

A Performance Comparison Between Buck-Boost Based Active Cell Balancing in Pairs and Passive Cell Balancing in Lithium-Ion Batteries Application

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DOI: <https://doi.org/10.30880/eeee.2023.04.02.036>

Received 27 June 2023; Accepted 20 August 2023; Available online 31 October 2023

Abstract: In designing a battery management system for lithium-ion batteries, the passive cell balancing method is more widely used compared to the active cell balancing method due to lower cost. The aim of this study is to determine the performance difference in terms of energy efficiency and balancing time between both passive and active cell balancing. The switching shunt resistor passive cell balancing and buck-boost active cell balancing in pairs are simulated and compared. The buck-boost active cell balancing uses an inductor as an energy transfer medium between cell-to-cell charging. The active cell balancing method proved to retain 3.93% SOC or 314.4 mAh more than the passive cell balancing method. Hence, the active cell balancing method is more superior and should be considered to increase lithium-ion battery lifespan in the long term.

Keywords: Passive Cell Balancing, Active Cell Balancing, Performance, Comparison

1. Introduction

Lithium-ion batteries have become the preferred power storage solution in a wide range of applications. This is due to their high energy density, lightweight, and long cycle life. One critical aspect of managing these batteries is the cell balancing system for multiple-cell battery packs. Cell balancing is the process of equalizing the state of charge (SOC) and voltage among individual cells within a battery pack. Lithium-ion battery packs are typically composed of multiple cells connected in series or parallel configurations to achieve the desired voltage and capacity. Over time, variations in the performance and degradation of individual cells can occur, leading to imbalances in SOC and voltage levels.

Cell imbalance in SOC and voltage levels may cause variations in the temperature of each individual cell. A rise in the temperature of lithium-ion batteries will cause increased aging effects while

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the capacity will drop significantly at temperatures above 80°C [1]. Hence, it is important to control the voltage equalization of the lithium-ion batteries.

Cell balancing is categorized into 2 types, which are passive cell balancing and active cell balancing. Passive cell balancing consists of 2 types which are the switching shunt resistor and the fixed shunt resistor [2]. On the other hand, active cell balancing uses a variety of methods such as capacitor, inductor, transformer, or DC-DC converter [2]. In some cases, both active and passive cell balancing can be integrated to achieve faster balancing speeds [3]. In this paper, the use of buck-boost active cell balancing which is categorized under inductor-based active cell balancing method [4] will be compared to the switching shunt resistor cell balancing.

2. Methodology

This chapter discusses the strategies used to accomplish the goal of the project. The performance of a conventional cell balancing method of passive switching shunt resistor cell balancing will be compared with active cell balancing in terms of speed of balancing and energy retention post-balancing. The conditions for the simulation will be focused on the idle condition where the batteries are neither charging nor discharging to fully compare the pure performance between both balancing methods. The comparison between the two balancing methods is done through simulation utilizing the Simulink software.

2.1 Switching shunt resistor passive cell balancing operation

The switching shunt resistor passive cell balancing represents the conventional cell balancing circuit due to low cost and simplicity however, overcharging may occur which will result in battery damage [5]. This passive cell balancing circuit operates by finding the cell with the lowest voltage, then dissipates the energy of other cells through a resistor by turning on the associated MOSFETs. The excess energy of higher voltage cells is wasted as heat in this process hence, the circuit is not optimized in terms of power management. Figure 1 shows the flowchart and the schematic diagram of the design.

