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Development Of Battery Management System

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Abstract. — A key aspect of a battery management system is its ability to assess the overall health of the battery pack. By monitoring the internal resistance of each cell and tracking the capacity of the weakest cell, the BMS calculates a cell health percentage ranging from 0 to 100%. This data is then compared against preset thresholds, and if any cells (or the entire pack) fall below these thresholds, a trouble code is generated, and freeze frame data is stored for future analysis. The Battery Monitoring System is equipped with a wide range of features aimed at safeguarding the battery pack. These systems not only monitor and protect the battery but also employ strategies to ensure it remains ready to deliver full power when required and extend its lifespan.

Keywords: Electric vehicles, Battery management system, Open Circuit Voltage (OCV), State of Charge (SOC), Simulation Etc.

Introduction

With the rising popularity of electric vehicles (EVs) attributed to their sustainability, efficiency, and lower carbon emissions, attention to their battery management system (BMS) has heightened. The BMS plays a crucial role in regulating the charging and discharging activities of the battery pack, significantly impacting the overall performance of the EV. A well-crafted BMS ensures the battery's optimal functioning, safety, and durability.

This paper introduces an Arduino-based BMS tailored for electric vehicles, facilitating real-time monitoring and control of the battery pack. The project focuses on enhancing battery operations efficiency, a critical aspect applicable in various industrial and automotive settings.

Electric vehicles (EVs) have emerged as a promising solution for sustainable transportation. However, a significant challenge facing EVs is their limited travel range, which relies heavily on the battery's capacity and health. Therefore, monitoring the battery's state is crucial to ensure the reliable and efficient use of EVs. In recent years, the Internet of Things (IoT) has garnered considerable attention across various industries, including automotive, for its potential to offer real-time monitoring and remote control of devices.

The integration of IoT in EVs holds the promise of enhancing battery performance, efficiency, and overall user experience. This paper proposes a battery monitoring system for electric vehicles based on IoT technology. The system comprises battery sensors, a microcontroller, a wireless communication module, and a cloud server. The battery sensors measure voltage, current, and temperature, transmitting this data to the microcontroller. The microcontroller processes the data and wirelessly transmits it to the cloud server.

Subsequently, the cloud server stores and analyzes the data to provide insights into the battery's health. This proposed system enables real-time monitoring of the battery's state, facilitating the optimization of its performance and extending its lifespan. Additionally, the system-generated data can be utilized to predict the EV's remaining range, aiding drivers in planning their journeys more efficiently.

The objective of the proposed model is to develop a battery management system (BMS) tailored for electric vehicles (EVs), ensuring the safe and efficient operation of the vehicle's battery pack. This BMS will oversee the state of charge, temperature, and voltage of each cell within the battery pack, while also regulating the charging and discharging processes. Additionally, it will furnish real-time data to the driver regarding the battery's health. The BMS will be characterized by a modular architecture, facilitating seamless integration into various EV models.

