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Design and Analysis of Battery Management System for Electric Vehicles

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Abstract: The capacity of a system for battery management (BMS) to evaluate the general condition of the battery pack is one of its most important features. The BMS monitors the capacity of the weakest cell and the internal resistance of each cell. Based on these variables, it calculates a cell healthiness percent that ranges from 0% to 100%. A fault code is created and freeze frame data is kept for later examination if any cells or the entire pack fall below the predetermined criteria when this health data is assessed against them. Numerous functions on the BMS are designed to protect the battery pack. These systems use techniques to make sure the battery lasts longer and is ready to give full power when needed, in addition to continuously monitoring and safeguarding it. The BMS extends the life of the battery pack and improves its performance by carefully controlling cycles of charging and discharging, balancing cell voltages, and guarding against situations that could harm the battery. This guarantees dependable operation and maximum efficiency.
Keywords: State on charge (SOC), simulation, electric vehicles, batteries management systems, and open circuit value (OCV).

I. INTRODUCTION

Because of their effectiveness, advantages for the environment, and smaller carbon footprint, electric vehicles (EVs) are becoming more and more popular.

As a result, systems for managing batteries (BMS) have received a lot of attention. An EV's total performance is greatly impacted by the charging and discharge procedures of the battery pack, and must be managed by a BMS. A well-thought-out BMS guarantees the durability, security, and maximum performance of the battery.

This paper presents an Arduino-based battery management system (BMS) designed specifically for electric vehicles, enabling battery pack control and real-time monitoring. The project's main goal is to increase battery operations efficiency, which is an important factor that may be applied in a variety of industrial and automotive contexts.

Electric cars (EVs) are becoming a more viable option for environmentally friendly transportation. The limited travel range of EVs, which is mostly dependent on the quantity and condition of the battery, is a major drawback. Thus, keeping an eye on the battery's condition is essential to guaranteeing the dependable and effective operation of EVs. To provide real-time device monitoring & remote control has attracted significant attention in recent years from a variety of industries, including the automotive one.

The integration of the Internet of Things (IoT) in electric vehicles (EVs) holds potential for enhancing user experience, efficiency, and battery lifespan. This paper proposes a charge monitoring system for electric vehicles based on IoT technology. The system comprises a cloud server, a wireless communication module, a central processing unit (CPU), and battery monitoring sensors. The microcontroller collects voltage, current, and temperature readings from the battery sensors. It then processes this data and transmits it wirelessly to a cloud server for further analysis.

The cloud server then stores and examines the data to determine the battery's state. By monitoring the battery's state in real time, the suggested approach helps extend its lifespan and optimum its performance. The data from the system can also be used to forecast how much spectrum the electric car will have remaining, which helps drivers plan their trips more effectively.

The proposed concept aims to create a system for managing batteries (BMS) specifically designed for electric cars (EVs), guaranteeing the battery pack's safe and effective operation. This battery management system (BMS) will control the charging and discharge procedures and monitor the temperature, voltage, and state of charge of every cell in the battery pack. It will also give the driver up-to-date information on the condition of the battery. The BMS's architecture will be modular, allowing for easy connection with a range of EV models.

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II. PROBLEM IDENTIFICATION

1) An electrical system called a battery management programme (BMS) is in charge of making sure a rechargeable battery operates safely and effectively. The primary responsibility of a system for managing batteries is to monitor various parameters related to individual battery packs and cells. After that, it makes use of the data it has gathered to reduce risks and increase battery efficiency.
2) Lithium-ion batteries are quite common and are utilised in many portable electronics. On the other hand, lithium-ion batteries have particular needs for charging parameters, in contrast to other battery types as lead-acid and nickel batteries.
3) Premature failure of batteries powered by lithium ion can occur if the procedures for charging and discharging are not controlled. Deep discharging can lead to battery failure, while overcharging may allow the cells to bulge and possibly explode.