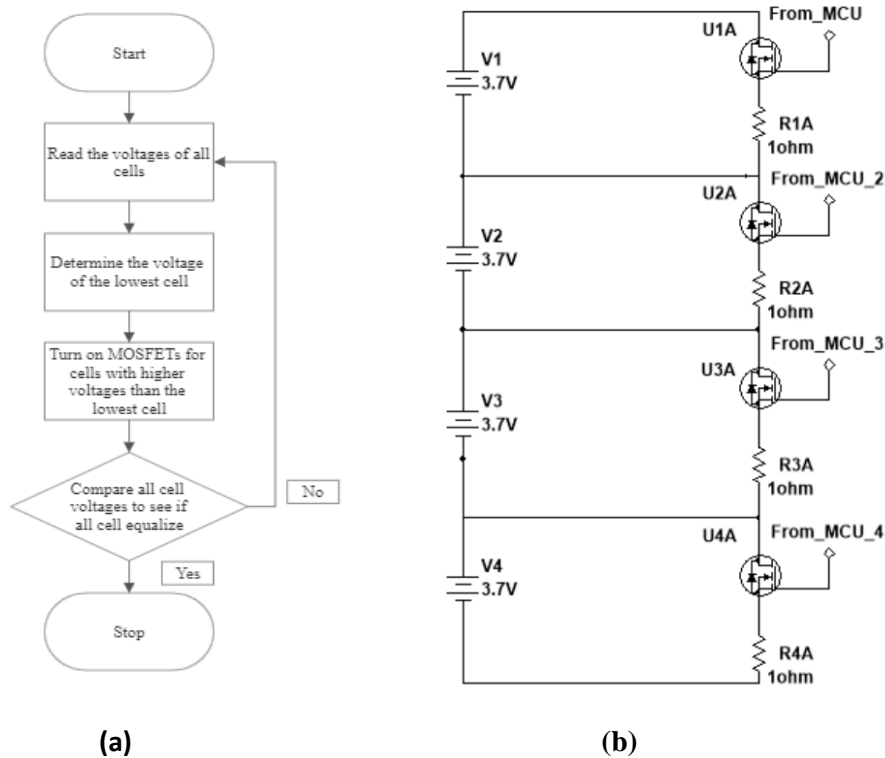


Figure 1: (a) Flowchart and (b) Schematic diagram of switching shunt resistor passive cell balancing circuit

2.2 Buck-Boost-based active cell balancing operation and design

Figure 2 shows the schematic diagram of the buck-boost-based active cell balancing circuit in pairs. In this design, the topology of the circuit is slightly different from a conventional active cell balancing circuit. This is because the lithium-ion batteries are arranged in pairs which allows more than 1 balancing operation to occur at the same time for each cell. To balance a string of cells connected in series, the conventional active cell balancing circuit, the cells can only transfer energy to adjacent cells. The energy from non-adjacent cells must go through the cells in between them which contributes to power loss. By using the pairing method, balancing can occur among any cells which causes less power loss.

The active cell balancing circuit measures the voltage of each cell and then transfers energy from the higher voltage cells to the lowest voltage cell. When there are 2 lowest voltage cells, the 2 cells will be charged simultaneously by the higher cells. This will occur until all voltages equalize. Power loss will still occur in terms of heat from the charging and discharging of the cells, switching losses, and inductor losses. Each pairing of cells will have its own buck-boost converter where there are 2 MOSFETs. For example, V1 and V2 are paired where U1A controls the charging of V2 by V1 while U2A controls the charging of V1 by V2. Similarly, V3 and V4 are paired where U3A and U4A control the charging between the two cells. The inductor L3 and MOSFETs U5A and U6A allow energy transfer between the equivalent of pairs V1, V2 and V3, V4. Hence, each cell can transfer energy to up to 3 other cells at the same time.

As for the switching algorithm, when U1A turns on, the inductor L1 will be charged by V1. When U1A is turned off, the inductor L1 will charge V2. V2 can charge V1 the same way by turning on U2A to charge L1, and then turning off U2A to allow L1 to charge V1. The operations are the same for L2 as well. For L3, the equivalent of V1 and V2 will charge L3 by turning on U5A. Turning off U5A will allow L3 to charge the equivalent of V3 and V4. The operation for U6A is the same where the equivalent of V3 and V4 charges the equivalent of V1 and V2. The duty cycle of the MOSFETs is set to 0.5.