BLOCK DIAGRAM

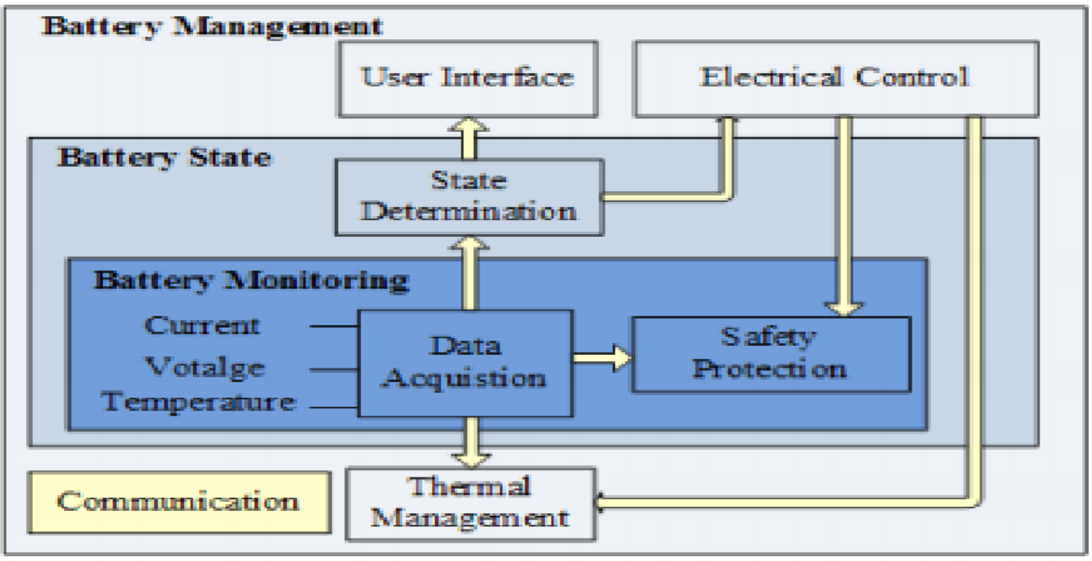

FIG 1. ARCHITECTURE OF BMS

Meissner and Richter introduced a hierarchical structure for the maintenance, monitoring, and management of battery health. BMS operations are categorized according to monetary considerations. Numerous sensors are integrated into the battery pack to gather information for the monitoring layer. Real-time data collection is conducted to ensure system safety and evaluate battery health. Battery state information, including charge times, discharge strategies, cell balancing, and cell-to-cell thermal management, is also relayed to the user interface.

Thermal monitoring during charging enhances the safety and effectiveness of batteries in Electric Vehicles (EVs). However, until now, no thermal sensing technologies have been able to conduct temperature sensing for battery cells in EVs due to cost, deployment complexity, and/or safety considerations

3.1 PROBLEM IDENTIFICATION

A battery management system (BMS) is an electronic system responsible for ensuring the safe and efficient operation of a rechargeable battery.

The primary function of a BMS is to monitor various parameters associated with the battery pack and its individual cells, utilizing the collected data to mitigate risks and optimize battery performance.

Lithium-ion batteries have become immensely popular and are widely used in portable electronics. However, unlike other battery types such as lead-acid or nickel batteries, lithium-ion batteries have specific requirements for charging parameters.

Failure to control the charging and discharging processes of lithium-ion batteries can lead to premature failure. Overcharging can cause the cells to swell and even explode, while deep discharge can result in battery failure.

3.2 BATTERY MANAGEMENT SYSTEM

The Li-ion cell BMS ensures that the cells in the battery remain within the safe operating limits and it takes action when the cell goes out of the operating limits. A BMS will disconnect loads if the voltage goes too low, and disconnect chargers if the voltage goes too high. It will also check that the voltage of each cell in the pack is the same, and bring down the voltage of any cell that is higher than the others. If the voltage (nominal voltage of 3.7V) of the lithium cell goes beyond 4.0V to 4.5V or below 3V then two things can happen [i] they can burst [ii] their life reduces. A BMS also monitors the temperature and regulates it. Cell balancing, i.e. equalizing the voltages of all batteries in the pack, is done by cell balancing which is broadly classified into 2 categories: passive cell balancing and active cell balancing [4].

From the charge and discharge cycles of Li-ion cell distinct drops and spikes in voltages can be observed. To understand the nature of these charging and discharging cycles the electrical equivalent circuit of the battery has to be modelled correctly. In equivalent circuit model shown in figure 1 passive components (resistors and capacitors) are used to model the behaviour of the battery during charging and discharging durations. From the charging and discharging intervals, sharp increase and decrease in terminal voltages of the Li-ion cell can be observed [1].

