CELL BALANCING OF BATTERY PACK FOR AN ELECTRIC VEHICLE APPLICATION

A PROJECT REPORT

Submitted by

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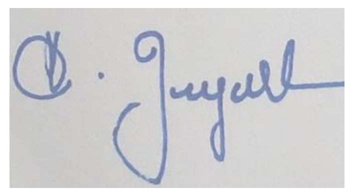

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INTERNAL EXAMINER

EXTERNAL EXAMINER

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ABSTRACT

The electric vehicle revolutionized the transportation sector in recent days. As a part of energy storage, batteries are the most important feature for Electrical Vehicles. The major problem in battery packs is improper charging. Batteries are more prone to failures caused by charge imbalance in the batteries connected in either series or parallel that forms a battery pack. In a battery pack, balanced cells take less time to charge than charging. There are different types of battery balancing schemes that are grouped into either passive or active schemes of balancing. In this project, Resistor and Capacitor based equalizer circuits are used to optimize the battery balancing and analyze the performance of balanced circuits. To perform the cell balancing, MATLAB / Simulink is used to design the most prominent method of cell balancing. The balancing time of the proposed system reduces the charging time and observes the battery State-of-Charge, battery voltage of each cell, temperature analysis and compare the charge equalization of the battery packs for passive and active balancing.

Index Terms: Battery cell balancing, Electric vehicles, MATLAB.

LIST OF TABLES

LIST OF ABBREVIATIONS

S. NO.	ABBREVIATION	DESCRIPTION
1	BMS	BATTERY MANAGEMENT SYSTEM
2	DOD	DEPTH OF DISCHARGE
3	SOC	STATE OF CHARGE
4	SOH	STATE OF HEALTH
5	EV	ELECTRIC VEHICLE

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CHAPTER 1
INTRODUCTION

Electric Vehicles are widely used as an alternative technology for energy-saving and environmentally sustainable for transportation. As the new traction sources of EV, lithium-ion batteries play a vast amount of attention for its excellent performance such as compact voltage, large capacity, lower weight and higher safety. Single cells are serially connected to form a battery stack or pack to achieve higher capacity and voltage. However, the charging process has to stop as soon as one cell is completely discharged. The capacity of the whole battery is completely limited by the capacity of the unbalanced cells need to be balanced in the pack, which can reduce the usable life of the battery pack, decrease the energy usage efficiencies, and also shorten the life of the battery pack. Therefore, battery cell balancing is one basic function of BMS and it is necessary for battery pack in EV. The two commonly used algorithms are

1. Voltage-based balancing algorithm
2. State of charge-based balancing algorithm

Voltage-based balancing algorithm is that when the difference between one cell voltage and the mean value of cell voltages is larger than the threshold voltage, the cell is probably considered to be an abnormal cell [1]. This method is simple and easy operating while the external voltage of the cell is affected by its internal state and environment. On the other hand, Some researchers pointed that state of charges(SOC) can also reflect the capacity of the battery pack and proposed the SOC-based balancing algorithms, which controls the range of the SOC smaller than the threshold. However, the SOC that is affected by the battery model, self-discharge, temperature and other factors can only be calculated by voltage or current indirectly and it is still difficult to get the accurate SOC of each cell.

1.1 ELECTRIC VEHICLE

- Electric vehicles (EV) revolutionized the transportation sector in recent years.
- Among different energy sources, battery plays a vital role in energy storage. The key parameters are
  - High specific power Density – Higher Speed
  - High Energy Density - Higher range
- EV can cover 100-250 km on one charge, whereas top models can go from 300-500 km, the ranges also depend on driving condition and style, vehicle configurations, road conditions, climate, battery type.

1.1.1 ADVANTAGES OF ELECTRIC VEHICLE

- Simple construction, operation and convenience not producing greenhouse gases and noise.
- Electric propulsion provides instant and high torques even at low speeds.

1.1.2 DRAWBACKS OF ELECTRIC VEHICLE

- The charging of the battery is large charging time depends on charger configuration, infrastructure and operating power level.
- Once depleted, charging takes longer time compares with conventional IC engine vehicles.

1.2 BATTERY MANAGEMENT SYSTEM (BMS)

- BMS is an electronic system that manages rechargeable batteries to ensure it operates safely and efficiently.
- BMS is designed to monitor the parameters associated with the battery pack and its individual cells and balancing cells in a battery pack and apply collected data to eliminate safety risks and optimize the battery performance.
- BMS improves levels of safety, performance, charge rates, improved range per charge, maximum battery life [2].
- BMS Performs battery cell balancing to ensure that charge is maximized and that the battery can deliver the required amount of charge at all times.

1.2.1 OVERVIEW OF BMS

This shows overview of battery management system and also the operations done by the battery management system. The role of BMS is shown in the figure 1.1.

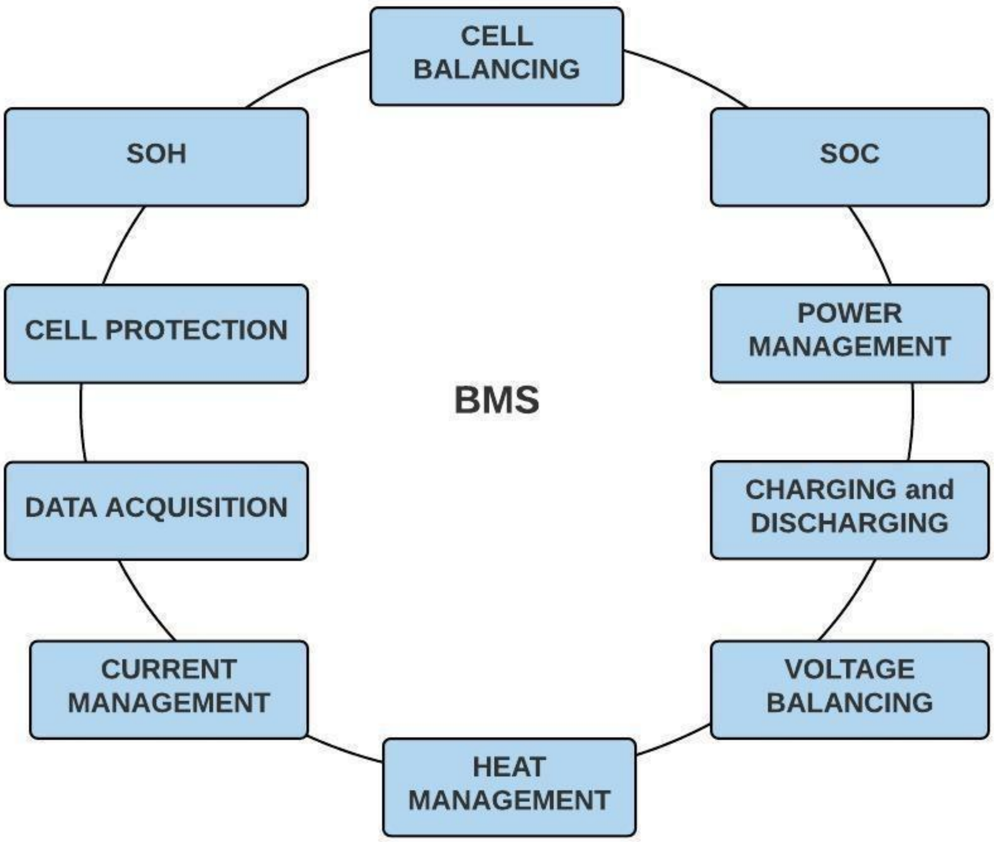


Figure.No.1.1 Battery Management System Overview

Thus the BMS operations are,

1. Estimation of SOC, SOH, DOD, SOP
2. Cell Balancing
3. Thermal Management
4. Battery aging
5. Vehicle Range Prediction, etc.

1.3 IMPORTANCE OF THE PROJECT

- Cell Balancing enables us to design a battery with larger capacity for an application because balancing allows the battery to achieve a higher state of charge (SOC).
- Cell balancing reduces the charging time of the battery pack.
- Cell balancing is not only important for improving the performance and life cycles of the battery, it adds an element of safety to the battery.
- The usable life of the battery pack is increased.
- Overall battery safety is enhanced.

1.4 OBJECTIVES OF PROJECT

- Our objective is to maintain an even distribution of charge among the cells connected in the battery pack.
- To provide faster cell balancing we use active and passive electronic components like Resistor and Capacitor based circuits [3].
- Cell balancing is not only important for improving the performance and life cycles of the battery, it adds an element of safety to the battery.

CHAPTER 2

LITERATURE REVIEW

Van -Tinh Duong and Woojin Choi (2020) designed a Low Cost and Fast Cell-to-Cell Balancing Circuit for Lithium-Ion Battery Strings. The control circuit is composed of a battery-monitoring IC and a digital signal processor (DSP) to monitor the cell voltage and to protect the batteries. The experimental results show that it takes only 50 min to balance twelve lithium-ion batteries during the charge with 89.5% maximum efficiency, because the energy in a battery cell is transferred directly from a high-voltage cell to a low-voltage cell. The cell balancing is achieved by transferring directly from one cell to another cell in a battery string by a push-pull converter.

A.K.M. AhasanHabib, Mohammad KamrulHasan, Md Mahmud, S.M.A. Motakabber, Muhammad IbrahimyaandShayla Islam (2020) designed an Energy storage system and balancing circuits for electric vehicle application. The comparative study has shown the different types of energy storage systems, and voltage balancing circuits. The Energy Storage Systems are mainly categorized into Electro chemical battery, Chemical, Electromagnetic and Hybrid Systems. Balancing circuits are mainly categorized as cell-to-heat, cell-to-cell, cell-to-pack, pack-to-cell, and cell-to-pack-to-cell. For fast balancing, Cell-to-pack, Pack-to-cell, or Cell-to-Pack-to-Cell circuits are applicable, but the overall efficiency is low compared with Cell-to-Cell balancing circuits.

ThiruvonasundariDuraisamy, Deepakaliyaperumal (2020) designed an Active-cell balancing for Electric Vehicle Battery Management System. The control strategies implemented on the switches are based on the voltage difference between the cells. Simple control and fast equalization are the advantages of this topology compared to the conventional Inductor based topology. The 16-cell Inductor based equalization topology is simulated in MATLAB/ Simulink and the ideal cell equalization is established. The capacity each cell is 3.3Ah.The Inductor value selected for this topology is 60mH.Voltage distinction between odd numbered cells with its continuous even numbered cells is more than threshold voltage, at that point overcharged cell is switched on Inductor is charged. When voltage distinction is underneath normal then the switch is turned off, the stored energy is given to the low charged cells through the body of diode of switch.