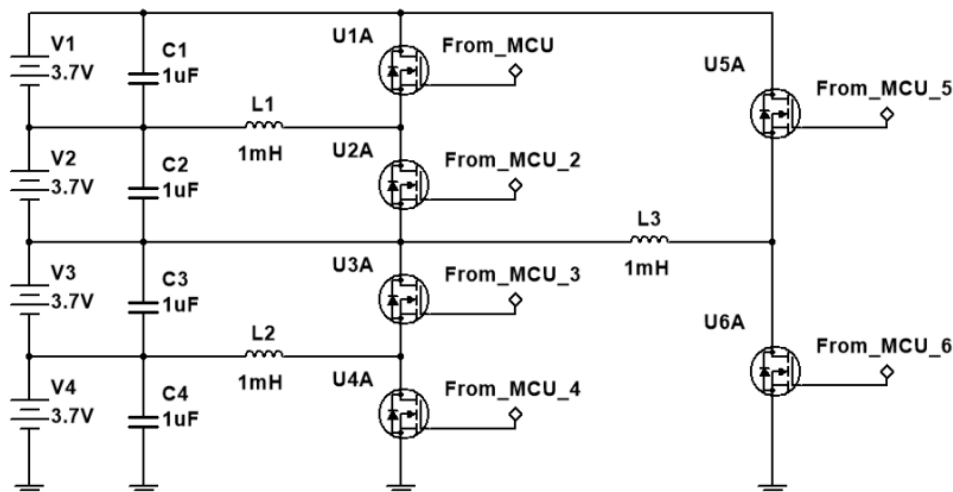


Figure 2: Schematic diagram of buck-boost-based active cell balancing circuit in pairs

The flow of operation of the active cell balancing circuit is similar to the passive cell balancing circuit. The only difference is the amount of MOSFETs to turn on. For example, the passive cell balancing method has only one MOSFET associated with each cell while the active cell balancing

method has 2 MOSFETs associated with each cell. V1 can charge V2 by turning on U1A and the equivalent of V3 and V4 by turning on U5A at the same time. The same goes for the rest of the cells. Figure 3 shows the flowchart of the active cell balancing circuit operation.

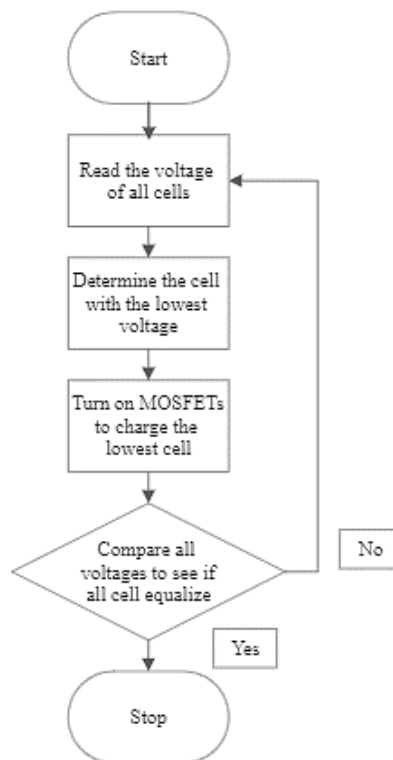


Figure 3: Flowchart of buck-boost based active cell balancing circuit in pairs

Since all batteries have variation in voltage, a closed loop system to control the output of the buck-boost converter can be considered. However, since charging of the higher SOC cell has higher voltage than the lower SOC cell, the potential is high enough for the lower SOC cell to be charged. Hence, a duty cycle of 0.5 can be used where V_{in} equals to V_{out} . This eliminates the need for a feedback loop which increases complexity and cost of the circuit. The buck-boost converter is used as an energy transfer medium between the cells. Since the output must be in continuous conduction mode (CCM) where V_{out} equals to V_{in} , the duty cycle can be obtained as follows:

$$\frac{V_{out}}{V_{in}} = \frac{D}{1 - D} \quad Eq. 1$$

$$D = \frac{V_{out}}{V_{in} + V_{out}} \quad Eq. 2$$

$$D = 0.5$$

Since $V_{in} = V_{out}$, the inductor value is obtained to be 0H due to canceling out in the formula. Hence, the default value of 1mH and 1µF capacitor is used in the simulation.

2.3 System Parameters

The balancing circuit will be applied on four cells with initial state of charge (SOC) of 80%, 90%, 75%, and 95%. The nominal voltage of the cells is set to 3.6V where the maximum voltage at full charge

is 4.19V. Since the rated capacity is set to 2Ah per cell, the total capacity of the system is 8Ah [6]. Table 1 lists the parameters specification of lithium-ion batteries.