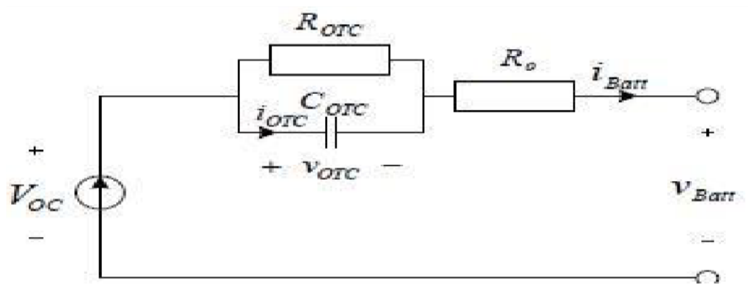

Fig.2 Equivalent Circuit model of a cell with Passive Components

This is the drop due to the internal resistance which can be modelled using a resistor. Internal resistance arises due to the electrochemical reactions inside the battery which resists charge or discharge. The cell voltage drop follows an exponential pattern as observed in [1].To account for the exponential discharge of the cell a parallel RC network is connected in series with internal resistance of the cell. When the charging current is removed, the battery voltage becomes a function of the capacitor voltage whose charge is decaying through the resistor and it follows an exponential pattern. Hence the battery can be modeled using an open circuit dependent voltage source (VOC), in series with an internal resistance (r) and parallel RC network (ROTC and COTC). [1].

3.3 Cell balancing techniques

Cell balancing is the method by which after each charging cycle, the voltages of all the cells in the battery pack are equalized by using passive components. This is either done by discharging the most charged cell or transferring the charge from one cell/pack to another cell. This is very important as any irregularities in the cell voltages after the charging is complete will cause the pack voltage to differ from the nominal value and it will give an inaccurate sense of the SoC of the whole pack [9]. Moreover, if during the charging cycle, cell voltages are not monitored and balanced, it may cause few cells to be overcharged and that may prove to be hazardous.

3.4 Passive cell balancing.

This method uses a resistor to dissipate the energy of the cell with the highest voltage in a series pack. Generally the weakest cell reaches maximum voltage threshold faster for the same current through the rest of the other cells in the pack. When the cell voltage exceeds the SOA (safe operational area), the switch is turned on and cell is allowed to discharge through the resistor also called bleeding resistor as shown in Figure 3, so that the cell voltage and SoC comes down to a safe level. This process is repeated until all the cells have reached the same voltage. The voltage is monitored using voltage monitoring ICs which convert the voltage from analog to digital using A/D converters.

Passive cell balancing, although it is a dissipative method, it is more commercially implemented due to its easier control. Charge and discharge rates of a battery are governed by Crates. The capacity of a battery is commonly rated at 1C, meaning that a fully charged battery rated at 1Ah should provide 1A for one hour. The same battery discharging at 0.5C should provide 500mA for two hours, and at 2C it delivers 2A for 30 minutes. Losses at fast discharges reduce the discharge time and these losses also affect charge times [5 & 6].

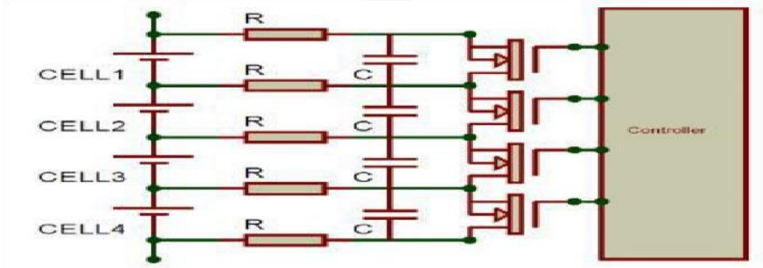

Fig 3. Passive balancing circuit using resistors and capacitors

3.5 Active cell balancing

Unlike passive balancing, active balancing does not dissipate the energy through a resistor; rather it stores or transfers the energy from one cell to other as shown in Figure 4. Switched capacitors do that by storing the energy from a higher voltage cell in a capacitor and then transferring it to another lower voltage cell. In the Flyback topology, as shown in Figure 5, the energy transfer happens by a transformer in which the pack is connected to the primary side of the transformer and each cell is connected individually to the secondary side, which is divided into many parts so as to provide the required voltage to the cells. Now, transformers do not work on DC, hence switches are used to convert constant DC into pulsated DC which activated the transformers