III. ARCHITECTURE OF BMS

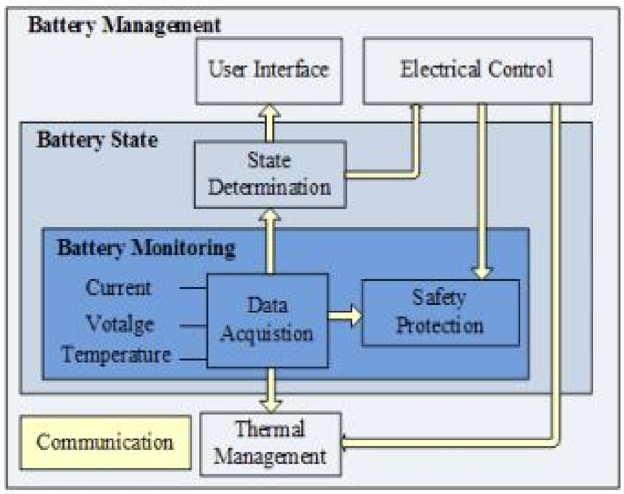

Fig.1. BMS architecture

Meissner and Richter developed a hierarchical system for managing, overseeing, and maintaining battery health. BMS activities are categorised based on financial considerations. Several sensors are integrated into the battery pack to gather information for the monitoring layer. Information is gathered in real-time to ensure system safety and evaluate battery health. Battery condition information, information is also sent to the user the interface, including charge times, discharge plans, cell balancing, or cell-to-cell heat under control. Thermal monitoring during charging enhances battery efficiency and safety in electric vehicles (EVs). Unfortunately, no thermal sensing device has been able to assess the battery the cell's temperature in electric cars (EVs) up until now due to deployment complexity, expenses, and/or safety concerns.

IV. BATTERY MANAGEMENT SYSTEM

The Li-ion unit Battery Maintenance System (BMS) steps in to make sure each cell stays within predetermined bounds when it surpasses safe operating constraints. The BMS will shut down loads if a cell's energy falls too low and will turn off the chargers if the voltage increases too high. Furthermore, by decreasing the voltage of every cell that surpasses the others, the BMS balances the power across all of the cells. If the nominal voltage of lithium cells is lower than 3V or exceeds 4.5V, there is a risk of an explosion and a shorter lifespan. In addition, the BMS controls and keeps an eye on temperatures to ensure security. There are two types of cell balancing: passive cell balance and active cell balancing. Cell balancing is crucial because it ensures the voltage for every battery in the packs [4].

A Li-ion cell's charges and discharges show a variety of voltage spikes and decreases. It is essential to model the electrical equivalent circuit of the battery in order to comprehend these cycles with accuracy. Passive parts such resistors and capacitors are used in this modelling to mimic the behaviour of the battery during these times. The terminal voltage fluctuations of the Li-ion cell during the charging and discharge intervals are accurately captured by the equivalent circuit model. This method helps clarify the changing characteristics that govern the battery's functioning [1].

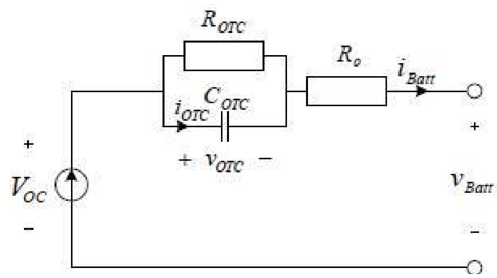

Fig. 2. An equivalent circuit model featuring passive components for a cell

The electrochemical processes that obstruct both charging and discharging result in a reduction in voltage caused by a battery's internal resistance, which is symbolised by a resistor. The pattern of this voltage drop is exponential. The parallel RC (resistor-capacitor) circuitry is linked in series with the internal resistance of the battery to replicate this behaviour. The battery voltage increases in direct proportion to the capacitor the voltage, which falls through the resistor, when the current used for charging is cut off. Therefore, it is possible to simulate the behaviour of a battery using a parallel RC system in conjunction with a series resistant plus a voltage-dependent supply (VOC) (ROTC and COTC). [1].

A. Methods of Cell Balancing

Cell balancing is the process of using passive components to balance the electrical charges in each of the energy pack's cells after each charging cycle. The most charged cell is either discarded or the charge is moved from 1 unit/pack to another. This is crucial because, once charging is finished, any anomalies in the cell energy will cause the pack voltage to deviate from the desired value, which will result in an inaccurate estimation of the SoC for the entire pack [9]. Furthermore, if cell tensions have not been correctly balanced or maintained throughout a charge cycle, a small number of cells could get catastrophically overcharged.