Ali FarzanMoghaddam and Alex Van Den Bossche (2019) designed a Fly-back converter balancing technique for lithium based batteries. This circuit is used to equalize the cells connected in series in a battery pack. Fly-back converter balancing method has fast balancing time and the control is also easier compared to forward converter which requires a supplementary circuit, RCD snubber circuit etc. It requires only one switch and N diodes at the output of each cell. In this way, the number of active switches used are reduced which is used to prevent losses. Batteries aremodelled with capacitors with the value of 5F and voltage that ranges from 3.1v to 3.6v.The switching frequency of 50 kHz and 50% duty cycle. In fly-back circuit, energy will be stored in the transformer during ON time and during the OFF time energy is transferred to the secondary. The Diodes used are ideal diodes. Cell balancing usually takes 2 seconds to reach the equalization voltage.

Edi Leksono, IrsyadNashirulHaq, EndangJuliastuti, LaluGhifarulZakyFahran and FahriMuhamadNabhan (2019) developed an Active Cell to Cell Battery Balancing System for Electric Vehicle Application. In this BMS uses a microprocessor to process battery data, a micro controller to control battery connecting switches, and a DC-DC converter circuit as well as a switched capacitor (SC) and switched converter. This provides an energy efficiency of 59 % by proposing an active balancing circuit [4].

Zachary BosireOmariba, Lijun Zhang, Dongbai Sun (2019) review a Battery Cell Balancing Methodologies for optimizing battery pack performance in EV. In this many types of battery balancing schemes have been reviewed to underscore the types of battery imbalance, and its effect on battery performance. Resistor, Inductor and Capacitor based circuits are used. In passive balancing the more the resting periods for highly charged and lowly charged cells, the estimation of the battery SOC improves. The results are based on the battery testing system HPPC test. Balancing complexity of the circuits is simple.

AbinashKhanal, AshutoshTimilsina, BinayPaudyal and SaugatGhimired (2019) designed Comparative Analysis of Cell Balancing Topology in Battery Management Systems. In this Switched Resistance method for Passive Cell Balancing and Single Switched Capacitor method for Active Cell Balancing were studied and simulated with the help of MATLAB/Simulink. Three battery cells with initial SOC of 100%, 90% and 60%is considered. SOC is balanced in 2200 seconds with 7.1mWh energy-loss, for passive balancing. Final SOC for single switched capacitor balancing is achieved after 43200 seconds. Increased efficiency of active balancing comes at the cost of higher balancing time.

Ali FarzanMoghaddam and Alex Van den Bossche (2019) designed an Efficient Equalizing Method for Lithium-Ion Batteries Based on Coupled Inductor Balancing. In this a Coupled inductor circuit was proposed to overcome cell voltage vibration among cells in series. In this method, less components and fast equalization is achieved compared to the conventional Battery Management System (BMS). All the inductors were coupled with only one magnetic core with an air gap, and were made with a well-chosen winding ratio. The switches were logic-level N-Channel MOSFET, and were triggered by a micro controller with a frequency of 45.5 kHz and duty cycle of 45% to avoid shoot-through between switches. The circuit was tested with different cell imbalances of 0.8 V and 1.2V.The balancing current is limited to 2A [7].

Thuc Minh Bui, Chang-Hwan Kim, Kyu-Ho Kim and Sang Bong Rhee (2019) designed a Modular Cell Balancer Based on Multi-Winding Transformer and Switched-Capacitor Circuits for a Series-Connected Battery String in Electric Vehicles. In this cell balancing topology in combination with Multi Winding Transformer Circuit (MWTC) and Switched Capacitor Circuit (SCC) has been proposed. This balancing circuit is based on the intra-module and outer-module balancers. The energy of cells in SCBS is transmitted from a high voltage level to a low voltage level in both the cells in each module and the modules by simultaneous intra and outer-module balancers. In this method the voltage sensors are eliminated. The energy efficiency of the proposed circuit can reach 83.31%.

Ginu Ann George, M.V. Jayan, Fossy Mary Chacko, and A.Prince (2019) designed a Novel Single Balancing Circuitry for Modular Cell for Electric Vehicle Applications. In this switched capacitor balancing method is used. Each module consists of three series connected LI-ion cells. A module selection switch S1 is used which is used to select the weakest module and switched capacitor active balancing method. After balancing, the switch is used to connect to the next weak module. Likewise the entire system is balanced.

KadlagSunildatSomnath, Mukesh Kumar Gupta (2019) reviewed a Paper on Electric Vehicle Charging and Battery Management System. In this cell balancing is done during the charging cycle. Various charging methods are used. The structure of EV battery charging systems using the combination of AC-DC and DC-DC convertors are used. For proper control, it should measure the current and voltage in the power grid side and also in the batteries.

JianOuyang, Ping Zhang, Shiyong Wang, Huiqi Li (2017) designed an Active Balancing Charging Module with Continuous and Controllable Isolation for battery management system.In this active balancing charging module with continuous and controllable isolation. The experimental process shows that active balancing performs well in the charging process. Efficiency is high Voltage balancing testing experimentsuse 20 LPB series, firstly the LPB is being charged by a high power charger with 20A current. Secondly, When BMS detects a single LPB or many LPB reaches the pre-set value, charger stop output immediately, active balancing charging module start working.

Lucian Andrei Perisoara, IonutConstantinGuran, and DumitrelCatalinCostache (2018) designed a Passive Battery Management System for Fast Balancing of Four LiFePO4 Cells. Fast balancing of four serially connected LiFePO4 cells is balanced in this work, passive BMS proposed in this contains power resistors and power transistors as main components to dissipate the surplus of energy. The main advantage of the proposed BMS is that the balancing time is decreased by several times than commercially available BMS, although for large capacity cells like the ones which we have tested. BMS was designed to implement and analyse the performances of different cells balancing algorithms and estimation techniques for SOC, SOH, RUL, etc.

Xiudong Cui, WeixiangShen, Yunlei Zhang and Cungang Hu (2017) designed a Fast Multi-Switched Inductor Balancing System Based on a Fuzzy Logic Controller for Lithium-Ion Battery Packs in Electric Vehicles. In this low-cost battery pack balancing system based on the MSIBC. Experimental results have demonstrated that the proposed

FL controller significantly improves the performance of the MSIBC compared with the existing PI controller, FL controller for the MSIBC only takes 950 s for pack balancing, which is only a third of the balancing time of the PI controller (3000 s). The FL controller for the MSIBC can recover 2% more pack capacity than PI controller. More pack capacity was recovered with the FL controller than with the PI controller, which extends the serving time of the battery packs in EV [14].

Mohamed Daowd, Noshin Omar, Peter Van Den Bossche, Joeri Van Mierlo (2012) designed a Capacitor Based Battery Balancing System. In this paper Switched capacitor battery balancing topologies, SC, DTSC, SSC and MSC have been reviewed and simulated using MATLAB/Simulink and detailed comparison is done. The single switched capacitors balancing method has been discussed in details with an optimal control strategy for reducing the system cost and balancing time by increasing the energy transfer between the cells and the capacitor [15].

CHAPTER 3
CELL BALANCING

When a lithium-ion battery pack is designed using cells connected in series, it is important to design the electronic circuit to continually balance the cell voltages. This is not only for the performances of the battery pack, but also for optimal life cycles. The use of cell balancing enables us to design a battery with larger capacity for an application, because balancing allows the battery to achieve a higher state of charge (SOC) at the minimal time.

3.1 CELL IMBALANCING

If lithium-ion cells are over-heated or over-charge, they are prone to accelerated cell degradation. The battery pack can catch fire or even explode which induces thermal runaway if a lithium ion cell voltage exceeds even a few hundred milli-volts.Every battery pack design and manufacturer has an over voltage protection circuit to provide the standard cell balancing that will prevent such an event. In a multi-cell battery pack, which is commonly used in electric vehicle batteries, laptop and medical equipment, placing cells in series open the possibility of cell imbalance, a slower but persistent degradation of the battery.

3.2 CELL BALANCING

Cell balancing is the process of equalizing the voltages and state of charge among the cells when they are at a full charge. No two cells are identical. There are always slight differences in the state of charge, self-discharge rate, capacity, impedance and temperature characteristics, Even if the cells are the same model, same manufacturer, and same production unit. Manufacturers will sort cells by similar voltage to match as close as possible, but there are still slight variations in the cells impedance, capacity and self-discharge rate that can eventually lead to a divergence in voltage over time. The figure 3.1 shows the proper and improper balancing method for cell balancing in the battery pack.

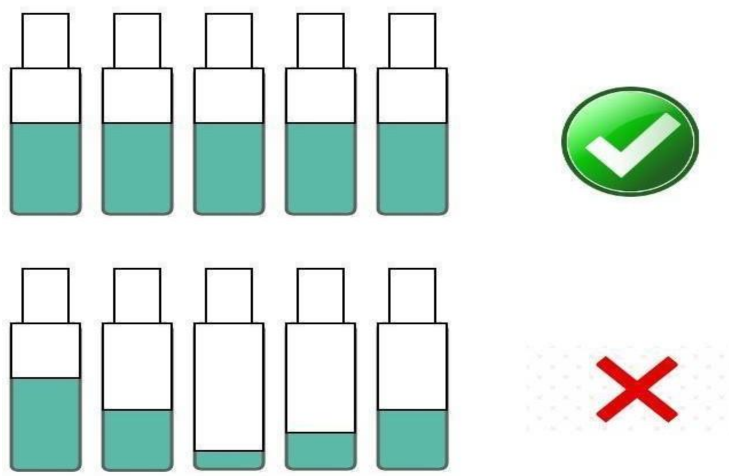


Figure.No.3.1 Proper and Improper Cell Balancing

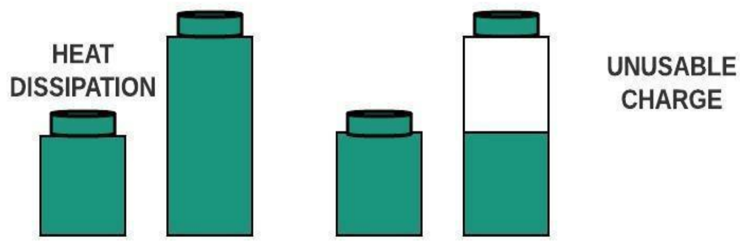
Most typical battery chargers detect full charge by checking the voltage of the entire string of cells has reached the voltage regulation point. Individual cell voltages can vary as long as they don't exceed the limits for over voltage protection [5] . However, weak cells tend to exhibit higher voltage than the rest of the series cells at the full charge termination. These cells are then weakened further by continuous overcharge cycles. The higher voltage of the weaker cells at charge completion causes accelerated capacity degradation [12]. If the maximal recommended charging voltage is exceeded even by as 10 percent, it will cause the degradation rate to increase by 30 percent. On the discharge side, the weaker cells tend to have lower voltage than the other cells, due to either higher internal resistance, or a faster rate of discharge that results from the lower capacity[11].

