OPTIMIZING BATTERY PERFORMANCE - ACTIVE AND PASSIVE CELL BALANCING

Venkata Sai Pavan M
Department of Electrical and Electronics Engineering
V.R. Siddhartha Engineering College
Vijayawada, India

Ravindranadh V
Department of Electrical and Electronics Engineering
V.R. Siddhartha Engineering College
Vijayawada, India

Imran Shareef MD
Department of Electrical and Electronics Engineering
V.R. Siddhartha Engineering College
Vijayawada, India

Venkata Sai Sathish D
Department of Electrical and Electronics Engineering
V.R. Siddhartha Engineering College
Vijayawada, India

Puneeth Sai Sankar J
Department of Electrical and Electronics Engineering
V.R. Siddhartha Engineering College
Vijayawada, India

***Abstract*— Electric vehicles (EVs) are the transportation mode of the future. Due to their zero tailpipe emissions and minimal dependency on oil and its byproducts, EVs have gained popularity over the past ten years, with electric vehicle purchases increasing by 109% globally in 2021. Lithium-ion (Li-ion) battery packs are the primary energy source for the most recent completely electric vehicles, which has both benefits and drawbacks. Catastrophic casualties, such as poisonous smoke or fire, may result if the battery parameters are not maintained optimally in all circumstances. This paper's major goal is to show how to balance the voltages in each battery pack cell using a variety of cell balancing methods, such as active cell balancing and passive cell balancing. By preventing any cell from failing, this guarantees the battery pack's optimal performance. Active cell balancing is 23 percent more rapid compared to the results obtained from passive cell balancing.**

***Keywords*— Cell balancing, Active cell balancing, Passive cell balancing, Electric vehicles, Lithium-ion battery.**

I. INTRODUCTION

In the upcoming years, electric automobiles and related technologies will be very important. One of them is battery technology. Running an EV securely requires maintaining a battery pack to its full potential, because failure may result in serious safety and logistical issues. Lithium-ion (Li-ion) battery packs are constructed from numerous Li-ion cells that are linked together in series and parallel arrangements to produce a total voltage for the battery and output power. These cells frequently have voltage inconsistencies, which can lead to overcharging or undercharging. Temperature variations may cause differences in the initial charging capacities and cell voltages, which may prevent the cell's full capacity from being utilized, resulting in reduced battery performance, shortened battery life, and a possible risk of fire. One method for removing these imbalances is cell voltage balancing, which ensures that all the cells are equally charged and discharged by employing either of the two forms of cell balancing techniques, which are passive cell balancing or active cell balancing. Both techniques will be thoroughly simulated and studied in this paper.

Assuring that each cell in an electric vehicle (EV) battery set is charged and drained equally helps to enhance the performance, duration, and safety of the battery, which is why cell balancing is so important. Some cells in the battery pack will be overcharged, whereas others will be undercharged if the cells are not balanced. Numerous issues arise as a result, including decreasing battery capacity overall, shorter driving distances, decreased performance, and potential safety risks. Undercharging can result in a cell failing before it should, while overcharging can hasten a cell's decline and potentially create a fire or explosion. Additionally, overcharged or undercharged cells can result in a voltage imbalance in the battery pack, which can affect both performance and safety. In order to ensure that all of the cells in an EV battery pack are performing at their peak efficiency and enhancing the overall performance and safety of the vehicle, cell balancing is essential.

The parameters used for obtaining optimal battery output include the state of charge, current, voltage, and temperature of the battery. The main objective of this project is to achieve the balance of cells in a battery pack, considering all the above parameters.

II. REVIEW FROM THE LITERATURE

The lithium-ion (Li-ion) batteries are stacked together in electric vehicles (EVs) and hybrid EVs to generate the required high voltage (HV). These layered cells are compared simultaneously with a reference voltage in order to balance the cells. An integrated circuit (IC) featuring a 12-bit successive approximation register (SAR) analog-to-digital converter was designed to measure, track, and balance Li-ion cell voltages [1]. Each IC is linked to the cells, depending on the test that was run. In order to balance the cell, the authors utilized integrated balancing switches.