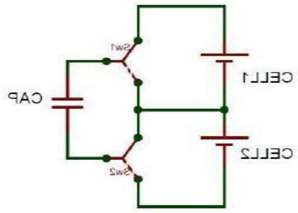

Fig. 4. Switched capacitors

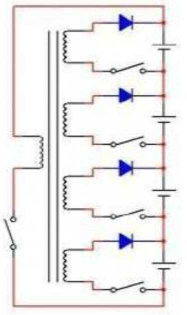

Fig. 5. Flyback Topology

3.6 DESIGN APPROACH

The BMS is implemented using passive balancing approach due to its simplicity and ease of control. Passive balancing uses a resistor, also called bleeding resistor, across every cell to dissipate the charge after the cell is fully charged. This prevents the overcharging of the cell and lets the other cells in the pack (the weaker cells) to get charged to 4.2V. Li-ion batteries are charged using a method called CCCV charging (Constant Current Constant Voltage
Charging). This method supplies constant current to the cell until the cell reaches 4.2V, after which the constant voltage mode starts which maintains 4.2V across the cell and current reduces exponentially. This method makes sure that the cell is fully charged (100% SoC). [5]

3.7 Realistic constraints

The following factors limit the functionality of the battery management system designed.

Faulty voltage measurements of cell (lower accuracy and resolution of the voltage measurement IC, 10mV accuracy is preferred for Li-ion cells).

Floating ground in the vehicle (ground terminal's voltage can vary from 0V to 24V in worst cases), where it becomes difficult to measure the accurate pack voltage, leading to faulty measurements.

Inaccurate SoC (State of Charge) measurement algorithms, which do not take into account the degrading cell capacity with life cycle. This can lead to overcharging or over discharging, thereby causing sub-optimal usage of the pack and potential fire hazards.

Preventing EMI (electromagnetic interference – influence of the magnetic field of one current carrying conductor on an adjacent current carrying conductor and introducing noise in the signals).

Detecting short circuit or open circuit faults.

Li-ion cells tend to degrade in terms of charge holding capacity/SoC with age. On an average Li-ion cells function optimally for 3-4 years, but sophisticated BMS can extend that up to 8-10 years.

Redundancy in BMS is a very important feature which ensures essential functioning even when a system fails, but this also increases the complexity and size of the circuit.

3.8 ALTERNATIVES AND TRADEOFFS

The alternative to passive balancing could be active balancing or Flyback topology. Alternative 1: Active Balancing

- Charge from higher voltage/higher SoC cells is stored inside a capacitor and transferred to a low voltage/low SoC cell.
- Charge can only be transferred from adjacent cells.
- Experimental method, not very commonly implemented.

Trade off: Expensive to implement, more complex control.

Alternative 2: Flyback Topology

- Charge is transferred from the pack to the weaker cells using a transformer.
- The pack transformer is the primary side, and the transformer attached to each cell is the secondary side.
- By switching MOSFETs at high frequencies, the transformers are activated and the energy from the pack is transferred to the weak cells.

Trade off: Complex control, circuit bulky due to the use of transformers.

3.9 Design specifications

The design specifications such as cell type, number of cells considered, capacity of each cell, nominal voltage, charging current, balancing technique and charging method of the Lithium ion Cell are given in the Table 1. The BMS for the specification listed in Table 1 is developed in the MATLAB/Simulink environment.

Table 1: Design Specifications of Lithium ion cell = 1h

In reality, charging time is almost double due to constant voltage mode of CCCV charging (discussed in chapter 4). Bleeding resistor value = 30 ohms (generally in the range of 25-40 ohms)

Bleeding current = Voltage of cell/bleeding resistor = 4.2/30 = 0.14 A

Power dissipated in the resistor over one cycle = I2 R=(0.14)*(0.14)*30 = 0.588 W

This power loss in each resistor is compensated by the charging current, hence for a large battery pack, passive balancing can prove to be a highly dissipative.