3.3 CELL BALANCING TECHNIQUES

The fundamental solutions of cell balancing methods are equalizing the voltage and state of charge among the cells when they are at a fully charged state. Cell balancing is typically categorized in two types:

1. Active cell balancing
2. Passive cell balancing

The passive balancing circuit is shown in figure 3.2.



Charging Discharging

Figure.No.3.2 Passive Balancing Circuit

The passive balancing technique is used to determine the lowest voltage and make other cells to discharge and balance at the same point.

3.3.1 PASSIVE CELL BALANCING

Passive cell balancing method is simple and easy to implement. The discharge of the cells occurs through a dissipative bypass circuit. This bypass circuit can be either internal or external to the integrated circuit(IC) [6]. Such an approach is favorable in low-cost system applications. The excess energy from a higher energy cell is dissipated as heat makes the passive method less preferable to use during discharging and also has an impact on battery run time.

3.1.1.1 MERITS OF PASSIVE BALANCING

- It allows all cells to have the same SOC.
- It can correct long-term mismatch of battery cells in self-discharge mode from cell to cell.
- This method is simple and less complex to implement.

3.1.1.2 DEMERITS OF PASSIVE BALANCING

- Poor thermal management.
- They do not balance during the full Soc. They only balance through the top of each cell of around 95%. This is because if you have different cell capacities, the excess energy is burst as heat.
- Its energy transmission efficiency is very low.
- It does not improve the run-time of a battery-powered system.

3.3.2 ACTIVE CELL BALANCING

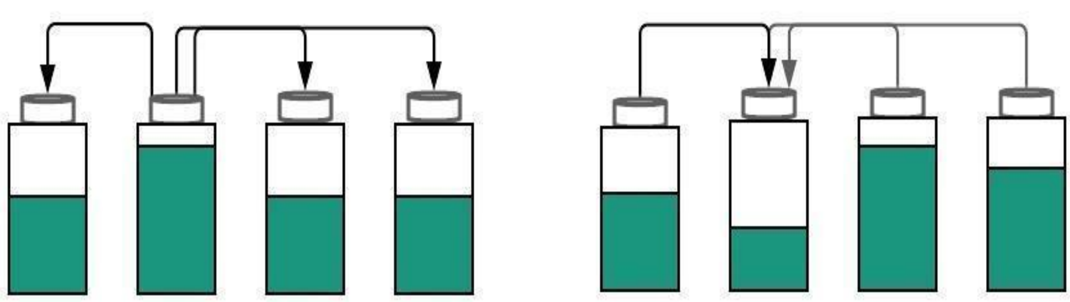
Active cell balancing is a more complex and efficient balancing technique that redistributes charge between battery cells during the charge and discharge cycles, thereby increasing system run-time by increasing the total usable charge in the battery stack, decreasing charging time. It utilizes capacitive or inductive charge shuttling to transfer charge between battery cells [8].

3.2.2.1 MERITS OF ACTIVE BALANCING

- It improves the battery capacity of the cell.
- It increases energy efficiency.
- It saves energy instead of burning the excess energy in a cell by transferring the excess energy to a lower cell.
- It improves the life expectancy of a cell.
- It improves thermal management and also good for the active balance methods.

3.2.2.2 DEMERITS OF ACTIVE BALANCING

- When transferring energy from one cell to another, approximately 10-20% of energy is lost.
- The charge could be transferred from higher to lower cells.
- Although active cell balancers have high energy efficiency, its control algorithm maybe complex and its production cost is expensive because each cell should be connected with an additional power electronic interface. The active balancing circuit shown in figure 3.3.



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CHARGING **DISCHARGING**

Figure. No. 3.3 Active Balancing Circuit

3.4 CELL BALANCING TECHNIQUES

The cell balancing are divided into various type based on the different categories. The cell balance methods are classified such as

Based on the method,

1. Passive Balancing
2. Active Balancing

Based on the Configuration,

1. Cell-By-pass
2. Cell- to –Cell
3. Cell-to-Pack
4. Pack-to-Cell
5. Cell-to-pack-to-cell

The cell balancing techniques majorly used are explained in this are shown the table 3.1.

Table No.3.1 Cell Balancing Techniques

S. No.	Active Cell Balancing	Passive Cell Balancing
1	Transformer and Inductor based circuits	Fixed shunting resistor
2	Capacitor based circuits	Switched shunting resistor
3	Converter based circuits	-

3.5 CELL BALANCING TOPOLOGIES

The cell balancing techniques based on the configuration is listed in the table 3.2.

Table.No.3.2 Cell Balancing Topologies

S. No.	Topology	Advantages	Disadvantages
1	Cell-By-pass	High Efficiency, High Speed, Less Control Complexity, Small Size, Low Switch Voltage Stress	High Switch Current Stress Low Power Applications
2	Cell- to –Cell	Efficient, Low Complexity, Lower Balancing Time, High Power Application	High Switch Voltage Stress, Relatively Big Size, Expensive, High Current Stress
3	Cell-to-Pack	High Power Applications, Low Complexity, Fast Equalization, Low Cost	High Switching Voltage / Current Stress, Difficult Modularity
4	Pack-to-Cell	Less Complexity, Easy Modularity, Fast Equalization Speed	High Switching Voltage / Current Stress, Big Size, Less Efficient
5	Cell-to-pack-to-cell	High Power Applications , Low Complexity, Fast Equalization	High Switching Voltage / Current Stress, Difficult Modularity

3.6 CELL BALANCING COMPARISON

In this comparison of active and passive cell balancing is explained are shown in the figure 3.4.

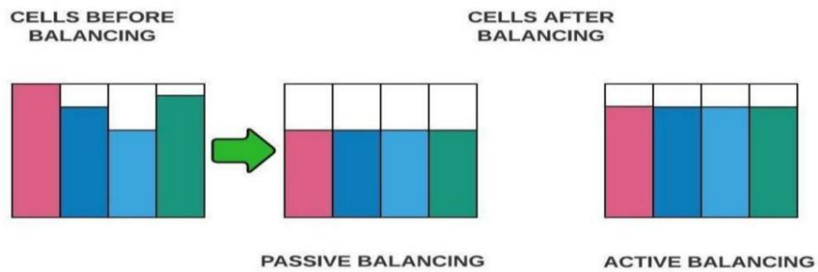


Figure.No.3.4 Cell Balancing Comparison

From this figure 3.4, the comparison clearly depicts the working of the passive and active balancing.

3.7 BATTERY EQUALISATION CONTROLLER TOPOLOGY

The different battery equalization controller topology used is shown in the Figure3.5

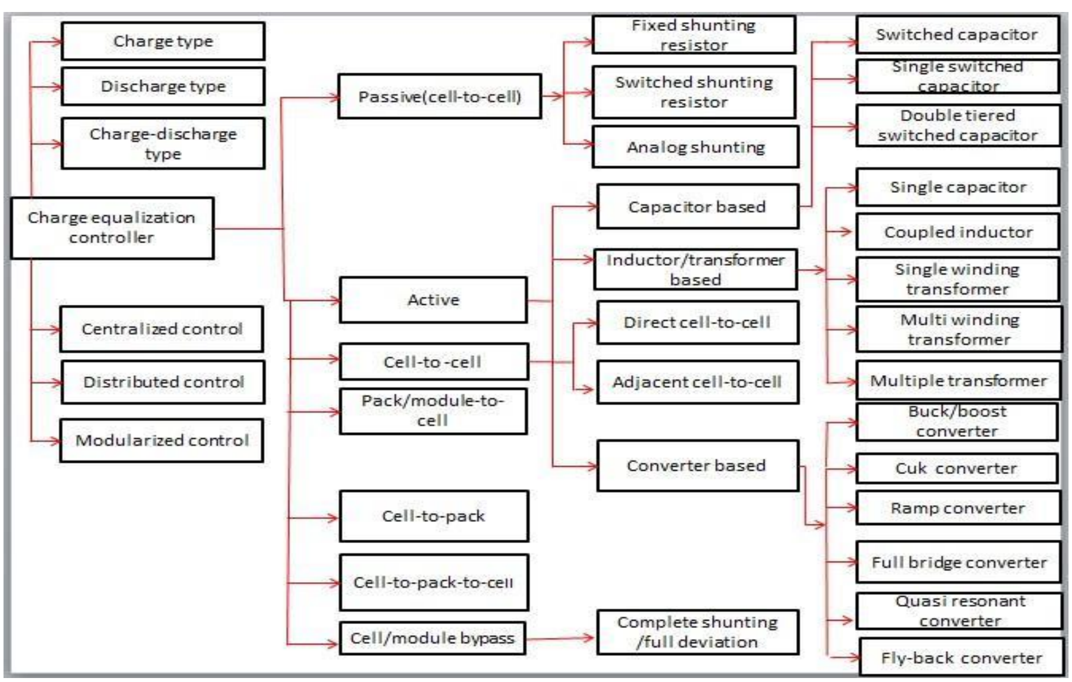


Figure.No.3.5 Battery Equalization Controller Topology

CHAPTER 4
MATLAB SIMULATION AND BATTERY PARAMETERS

This chapter explains the software implementation of this project. The MATLAB / Simulink is used to design the cell balancing circuits and analyze performance of the cells before and after balancing using passive and active balancing.

4.1 BATTERY AND ITS PARAMETERS

For the purpose of modeling the battery, the battery packs and EV drives in different driving modes, the MATLAB software is used. It is modelled as a controlled voltage source dependent on the actual state of the battery charge (SOC) [13].The used battery specifications are shown in table 4.1.