Cell balancing is performed for batteries connected in series in the paper [2]. Two switches per cell are used to achieve cell-to-cell balancing because they provide strong balancing ability. Reduced numbers of switches are chosen since adding more switches would increase their size and expense. This study suggested a brand-new center-cell concentration-based cell-to-cell balancing circuit. The suggested circuit redistributes the charges gathered from an overloaded cell to the remaining cells after collecting them in the center cell.

To reduce the difference between the cells during battery operation, a test approach is applied to obtain better battery utilization results from lowering cell-to-cell variance. Two batteries aging behavior has been studied for this purpose for about 1.5 years. A traditional passive balancing battery management system (BMS) is connected to one battery, while an active balancing BMS is attached to the other. Each cycle records crucial battery characteristics like capacity and internal resistance. The amount of charge balanced by the BMS and the voltage differentiation of each cell at the end of the discharge process are utilized to compute the battery behaviour [3]. Additionally, it is hypothesized that active cell balancing, as opposed to passive cell balancing, can slow down the battery's aging process.

Active cell balancing is accomplished via a switched capacitor circuit [4]. It suggests using a switched capacitor in chain construction to speed up balancing. Using a typical switched capacitor, the cell balance is achieved. Two chain-structured circuits with faster cell balancing are suggested. The biggest disadvantage of the switched capacitor technique is that adding more switches and capacitors would result in higher losses and higher balancing system costs.

It is noted that the report [5] discusses how crucial batteries are for EVs. An overcharging and overdischarging protection system for batteries has been introduced. When there is a stack of cells, the system's overcharge protection is activated by the cell with the lowest State of Charge(SoC) since each cell in the stack has a different SoC from the others. The overcharging protection system will also be activated by an overcharged cell, which is undesirable and could cause the battery to malfunction. There are various approaches to cell balancing, and in this project, a hardware prototype for switched shunt resistor passive cell balancing is created using the Arduino IDE. Low energy efficiency and heat issues are drawbacks of switched shunt resistor passive cell balancing.

Electric vehicles, portable electronics, and energy storage systems all make substantial use of lithium-ion battery (LiB) technology. For the battery management system to function properly, the best cell balancing methods must be used. In order to reduce balancing time and power dissipation with straightforward hardware and management, According to the research in the study [6], a hybrid cell balancing method utilizing switched capacitor and switched resistor balancing techniques is introduced. When compared to the traditional capacitive balancing technique, balancing time increased by 30%, according to mathematical modeling and simulations. The disadvantages of switched resistor balancing include low energy efficiency and heat concerns. The main drawback of the switched capacitor method is that adding more switches and capacitors would result in higher losses and higher balancing costs.

An example of a common BMS block diagram is included in the paper [7]. Since the battery system affects safety, functionality, and even the passenger's life in the majority of electric cars (EVs), battery monitoring is essential. Utilizing both the Coulomb counting and open-circuit voltage methods, the State of Charge (SoC) estimation has been performed, removing the drawback of the standalone Coulomb counting method. SOC can be estimated and then corrected using the Kalman filtering technique by modeling a battery with SoC.

Numerous cutting-edge applications, including drones, satellites, electric and hybrid automobiles, require battery packs. In comparison to contemporary cell balancing methods, the article [8] proposes a cell balancing mechanism for the battery pack employing a PID-controlled, bidirectional flyback converter-based active cell balancing methodology. Using a PID-controlled, bidirectional flyback converter has drawbacks like As the complexity and cost scale with the number of cells. Using bidirectional flyback converters for cell balancing may become unfeasible in very large battery packs, and careful tuning is required to implement a PID controller for cell balancing. Flyback converters and switching converters both have the potential to produce EMI, which may necessitate additional filtering and shielding procedures to meet electromagnetic compatibility (EMC) standards.

In the paper [9], Three modules (nine cells) and five cells each have prototypes that have been constructed and tested. Results from experiments support the applicability and features of the suggested equalizer. It proposes employing the half-bridge LC converter to balance cells. But this method cannot ensure absolute voltage consistency between cells due to the voltage drop across the power devices.

In the study [10], flyback converter-based and inductor-based cell balancing approaches are examined using MATLAB Simulink. Flyback converters may have limitations when it comes to handling high currents. Typically, flyback converters require larger transformers and inductors compared to some other converter topologies, which may be a concern in space-constrained applications.