B. Balance of Passive Cells

In order to distribute energy among the cells in a number configuration with the highest voltage, this method uses a resistor. When every cell in the battery receives the same degree of current, the weakest cell usually approaches the maximum pressure limit first. A discharge resistor, sometimes referred to as a bleeding a resistor is used to allow a cell to discharge when its voltage beyond the safe operating zone (SOA). The cell continues to do this until its current and state of charging (SoC) decrease to a safe level. Until all of the cell voltage are equivalent, this process is repeated. Integrated circuits (ICs) for monitoring voltage levels are utilised, and analog-to-digital (A/D) converters are used to convert analogue voltage to digital for precise measurement.

Despite being a dissipative technology, passive cell balance has a higher popular in the corporate sector due to its ease of use. C-rates control the battery's charge and discharge rates. A battery's functionality is often rated as 1C, which indicates that an hour's worth of power should be provided by an entirely charged battery rated as 1Ah. 500mA should be provided by the same battery that is depleted at 0.5C per a full hour followed by at 2C for 30 seconds. Charge and discharge times are impacted by rapid discharge losses [5 & 6].

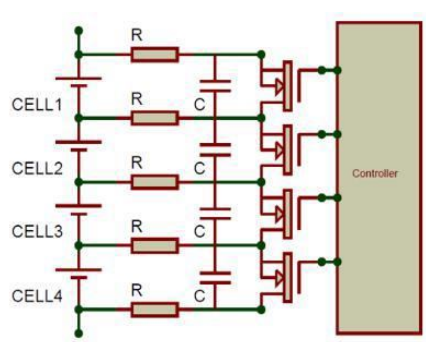

Fig. 3. Circuit for passive balancing with resistors and capacitors

C. Active Cell Balancing

Active balancing includes storing or transmitting energy from one cell to another, as opposed to passive dissipation through resistors. Switched capacitors, which gather energy from a cell having a higher voltage and subsequently transfer it to a cell having a voltage that is lower, can be used to achieve this. This approach is illustrated in Figure 4. Furthermore, energy transfer with a converter in a Flyback architecture is depicted in Figure 5. To guarantee that every cell receives the proper voltage, in this configuration the pack is linked to the transformer's primary side and each cell is attached to a separate section of the secondary side. Switches are used to change continuous DC into pulsing DC so that transformers can function because they are unable to operate on continuous direct current (DC).

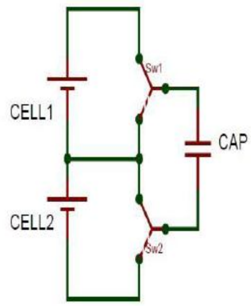

Fig. 4. Switched capacitors

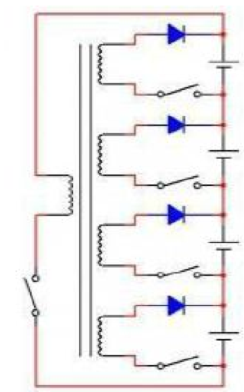

Fig. 5. Flyback Topology

V. DESIGN APPROACH

Because of its simplicity and controllability, the system that manages batteries (BMS) is built with a passive balancing technique. A resistor known as a bleed resistor is positioned across each cell in passive balancing. This resistor drains the power source once the cell gets full charge, avoiding overcharging and allowing less powerful cells within the group for charging beyond 4.2V. It is common practice to charge lithium-ion batteries with the Constant Current Consistent Voltage (CCCV) method. This technique makes sure the battery stays at 4.2V until the battery reaches an equilibrium state by keeping a constant voltage although the current drops exponentially. By using this method, the battery is guaranteed to reach a full charge [5].

A. Realistic Constraints

A number of variables restrict the battery management system's (BMS) intended functionality:

Unreliable Voltage Measurements: Battery cell voltage readings that are too high or too low can impair BMS functionality. A lower precision voltage measuring circuitry (IC), ideally with an accurate measurement of 10 mV, is recommended for Li-ion packs.

Floating Ground in Cars: Vehicles have floating ground, which can make it difficult to measure pack voltage accurately and lead to inaccurate readings. Measurements may become erroneous due to high fluctuations in the grounding point voltage, which can range from 0V to 24V.