Table 1: Design Specifications of Lithium ion cell

Parameter	Detail
Type of cell	Lithium Ion cell
Number of cells	1/4
Capacity of each cell	1300mAh
Nominal voltage	3.7V
Charging current	1.3A (1C)
Balancing technique	Passive balancing
Charging method	Constant current Constant voltage

Analytical Calculations

Capacity of battery = 1300 mAh = 1.3Ah (1000 mAh = 1 Ah)
Charging current = 1.3A (according to datasheet charging current should be 1 C (c-rating), hence in this case Icharge = 1C*1300mAh = 1.3A)
Time taken to charge = Capacity/charging current = 1.3/1.3 = 1h

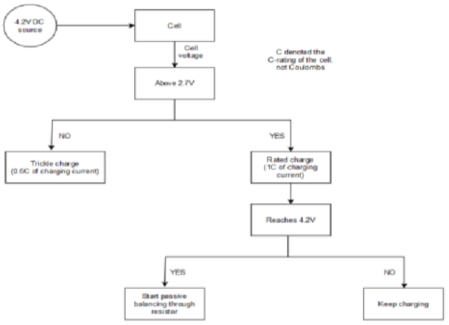

Fig. 6. Flowchart of passive balancing of single cell

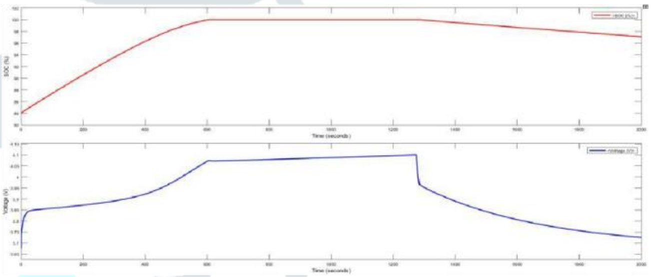

Fig. 7. SoC and Voltage graphs of passive balancing of single

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IV SIMULATION RESULTS

This section presents the simulation results of passive balancing circuit in detail using Simulink.

As seen in Figure 6, a single cell is connected to a 4.2V DC voltage source. First it is checked if the cell is above 2.7V. If it is lower than 2.7V, it is initially charged by a method called trickle charge, which is supplying a very low current (0.5C) to bring up the voltage of the cell. Once the voltage of the cell reaches 2.7V, it can be charged using the rated charging current (usually 1C). A passive balancing bleeding resistor is placed in series with the cell. If the cell voltage goes beyond 4.2V, the charging switch is turned off and the balancing will turn on.

This way the charging will stop and the cell will start discharging through the resistor till the voltage reaches a safe voltage. The sudden voltage drop, as observed in Figure 7, when the balancing switch is turned on is due to drop across the internal resistance which appears as –IR, hence the terminal voltage becomes Vterminal = VOCV – Icharge*R [1]. (Note: CCCV mode has not been implemented in this circ

4.1 BALANCING OF 4 CELLS IN SERIES

seen in Figure 8 the voltages of all the 4 cells are checked to see if they cross 4.2V. The output of the cell voltages blocks is As given to an OR gate, which gives output 1 if anyone of the voltages exceeds 4.2V. Output of the OR gate will be 1 if any one of the cell is crossing 4.2V. As soon as that happens, the charging switch S is turned off and that particular cell's energy is dissipated through a resistor. Figure 9 shows the circuit, where the 4 cells are connected to individual resistors for passive balancing.

