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Review on Comprehensive Design and Analysis of Battery Management Systems for Next-Generation Electric Vehicles

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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.

I. 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.

II. PROBLEM IDENTIFICATION

1) A battery management system (BMS) is an electronic system responsible for ensuring the safe and efficient operation of a rechargeable battery.
2) 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.
3) 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
4) • 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.

III. OBJECTIVES

A. Aim

The objective of this project is to enhance the reliability and performance of electric vehicles (EVs) by guaranteeing the safe and efficient operation of their battery packs.

B. Objectives

1) Cell Protection: One of the primary functions of the Battery Management System (BMS) is to provide cell protection, which can be external to the battery.
2) Charge Control: BMS plays a crucial role in charge control, as inappropriate charging is a leading cause of battery damage.
3) Demand Management: Although not directly related to battery operation, demand management pertains to the application in which the battery is utilized.
4) Monitoring Battery Parameters: The BMS is responsible for monitoring various battery parameters, including voltage, current, temperature, and state of charge (SoC), to ensure optimal performance and prevent overcharging or over-discharging.

IV. LITERATURE SURVEY

The availability of energy resources for conventional vehicles, such as gasoline, is limited, leading to high costs due to high demand for finite sources. Studies indicate that reserves of oil, coal, and natural gas may be depleted within the next 200 years. Consequently, modern automotive research is focusing on reusable energy sources, such as electric vehicles (EVs).

Another critical consideration driving the need for EVs and battery management systems (BMS) is the issue of CO2 emissions from conventional vehicles. The emissions generated by conventional vehicles contribute to global warming, leading to adverse effects such as rising global temperatures, sea levels, negative impacts on ecosystems, and extreme weather events.

Research indicates that EVs produce significantly fewer emissions compared to conventional gasoline-powered internal combustion engines, even when considering that electricity used to power EVs may be generated from coal. Additionally, renewable energy resources such as wind, solar, and battery power produce minimal to no emissions. Despite the clear environmental advantages of EVs, the question arises as to why the industry is not yet dominated by battery vehicles.

A study by Zhang et al. (2021) A battery management system was proposed for an electric vehicle, incorporating voltage and current sensors, along with a temperature sensor and a microcontroller for data acquisition and analysis. This system aimed to monitor the state of charge and temperature of the battery, activating a cooling system when the battery temperature surpassed a safe threshold. The research concluded that the implemented system effectively regulated the battery temperature, thereby enhancing the overall battery performance.

In another study, Liu et al. (2020) A battery management system tailored for electric vehicles was proposed, integrating an Arduino microcontroller, voltage, and current sensors, along with a wireless communication module for data transmission. The system's primary objective was to monitor the battery's state of charge, health, and temperature, while also providing real-time data to drivers or fleet operators through a mobile application. The research concluded that the implemented system significantly enhanced battery efficiency and safety, while also offering valuable insights for vehicle operators.

A paper by Saha et al. (2020) The development of a battery management system for an electric rickshaw was explored, incorporating voltage and current sensors, a microcontroller, and a temperature sensor. The primary purpose of this system was to monitor the battery's state of charge, temperature, and health, and to trigger a cooling system if the battery temperature surpassed a safe limit. The research concluded that the implemented system significantly enhanced the battery's overall performance and reliability.

Another study by Ghaffari et al. (2019A battery management system for an electric vehicle was proposed, integrating a current sensor, voltage sensor, temperature sensor, and microcontroller for data acquisition and analysis. The system aimed to monitor the battery's state of charge, temperature, and health, and to trigger a cooling system if the battery temperature surpassed a safe threshold. The research concluded that the implemented system effectively improved the battery's overall performance and safety while extending its lifespan.

In a different study, Khan et al. (2019) A battery management system was suggested for electric vehicles, employing a microcontroller, voltage and current sensors, and a GSM module for data transmission. The system's purpose was to oversee the battery's state of charge, health, and temperature, and to deliver real-time data and alerts to vehicle operators or fleet managers through SMS. The research determined that the proposed system significantly enhanced battery efficiency and reliability, offering valuable insights for vehicle operators.

A study by Kasmi et al. (2019) A battery management system was proposed for electric vehicles, utilizing a current sensor, voltage sensor, and a microcontroller for data acquisition and analysis. The system's objective was to monitor the battery's state of charge, health, and temperature, while also triggering a cooling system if the battery temperature surpassed a safe threshold. The research concluded that the proposed system effectively regulated battery temperature and prolonged battery lifespan.

V. ARCHITECTURE OF BMS

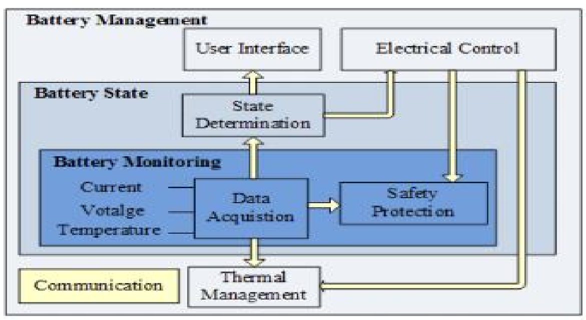

Fig.1. Architecture of BMS

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.

VI. 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].

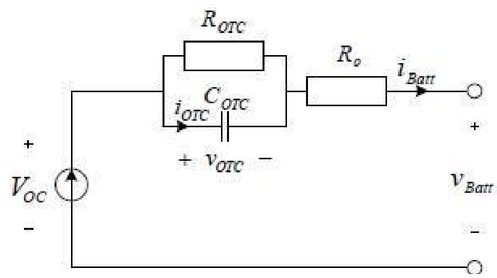

Fig. 2. Equivalent Circuit model of a cell with Passive Components

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].