State of Charges (SoC) methods that are ineffective While some methods measure the SoC accurately, they do not take into consideration the cells' gradual capacity decline. This mistake could result in overcharging or over discharging, which would lower a battery pack's efficiency and raise the possibility of a fire.

In order to maximise the battery management system's (BMS) efficiency, the following elements must be taken care of:

Keeping away from electromagnetic interference (EMI) When the magnetic fields of two conductors collide—one carrying current, one carrying no current—EMI results. To preserve accurate data transfer and system performance, it's critical to limit electromagnetic interference (EMI), as it has the potential to distort transmissions.

Finding Problems with Open or Short Circuits: To guarantee safety and correct functioning, the BMS must be able to recognise and handle open or short circuit issues within the battery pack.

Taking Care of Ageing Li-ion Batteries: Over time, Li-ion batteries lose some of their capacity to hold a charge and status of charge (SoC). Advanced BMS can efficiently manage the ageing process to extend the optimal lifetime of Li-ion cells, which is typically 3–4 years.

Making Certain Reliability Maintaining important operations in the event of a system failure requires a dependable BMS. On the other hand, increasing circuit complexity and size frequently results in improved reliability.

The BMS can more successfully maintain the battery's longevity, safety, and performance by taking care of these factors.

B. Alternatives and Tradeoffs

Flyback topology or active balancing could be used as an alternative to passive balancing.

Option 1: Dynamic Equilibrium

• A capacitor stores the charge from greater voltage/higher SoC unit and transfers it to a low voltage/low SoC unit.

The only cells that can transfer charge are those that are adjacent.

• The unusual deployment of an experimental strategy.

Trade-off: More expensive to implement but more challenging control.

The backup strategy is called Flyback Topology.

• A transformer is used to transmit charge from the pack through the weaker cells.

• The transformer that links with each cell is on the other side of the cell, and the pack converter is on the main side.

• To move energy from the battery packs to the weak cells, MOSFETs operate at high frequencies when the converters have to be on.

Trade-offs include a huge, bulky circuit due to the transformers and complex control.

C. Design Specifications

Table 1 lists all of the important specifications for the design of the Lithium-Ion cell, including cell type, amount, capacity per cell, maximum voltage, recharging current, balancing technique, and charging methodology. Within the MATLAB/Simulink environment, the Battery Management System (BMS) is being developed for the standards listed in Table 1.

Table 1: Design parameters for a lithium-ion battery

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

D. Analytical Calculations

The battery has a capacity of 1,001 mAh x 1 Ah (1,300 mAh x 1.3Ah).

Charging current = 1.3A; in this instance, Icharge = 1C*1300mAh = 1.3A because the datasheet states that the current used for charging should be 1 C (c-rating).

One hour, approximately 1.3/1.3 (capacity/charging current), is needed for charging.

In fact, with the constant voltage technique known as CCCV charging, the charging time almost doubles (see chapter 4).

The bleeding resistor has a value of 30 ohms (often around 25 and 40 ohms).

The bleeding current is equal to 4.2/30 = 0.14 A (voltage on cell/bleeding resistance).

One cycle's worth of power lost in the resistor is equal to I2 R = (0.14) * (0.14) * 30 = 0.588 W.

With a large battery pack, passively balancing can be highly dissipative because the charging current makes up for each resistor's energy loss.

VI. SIMULATION RESULTS

This section provides a detailed presentation of the results of the Simulink simulation for the passive balance circuit.

A. Balancing of Single Cell Circuit

One cell is linked to a 4.2V DC (direct current) supply, as seen in Figure 6. First, the voltage of the cell is measured to see if it is higher than 2.7V. A technique called trickle charging is used if the voltage drops below 2.7V. In this method, an extremely small current (0.5C) is used gradually to raise the voltage. The battery can be recharged at the highest permitted current rate, usually 1C, after the voltage hits 2.7V. A passive bleed resistors is attached in series wit the cell to balance the voltage across it and guarantee balance. The electrical charging circuit is turned off and the balancer is triggered when the voltage of the cell exceeds 4.2V.

Once the voltage reaches a safe level, the cell stops charging in this manner and starts discharging through the resistor. When the balancing switches activate, there's a discernible voltage drop, illustrated in Figure 7. This drop is due to a reduction in the internal resistance of the switch, denoted by the symbol -IR. Consequently, the terminal voltage is determined by the formula V_terminal = V_OC - I_charge * R [1]. (Note: This circuit does not employ the CCCV mode.)