Table 1: Parameters specification of lithium-ion battery

Item	Parameter Name	Variable Value	Unit or Dimension
1	SOC of Battery 1	80.00	%
2	SOC of Battery 2	90.00	%
3	SOC of Battery 3	75.00	%
4	SOC of Battery 4	95.00	%
5	Nominal Voltage	3.60	V
6	Rated Capacity	2.00	Ah
7	Battery Response Time	30.00	s
8	Fully Charged Voltage	4.19	V
9	Nominal Discharge Current	0.87	A
10	Internal Resistance	0.018	Ω
11	Initial Cell Temperature	20.00	$^{\circ}\text{C}$
12	Capacity at Nominal Voltage	1.81	Ah

The buck-boost converter uses a 1mH inductor as an energy storage medium and a 1 μ F capacitor to suppress high-frequency fluctuation in current due to the fast switching of the MOSFETs [4]. Table 2 lists the parameters specification of buck-boost converters.

Table 2: Parameters specification of buck-boost converters

Item	Parameter Name	Variable Value	Unit or Dimension
1	Duty Cycle	0.5	Dimensionless
2	Inductor Value	1	mH
3	Capacitor Value	1	1 μ F

3. Results and Discussion

This section will discuss the performance comparison between the passive cell balancing method and the active cell balancing method. By comparing the average SOC post-balancing operation, the method with the higher average SOC is superior in terms of energy retention and efficiency. The SOC balancing graph will be illustrated and discussed.

3.1 Conventional switching shunt resistor passive cell balancing simulation

A user-defined function is used to program the comparison between cell voltages where the output is the MOSFET operation. The program is based on the flowchart in Figure 1(a) where the lowest cell

is set to the desired value. The resistors are set to the default value which is 1Ω . Figure 4 shows the switching shunt resistor passive cell balancing simulation.

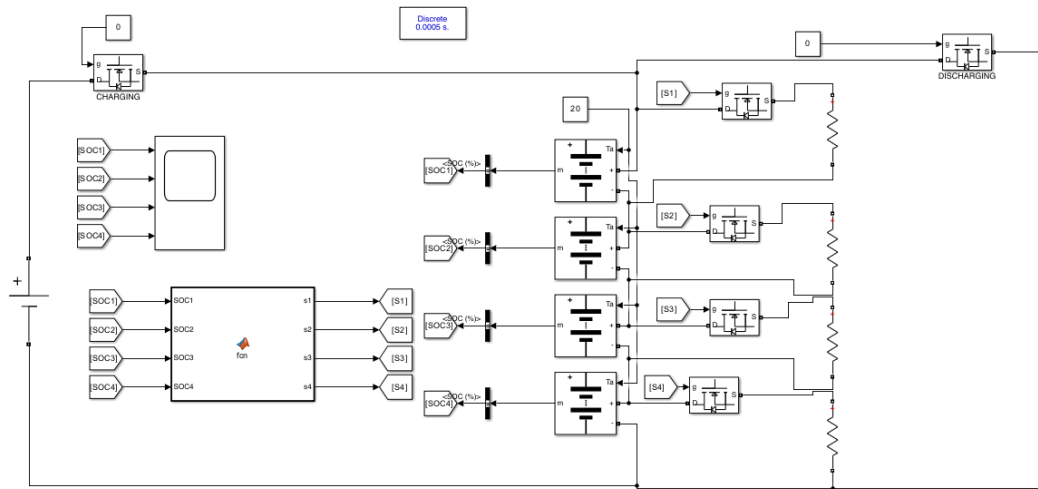


Figure 4: Switching shunt resistor passive cell balancing simulation

A user-defined function is used to program the comparison between cell voltages where the output is the MOSFET operation. The program is based on the flowchart in Figure 1 (a) where the lowest cell is set to the desired value. The resistors are set to the default value which is 1Ω .