Table. No. 4.1 Battery Specifications

S. No.	Parameters	Range
1	Maximum Capacity (Ah)	5.4
2	Cut off voltage (V)	5.4
3	Fully charged voltage (V)	8.3807
4	Nominal Discharge current (A)	2.3478
5	Internal resistance (Ω)	0.013333
6	Capacity (Ah) at nominal voltage	4.8835
7	Experimental Zone [Voltage(V), Capacity(Ah)]	[7.7788 0.2653]

CHAPTER 5

MATLAB SIMULATION RESULTS FOR PASSIVE BALANCING

This chapter shows the overall block diagram of the project, the design of circuits and the overall implementation.

5.1 BLOCK DIAGRAM OF CELL BALANCING CIRCUIT

The block diagram of cell balancing circuit is shown in the figure 5.1.

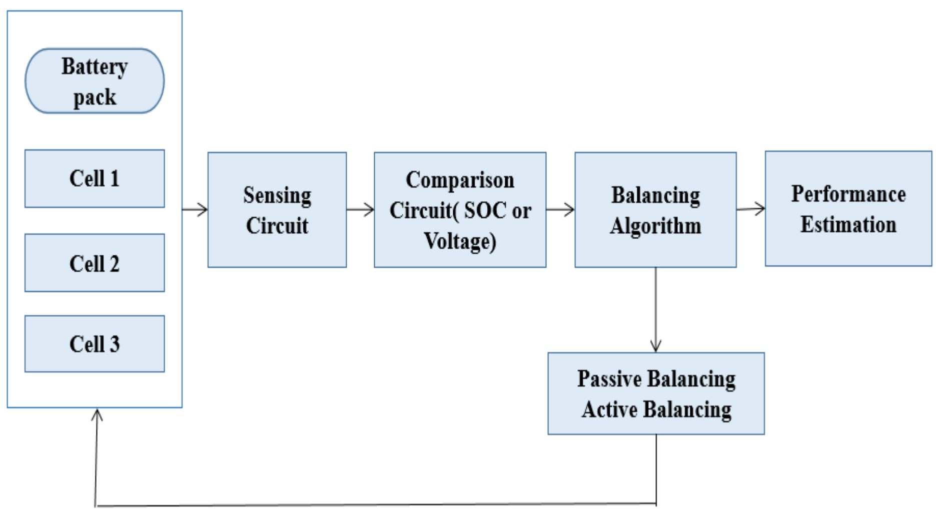


Figure. No. 5.1 Block Diagram of Cell Balancing Circuit

5.2 CELL BALANCING CIRCUIT

In this, passive cell balancing circuit is explained and implemented using a switching resistor method.

5.2.1 PASSIVE BALANCING CIRCUIT

Passive cell balancing dissipates excess energy in the form of heat. It allows all batteries to have the same SOC, but it does not improve the run-time of the battery powered system. It provides a fairly low cost method for balancing the cells.

5.2.2 CIRCUIT IMPLEMENTATION

In this passive cell balancing implementation, each cell state of charge make to same or common cell value which has a low state of charge. The state of charge of each cell is different and when the passive cell balancing will be applied, the state of charge of each cell will reach to the lowest cell value. In this passive balancing circuit, Lithium-ion battery pack is used. The battery pack of 12 volts and 2.6 Ah is used in the specification. It consists of three lithium-ion cells connected in series. Each cell is connected to the balancing resistance through MOSFET switch. The passive cell balancing will be applied. The state of charge of each cell will come to the minimum lowest SOC, because cell 1 has the lowest state of charge compared to others. In this balancing circuit, the comparison of state of charge of each cell is observed using MATLAB function block. Initially, the state of charge of each cell is different, the state of charge value is given to the MATLAB function block (controller), whereas the passive balancing algorithm is compared with the state of charge of each cell and allow the required gate pulses to trigger the MOSFET switch and the output is taken out. The output is connected to the gate of the MOSFET, by which the circuit is controlled. Suppose if the state of charge of cell 1 is low then, it will give output high for cell 2 and 3 [9]. When the code output is low the gate is not triggered, but if the output is high gate will turn on and the balancing takes place once all the cells are balanced the gate will be low [10]. All the SOC will be the same and the battery pack is balanced.

5.2.3 RESISTOR BASED BALANCING

This method uses resistors as balancing circuits which equalizes the voltage or SOC of each cell by the dissipation of energy from higher cell voltage or SOC and formulate the entire cell voltage or SOC equivalent to lowest cell voltage.

5.2.4 RESISTOR BASED SOC BALANCING

1. Ideal Mode
2. Charging Mode

The discharging mode is not applicable to the passive balancing method.

5.2.5 SOC AND VOLTAGE BALANCING CONDITIONS

The different conditions are assumed to get the balancing time and temperature variations are shown in 5.1.

Table. No. 5.1 Ideal Balancing Conditions

Condition	SOC (%)	Voltage (V)
Case 1	45, 46, 47	3, 3.5, 4
Case 2	45, 47, 49	3, 4, 5
Case 3	45, 48, 51	3, 4.5, 6
Case 4	45, 49, 53	3, 5, 7
Case 5	45, 50, 55	3, 5.5, 8

From the above mentioned conditions, case 5 is analyzed using waveform for SOC based balancing and for case 2 condition is analyzed using waveform for voltage based balancing .

5.2.6 FLOWCHART RESISTOR BASED SOC BALANCING

The resistor based SOC flowchart shown in figure 5.2

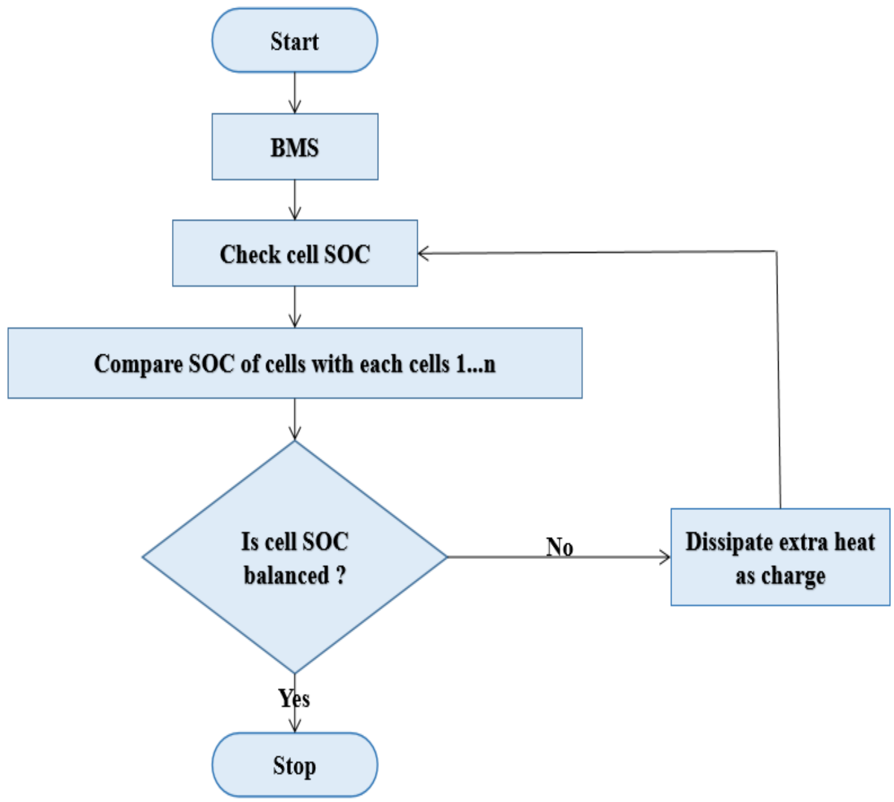


Figure. No. 5.2 Resistor Based SOC Flowchart

5.3 SOC BALANCING IDEAL MODE

In this project, the circuit with MATLAB/Simulink is analyzed using waveform for ideal and charging mode.

5.3.1 PASSIVE BALANCING WITH SOC

In this circuit, SOC values are sensed and given it to the controller circuit as input. If cell is not balanced, switching circuit is activated and the cells are balanced at ideal condition. The Passive balancing circuit with ideal case 5 implemented is shown in figure 5.3.

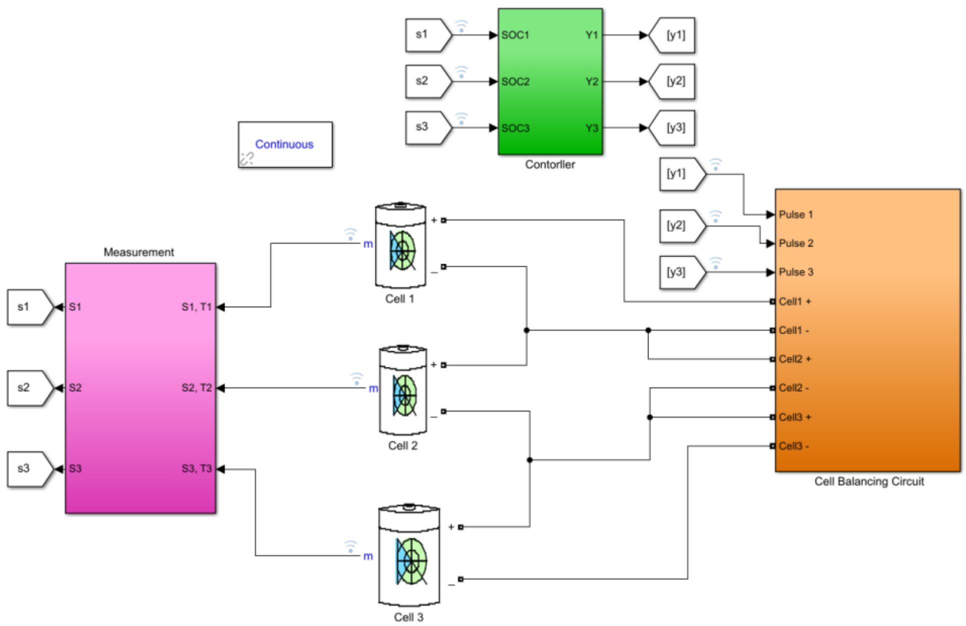


Figure.No.5.3 SOC Balancing Circuit

The SOC balancing output waveform of ideal case condition is shown in figure 5.4.

