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Research Paper

BATTERY MANAGEMENT SYSTEM FOR ELECTRIC VEHICLES

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ABSTRACT

Battery Management Systems (BMS) play a critical role in improving the safety, efficiency, and reliability of electric vehicle battery packs. This paper presents an Internet of Things (IoT)-based Battery Management System for Electric Vehicles using an ESP32 microcontroller, INA219 current-voltage sensor, DHT11 temperature sensor, cooling fan, buzzer alerts, and cloud monitoring through ThingSpeak. The proposed system performs continuous monitoring of battery voltage, current, temperature, and load behavior in real time. It detects abnormal conditions such as under-voltage, overload, and overheating, and activates protective mechanisms including alarms, thermal control, and automatic load cutoff. The integration of IoT enables remote battery supervision through mobile devices and cloud dashboards, allowing users to access live data, historical trends, and warning notifications. Compared with traditional battery monitoring systems, the proposed architecture improves fault detection, safety response, and battery lifespan while maintaining low implementation cost. Experimental implementation demonstrates reliable sensing, remote monitoring capability, efficient thermal management, and effective
fault prevention. The developed system is suitable for electric vehicles, renewable energy storage, and portable battery-operated applications.

Keywords: Battery Management System, Electric Vehicles, IoT, ESP32, INA219, ThingSpeak, State of Charge, Thermal Protection, Smart Monitoring.

1. Introduction

The increasing adoption of Electric Vehicles (EVs) has created a strong demand for efficient, reliable, and intelligent battery management systems. As batteries serve as the primary energy source in EVs, their performance directly influences vehicle range, safety, charging efficiency, and overall lifespan. However, lithium-ion batteries used in electric vehicles are vulnerable to several operational challenges such as overcharging, over-discharging, excessive temperature rise, overload conditions, and cell imbalance, which can lead to reduced battery life, poor performance, and even hazardous conditions like thermal runaway or fire. Therefore, an effective

Battery Management System (BMS) has become an essential component in modern electric vehicles. A Battery Management System is responsible for monitoring critical battery parameters such as voltage, current, temperature, State of Charge (SOC), and State of Health (SOH), while also ensuring protection against abnormal operating conditions. Conventional battery management systems often provide only basic monitoring and protection features, with limited capabilities for remote access, intelligent fault prediction, and real-time user notifications. With the emergence of Internet of Things (IoT) technologies, battery monitoring systems can be enhanced with cloud connectivity, remote supervision, and smart control functions to improve battery safety and operational efficiency. IoT-enabled battery management systems integrate embedded controllers, sensors, wireless communication, and cloud platforms to continuously monitor battery conditions and provide users with real-time access to battery performance data. This approach not only improves fault detection and preventive maintenance but also supports intelligent decision-making for battery protection and energy optimization. In electric vehicle applications, such smart monitoring systems can significantly improve battery reliability while reducing maintenance costs and safety risks. In this work, an IoT-based Battery Management System for Electric Vehicles is proposed using the ESP32 microcontroller, INA219 current and voltage sensor, DHT11 temperature sensor, cooling fan, buzzer alerts, and ThingSpeak cloud platform. The proposed system continuously measures battery voltage, current, temperature, and load conditions, detects abnormalities such as undervoltage, overload, and overheating, and triggers protective actions including alarms, cooling mechanisms, and automatic load cutoff. Through cloud integration, the system also enables remote battery monitoring through mobile devices, allowing users to observe live battery status and receive alerts in real time. The proposed system aims to provide a low-cost, scalable, and intelligent battery monitoring solution that enhances battery safety, extends lifespan, and supports sustainable electric mobility. This paper presents the design, implementation, and performance evaluation of the proposed IoT-enabled BMS and demonstrates its effectiveness for electric vehicle applications.

2. Literature Survey

Dandge Vishal et al. proposed an IoT-based battery management system for electric vehicles to monitor battery performance using internet connectivity. Their work highlighted the need for remote monitoring of EV battery voltage and performance because the vehicle depends completely on battery energy. This study supports the use of IoT platforms for real-time battery status monitoring and user alert generation.