The charging and discharging of capacitors are depicted in the first segment of the paper[11]. The cell balancing procedure is represented in the second segment of the work, and the constant current and constant voltage charging approach for lithium-ion battery MATLAB simulation is represented in the third segment. The passive cell balancing method is simulated using MATLAB in this study, which can take a long time to bring all cells to the same voltage level, especially when dealing with cells that have significant voltage differences.

III. PROBLEM DEFINITION

A battery pack's cell balancing is a crucial component for overcoming a variety of issues and negative effects, including safety concerns, battery pack performance issues, and battery pack usability issues. One of the main causes of cell balancing failure is safety risks such as thermal runaway, which can result in fires and hazardous situations. This paper's major goal is to show how to achieve cell balancing in each cell of a battery pack using active and passive cell balancing techniques to obtain efficient and accurate results by preventing any cell from failing to guarantee the battery pack's optimal performance.

IV. METHODOLOGY

A. *Passive Cell Balancing*

The purpose of cell balancing is to equalize the state of charge (SoC) or voltage of individual battery cells within a battery pack. The passive cell balancing works by dissipating the excess charge from the higher-charged cells into a resistor, so the excess energy will be converted into heat and dissipated via the thermal management system, as shown in Fig. 1. Thus, the resistor is known as a discharge resistor. Therefore, when cells are balanced, they can operate more efficiently and avoid issues like overcharging, over discharging, and capacity imbalances, which can lead to reduced battery life and performance.