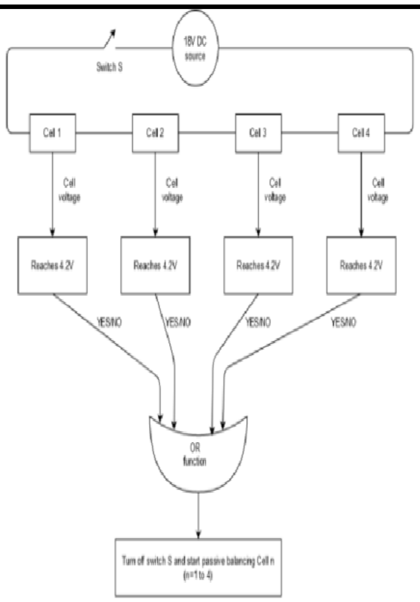


Figure 8. Flowchart showing the logic of passive balancing 4 cells in series

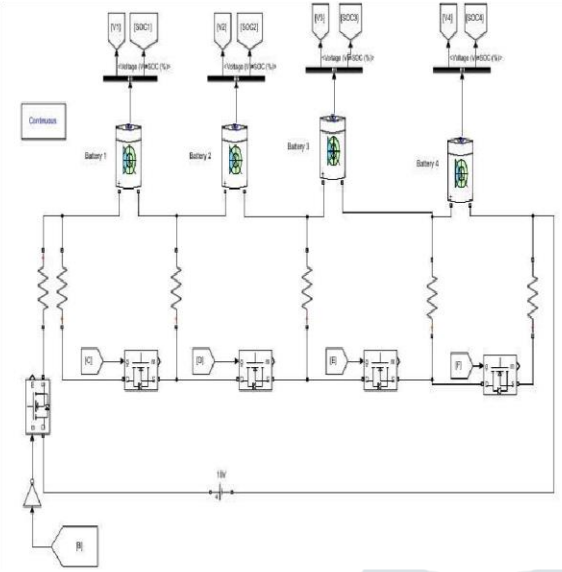


Figure9. Circuit of passive balancing 4 cells in series usin SIMULINK

Figure 10 and Figure 11 present the voltage and SoC graphs of the 4 cells, with the break point being the turning off of the charging switch. Similar approach i implemented in battery management integrated chips in which the voltages are measured and compared using comparators and appropriate action is taken.

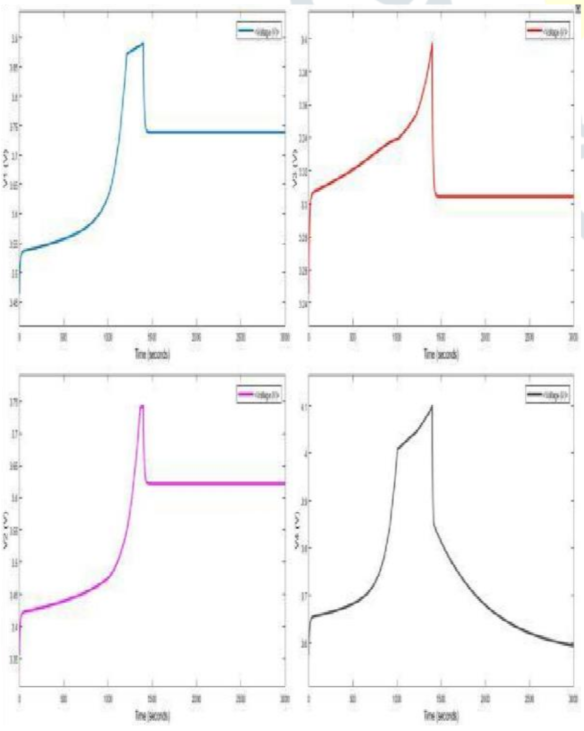


Figure10. Voltage graph of passive balancing of 4

Constant current constant voltage (CCCV) charging

In Figure 12, cell is connected to a constant current source which supplies 1C of current to the cell and the cell voltage rises. Once the voltage reaches 4.2V, it is switched to constant voltage mode as the current is exponentially reduced to 0. This ensures that the cell is fully charged. Figure 13 shows the voltage, SoC, charging current and switch graph of the circuit, in which the break point shows the point of switching over to constant voltage mode. [3]