The results show that the cell with the highest SOC will be prioritized to be discharged until it meets the second-highest SOC cell. Battery 4 balances with battery 2 and both batteries are discharged by the shunt resistor until both cells reach the SOC of battery 1. All 3 cells will continue to discharge at a simultaneous rate to meet the lowest SOC cell at 75%. It takes 154.89s to balance all four cells. After balancing, further discharge occurs due to the simulation algorithm trying to balance insignificant voltage differences between the 4 batteries. Because of this, the batteries continue to further discharge through the shunt resistor. To resolve this issue, the sensitivity can be decreased to ignore insignificant voltage differences between the batteries. Figure 5 shows the switching shunt resistor passive cell balancing results.

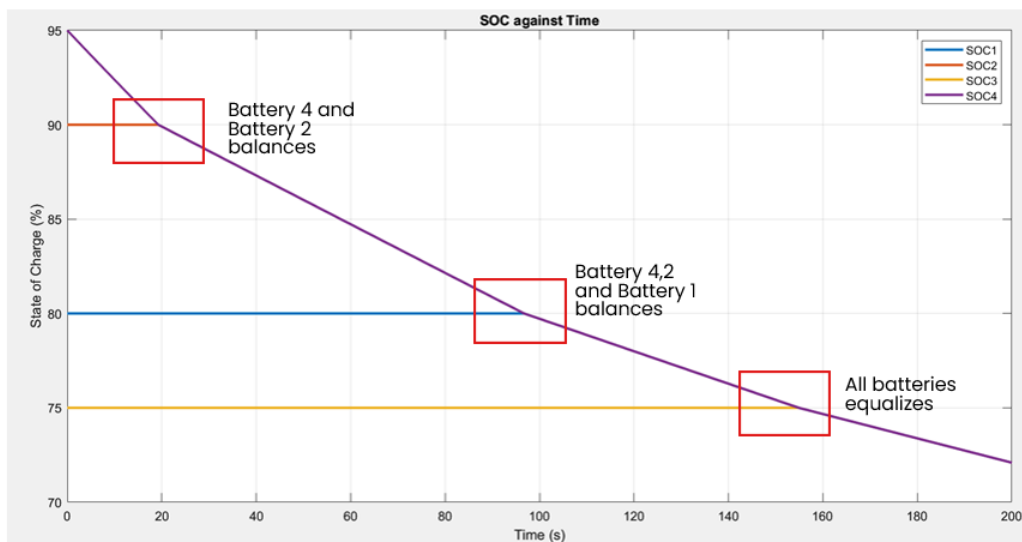


Figure 5: Switching shunt resistor passive cell balancing results

3.2 Buck-Boost-based active cell balancing simulation

Like the passive cell balancing programming, a user-defined function is set to input the voltage of each cell, compare them and output the switching of the MOSFETs. However, the passive cell balancing method only needs to find the lowest SOC cell. In this case, each cell voltage must be compared to the other cell voltages. Comparison between voltages is done in pairs where battery 1 is compared with battery 2, battery 3 is compared with battery 4, and battery 1 is compared with battery 3. After comparing the voltages, the function will output the MOSFET switching to control the balancing operation. This will be done until all cells are balanced. Figure 6 shows the Buck-boost Active cell balancing simulation.