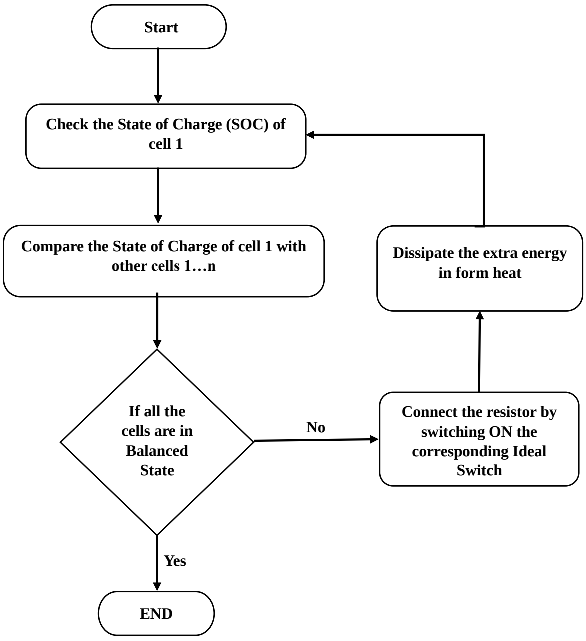

Figure. 1. Flow Chart Representation of Passive Cell Balancing

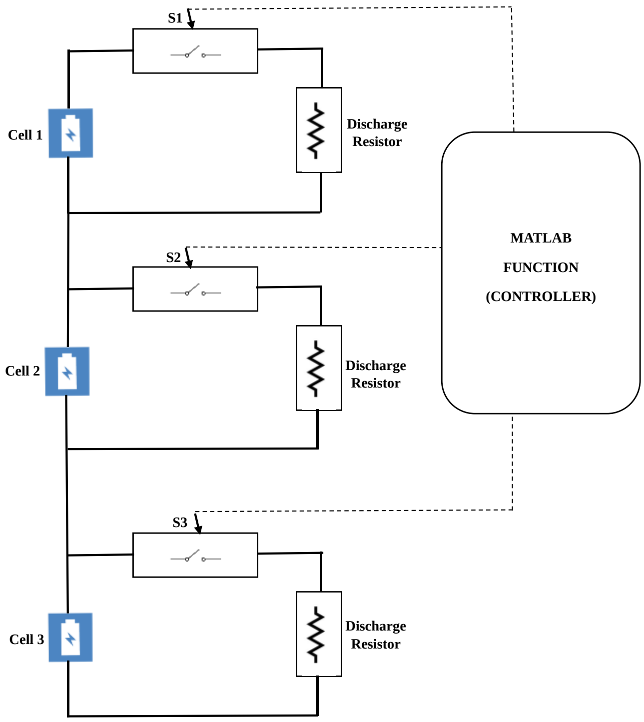

Figure. 2 Circuit of Passive Cell Balancing

In this method, a resistor with a switch is connected across each cell. If one of the cells obtains a higher state of charge (SoC) than the other cells, the excess energy from that cell is dissipated through the resistor in the form of heat. The resistor of the higher-energy cell will be connected to the cell until it reaches the state of charge, which will be equal to that of the lower-energy cell. The ideal switch enables quick control over the working of the resistor at the right time with the help of an algorithm generated in the MATLAB function controller.

Three individual cells are connected in series, representing a battery pack, as shown in Fig. 2. Each cell is individually connected to a resistor through an ideal switch (S). A MATLAB function controller is used to allow switches to turn on and off based on the algorithm. The parameters SoC, voltage, current, and temperature are considered for each individual cell of a battery pack in order to prove the condition of achieving a balanced state in each cell. An ambient temperature is assumed to be constant for an operation, which is not ideal in real time.

ALGORITHM 1: ALGORITHM TO ACHIEVE PASSIVE CELL BALANCING

```
Input: Three input parameters u1, u2, u3 representing numerical values
Output: Return the results s1, s2, and s3 representing the outcomes of the comparative analysis
Initialization: Convert the input parameters u1, u2, u3 to 32-bit signed integers
Comparative Analysis:
    Evaluate s1 based on comparisons involving u1:
        If u1 > u2 or u1 > u3:
            Set s1 ← 1
        Else:
            Set s1← 0
        end
    Evaluate s2 based on comparisons involving u2:
        If u2 > u1 or u2 > u3:
            Set s2 ← 1
        Else:
            Set s1← 0
        end
    Evaluate s3 based on comparisons involving u3:
        If u3 > u1 or u3 > u2:
            Set s3 ← 1
        Else:
            Set s1← 0
        end
end
```

Taking the SoC of each cell as the basic parameter to achieve balance, the algorithm is developed in such a way that the switch corresponding to the cell with the greater SoC turns on by receiving a gate pulse from the controller, and all the remaining switches stay in the OFF position.

Whenever a switch turns on, then the corresponding cell to the switch is connected to the discharge resistor, and the external energy of that cell is converted into heat and discharged in the form of heat energy via a thermal management system, thus achieving balance between all the cells of a battery pack.

In the passive cell balancing technique, each cell in the battery pack is not interactive, whereas in the active cell balancing technique, every cell is interactive with each other. So in the case of the active cell balancing technique, each cell is not connected to a discharge resistor, hence the external energy is not dissipated in the form of heat.

B. Active Cell Balancing

In the active cell balancing technique, energy is transferred from one cell to another. The active cell balancing technique primarily shifts energy from a cell with a high voltage or high SoC to a cell with a lower voltage or low SoC. Using the active cell balancing technique can increase the life of the SoC even if we have a bundle of cells with reduced capacity. Here, energy will be transferred from a cell to another cell in order to equalize the level of charge of every cell, as shown in Fig. 3.

