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Battery Cell Balancing Optimisation for Battery Management System

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Abstract. Battery cell balancing in every electrical component such as home electronic equipment and electric vehicle is very important to extend battery run time which is simplified known as battery life. The underlying solution to equalize the balance of cell voltage and SOC between the cells when they are in complete charge. In order to control and extend the battery life, the battery cell balancing is design and manipulated in such way as well as shorten the charging process. Active and passive cell balancing strategies as a unique hallmark enables the balancing of the battery with the excellent performances configuration so that the charging process will be faster. The experimental and simulation covers an analysis of how fast the battery can balance for certain time. The simulation based analysis is conducted to certify the use of optimisation in active or passive cell balancing to extend battery life for long periods of time.

1. Introduction

Battery management system is one of the crucial part in various electrical and electronic systems, e.g., commercial electronics device and electric vehicles that help to monitors and reports the state-of-charge (SOC), state-of-health (SOH) and remaining useful life for every rechargeable multi-unit batteries cell [1]–[4]. The battery management system be able to manage and adapt towards the changing of batteries characteristic over time since the applications require the parallel or series attachment of multiple unit battery cells [5]–[7]. A study conducted in [4], shows that battery management system can tolerate with the batteries at the temperature variation range of -30°C to 50°C. This means that the battery still need cell balancing in order to help the management system and help to tolerate with power of the battery.

A research that have been done by [8] show that they are using active cell balancing for their system. The research are conducted from 10 cells of battery and make the comparison between with balancing and without balancing. When they discharge the cells without balancing, one of the cell reach to the discharge voltage limit (DVL) compare to others cell. Even only one of the cell reach the



DVL, the battery is stop working in order to care about the battery life. From that point, it shown that the battery is not fully utilized and make the cycle life shorter. The experiment with balancing show that the discharge voltage limit time is increased by 15%.

In the paper [9], they have done with the balancing algorithm based on outlier detection. The method they been used is by calculate each cell outlier value. Moreover, the cell been balanced if the threshold value of each cell is not less than the threshold assigned. From the result, it shown the frequency of on/off switching significantly reduced from 1150 to 2 and also reduce the voltage cut-off. The algorithms is extremely good, however, it make some disturbing in the cut-off voltage value.

This paper will concentrates on the cell balancing and discuss several proposed balancing method from different point and method by using MATLAB/Simulink. This method is useful based on final voltage information. The value for each cell will be calculated. After get each value, it will compare between others. If the threshold value between maximum and minimum voltage is not over the set value, then the algorithm will proceed with the final-voltage algorithm.

The research work is organized that started with balancing algorithm which explain the type of algorithms. At the second part will discuss about the methodology for this system. In the final section is about the simulation experiments that been done and followed by conclusion.

2. Balancing Algorithm

2.1 Voltage based

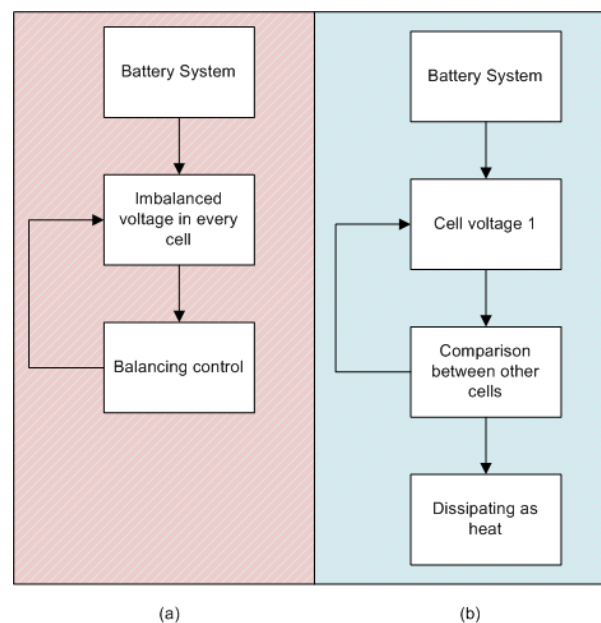


Fig. 1. (a) Voltage based flowchart, (b) Final voltage based flowchart

Figure 1 shows the voltage based algorithm which includes two modules that are imbalanced voltage and balancing control module. Basically, the cell will be charge and discharge up to certain point [5]. However, during the charging process, each cell is charged at different rate resulting of voltage difference between each individual cell. With the different value in voltage reading at each cell, the cell balancing circuit will make an attempt to balance out the voltage reading of individual cell [6], [7]. Cells with abnormal voltage reading will automatically give a feedback information to the previous cell. However, if the voltage reading is under load, it will depend only on the internal cell resistance of every cell.