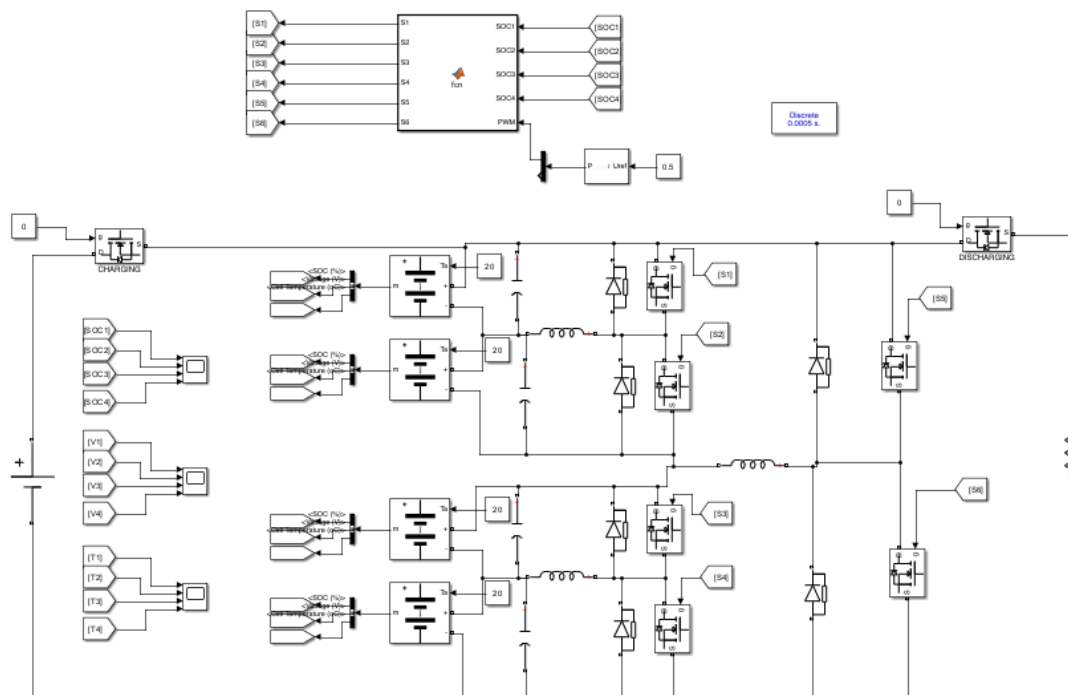


Figure 6: Buck-Boost active cell balancing simulation

Like the passive cell balancing programming, a user-defined function is set to input the voltage of each cell, compare them, and output the switching of the MOSFETs. However, the passive cell balancing method only needs to find the lowest SOC cell. In this case, each cell voltage must be compared to the other cell voltages. Comparison between voltages is done in pairs where battery 1 is compared with battery 2, battery 3 is compared with battery 4, and battery 1 is compared with battery 3. After comparing the voltages, the function will output the MOSFET switching to control the balancing operation. This will be done until all cells are balanced.

Unlike the passive cell balancing results where the highest cell voltage was prioritized, the cell with the lowest voltage is charged. Battery 3 was initially 75% charged by all 3 other batteries up until batteries 1 and 3 converged. At that point, both batteries are then charged by both battery 2 and 4 until battery 1,2 and 3 equalizes. The rate of SOC increment of the equalization gradually slows down as the greater number of cells equalizes due to the capacity to be charged increases. At the point of equalization, the SOC is recorded at 78.93% and took 72.39s to balance. The time taken to balance is significantly less than the passive balancing method while at the same time, the circuit was able to retain

3.93% average SOC more than the conventional passive balancing method. Figure 7 shows the Buck-boost Active cell balancing results.