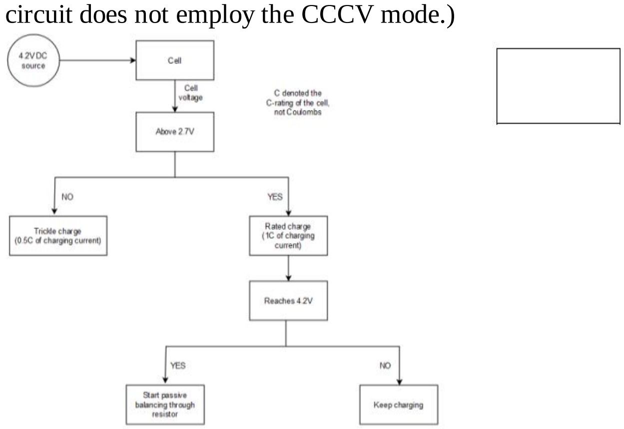

Fig. 6. Diagram showing how to balance a single cell passively

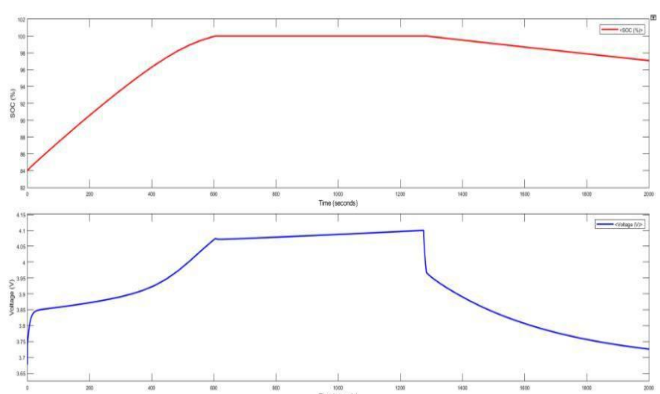

Fig. 7. SoC & Voltage graphs for single-phase passive balancing

B. Four Cells Balancing in Series

Each of the four cells in question has its voltage checked to see if it rises beyond 4.2V, as shown in Figure 8. An OR gate receives the outputs of the voltage block of the cells, and if any of the readings are less than 4.2V, an output of 1 is produced. The OR gate produces 1 if any cell exceeds 4.2V. The battery charge switch designated as S is then switched off and the power from that particular cell is released via a resistor. The passive balance circuit, which links the four cells to different resistors, is shown in Figure 9.

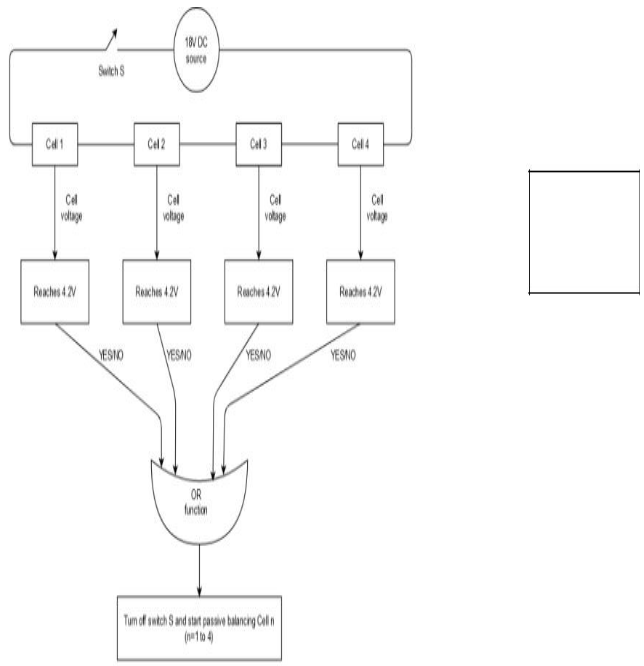

Figure 8. Diagram illustrating the reasoning behind passively balancing four cells in series