2.2 Final Voltage based

The abnormal cell will then send feedback information to the previous cell in series next to it. The balancing circuit will be activated when the cell reach an acceptable voltage range. It will then compare its voltage reading to others cell and starts to preform battery balancing operation. The excess power will be dissipated through the resistor and as heat dissipation [3]. The voltage reading will remain around the predetermined nominal voltage value. The voltage reading from the first cell will be compared to the second cell as to validate the value of voltage [10].

2.3 SOC History based

The algorithm attempting to match SOC with cells history based. The balancing will occur at every time intervals [10]. The advantages of this algorithms is it can balance with less current since it occur at any time. However, it requires more power in order to save the memory in the store for every cell.

3. Methodology

In this paper, the system consists of electronic and software parts. It contain two main stages which are designing the control algorithm and electronic implementation in order to measure its performance in the real world environment. Here is the common form of calculation related to the SOC algorithms.

$$SOC_c(t) = SOC_c(0) - \left(1/Q\right) \int_0^t t I(t) dt \quad (1)$$

The SOC that shown in Equation 1, use the integration of all charge and having left the cell by the amount of the current [11]. Some battery are extremely sensitive towards the overcharge or discharge. In order to prevent from overcharge or discharge, the additional equation is required.

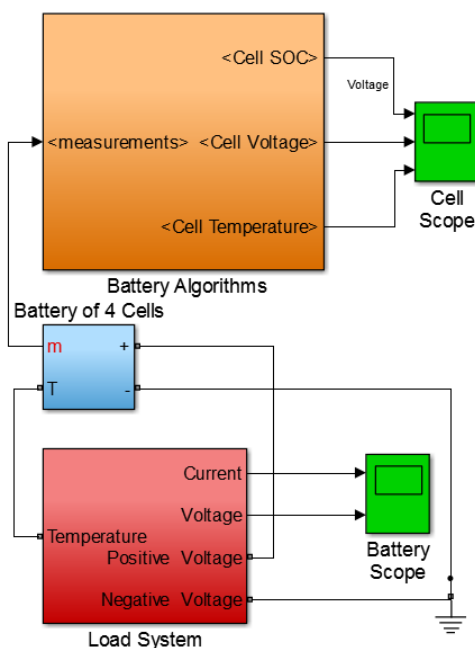


Fig. 2: Full Overview of the Design Software

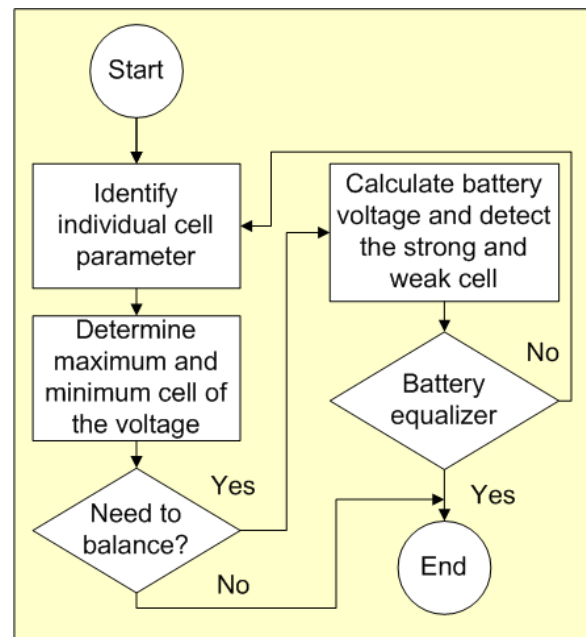


Fig. 3: Cell balancing flowchart

Equation 2 shows the basic equation for comparison of each other cell. V is representative of the voltage of each cell. The voltage been charge or discharge, it will continuously deduct with the voltage equation. If voltage value after operation is the same with the battery cell, the excess charge will be dissipated through the resistor while discharging will stop working.