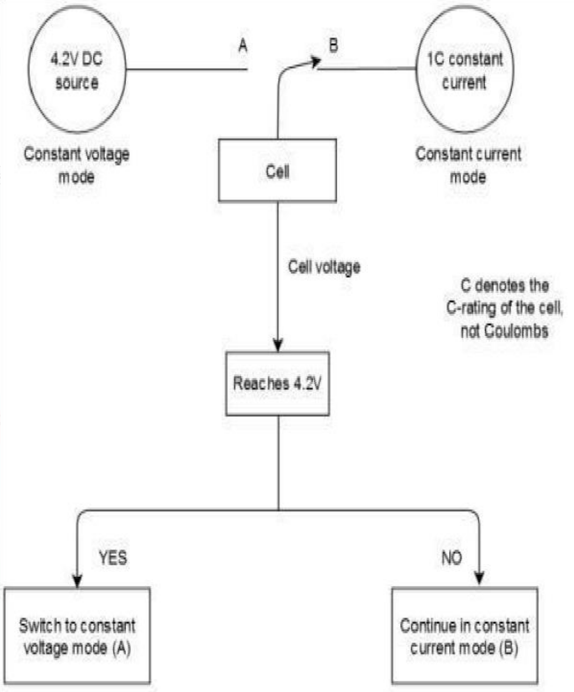
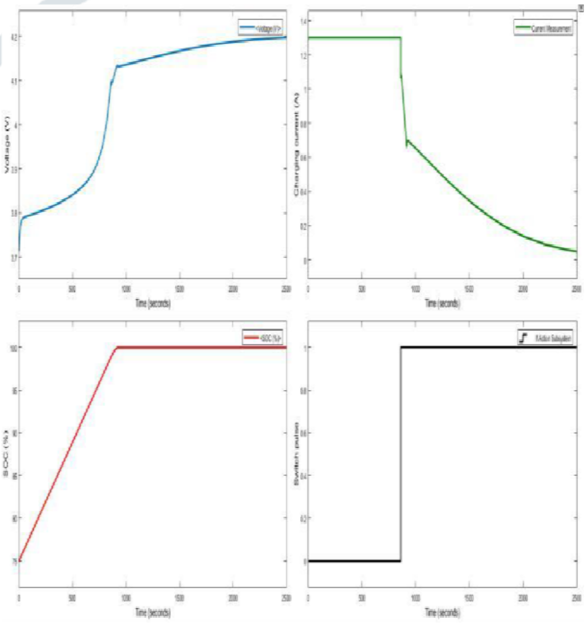


Fig.12. Circuit for CCCV charge with constant voltage source and constant current source



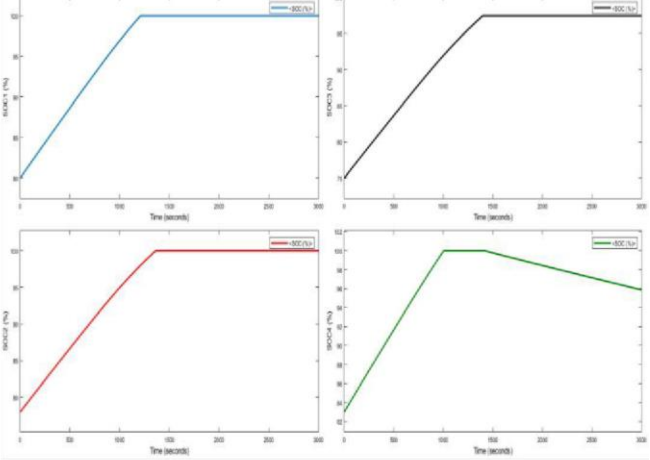


Figure 11. SoC graph of passive balancing of single cell Fig.13. Simulation of CCCV charge

4.2 ADVANTAGES

Advantages of battery management systems in EVsA BMS enhances the life span of the battery cells in EVs.
This is an effective system to measure and control the cell's voltage.
It provides stability and reliability.
It ensures the safety of the battery pack, especially large format lithium-ion batteries. It optimizes the performance of the electric car battery.
It monitors the battery cells constantly to avoid the occurrence of failure or explosion.

V CONCLUSION

This paper presented the basics and importance of battery management systems in a Li-ion battery pack. This is followed by battery modelling using equivalent circuit and the charge and discharge graph, which is explained with the help of the equivalent circuit model. Then the cell balancing techniques are discussed with major focus on passive balancing (switched resistor). The trade-offs of using active balancing are discussed so as to give a clear understanding of why passive balancing is chosen. MATLAB/Simulink modelling of single cell and four cells, with their charge and discharge graphs are discussed after balancing techniques. Finally, the charging method for Li-ion battery packs is discussed and it is highlighted as to why this method is the required to charge Li-ion battery packs.

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