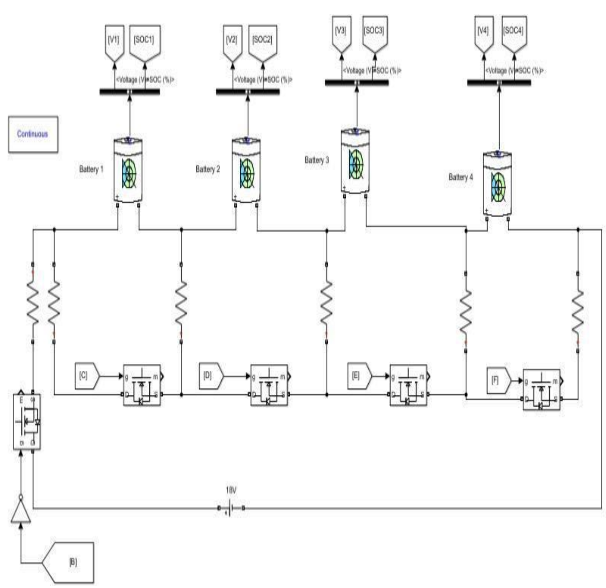

Figure 9. Circuit for four series cells to be passively balanced using SIMULINK

The voltage & SoC graphs for each four cells are shown in Figures 10 and 11, with the switching off of the power button serving as the break point. Battery control integrated chips use a similar method, measuring and comparing voltages with comparators before taking the necessary action.

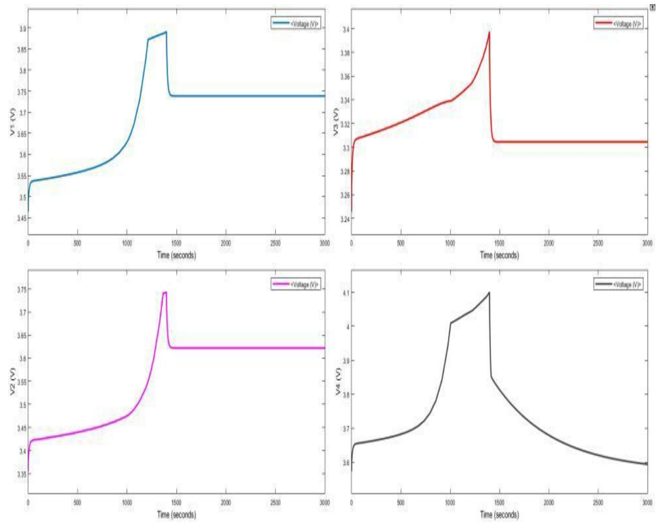

Figure 10. Voltage graph for four cells that are passively balanced

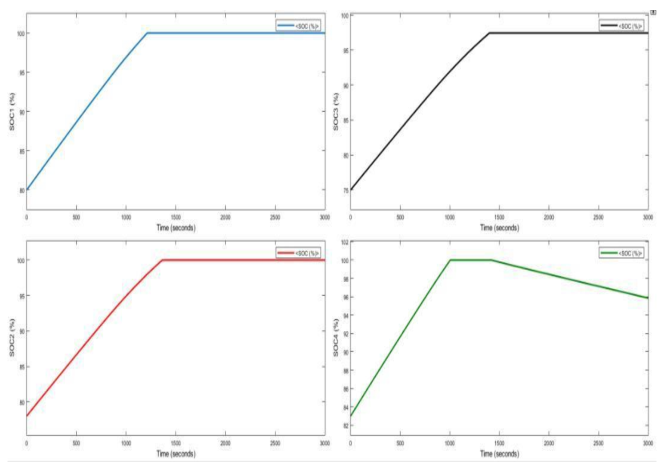

Figure 11. SoC diagram for a single cell's passive balancing

C. Charging with Constant Current, Constant Voltage, or CCCV

The cell shown in Figure 12 receives 1C of current and increases in voltage when connected to a continuous current source. The system quickly lowers the current to zero and enters constant voltage mode as soon as the voltage reaches 4.2V, guaranteeing that the cell is fully charged. Figure 13 shows the circuit's voltage, charging current, State of Charging (SoC), and switch graph. The breakpoint in the circuit predicts when it will go into constant voltage mode. [3]