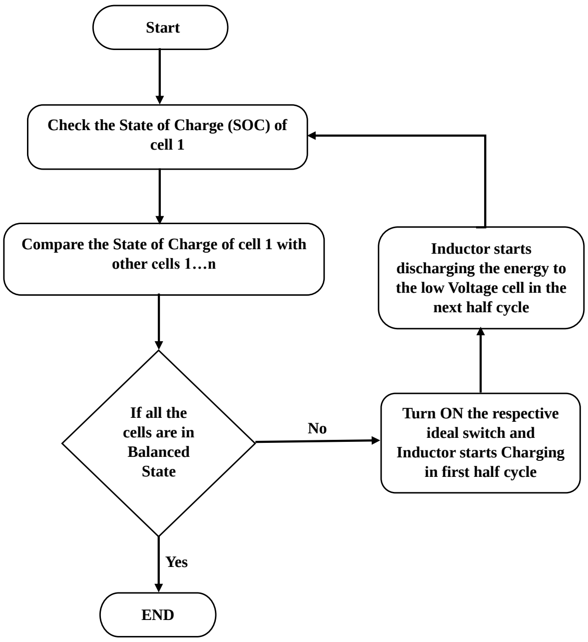

Figure. 3 Flow Chart Representation of Active Cell Balancing

During the operation of the battery pack in the active cell balancing technique, if the cells of the battery pack have different states of charge (SoCs), then switches connected to the cells act accordingly depending on the algorithm, which helps the MATLAB function controller generate the PWM signal such that the switch (S) connected to the cell with excess energy turns on and the inductor charges. The inductor stores the energy and discharges it to the cell having less energy to achieve accurate cell balancing.

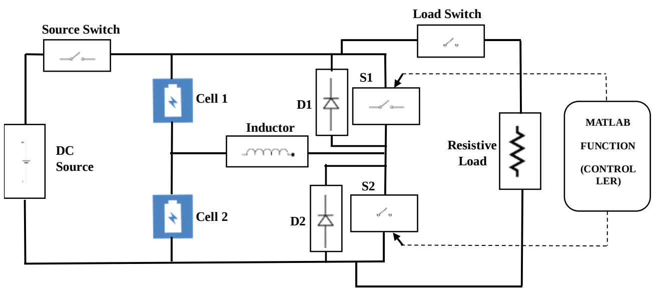

Figure. 4 Circuit of Active Cell Balancing

Two individual cells are connected in series, representing a battery pack in the above circuit, as shown in Fig. 4. For each cell, an individual ideal switch is connected across it, which will be fired or triggered based on the logic or algorithm. A DC voltage source is connected across the cells, which provides the voltage to both cells during the charging condition, and an ideal source switch is connected in series to the DC voltage source, which will be ON during charging and OFF during the discharging of cells. Depending on the SoCs of both cells, the algorithm generates an output signal for the respective switches S1 and S2. The MATLAB Function Controller decides which cells need to be balanced and activates the appropriate balancing circuitry for those cells. In the active cell balancing method, an inductor is connected parallel to both the battery cells, and this inductor is used to control the transfer of energy between the two cells actively. The inductor is an energy storage element. If cell 1 has a higher state of charge (SoC) than cell 2, then the switch (S1) will be turned on, and the current flows from cell 1 to switch 1, which offers the least resistance path in the positive half (1st half) cycle, and thus the inductor starts charging and stores the energy. During the negative half (2nd half) cycle, the inductor changes its terminals and starts discharging its energy to the cell having less energy by allowing the current to flow through the diode (D2) while controlling the switch (S2) to be in OFF condition using the MATLAB Function Controller, and this process is vice versa if cell 2 has greater energy than cell 1. Thus, the amount of energy discharged in the second half cycle depends upon the amount of energy charged in the first half cycle of inductor action. A resistive load is connected across the cells along with the load switch, which turns on during the discharging of the cells. The balancing process is continuous as the battery cells operate, ensuring that the voltage levels among all cells remain relatively uniform.

ALGORITHM 2: ALGORITHM TO ACHIEVE ACTIVE CELL BALANCING

Input: *Three input parameters soc1, soc2, and PWM representing state of charge values and pulse width modulation*
Output: *Return the results s1, and s2 representing the PWM control signals*

```
PWM Control Logic:
    If soc2 < soc1:
        Set s1 ← PWM
        Set s2 ← 0
    Else, if soc1 < soc2:
        Set s1 ← 0
        Set s2 ← PWM
    Else:
        Set s1 ← 0
        Set s2 ← 0
    end
end
```

Taking the SOC of each cell as the basic parameter to achieve balance, the algorithm is developed in such a way that the switch corresponding to the cell with the greater SOC turns on by receiving a gate pulse from the Function block, and all other switches stay in the OFF position.

Table 1: Comparison of Active and Passive Cell Balancing Methods

Active Cell Balancing	Passive Cell Balancing
Advantage - Energy is not dissipated and lost in form of heat.	Drawback - Energy is dissipated and lost in form of heat.
Advantage - Power losses are reduced.	Drawback - Higher loss of energy and power.
Drawback - Implementation is highly complex.	Advantage - Implementation is less complex compared to Active Cell Balancing.
Drawback - Expensive Implementation.	Advantage - Economic implementation.
Advantage – More rapid compared to Passive Cell Balancing.	Drawback – Less rapid compared to Active Cell Balancing.