P. S. Kumar et al. developed an IoT-based battery management system using parameter estimation methods for accurate SOC and SOH monitoring. Their system used IoT communication and gateway topology to improve fault tolerance and convergence in battery condition estimation. This contribution is useful for EV applications where accurate battery health prediction is required. Mumtaz Noreen et al. presented an advanced EV battery management system focused on safety, performance, and battery lifetime. Their system monitored voltage, current, and temperature using dedicated sensors and displayed real-time battery data through an IoT cloud interface. This work is closely related to the proposed system because it emphasizes real-time monitoring and cloud-based visualization. Ramya et al. proposed a battery management system for electric vehicles using IoT and AI technology. Their work collected battery parameters such as temperature, voltage, and current from sensors and updated the values to an ESP32 controller and ThingSpeak cloud. This contribution is directly useful for the proposed project because it uses ESP32 and ThingSpeak for remote battery monitoring. The IJERT study on IoT-based BMS for electric vehicles described a system that measures voltage, current, and temperature using sensors and sends data to the cloud through a Wi-Fi module. The system uses ThingSpeak for real-time monitoring, which helps users observe battery performance remotely. This work supports the cloud-monitoring part of the proposed ESP32-based system. The IJSREM study on individual cell monitoring for a 3S lithium-ion battery pack used ESP32 and INA219 sensors for IoT-enabled battery monitoring. The system focused on individual cell voltage/current monitoring to improve safety and reliability. This contribution is important because the proposed project also uses the INA219 sensor for accurate voltage and current measurement. The JISEM study proposed an IoT-based BMS for EVs using ESP32 and different sensors such as voltage, current, temperature, smoke, and flame sensors. The system sends processed data to a mobile application for user monitoring. This work contributes to safety-oriented battery monitoring and supports the use of ESP32 for sensor data collection and wireless communication. The IJIRSET study explained that voltage, current, and temperature measurements are essential for estimating battery impedance, capacity, state of charge, state of health, and remaining useful life. Their work also discussed the importance of battery-level monitoring, charging control, and thermal balancing. This contribution supports the proposed system's focus on voltage, current, temperature, load, and cooling fan control.

The EV battery fire protection study discussed IoT-based battery monitoring using ESP8266 and ThingSpeak to notify users remotely. It stated that earlier BMS systems only displayed battery condition locally, whereas IoT-based systems allow users to check battery status on smartphones or computers. This supports the proposed system's mobile alert and remote monitoring feature. The battery parameter monitoring and control system study presented a low-cost EV battery monitoring system that measures voltage, current, and temperature and detects fire conditions using a microcontroller and Android smartphone interface. This contribution is useful for designing affordable battery protection systems with alert mechanisms for abnormal conditions.

3. Existing System

Existing battery management systems for electric vehicles primarily focus on basic monitoring and protection functions such as voltage sensing, current measurement, temperature monitoring, and overcharge or deep discharge protection. Conventional Battery Management Systems (BMS) generally use dedicated sensors and microcontrollers to supervise battery operation and prevent critical failures. These systems are commonly employed in electric vehicles and energy storage applications to monitor battery pack conditions and ensure safe operation. However, many traditional systems are limited to local monitoring and provide only basic protective mechanisms without intelligent fault prediction or remote accessibility.

Standalone battery monitoring systems are also used in many applications where voltage, current, and temperature are measured and displayed locally using simple display interfaces. Although these systems provide real-time parameter observation, they often lack automatic control features such as dynamic thermal management, overload response, and remote user notifications. In many cases, users must manually observe battery conditions and take corrective action, which may lead to delayed responses during abnormal situations.

Commercial centralized battery management systems used in advanced electric vehicles offer more sophisticated functions such as cell balancing, charge control, thermal management, and fault diagnostics. While these systems provide improved reliability and safety, they are often expensive, complex, and difficult to implement for low-cost or small-scale applications. Their high hardware and software complexity also increases maintenance requirements and limits their adaptability for customized monitoring solutions.

Some existing battery monitoring methods rely on manual inspection and periodic maintenance to assess battery condition. In such systems, battery voltage, temperature, and load conditions are checked at intervals rather than continuously, making them unsuitable for real-time fault detection. Similarly, passive cooling methods such as heat sinks or thermal insulation are commonly used to control battery temperature, but these approaches lack active temperature regulation based on real-time sensor data and may be ineffective during heavy load or extreme environmental conditions.

Although some recent IoT-based battery monitoring systems have introduced cloud connectivity and remote supervision, many of them focus mainly on data monitoring rather than integrating comprehensive protection mechanisms such as automatic cutoff control, intelligent alert generation, and active cooling management. As a result, existing systems still face limitations including lack of real-time intelligent monitoring, inadequate safety response, limited remote accessibility, and higher implementation costs.