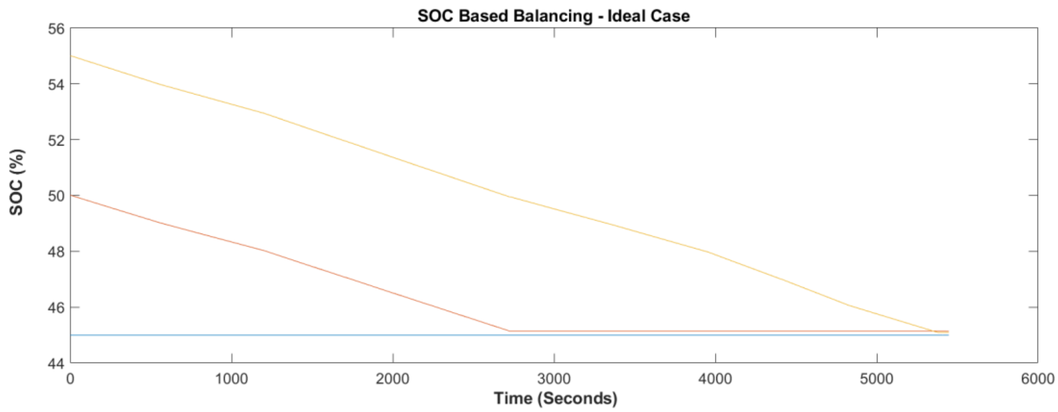


Figure.No.5.4 SOC Balancing Waveform

The SOC equalization time of the passive balancing of three cell battery pack is 5500 seconds shown in the figure 5.4.

5.3.2 PASSIVE BALANCING WITH SOC CHARGING CIRCUIT

The passive balancing with SOC charging case 5 circuit implemented is shown in figure 5.5. In this circuit SOC values are sensed and given it to the controller circuit as input. If cell is not balanced, switching circuit activated and the cells are balanced at ideal condition.

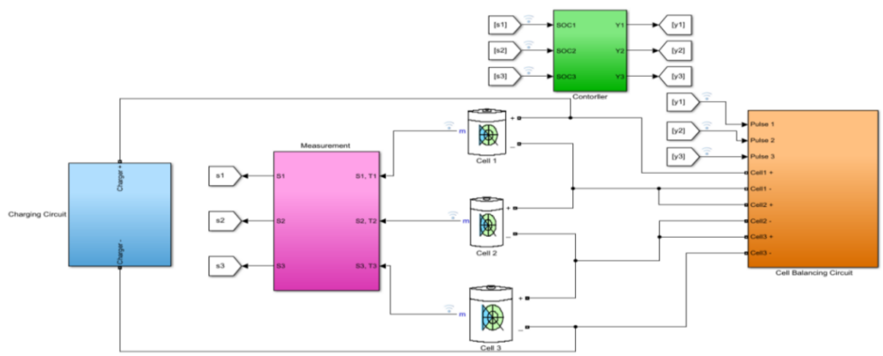


Figure.No.5.5 Charging SOC Balancing Circuit

The SOC balancing output waveform of charging case condition is shown in figure 5.6.

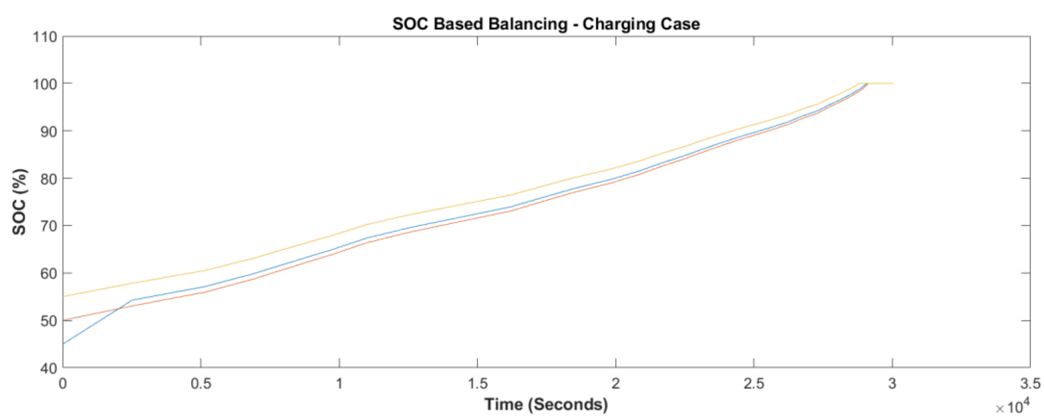


Figure.No.5.6 Charging SOC Balancing Waveform

The charging equalization time of the passive balancing of three cell battery pack is 29000 seconds shown in the figure 5.6.

5.4 FLOW-CHART FOR RESISTOR VOLTAGE BALANCING

The flowchart for voltage based passive balancing is shown in figure 5.7.

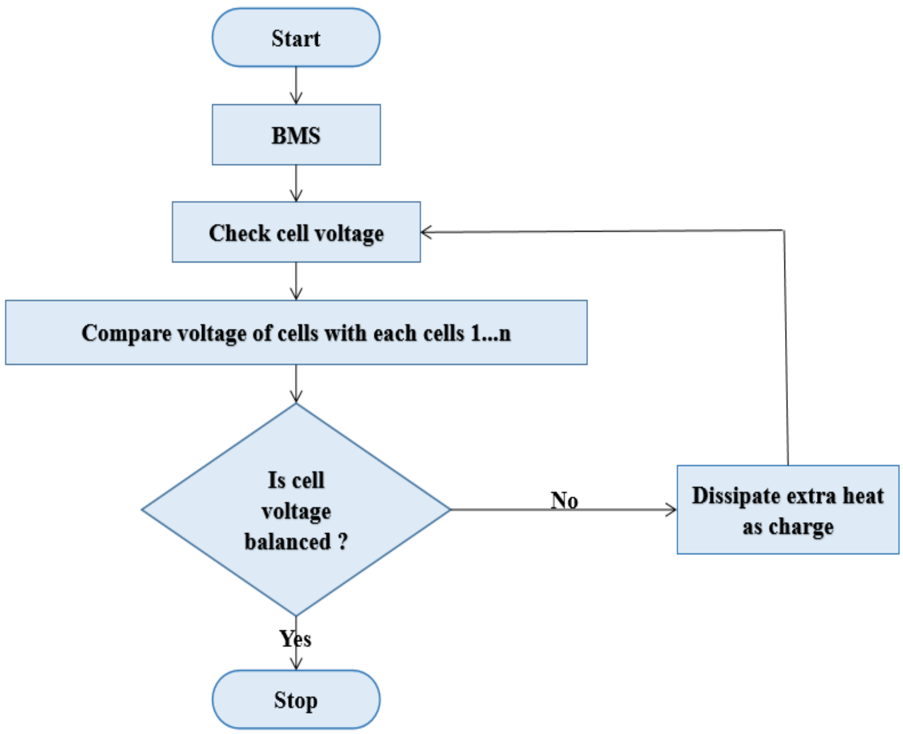


Figure.No.5.7 Resistor Voltage Balancing Flowchart

5.5 VOLTAGE BALANCING

In this, the implementation of the circuits with Simulink is analyzed using waveform for ideal and charging mode.

5.5.1 PASSIVE BALANCING WITH IDEAL VOLTAGE

In this circuit voltage values are sensed and given it to the controller circuit as input. If cell is not balanced, switching circuit activated and the cells are balanced at ideal condition. Passive balancing with ideal voltage case 2 is implemented in figure 5.8.

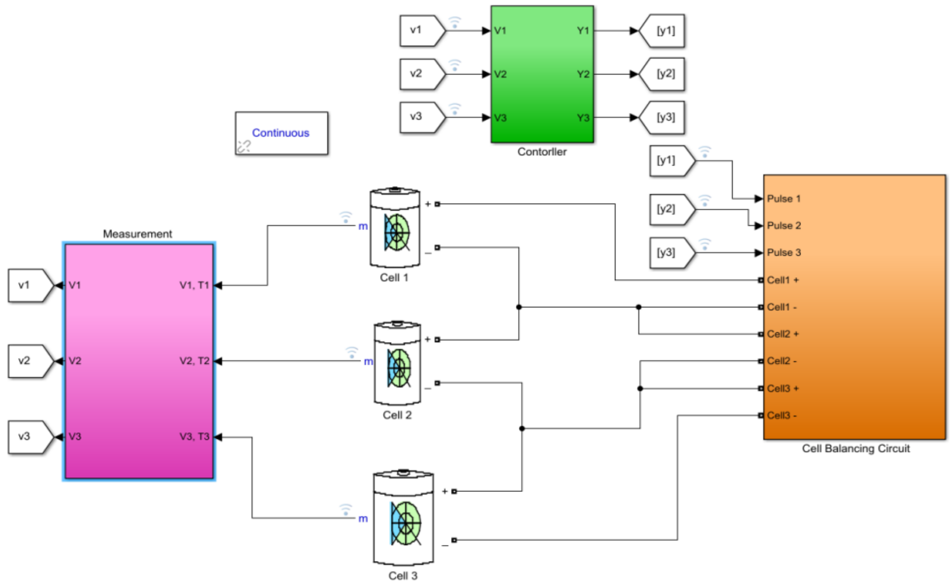


Figure.No.5.8 Voltage Balancing Circuit

The voltage based cell balancing of ideal case output waveform is shown in the figure 5.9.

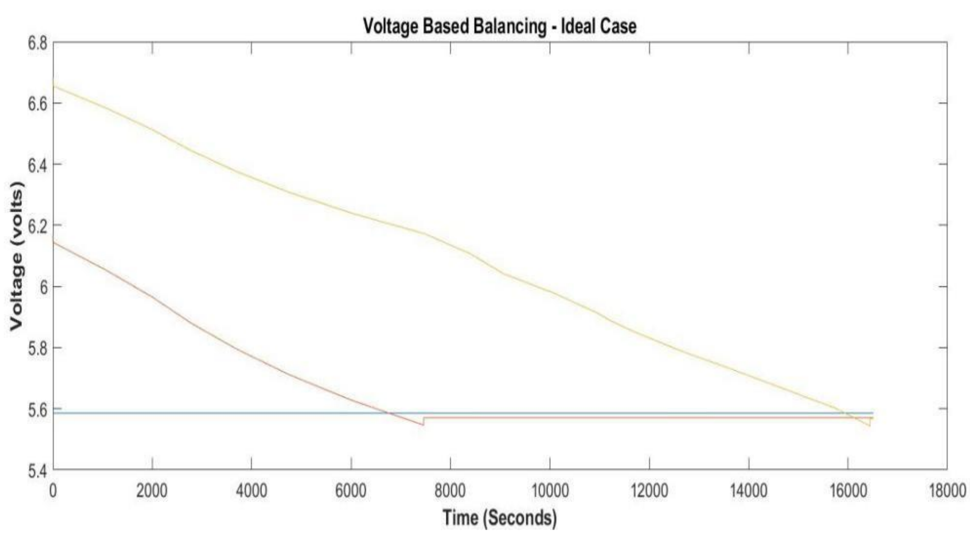


Figure.No.5.9 Voltage Balancing Waveform

The voltage equalization time of the passive balancing of three cell battery pack is 16500 seconds.