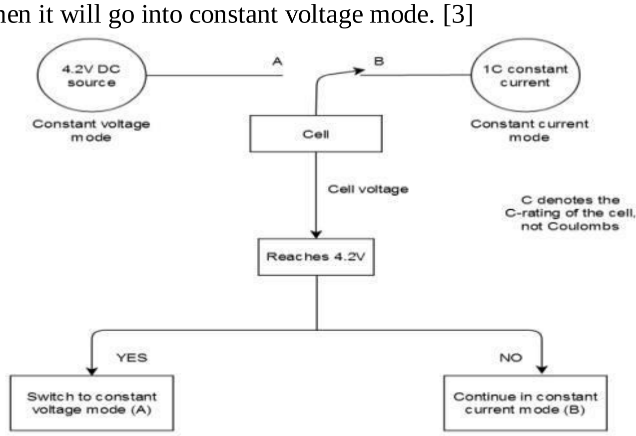

Fig.12. Constant voltage and constant current sources are used in this CCCV charging circuit.

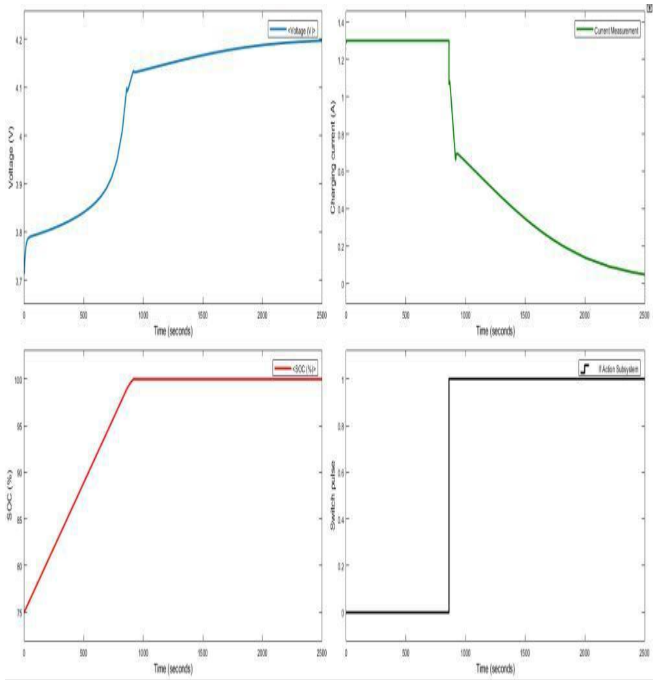

Fig.13. CCCV charge simulation

The first section of the paper explains the fundamentals and importance of systems for managing batteries for Li-ion batteries. It then presents an analogous battery circuit model and describes the charge and discharging profiles that make use of this model. After that, the topic of cell balancing strategies is covered, with an emphasis on passive balancing with switched resistors. In order to provide light on the decision between both active and passive balancing techniques, the paper explores the trade-offs related to active balancing. After that, it discusses MATLAB/Simulink simulations of single-cell and four-cell setups, displaying profiles of charging and discharging. The study continues by examining the lithium ion battery pack recharging procedure and highlighting its significance for the management of batteries.

VII. ADVANTAGES

1) Benefits of EV battery management systems BMS extends the battery cells' lifespan in electric vehicles.
2) This method of measuring and regulating the voltage of the cell works well.
3) It offers dependability and steadiness.
4) It guarantees the safety of the battery pack—large format lithium-ion batteries in particular.
5) It enhances the electric car battery's performance.
6) It continuously checks the battery cells to prevent failure or explosion.

VIII. CONCLUSION

A system for managing batteries is required for electric cars and other systems that use rechargeable batteries (BMS). To ensure the longevity and safety of batteries, a BMS's main job is to supervise, control, and optimise the charging and discharge procedures. A well-designed BMS can prolong the battery's life, improve performance and dependability, and reduce the risk of catastrophic failures like fire or explosion. Therefore, a BMS is essential to the long-term growth of energy storage and electric vehicles.

By addressing heat-related problems, the suggested method improves battery efficiency and provides a financially viable alternative for battery management. The BMS is also very economical and dependable. The foundation for figuring out the battery's charging and discharging properties is the MATLAB/Simulink technique used in this project. It makes it easier to browse through requirements, generated software, tests, and projects. It also makes it easier to annotate diagrams with relevant needs. The algorithm also helps with building drag-and-drop links and researching requirements and traceability. It is essential for identifying modifications to associated tests, diagrams, and specifications. In compliance with the standards, it also computes the performance or verification status. In order to accurately represent the electrical system, Simulink and the simulation technique are needed.