Therefore, there is a need for an improved battery management system that combines real-time sensing, intelligent fault detection, thermal protection, automatic control, and IoT-based remote monitoring in a single scalable and cost-effective solution. The proposed system is developed to overcome these limitations and provide enhanced battery safety, performance, and reliability for electric vehicle applications.

4. Proposed System

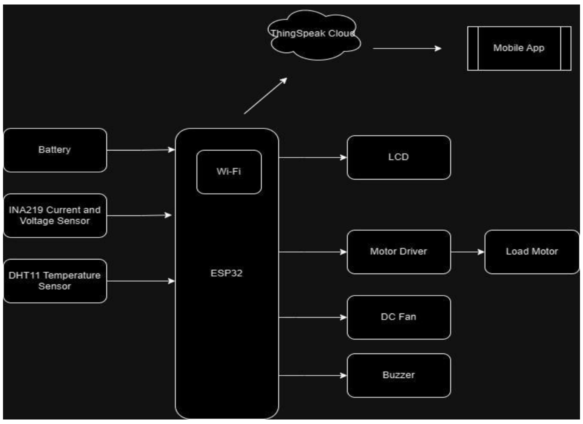

Fig.1. Block Diagram of proposed system

The proposed system is an IoT-based Battery Management System (BMS) designed to provide intelligent monitoring, protection, and control for electric vehicle batteries. The system integrates sensing modules, control units, protection mechanisms, and cloud connectivity to continuously supervise battery operating conditions and improve safety, performance, and battery lifespan. The architecture consists of an ESP32 microcontroller as the central processing unit, INA219 current and voltage sensor, DHT11 temperature sensor, LCD display, motor driver with load motor, cooling fan, buzzer alert system, and ThingSpeak cloud platform for rembLOAote monitoring through a mobile application.

In the proposed system, the battery acts as the main energy source whose parameters are continuously monitored. The INA219 sensor measures battery voltage and current in real time and sends this information to the ESP32 controller. These measurements are used to determine battery operating status, detect under-voltage or overload conditions, and monitor power consumption. Simultaneously, the DHT11 temperature sensor continuously senses the ambient and battery temperature to identify overheating conditions that may affect battery performance or safety.

The ESP32 microcontroller serves as the core controller of the entire system. It collects sensor data, processes battery parameters, compares them with predefined threshold values, and makes intelligent decisions for protection and control. Based on the monitored conditions, the ESP32 activates different peripherals connected to the system. An LCD module is interfaced to display real-time battery voltage, current, temperature, and system status locally for direct user observation.

For load simulation and battery discharge analysis, a DC load motor controlled through a motor driver module is included in the system. The motor driver regulates the load conditions and allows the system to evaluate battery behavior under varying load demands similar to practical electric vehicle conditions. If the sensed current exceeds a safe operating limit indicating overload, the ESP32 triggers protection actions such as activating an alarm and disconnecting or reducing the load to prevent battery damage.

Thermal protection is implemented using an automatic cooling fan controlled by the ESP32. When the battery temperature rises above a predefined threshold, the controller turns on the DC fan to dissipate heat and prevent overheating. This active cooling mechanism improves battery safety and enhances lifespan compared to passive cooling methods. In addition, a buzzer is integrated as an audible warning system to alert users whenever critical conditions such as under-voltage, overload, or excessive temperature are detected.

A major feature of the proposed system is IoT integration through the built-in Wi-Fi capability of the ESP32. The sensed battery parameters are transmitted wirelessly to the ThingSpeak cloud platform for real-time monitoring, storage, and analysis. Through the cloud interface and mobile application, users can remotely observe battery performance, receive warning notifications, and analyze historical battery data. This remote monitoring capability allows preventive action before faults become severe and supports intelligent battery management from anywhere.

The proposed system operates in a continuous monitoring and protection cycle. Sensor data is acquired, processed by the controller, compared against threshold values, and corresponding protective actions are initiated automatically whenever abnormal conditions occur. Under normal conditions, the system performs monitoring and cloud updates, while during fault conditions it activates alarms, cooling, or load cutoff mechanisms. This closed-loop operation ensures both battery safety and efficient energy utilization.