A. 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.

B. 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 C-rates. 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].

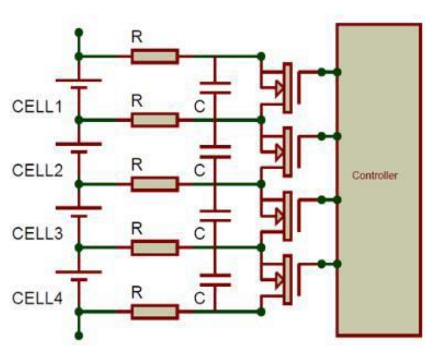

Fig. 3. Passive balancing circuit using resistors and capacitors

C. 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.

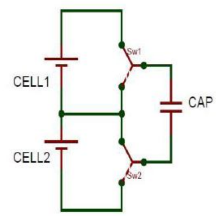

Fig. 4. Switched capacitors

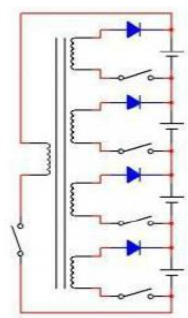

Fig. 5. Flyback Topology

VII. ADVANTAGES

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

VIII. CONCLUSION

Electric vehicles and other systems utilizing rechargeable batteries necessitate a battery management system (BMS). The primary function of a BMS is to oversee, regulate, and optimize the charging and discharging processes of batteries, ensuring their longevity and safety. A well-engineered BMS can enhance the performance and reliability of the battery system, extend the battery's lifespan, and mitigate catastrophic failures such as fire or explosion. Thus, a BMS plays a critical role in the sustainable development of electric transportation and energy storage.

The proposed approach offers a cost-effective solution for battery management by addressing heat issues, thereby improving battery efficiency. Moreover, the BMS is highly dependable and cost-efficient.

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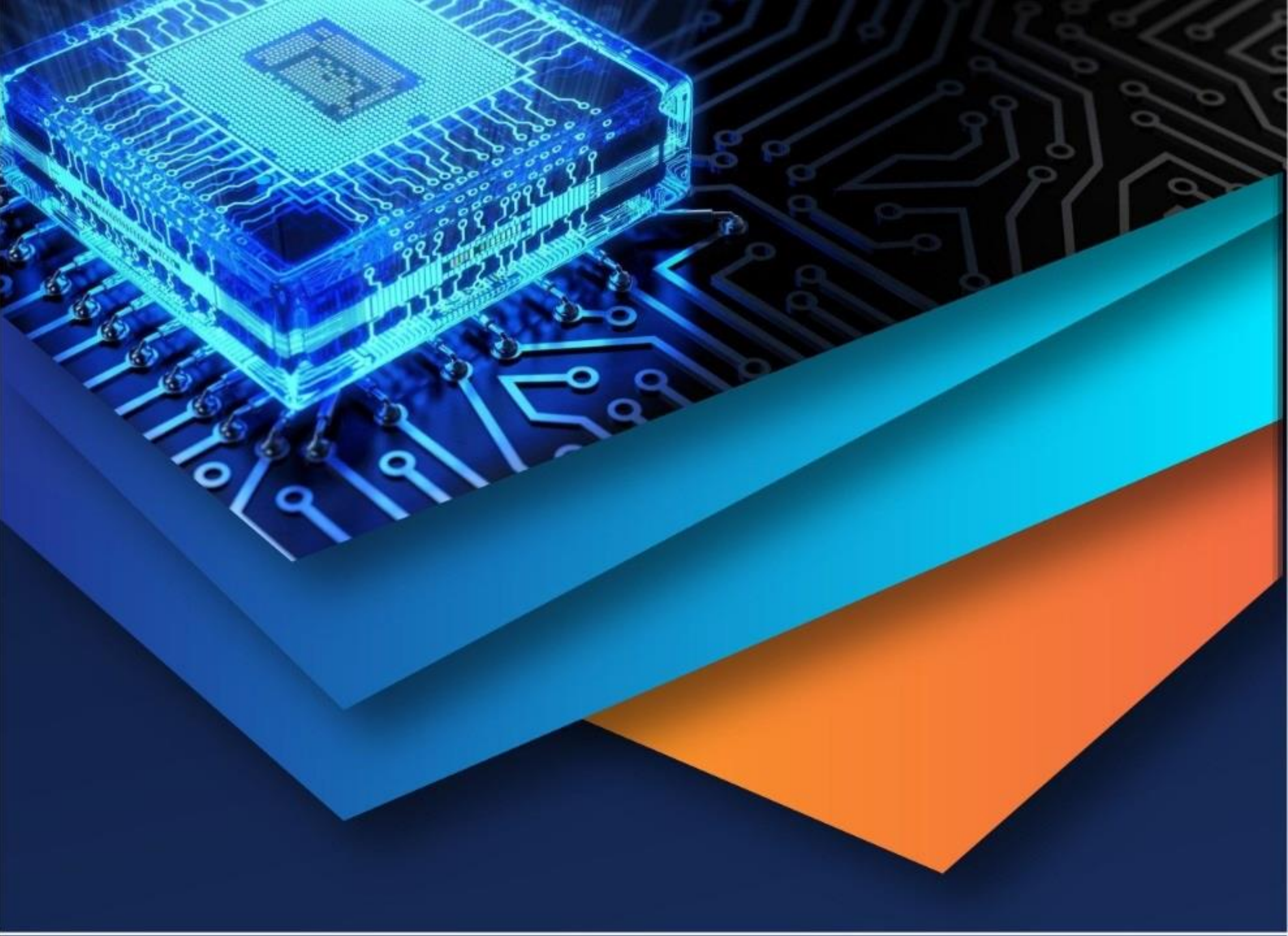

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