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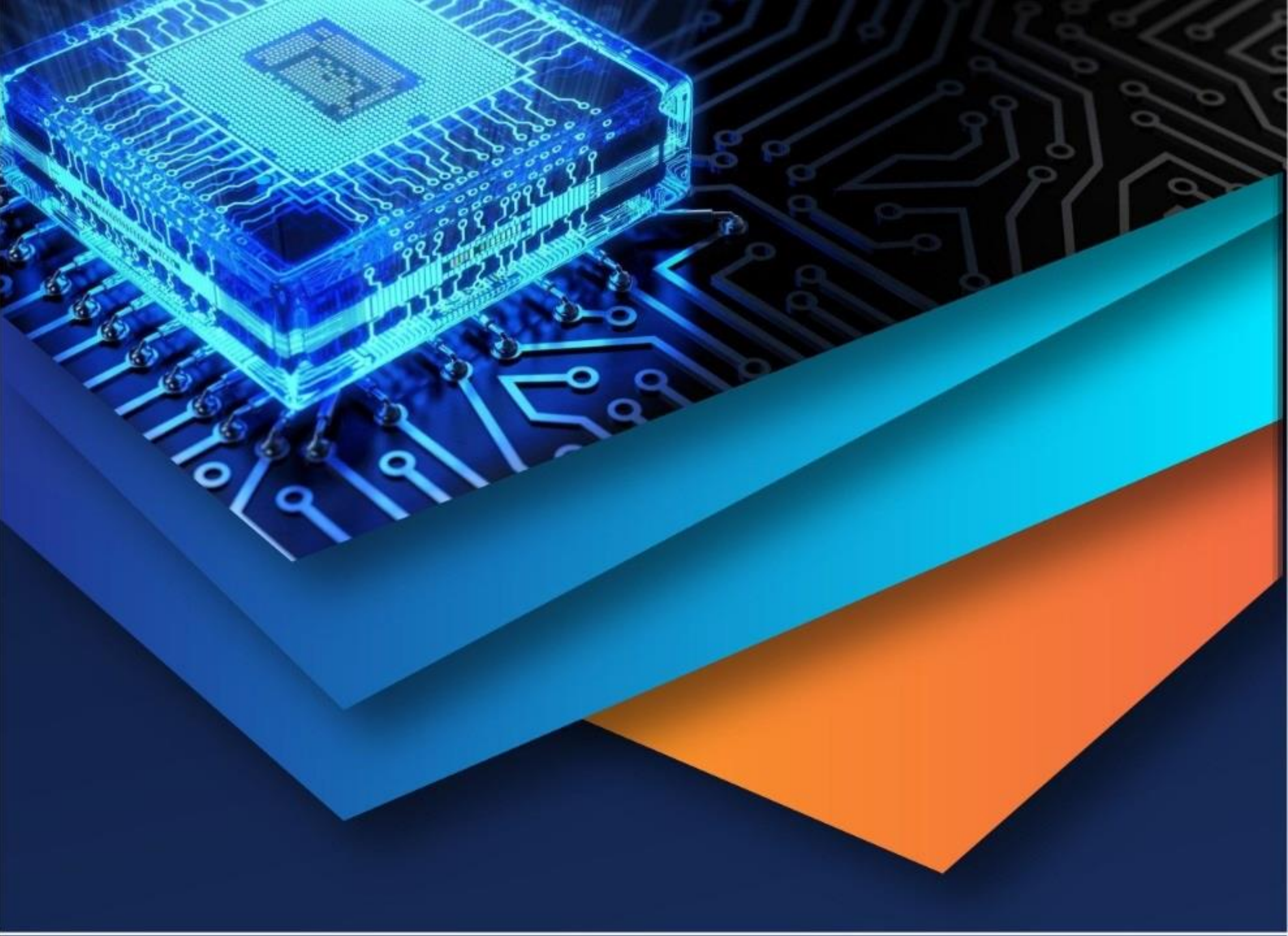

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