Active cell balancing can improve battery performance by producing rapid balancing results for the parameters of the battery, such as the SoC, current, and voltage, compared to passive cell balancing methodology. So, though the passive cell balancing strategy is economical and less complex, active cell balancing is considered for better optimizing battery performance (Table 1).

V. RESULTS

A. *Passive Cell Balancing*

During passive cell balancing, the three cells operating at different SoCs, voltages, and currents achieved complete balancing after 95 seconds of operation of the battery pack. The surplus energy from cells 1 and 2 dissipated in the form of heat from the discharge resistors connected to both cells via thermal management and attained a balanced state.

1) SoC:

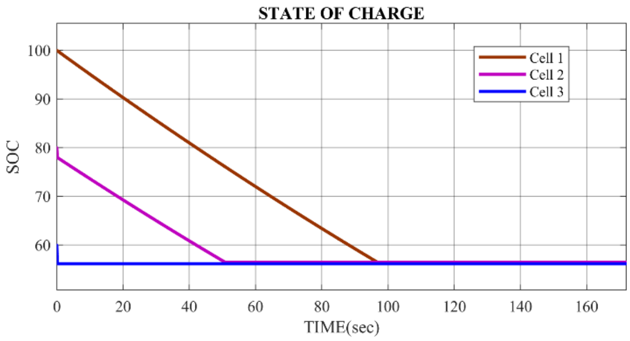

Figure. 5 State of Charge

All three cells have attained a balanced SoC, i.e., the SoC of cell 3, which is the lowest SoC of all three cells, as shown in Fig. 5. The cell 1 with the highest SoC has attained SoC similar to cell 3 after 95 seconds of passive cell balancing operation, and cell 2 has attained SoC similar to cell 3 after 45 seconds of passive cell balancing operation.

2) Current:

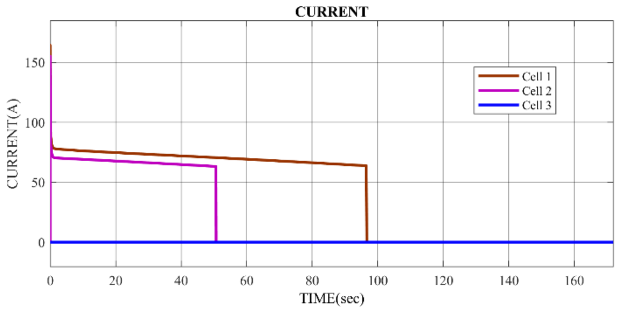

Figure. 6 Current

All three cells have attained balanced current, i.e., the current in cell 3, which is the lowest current of all three cells, as shown in Fig. 6. The cell 1 with the highest current has attained a level of current equal to the current in cell 3 after 95 seconds of passive cell balancing operation, and the cell 2 has attained a level of current equal to the current in cell 3 after 45 seconds of passive cell balancing operation.

3) Voltage:

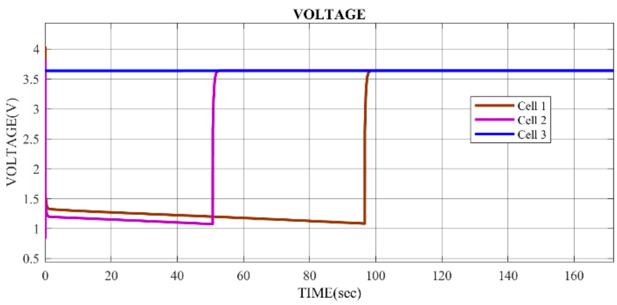

Figure. 7 Voltage

All three cells have attained balanced voltage, i.e., the voltage of cell 3, which is the highest voltage of all three cells, as shown in Fig. 7. Cell 1 has attained a voltage similar to that of Cell 3 after 95 seconds of passive cell balancing operation, and Cell 2 has attained a voltage similar to that of Cell 3 after 45 seconds of passive cell balancing operation.