$$V_{Cell,n} = v_{charge/discharge} - V_{eq,n} \quad (2)$$

Figure 2 shows the overall view of the system. The battery pack consists of 4 cells and the load comes from the current. The current is converted in term of positive and negative voltage. The measurement and balancing calculation is achieved within the battery algorithms. The software used is Matlab 2015 which includes the Simulink and Simscape. Simscape acts as a circuit design which is easy to design the balancer circuit. While the Simulink act as virtual connection between hardware. The using of Matlab give a great result since it already stable and also can be written in the C / C++ language. The software is divides into three parts which are mechanical part, battery and balancing algorithms. However, this paper is focused only on the algorithms. Figure 3 depicts the flowchart of the cell balancing to works.

4. Results and discussion

In order to compare the efficiency of the balancing algorithms, the constant-current charging-discharging model been used to get the result. In general, most of the parameter that are hard to set; however, the model need to be simplified for the real-time BMS application (Ahmed et al. 2015). The battery pack is modelled in in both Simulink and the circuit in Simscape environments. Table 1 shows the parameters of the battery cell which is LiFePO_4 . This battery been categories as slight power density compared to the higher power density which is better, but the higher power density is typically more pricy [3].

Table 1. Parameters of the battery

Parameters	Value	Unit
Nominal voltage	3.5	V
Fully charge voltage	4.45	V
Rated capacity	40	Ah

4.1 Constant Current Charging-Discharging Model and simulation

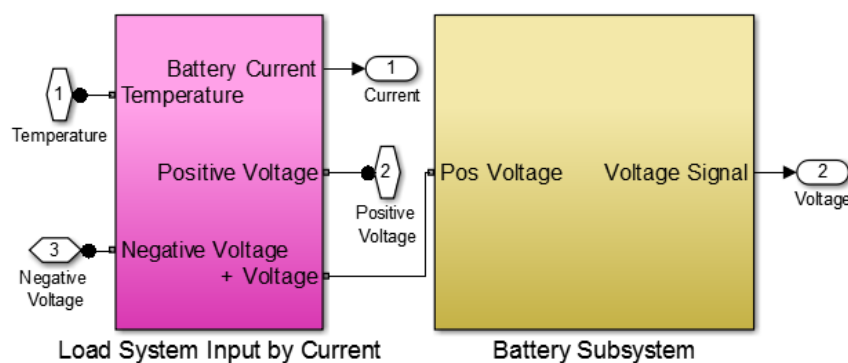


Figure 4: Load operating in the Load System

Figure 4 shows the system of cells balancing. The balancing system is based on the battery pack modularization [5]. The subsystem box contained the algorithm for the balancing. The graph will be shown at the Cell Scope. The constant charging and discharging current progress will be stopped when one of the terminals has reached at below discharging voltage limit or exceeds the charging voltage limit [6]. The discharge voltage level in this paper is 3.23v and charge voltage level is 4.46v.

