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IoT-Enabled Battery Management System with Cell Balancing and Thermal Monitoring for Electric Vehicles

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Abstract: *The growing adoption of electric vehicles (EVs) has increased the need for reliable Battery Management Systems (BMS) to improve battery safety, performance, and service life. This review examines research on EV technologies, IoT-based battery monitoring, microcontroller-based battery management, and advances in battery modeling. Existing studies discuss the importance of battery management, charging, and traction motors, while IoT-based approaches enable real-time monitoring and remote access to battery information. Hardware-based BMS designs using the LTC6804 battery-monitoring microcontroller demonstrate approaches to measuring and managing battery parameters. Recent research also highlights State of Charge (SOC) and State of Health (SOH) estimation, cell balancing, thermal management, and charge–discharge characteristics. Based on these studies, this paper proposes a BMS for electric vehicles, illustrated in the supplied block diagram. The proposed system integrates battery voltage, current, and temperature sensing with an ESP32 microcontroller, Wi-Fi communication, cloud monitoring, and a mobile application. Cell balancing and cooling control are also included to support improved battery monitoring, fault detection, and operational safety.*

Keywords - Battery Management System (BMS), Electric Vehicles (EVs), Internet of Things (IoT), State of Charge (SOC), State of Health (SOH), ESP32 Microcontroller, Cell Balancing, Battery Thermal Management, Wireless Monitoring, Fault Detection.

I. INTRODUCTION

In an electric vehicle (EV), the battery energy storage system plays an important role in determining the vehicle's driving range, reliability, size, and overall performance. Lithium-ion batteries are widely used in EV applications because of their high energy density, high power density, and low self-discharge rate. To achieve the required voltage and current, multiple battery cells are connected in series or parallel to form a battery pack. However, variations in cell voltage, temperature, and capacity can affect battery performance and may create safety risks. Therefore, an efficient Battery Management System (BMS) is essential for monitoring and protecting the battery pack.

Two important parameters used to assess battery performance are the State of Charge (SOC) and State of Health (SOH). Accurate estimation of these parameters helps determine the remaining battery capacity and the overall condition of the battery. Since lithium-ion battery characteristics are nonlinear and influenced by temperature, reliable estimation methods and continuous monitoring are required. A BMS generally uses voltage, current, and temperature sensors together with an embedded processor to collect and process battery data.

Several approaches have been investigated for BMS development, including direct and indirect SOC estimation methods, hardware-in-the-loop (HIL) testing, and microcontroller-based monitoring systems. Dedicated battery-monitoring integrated circuits, such as the LTC6804, and microcontrollers, such as the STM32F4, can be used to measure individual cell voltages and manage battery operation. Internet of Things (IoT) technology further enables remote monitoring and data communication. Cell balancing is another essential BMS function, commonly classified into passive and active balancing, which helps reduce voltage differences between cells.

Based on these developments, this paper proposes an IoT-enabled BMS for electric vehicles, as illustrated in the supplied block diagram. The proposed system uses an ESP32 microcontroller to collect battery voltage, current, and temperature measurements and transmit the data through Wi-Fi to a cloud platform and mobile application. Cell balancing and cooling control are also incorporated into the proposed design. The objective is to support real-time battery monitoring, fault identification, and improved operational safety while providing a foundation for future hardware implementation and experimental validation.

II. LITERATURE SURVEY

This study present a comprehensive review of electric vehicles, focusing on battery management systems (BMS), charging stations, and traction motors. The paper discusses battery monitoring, state of charge (SOC), state of health (SOH), thermal management, and safety techniques. It highlights the importance of efficient

battery management for improving battery performance, reliability, and lifespan in electric vehicles. The authors also explain the role of battery protection mechanisms in preventing overcharging, over-discharging, and overheating. Furthermore, the study examines technological developments in electric vehicle charging infrastructure and motor systems. It provides an overview of the challenges associated with battery efficiency, energy consumption, and system reliability. The review helps researchers understand current developments and identify opportunities for improving electric vehicle technology. [1]

This study presented an IoT-based battery management system for electric vehicles. The study focuses on integrating Internet of Things (IoT) technology with battery monitoring to collect and monitor battery parameters in real time. Such a system can help users observe battery conditions remotely, identify abnormal operating conditions, and improve battery safety and performance. IoT connectivity can provide continuous access to battery information through a web dashboard or connected device. Monitoring parameters such as voltage, temperature, and battery status can support early fault detection. The system can also improve the accessibility of battery information and reduce the need for frequent manual inspections. This approach demonstrates the potential of smart monitoring technologies for developing efficient and connected battery management systems. [2]

Proposed a battery management system for electric vehicles using the LTC6804 battery-monitoring IC and an STM32F4 microcontroller. The design focuses on monitoring individual cell voltages and managing battery operation to improve accuracy and safety. The use of dedicated monitoring hardware and a microcontroller supports reliable battery supervision and helps identify cell-level abnormalities. The LTC6804 enables the measurement of multiple battery cell voltages, which is important for detecting voltage imbalances within a battery pack. The STM32F4 processes the acquired measurements and supports the implementation of monitoring and protection functions. This hardware-based approach can improve the reliability of battery data and support effective battery pack management. The study highlights the importance of accurate cell-level monitoring in electric vehicle applications. [3]

A reviewed recent advances in batteries, battery modelling, battery management systems, and thermal management for electric vehicle applications. The paper discusses SOC and SOH estimation, battery charging and discharging characteristics, and temperature control. It emphasizes that accurate battery modelling and effective thermal management are essential for improving battery efficiency, extending battery life, and ensuring safe electric vehicle operation. The authors also examine different battery models used to predict battery behaviour under varying operating conditions. Accurate SOC estimation helps determine the remaining available energy, while SOH estimation provides information about battery ageing and degradation. The study further highlights the importance of controlling temperature variations to prevent thermal damage and maintain stable performance. Overall, the review provides valuable insights into developing advanced battery management strategies for safer and more efficient electric vehicles. [4]

III. MOTIVATION

The increasing demand for electric vehicles has created a need for efficient, reliable, and intelligent battery monitoring systems. Lithium-ion batteries are widely used in EVs because of their high energy density and good performance. However, improper charging and discharging, excessive temperature, voltage variations, and cell imbalance can reduce battery life and affect vehicle safety. Therefore, continuous monitoring and effective battery management are essential.