4) Cell Temperature:

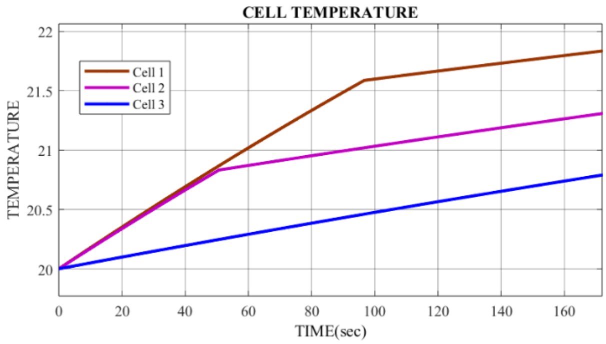

Figure. 8 Cell Temperature

In this passive cell balancing circuit, all the cells of the battery pack are preset to a constant temperature, as shown in Fig. 8, using a constant block in MATLAB software.

B. Active Cell Balancing

1) Cell Balancing:

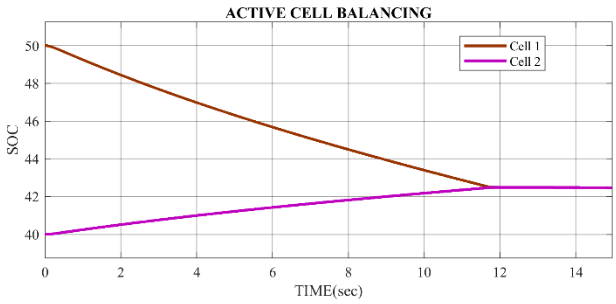

Figure. 9 Active Cell Balancing

The batteries operating at different SoCs achieved balance, i.e., the energy from cell 1 (having a higher SOC) was stored in the inductor, and the inductor dissipated the energy into cell 2 (having a lower SOC) and attained balance at 11.8 seconds of operation, as shown in Fig. 9.

2) During Cell Charging:

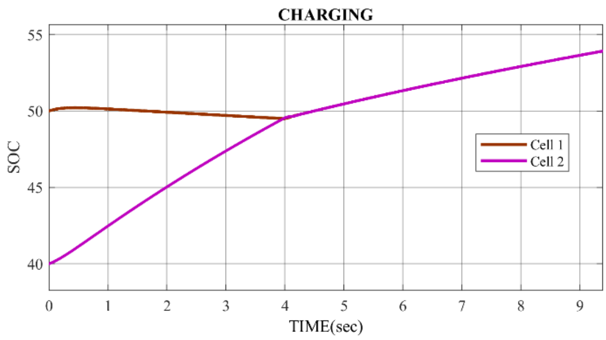

Figure. 10 Active Cell Balancing During Charging of Cells

During charging of the battery pack, the cells at different SoCs attain balance by the inductor-based active cell balancing technique, and all the cells charge equally, maintaining the balanced state to avoid cell imbalances and faulty operation of the battery pack, as shown in Fig. 10.

3) During Cell Discharging(Connected to Load):

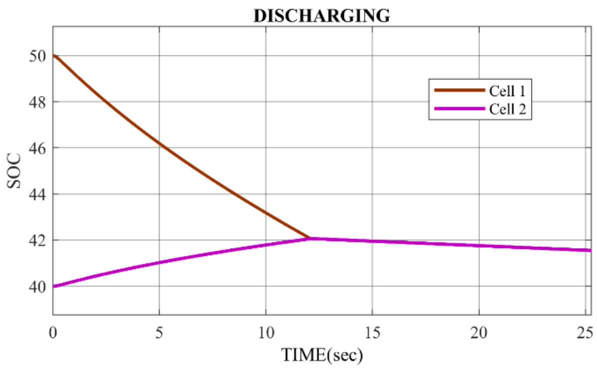

Figure. 11 Active Cell Balancing During Discharging of Cells

When the load is connected to the battery pack, then the cells of the battery pack discharge. After 12 seconds of discharging cells in an imbalanced state, the cells have attained a balanced state by the inductor-based active cell balancing method, as shown in Fig. 11.

From the output graphs of both passive and active cell balancing techniques, active cell balancing is the most effective approach to cell balancing, as the energy is not dissipated in the form of heat as in passive cell balancing, and the balancing time of cells in a battery pack is less in active cell balancing when compared to passive cell balancing.