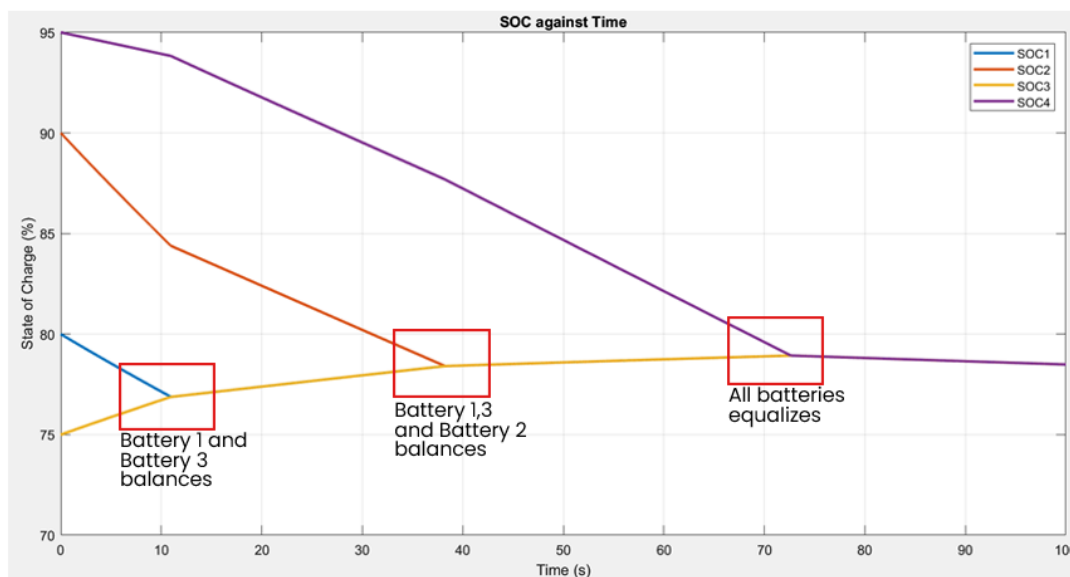


Figure 7: Buck-Boost active cell balancing results

The active balancing method retained 3.93% more capacity compared to the passive cell balancing method. This is because the active balancing method reduces power loss as heat by transferring energy from higher voltage to lower voltage cells whereas the passive balancing method dissipates the higher energy cells as heat to equalize with the lower energy cells. By using the ratio method, the capacity retention can be calculated as shown below:

$$Capacity\ Retention = Average\ SOC\ Difference \times Total\ Capacity \quad Eq. 2$$

$$Capacity\ Retention = 3.93\% \times 8Ah$$

$$Capacity\ Retention = 314.40\ mAh$$

Hence, the active balancing method is able to retain 314.40 mAh more than the passive cell balancing method. This is true in an ideal condition where the battery conditions are set to the exact parameters in the simulation. Table 2 shows the comparison of passive and active cell balancing.

Table 2: Comparison of passive and active cell balancing

Item	Parameter Name	Variable Value	Unit or Dimension
1	Average Pre-Passive Cell Balancing SOC	85.00	%
2	Average Post-Passive Cell Balancing SOC	75.00	%
3	Time Taken (Passive Cell Balancing)	154.89	s
4	Average Pre-Active Cell Balancing SOC	85.00	%
5	Average Post-Active Cell Balancing SOC	78.93	%

6	Time Taken (Active Cell Balancing)	72.39	s
7	Difference of Capacity between Active and Passive Cell Balancing	314.40	mAh

4. Conclusion

The objective of this project was met where the performance between both balancing methods was studied and discussed. It was proven that the active cell balancing method is superior in terms of energy efficiency and balancing time compared to the passive cell balancing method. The use of any active cell balancing method is highly recommended in all battery management systems although most active cell balancing circuits require large volume and high cost. The benefits of active cell balancing lies in the life span preservation of lithium-ion batteries.

Acknowledgement

This research was able to be completed through the guidance from the corresponding author. The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

References

- [1] Ma, S., Jiang, M., Tao, P., Song, C., Wu, J., Wang, J., Deng, T., & Shang, W., "Temperature effect and thermal impact in lithium-ion batteries: A Review", *Progress in Natural Science: Materials International*, 28(6), 653–666, 2018. <https://doi.org/10.1016/j.pnsc.2018.11.002>.
- [2] Lee, Y., Jeon, S., & Bae, S. "Comparison on cell balancing methods for energy storage applications," *Indian Journal of Science and Technology*, 9(17), 2016. <https://doi.org/10.17485/ijst/2016/v9i17/92316>.
- [3] E. M. A. G. N. C. Ekanayake, K. T. M. U. Hemapala and U. Jayathunga, "Active and Passive Based Hybrid Cell Balancing Approach to Series Connected Lithium-ion Battery Pack, "Moratuwa Engineering Research Conference (MERCon)", Moratuwa, Sri Lanka, 2022, pp. 1-6, 2022. doi: 10.1109/MERCon55799.2022.9906172.
- [4] Lu, M., Fan, Y., & Chong, B., "A novel comprehensive SOC-voltage control scheme for lithium-ion battery equalization," *International Conference on Power, Instrumentation, Control and Computing (PICC)*, 2020. <https://doi.org/10.1109/picc51425.2020.9362458>.
- [5] R. Paidi and S. K. Gudey, "Active and Passive Cell Balancing Techniques for Li-Ion Batteries used in EVs," *IEEE International Power and Renewable Energy Conference (IPRECON)*, Kollam, India, pp. 1-6, 2022. doi: 10.1109/IPRECON55716.2022.10059573.
- [6] Samsung SDI, "Lithium-ions rechargeable cell for power tools," INR-18650-20R datasheet, Dec. 2011.