells or the battery pack.
- Finally, the BMS should be able to notify the users about the cells which should be replaced, because a cell with low SOH value can hinder the overall battery performance.

In order to design a Battery Management System, due calculations need to be done as for what applications, the BMS is needed or for what value of Battery voltage and so on. Though there are lots of methods in designing a Battery management System, the best method would be to use a simulation software to build the control blocks based on the battery parameters and to run a simulation on the model built. Finally, based on the test results readings and important details can be noted down as on how the practical Battery Management System can be implemented.

6. **Design and Simulation of Passive Cell Balancing Circuit**

In here, a circuit is built based on passive cell balancing principle and the output current, voltage and SoC values are analysed. The Battery employed here has parameters similar to that of Tesla’s Li-ion cell. The cell characteristics is presented in Figure 1 and the cell specification is given in Table 1.
Figure 1. Cell Characteristics

Table 1. NCR 18650BE Cell parameters – Our simulation work employs a cell with similar characteristics [24]

| Parameters       | Specifications |
|------------------|----------------|
| Rated Capacity   | 3200mAh        |
| Nominal Voltage  | 3.6V           |
| Charging Voltage | 4.2V           |
| Weight (Max.)    | 48.5g          |
| Diameter (D)     | 18.20mm        |
| Height (H)       | 65.50mm        |

With reference to the concept of passive cell balancing, a three cell and five cell battery pack model with passive cell balancing technique have been developed using MATLAB Simulink as shown in Figure 2.

Figure 2. Five cell battery pack model with passive cell balancing based on [25].

The cell balancing algorithm is implemented using the MATLAB function black and for circuit simplicity and easy understandability, signal routing blocks are used. At the output terminals of the
battery a series network having a power dissipation / balancing resistor and a solid-state switch is used. When the passive cell balancing algorithm is implemented, the output behaviour is studied by means of the graphs obtained from the scope. The passive cell balancing algorithm implemented in this work is presented in Figure 3. The algorithm receives the SoC (Sx) of each cell in the battery as input and identifies the cell with the least SoC level and activates the passive cell balancing by turning on the MOSFET connected across the other cells having higher SoC level using the control signal (Yx). Where x indicates the number of cells being used in the battery pack.

Figure 3. Flowchart.

Initially, the input (s1, s2, s3, s4, s5) and the output (y1, y2, y3, y4, y5) variables are initialized, following which we assign predefined values to the input ‘s’ values and then with help of if else condition logic, we verify the values in each batteries, if the parameter in one battery is greater comparing to the other batteries then the parameter is vented out by the logic implemented by means of the bypass resistors in the circuit, this operation continues until the parameters are the same in all the five batteries.

The balancing takes place only when the battery power is not used for the application. The simulation is started considering that the battery pack has delivered power to the load and the SoCs of each battery pack is different as shown in Table 2. The simulation results for three cell balancing technique and five cell balancing techniques are presented in Figure 4 and 5. In both these cases, the SoC of every cell is discharged to the level of the cell having minimum SoC value.
Table 2. Initial values of SoC

| Battery # | 3 Cell Model | 5 Cell Model |
|-----------|--------------|--------------|
| 1         | 62           | 55           |
| 2         | 67           | 65           |
| 3         | 82           | 67           |
| 4         | -            | 82           |
| 5         | -            | 85           |

Time taken for cell balancing (s)

|   |   |
|---|---|
| 1 |   |
| 2 |   |

Figure 4. SoC stabilization for 3 cell battery pack.

Figure 5. SoC stabilization for 5 cell battery pack.

From the output graphs, it is evident that how the battery parameters are stabilizing from their peak values to that of the values of the other batteries in the circuit.

7. Conclusion
The significance of Li-Ion batteries for electrical applications and the need for safe operation of these cells when used as battery packs are being discussed. In order to have longer life span for the battery pack, the need for cell balancing technique is also presented. A simple algorithm for performing cell balancing using passive balancing technique is presented and simulated using MATLAB Simulink. This paper is aimed at serving as a tutorial paper that delivers complex information and concepts about
batteries, battery management systems, cell balancing techniques etc., in a nutshell thereby eliminating the need for the reader to spend more time in learning about the working mechanism and concepts. In this paper we are focused more on the development and simulation of a passive cell balancing circuit in detail, while a glimpse of active cell balancing is given.

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