VI. Conclusion

In an electric vehicle The overall performance of battery packs was thought to be harmed by voltage and energy imbalances. This problem was resolved using both passive balancing and active balancing cell balancing strategies. This increased the battery's total capacity by ensuring each cell of the battery pack did not get overcharged and by maintaining an even voltage across all of them. The results of designing and simulating the balancing circuits in MATLAB were graphically displayed. A comparison study was conducted, and it was discovered that the active cell balancing strategy, which is more effective at managing energy between the cells, was a superior method of compensating for the imbalance in the cells than the passive balancing methodology.

References

[1] Veeresh Babu Vulligaddala, Sandeep Vernekar, Sudhakar Singamla, Ravi Kumar Adusumalli, Vijay Ele, Manfred Brandl, Srinivas M.B, *“A 7-Cell, Stackable, Li-Ion Monitoring And Active/Passive Balancing IC With In-Built Cell Balancing Switches For Electric And Hybrid Vehicles”,* VOL. 16, NO. 5, May - 2020.

[2] Moon-Young Kim, Student Member, IEEE, Jun-Ho Kim, Student Member, IEEE, And Gun-Woo Moon, Member, IEEE,*“Center-Cell Concentration Structure Of A Cell-To-Cell Balancing Circuit With A Reduced Number Of Switches”*, VOL. 29, NO. 10, October 2014.

[3] Andreas Ziegler 1 , David Oeser1 ,Thiemo Hein 1 , Daniel Montesinos-Miracle 2 , And Ansgar Ackva, *“Reducing Cell To Cell Variation Of Lithium-Ion Battery Packs During Operation ”*,Vol9,Published On N February 4, 2021.

[4] Moon-Young Kim, Student Member, IEEE, Chol-Ho Kim, Student Member, IEEE, Jun-Ho Kim, Student Member, IEEE, And Gun-Woo Moon, Member, IEEE *“A Chain Structure Of Switched Capacitor For Improved Cell Balancing Speed Of Lithium-Ion Batteries”*, VOL. 61, NO. 8, August 2014.

[5] Ramkumar Paidi, Sathish Kumar Gude, *“Active And Passive Cell Balancing Techniques For Li-Ion Batteries Used In EV”*, Published In IEEE International Power And Renewable Energy Conference (IPRECON),16 March 2023.

[6] E.M.A.G.N.C. Ekanayake, K.T.M.U. Hemapala, Upuli Jayathunga, *“Active And Passive Based Hybrid Cell Balancing Approach To Series Connected Lithium-Ion Battery Pack”*,Published By (Mercon),04 October 2022.

[7] Cheng, K.W.E., Divakar, B.P. Hongjie Wu, Kai Ding, Ho Fai Ho, *“Battery-Management System (BMS) And SOC Development for Electrical Vehicles”*, IEEE Transactions on Vehicular Technology, Vol. 60, Issue: 1, 2011.

[8] A. Sarkar, R. Dutt, S. Sahu, A. Acharyya, *“Energy-efficient and High-Speed Active Cell Balancin Methodology for Lithium-ion Battery Pack,”* 2023 21st IEEE Interregional NEWCAS Conference (NEWCAS), Edinburgh, United Kingdom, 2023, pp. 1–5.

[9] F. Liu, R. Zou, Y. Liu, *“An Any-Cell-to-Any-Cell Battery Equalizer Based on Half-Bridge LC Converter,”* in IEEE Transactions on Power Electronics, vol. 38, no. 4, pp. 4218–4223, April 2023.

[10] S. Koraddi, K. V. Samprita, K. S. Yadgir, L. M. Biradarpatil, S. V. Nayak, *“Analysis of Different Cell Balancing Techniques,”* 2022 International Conference for Advancement in Technology (ICONAT), Goa, India, 2022, pp. 1-4.

[11] A. P. Shukla, R. A. Patel, *“Battery Management System by Passive Cell Balancing for Electric vehicle,”* 2022 2nd International Conference on Power Electronics & IoT Applications in Renewable Energy and its Control (PARC), Mathura, India, 2022, pp. 1-6.