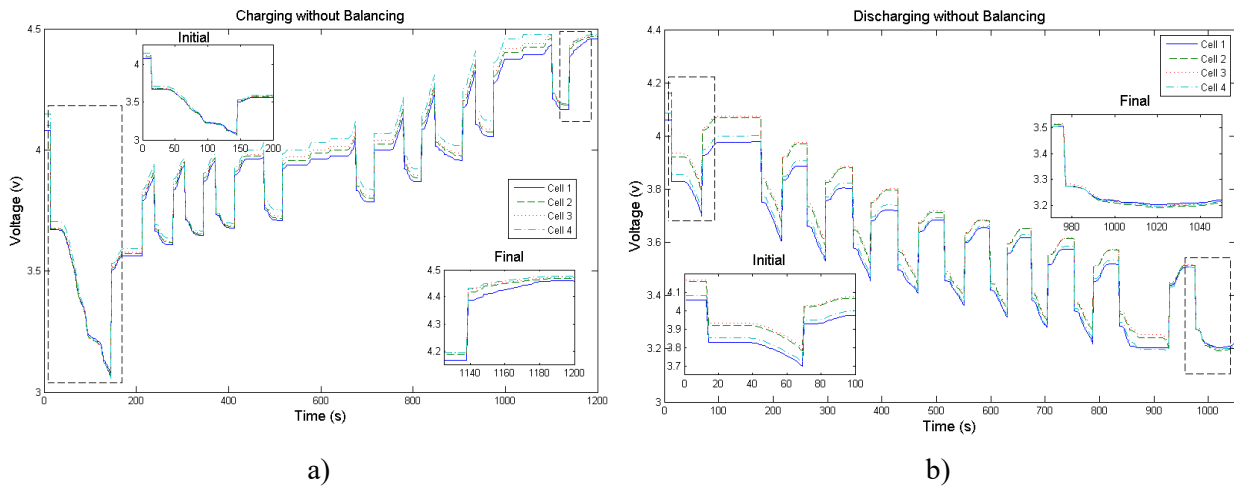
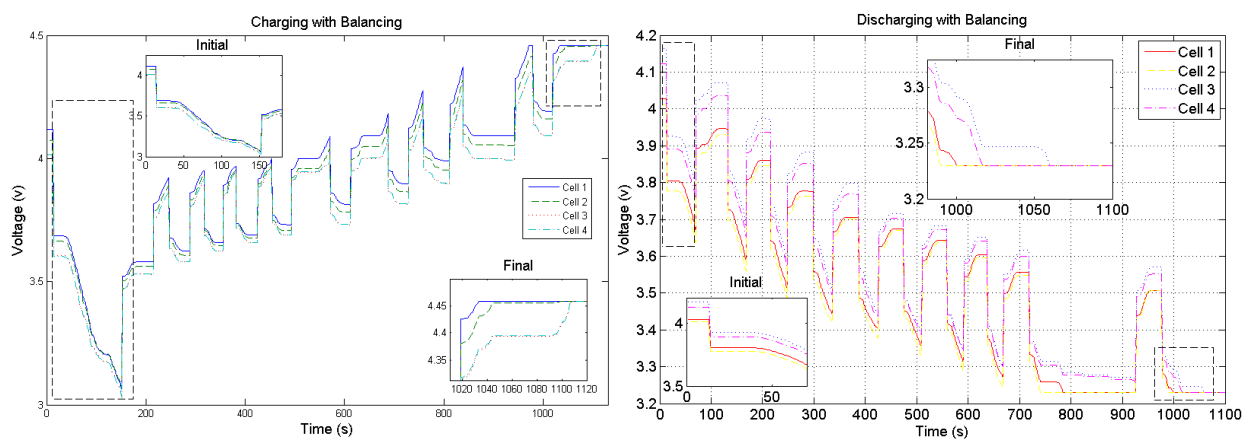


Figure 5: (a) Charging process without balancing, (b) Discharging process without balancing

Figure 5 shows the voltage of 4 battery cell during one cycle of charging and discharging. At the charging point, when the cell near 4.45v, the charging process will not continue. The early voltage of each cell is different as the value of initial state is not same. It had been shown at all figure as to show the result of balancing. When the discharging process happen, the battery will not been used anymore when the voltage reach 3.23v. The cell charge and discharge is not balance until the end. Even the gap value is near, but it still needs a balancer to make it more stable. The earlier voltage is started at different value and converges at the same value. After the balancing at certain value, the end of the graph show the value between cells is almost same. It shows that the cell balancing is activated at the end of set value. For Figure 6(a) it shows that the graph of 4 cells battery charging been balanced at some point while Figure 6(b) show the graph of battery discharging been balanced. Each cell compare between each other in order to get the best value.



a) b)
 Figure 6: (a) Charging with balancing (b) Discharging with balancing

5. Conclusion

The objective of this paper which is to obtain battery cell equalization state during both charging and discharging process are achieved. This results will be further useful for the development of cell balancing circuit and will be tested on Lithium Iron Phosphate (LiFePO₄) to reduce both charging and discharging time as well as prolonging battery shelf life in a long run. The balancing circuit implemented within battery stack is vita not only to optimise battery life-time but also will reducing overall system cost as well as the process operation time. The battery balancing must be applied to the electronic and electrical vehicle to achieve a longer lifetime as well as reliability and also safety.

Acknowledgement

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