5.5.2 PASSIVE BALANCING WITH VOLTAGE CHARGING CIRCUIT

In this circuit, cell voltage values is sensed and given it to the controller circuit as input. If cell is not balanced, switching circuit activated and the cells are balanced at the time of charging. The passive balancing with voltage charging case 2 circuit is shown in figure 5.10.

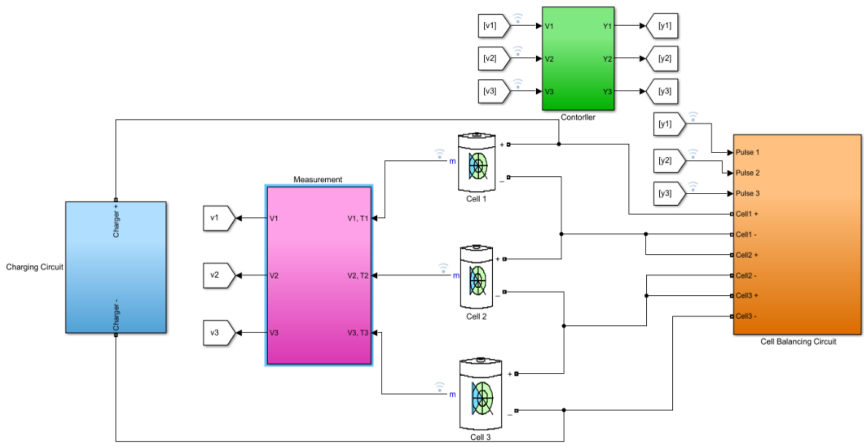


Figure. No. 5.10 Charging Voltage Balancing Circuit

The charging voltage waveform passive resistor balancing is shown in figure 5.11.

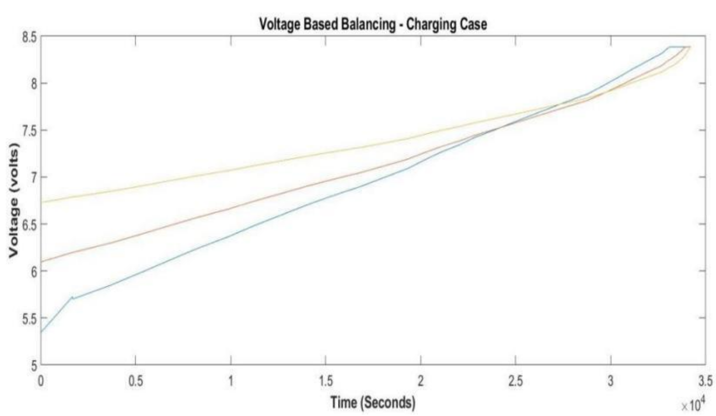


Figure. No. 5.11 Charging Voltage Balancing Waveform

The voltage equalization time of the passive balancing of three cell battery pack is 34000 seconds.

5.5.3 TEMPERATURE VARIATION FOR SOC AND VOLATGE CASES

In this, the thermal variation for SOC and voltage based passive balancing is shown for both ideal and charging cases.

5.5.3.1 PASSIVE SOC TEMPERATURE VARIATION

The thermal variation for SOC based balancing at ideal case 5 is shown in the figure 5.12.

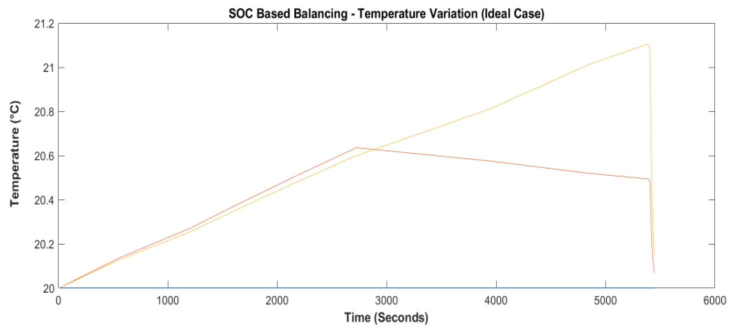


Figure. No.5.12 Ideal SOC Temperature Variation

The temperature variation shown in the figure is 1.10 Degree Celsius.

5.5.3.2 PASSIVE SOC CHARGING TEMPERATURE VARIATION

The thermal variation for SOC based balancing at charging case 5 is shown in figure 5.13.

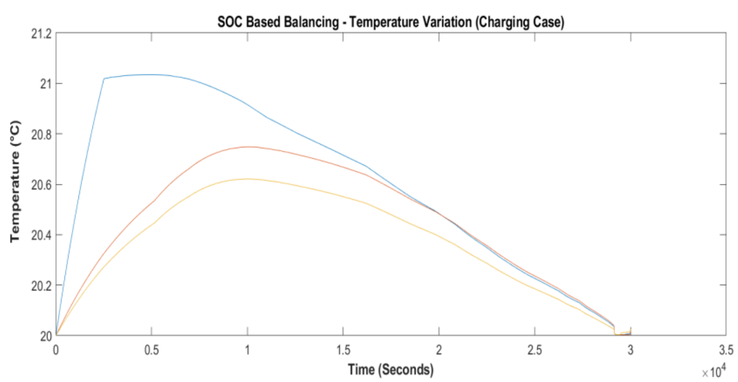


Figure. No.5.13 Charging SOC Temperature Variation

The temperature variation shown in the figure is 1.00 Degree Celsius.

5.5.3.3 PASSIVE VOLTAGE IDEAL TEMPERATURE VARIATION

In this thermal variation for voltage at ideal case 2 is shown in figure 5.14.

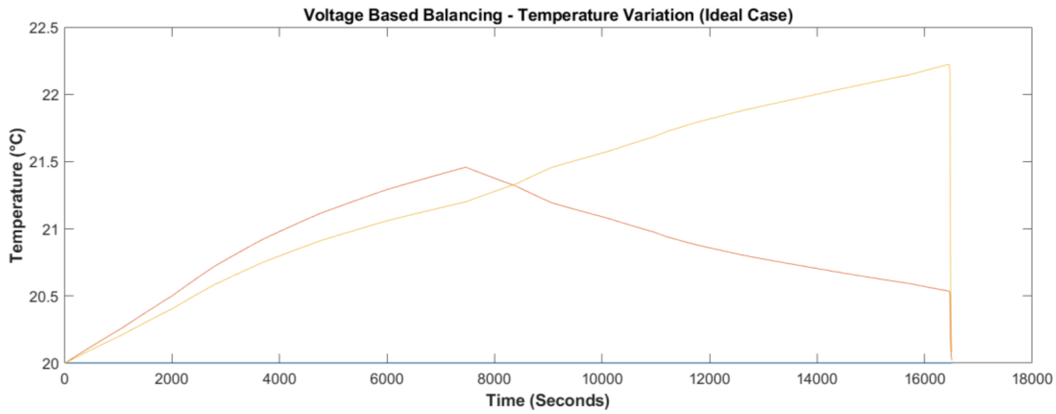


Figure.No.5.14 Ideal Voltage Temperature Variation

The temperature variation shown in the figure is 2.3 Degree Celsius.

5.5.3.4 PASSIVE VOLTAGE CHARGING TEMPERATURE VARIATION

In this thermal variation for voltage at charging case 2 is shown in figure 5.15.

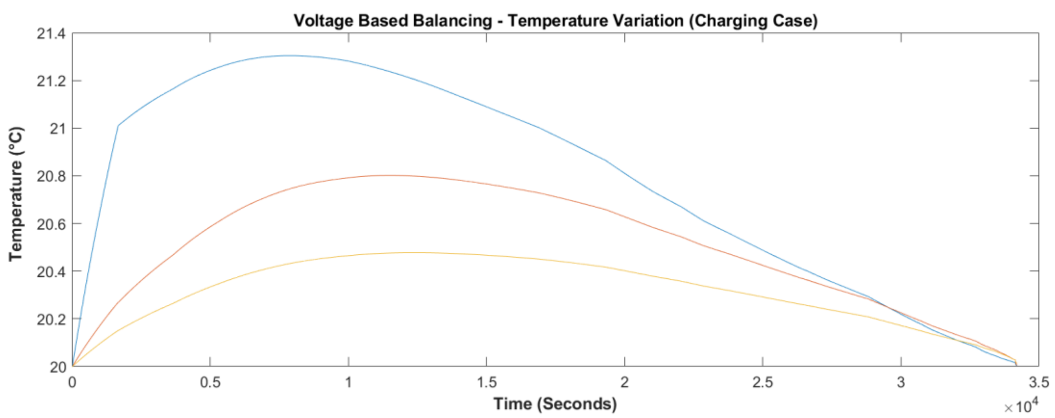


Figure.No.5.15 Charging Voltage Temperature Variation

The temperature variation shown in the figure is 1.30 Degree Celsius.

5.6 COMPARISON RESULTS

In this, the comparison for the output at different conditions in ideal case.

5.6.1 IDEAL MODE OUTPUTS

The ideal mode output of SOC based and voltage based cell balancing is shown in table 5.2.