Overall, the proposed Battery Management System combines real-time sensing, intelligent control, thermal management, fault protection, load monitoring, and cloud-based remote supervision into a single integrated platform. Compared to conventional battery management approaches, the proposed system offers improved reliability, lower implementation cost, remote accessibility, and enhanced battery safety, making it suitable for electric vehicle applications and other battery-powered systems.

5. Results and Discussions

Fig.2. Hardware Output of Proposed system

Our project demonstrates how smart monitoring and control can enhance battery performance, safety, and efficiency. By integrating sensors to measure voltage, current, temperature, and SOC, this setup ensures real-time data acquisition and visualization through both an LCD display and a mobile application. It allows for precise tracking of battery health, early detection of anomalies, and optimization of energy usage. Such a system is crucial in electric vehicles, where battery reliability directly impacts driving range, safety, and overall sustainability. It highlights the importance of IoT-based monitoring in modern EVs, bridging hardware and software to create a practical, scalable solution for future mobility.

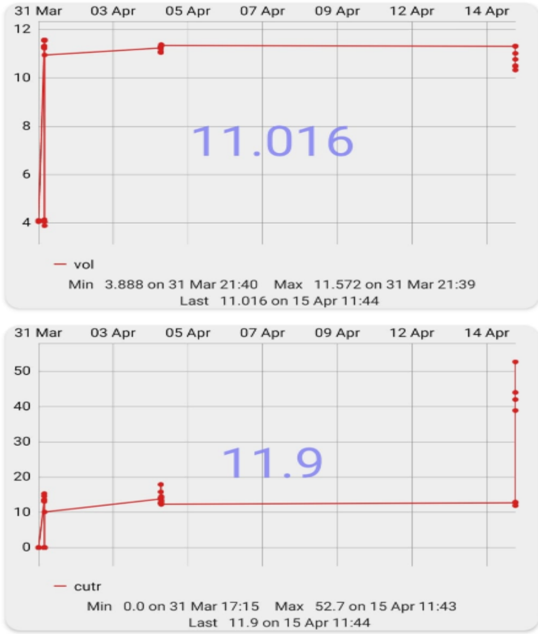

Fig.3. Graphical Output Voltage and Current

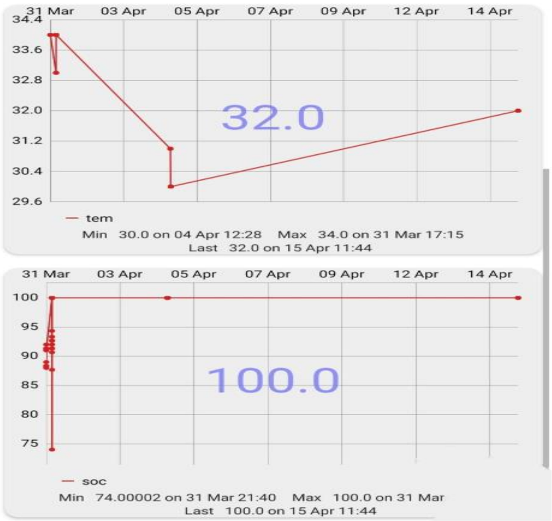

Fig.4. Graphical Output of Battery Temperature

6. Conclusion

In conclusion, the development of the IoT-based battery management system represents a significant advancement in addressing the challenges associated with monitoring, alerting, and controlling batteries in various applications. By leveraging technologies such as the ESP32 microcontroller, INA219 sensor, buzzer, cooling fan, and mobile application integration, the proposed system offers comprehensive functionality to enhance battery performance, longevity, and safety. Throughout the implementation process, careful attention was paid to designing a robust system architecture, integrating components effectively, and developing firmware with intelligent monitoring and control logic. The system's ability to monitor key battery parameters in real-time, provide timely alerts for critical conditions, and implement proactive measures such as cutoff mechanisms and temperature control ensures optimal battery health and safety. Moreover, the integration with the Thing Speak platform enables.remotemonitoringandcontrolofthebatterymanagementsystemviaamobileapplication,enhancing accessibility and convenience for users. This feature allows users to stay informed about battery status, receive alerts on their smart phones, and take preemptive actions to address potential issues from anywhere, at any time. Theproposedbatterymanagementsystemoffersa scalableandadaptablesolution suitable for variousapplications, including renewable energy systems, electric vehicles, and portable electronics. Its comprehensive functionality, user-friendly interface, and safety features make it a valuable asset for battery-powered systems, contributing to improved performance, longevity, and sustainability.

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