The motivation of this project is to develop a cost-effective, IoT-based Battery Management System using an ESP32 microcontroller. The system is designed to monitor battery voltage, current, and temperature in real time and transmit the collected information through Wi-Fi to a cloud platform and mobile application. This enables users to observe battery conditions remotely and identify potential problems. In addition, cell balancing and temperature-based cooling control are included to support better battery operation. The proposed system aims to integrate monitoring, communication, and control functions into a single platform, providing a foundation for improving battery safety, reliability, and performance in electric vehicles.

IV. PROBLEM STATEMENT

Lithium-ion batteries are widely used in electric vehicles due to their high energy density and power capability. However, variations in cell voltage, current, and temperature during charging and discharging can affect battery performance, safety, and service life. Without continuous monitoring and appropriate protection, conditions such as overvoltage, undervoltage, excessive current, overheating, and cell imbalance may occur. Conventional monitoring methods may also limit the user's ability to access battery information remotely.The main problem is to integrate these monitoring, communication, and control functions into a single system that improves battery visibility, supports fault detection, and enhances operational safety in electric vehicles. The effectiveness of the proposed design will be evaluated through hardware testing and measurement of

its monitoring accuracy and response to abnormal conditions.

V PROPOSED METHODOLOGY

The proposed Battery Management System (BMS) for Electric Vehicles (EVs) consists of a battery pack, sensing units, an ESP32 microcontroller, a Wi-Fi communication module, a cloud platform, a mobile application, a cell-balancing circuit, a cooling fan, and a charging/discharging control circuit. The block diagram illustrates how these components work together to monitor battery conditions, control temperature, and provide battery information to the user.

A. Battery Pack

The battery pack is the main energy storage unit of the proposed system. It consists of lithium-ion battery cells connected to provide the required voltage and current for the electric vehicle. The battery pack supplies electrical energy to the motor during vehicle operation and receives energy during charging. Monitoring individual cell voltages is important for identifying abnormal conditions and maintaining reliable battery operation.

B. Voltage, Current, and Temperature Sensors

The sensing section measures important battery parameters. Voltage sensors monitor individual cell voltages, while a current sensor measures the current flowing during charging and discharging. A temperature sensor monitors the battery pack temperature and helps identify overheating conditions. The collected measurements are provided to the ESP32 microcontroller for processing and monitoring.

C. Wi-Fi, Cloud Platform, and Mobile Application

The ESP32 transmits battery information through Wi-Fi to a cloud platform, where the data can be stored and displayed. A mobile application allows users to remotely monitor battery voltage, current, temperature, and other calculated battery parameters. This communication system improves accessibility to battery information and supports remote observation of battery operating conditions.

D. Cell Balancing Circuit

Cell balancing helps reduce voltage differences between individual battery cells. During charging and discharging, cells may develop different voltage levels due to variations in capacity and operating conditions. The balancing circuit helps maintain a more uniform voltage distribution across the cells, supporting battery utilization and service life. The balancing method and circuit must be selected according to the battery configuration.

E. Charging/Discharging Control and Motor Load

The charging/discharging control section uses a suitable switching device, such as a MOSFET or relay, to manage the connection between the battery, charger, and load. The battery supplies power to the DC motor during vehicle operation and receives electrical energy from the charger during charging. Appropriate protection circuits are required to prevent unsafe charging, excessive current, and other battery faults.

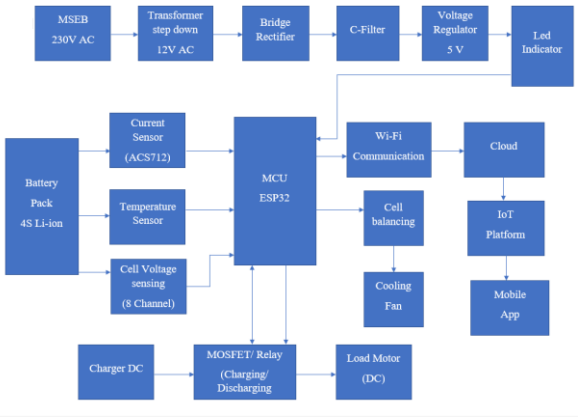

Fig.1: Proposed block diagram

VI. CONCLUSION

This paper reviews existing research on electric vehicle battery management, IoT-based monitoring, battery-monitoring hardware, and battery thermal management. The reviewed studies highlight the importance of monitoring battery voltage, current, and temperature, estimating SOC and SOH, maintaining cell balance, and controlling battery temperature. Based on these studies, an IoT-enabled Battery Management System using an ESP32 microcontroller is proposed, as illustrated in the block diagram. The proposed system integrates battery sensors, Wi-Fi communication, cloud monitoring, and a mobile application, along with cell balancing and cooling control. These features aim to improve battery monitoring, facilitate remote access to battery information, and support the identification of abnormal operating conditions. The proposed design provides a cost-effective approach to integrating monitoring and communication functions into a single platform. Future work will focus on hardware implementation, sensor calibration, protection testing, and experimental evaluation to verify the system's accuracy, reliability, and effectiveness in electric vehicle applications.

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