Table. No. 5.2 Ideal Mode Outputs

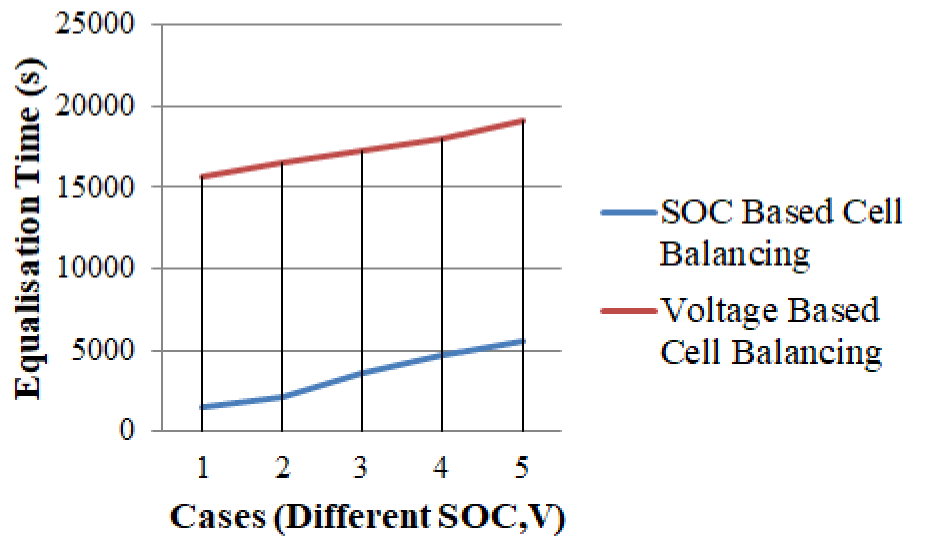
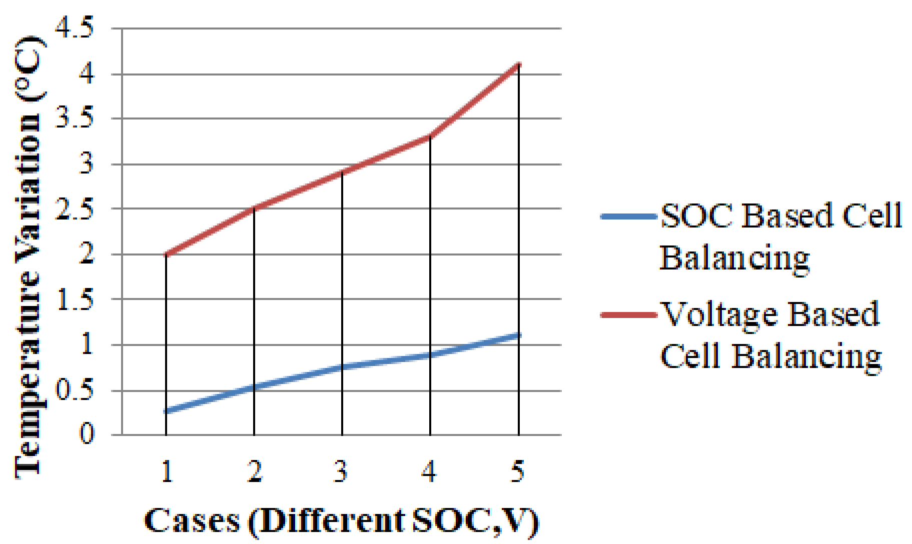
Cases	SOC based Balancing		Voltage based Balancing	
	Equalization Time (Seconds)	Temperature Variation (Degree Celsius)	Equalization Time (Seconds)	Temperature Variation (Degree Celsius)
Case 1	1450	0.28	15700	2.0
Case 2	2100	0.53	16500	2.3
Case 3	3600	0.75	17300	2.9
Case 4	4700	0.90	18000	3.3
Case 5	5500	0.10	19100	4.1

5.6.2 IDEAL CASE COMPARISONS AND INFERENCE

In this, the temperature and equalization time waveform of both voltage and SOC based cell balancing is compared. Accordingly, voltage base SOC equalization technique of the circuit is faster. In case of voltage based balancing cell, temperature is also increased.

The ideal case outputs and comparisons are shown in table 5.3.

Table. No. 5.3 Ideal Case Comparison and Outputs

Equalization Time	
Temperature	

The SOC based balancing takes less equalization time compare to voltage based cell balancing under ideal condition. Thus, SOC based balancing better than voltage based circuits. The temperature variation is also less in SOC based balancing compare to voltage based balancing circuits.

5.7 CHARGING MODE OUTPUTS

The output of charging mode conditions SOC based and voltage based cell balancing is shown in table 5.4.

Table. No. 5.4 Charging Mode Outputs

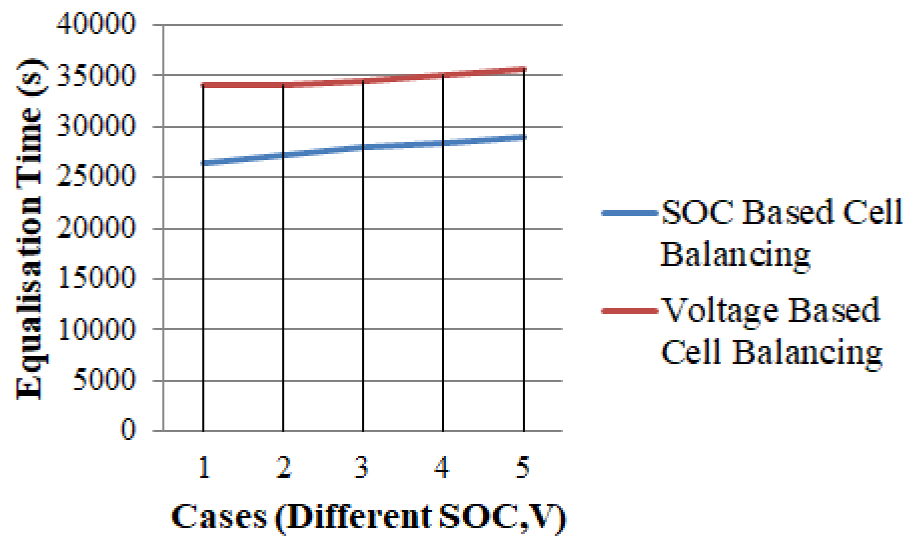
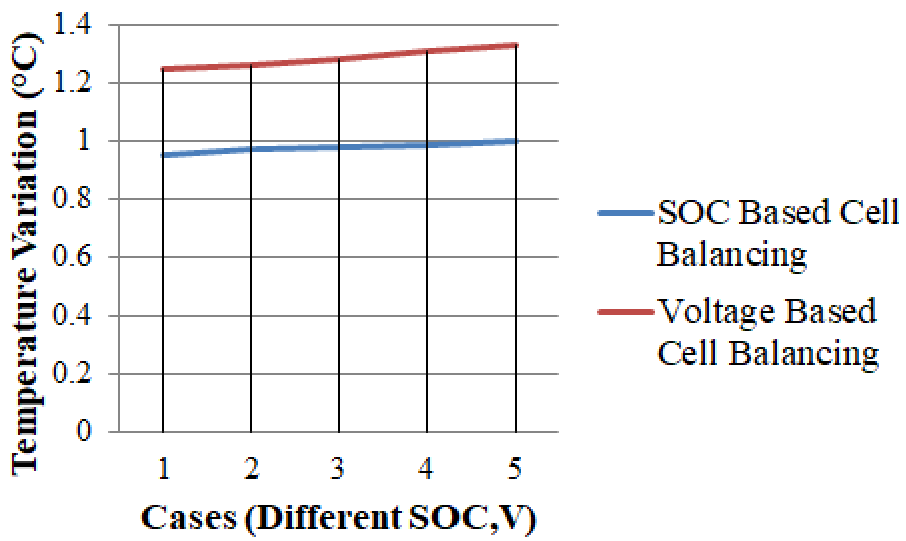
Cases	SOC based Balancing		Voltage based Balancing	
	Equalization Time (Seconds)	Temperature Variation (Degree Celsius)	Equalization Time (Seconds)	Temperature Variation (Degree Celsius)
Case 1	26500	0.95	34000	1.25
Case 2	27200	0.97	34000	1.30
Case 3	27900	0.98	34500	1.31
Case 4	28400	0.99	35100	1.31
Case 5	29000	1.00	35700	1.33

5.7.1 CHARGING CASE COMPARISONS AND INFERENCE

In this Charging mode, the temperature and equalization time waveform of both voltage and SOC based cell balancing methods is compared. Compared to voltage based balancing, the SOC based equalization of the circuit is faster. The equalization time is fast in SOC based balancing. In case of voltage based balancing cell temperature is also increased.

The charging case comparisons and inference are shown in table 5.5.

Table. No. 5.5 Charging Case Comparisons and Inference

Charging Time	
Temperature	

The SOC based balancing takes less equalization time compared to voltage based cell balancing under ideal condition. Thus, SOC based balancing better than voltage based circuits. The temperature variation also less in SOC based balancing compare to voltage based balancing circuits.

CHAPTER 6

MATLAB SIMULATION RESULTS FOR ACTIVE BALANCING

6.1 ACTIVE CELL BALANCING IMPLEMENTATION

Active cell balancing circuit is implemented with Lithium-Ion cells and converter circuits. Ideal switch is used as the switching device. The ON and OFF will be used to balance the Lithium-Ion cells. In this circuit SOC based and Voltage based balancing circuit is implemented. Switching circuits and boost converter circuits are used as a sub system. The SOC values used for balancing are 60, 63 and 68 %. The equalization time is fast compare to passive balancing.

The different conditions are assumed to get the balancing time and temperature variations are shown in table 6.1.

Table.No.6.1 Conditions for Active Balancing

Condition	SOC (%)
Case 1	68,60,63
Case 2	71,63,66
Case 3	74,66,69
Case 4	82,69,72
Case 5	80,72,75

From this, the case 1 condition is analyzed with temperate variation and balancing time using active balancing.

6.2 FLOWCHART FOR ACTIVE BALANCING

The active balancing flowchart is shown in figure 6.1.

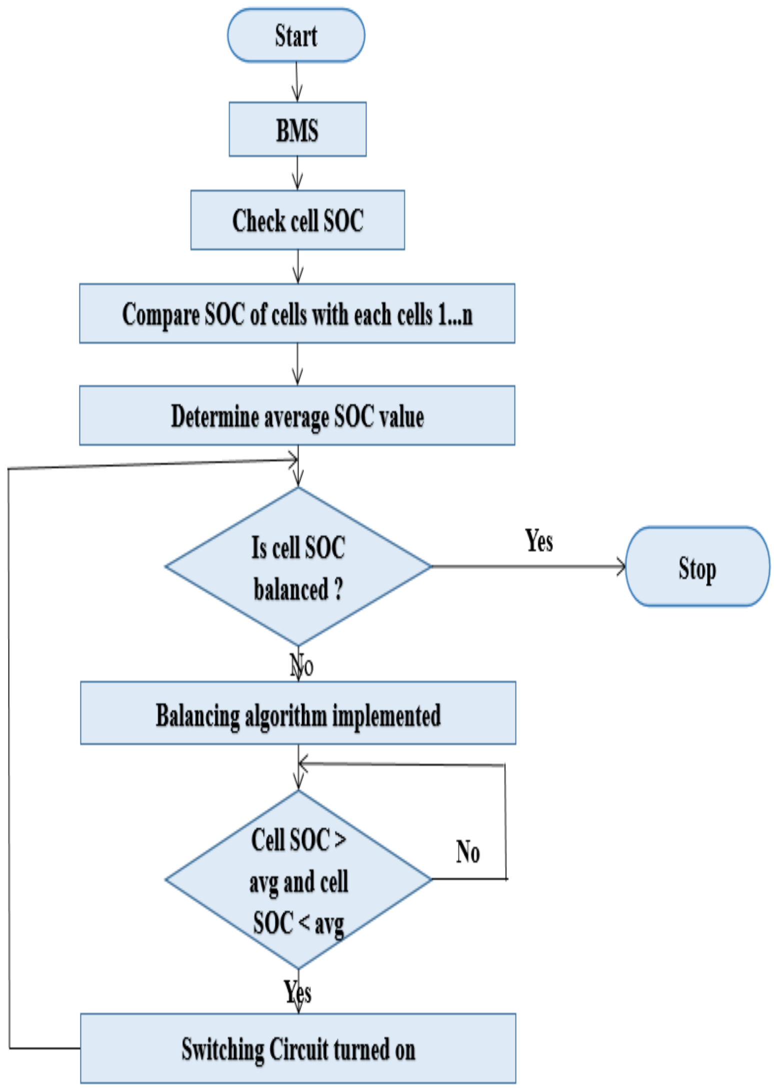


Figure.No.6.1 Active Balancing Flowchart

6.3 ACTIVE BALANCING CIRCUIT IMPLEMENTATION

Active balancing implementation is shown in figure 6.2. In this circuit SOC values are sensed and given it to the controller circuit as input. If cell is not balanced, switching circuit activated and the cells are balanced.

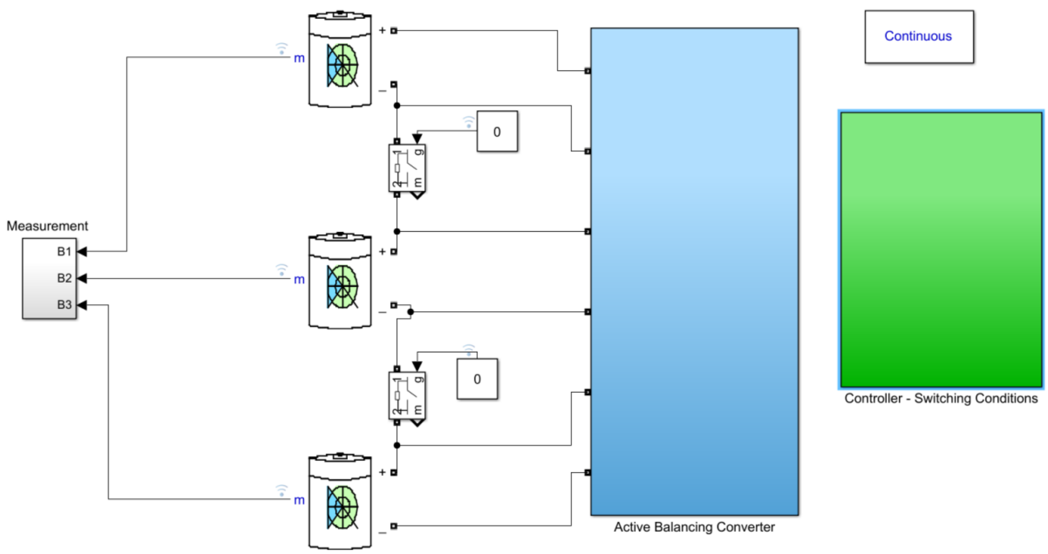


Figure. No. 6.2 SOC Balancing Circuit

6.3.1 CONTROLER and SWITCHING CIRCUIT

The Controller and switching circuit for SOC balancing is shown in figure 6.3. and figure 6.4.

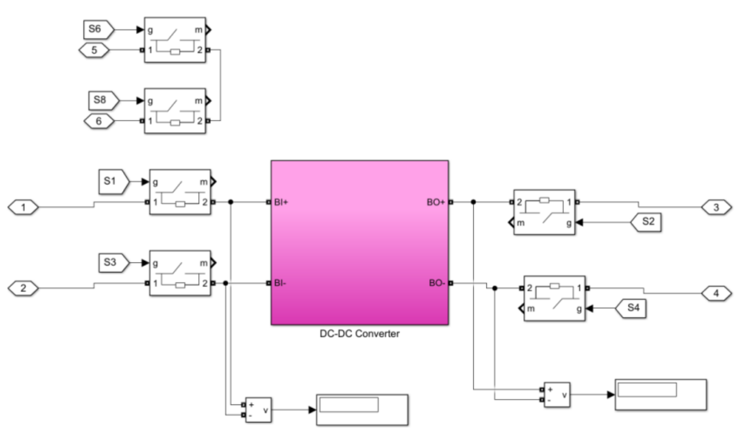


Figure. No. 6.3 SOC Controller Circuit

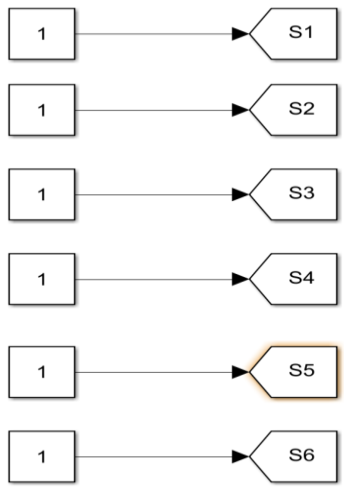


Figure. No. 6.4 Switching Combinations

6.3.2 BOOST CONVERTER CIRCUIT

Boost Converter circuit is used to boost the SOC or Voltage of the battery cells. The circuit is shown in figure 6.3.

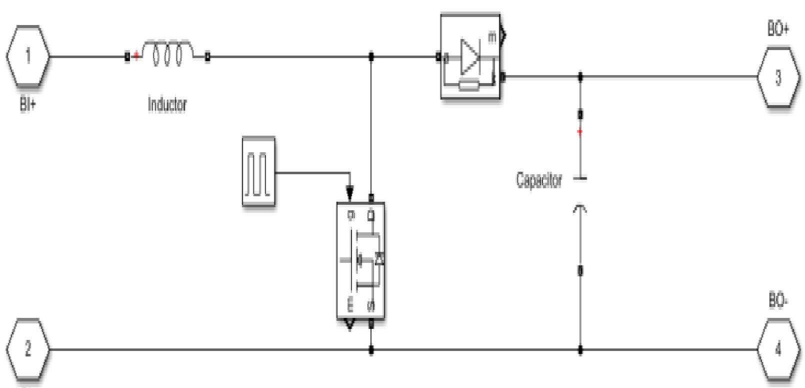


Figure. No. 6.5 Boost Converter Circuit

6.3.3 ACTIVE BLANCING OUTPUT WAVEFORM

The output of active based balancing algorithm is shown in figure 6.6.

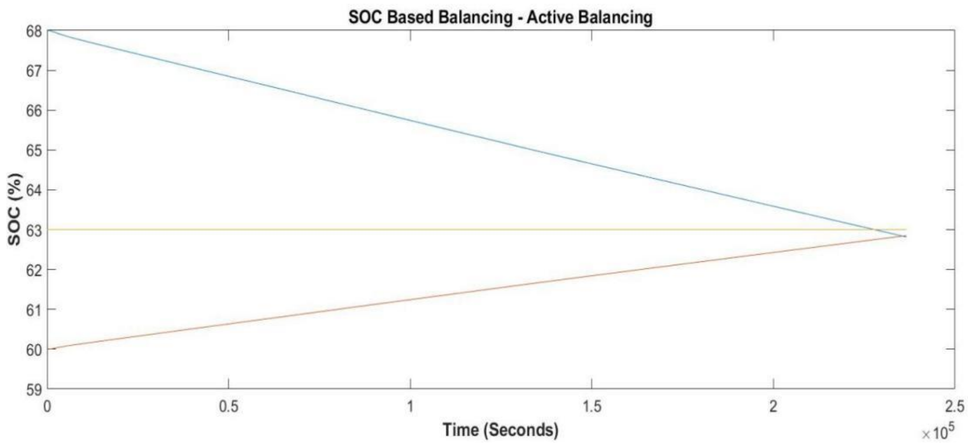


Figure.No.6.6 Active Balancing Waveform

The SOC equalization time of the active balancing of three cell battery pack is 24000 seconds.

6.4 SOC EQUALIZATION OUTPUT

This show the equalization time and temperature variation for different SOC values is shown in table 6.1.

Table.No.6.2 SOC Equalization Output

Cases	Equalization Time(Seconds)	Temperature Variation (Degree Celsius)
Case 1	24000	6
Case 2	24300	5.2
Case 3	24900	5.2
Case 4	25300	5.2
Case 5	25700	4.8

The different equalization time and temperature variation for different SOC conditions.

CHAPTER 7

RESULT AND FUTURE WORK

7.1 RESULT

The development of an efficient battery for energy storage system in EV application is a quite challenging issue. Cell balancing is one of the key issues in battery management system. This project elaborates design, implementation and simulations of cell balancing circuits using MATLAB. Both Active and Passive balancing circuits is implemented and discussed. In Passive cell balancing, MOSFET is used to control the circuit by using a control algorithm. The active balancing circuit is complex and takes less time to balance. In case of passive balancing circuit, SOC based balancing takes less time to balance compared to voltage based passive balancing, but passive balancing is simple to implement compared to active balancing circuit. Active cell balancing circuit implementation is complex. The temperature variation for the battery is compared for the active and passive balancing.

7.2 FUTURE WORK

In active cell balancing, the control algorithm is implemented with Switching Circuit logic. The future work can be extended to propose the control algorithm for active balancing topology.

CHAPTER 8

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APPENDIX

PASSIVE BALANCING ALGORITHM

```
function [y1, y2, y3]= function(s1, s2, s3)
persistent a;
s1 = int16(s1);

s2 = int16(s2);

s3 = int16(s3);

ifis empty(a)
a = min([s1 s2 s3]);
end
if (((s1==a)&&(s2==a)&&(s3==a))==0)
if(s1<=a)
        y1=0;
else
        y1=1;
end
if(s2<=a)
        y2=0;
else
        y2=1;
end

if(s3<=a)
        y3=0;
else
        y3=1;
end
else
    y1=0;
    y2=0;
    y3=0;
end
end
```