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IoT-Enabled Smart Battery Management System for Electric Vehicles with Real-Time Charge Monitoring, Thermal Protection, and Intelligent Fire Prevention

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ABSTRACT

The rapid adoption of Electric Vehicles (EVs) has increased the demand for advanced Battery Management Systems (BMS) that ensure battery safety, efficiency, and reliability. This project proposes an IoT-Enabled Smart Battery Management System (BMS) with real-time charge monitoring and intelligent fire protection for lithium-ion battery packs. The system continuously monitors critical battery parameters such as voltage, current, temperature, state of charge (SOC), and battery health using multiple sensors interfaced with a microcontroller. The collected data is transmitted to a cloud-based IoT platform, enabling users to monitor battery status remotely through a mobile application or web dashboard. To improve safety, the system incorporates a temperature sensor and smoke/flame detection module that continuously monitor abnormal operating conditions. If excessive temperature, smoke, or fire is detected, the controller immediately disconnects the battery from the load using a relay, activates an alarm, and sends instant notifications to the user through the IoT platform. The proposed system also supports overcharge, over-discharge, and short-circuit protection, thereby extending battery life and preventing hazardous situations. By integrating IoT connectivity, intelligent monitoring, and automatic fire protection into a single platform, the proposed solution enhances battery reliability, user safety, and operational efficiency. This system provides a cost-effective and scalable solution for modern electric vehicles and contributes toward the development of safer and smarter EV energy management systems.

Keywords: Electric Vehicle (EV), Battery Management System (BMS), Internet of Things (IoT), State of Charge (SOC), Battery Monitoring, Fire Protection, Thermal Management, Lithium-Ion Battery, Temperature Sensor, Smoke Sensor, Cloud Monitoring, Smart Energy Management.

I.INTRODUCTION

The increasing adoption of Electric Vehicles (EVs) has created a growing demand for efficient and reliable energy storage systems. Lithium-ion batteries have become the preferred energy source for EVs because of their high energy density, long cycle life, lightweight construction, and superior charging characteristics. However, improper charging, excessive temperature, overcharging, over-discharging, and short circuits can significantly reduce battery life and create serious safety hazards. Therefore, an effective Battery Management System (BMS) is essential for ensuring battery safety, performance, reliability, and longevity [1], [2], [4].

A Battery Management System continuously monitors critical battery parameters such as voltage, current, temperature, and State of Charge (SOC). Based on these measurements, the BMS protects the battery from unsafe operating conditions while maintaining optimal charging and discharging performance. Modern BMS technologies also estimate battery health and remaining useful life, enabling efficient battery utilization and improving the overall performance of electric vehicles [3], [12], [13].

Recent advancements in the Internet of Things (IoT) have enabled real-time monitoring and remote management of battery systems. IoT technology allows battery information to be transmitted to cloud platforms, where users can monitor charging status, battery temperature, voltage levels, and system health through smartphones or web-based dashboards. This real-time accessibility enables timely maintenance, fault diagnosis, and improved operational efficiency, making IoT an important component of next-generation battery management systems [8], [9].

Battery safety remains one of the most critical challenges in electric vehicles. Excessive heat generated during charging or discharging may lead to thermal runaway, battery damage, and even fire accidents. Integrating temperature sensors, smoke sensors, flame detectors, and automatic protection mechanisms into the Battery Management System significantly improves vehicle safety by detecting abnormal conditions at an early stage. Upon identifying dangerous operating conditions, the system can disconnect the battery using protective relays, activate warning alarms, and notify users through IoT-based communication, thereby minimizing potential risks [10], [11], [14].

The proposed IoT-Enabled Smart Battery Management System with Charge Monitoring and Fire Protection integrates battery monitoring, cloud connectivity, and intelligent safety mechanisms into a single embedded platform. The system continuously monitors battery voltage, current, temperature, charging status, and State of Charge while simultaneously detecting fire hazards using dedicated sensors. The collected data is transmitted to an IoT platform for remote monitoring, enabling users to access real-time battery information from anywhere. In emergency situations such as overheating or fire detection, the system automatically disconnects the battery, activates an alarm, and sends instant notifications to ensure maximum safety [7], [8], [14].

Overall, the proposed system provides a reliable, cost-effective, and intelligent solution for enhancing battery safety, extending battery lifespan, and improving the efficiency of electric vehicle energy management. By combining IoT technology, intelligent monitoring, and automatic fire protection, the system contributes to the development of safer, smarter, and more sustainable electric transportation systems while supporting future advancements in connected and autonomous electric vehicles [4], [11], [15].

II.LITERATURE SURVEY

Gregory L. Plett (2015):
Gregory L. Plett presented a comprehensive study on Battery Management Systems (BMS) for lithium-ion batteries. The author explained battery modeling, State of Charge (SOC) estimation, State of Health (SOH) prediction, and battery protection techniques. The work emphasized that an efficient BMS significantly improves battery safety, lifespan, and performance in electric vehicle applications.

Davide Andrea (2010):
Davide Andrea discussed the design and implementation of Battery Management Systems for large lithium-ion battery packs used in electric vehicles. The study focused on battery balancing, fault detection, thermal management, charging control, and safety protection. The author concluded that intelligent BMS technology is essential for ensuring reliable battery operation and preventing battery failures.

Heisler (2002):
Heisler explained the evolution of advanced vehicle technologies and highlighted the importance of electronic control systems in improving vehicle safety and efficiency. The study described the integration of embedded electronics into modern electric vehicles for monitoring battery performance and enhancing operational reliability.

Mazidi, Mazidi, and McKinlay (2008):
The authors explained the architecture and programming of embedded microcontrollers used in intelligent control systems. Their work demonstrated how microcontrollers interface with sensors, relays, and communication modules to develop automated monitoring and protection systems suitable for Battery Management System applications.

Simon Monk (2016):
Simon Monk presented practical techniques for developing Arduino-based embedded systems. The book demonstrated sensor interfacing, relay control, LCD communication, and wireless connectivity, making it highly useful for implementing real-time battery monitoring and protection systems.

Raj Kamal (2017):
Raj Kamal described the architecture and design principles of the Internet of Things (IoT). The author explained cloud communication, wireless sensor networks, remote monitoring, and real-time data acquisition, which provide the technological foundation for IoT-enabled Battery Management Systems.

Vijay Madisetti and Arshdeep Bahga (2014):
The authors discussed practical IoT applications involving cloud computing, embedded devices, sensor integration, and remote monitoring. Their work demonstrated how IoT technology enables continuous monitoring of industrial and automotive systems through internet-based communication.

Chen and Rincon-Mora (2006):
Chen and Rincon-Mora proposed an accurate electrical battery model capable of estimating battery runtime and electrical characteristics. Their research improved battery monitoring accuracy and contributed to more reliable battery management and charge estimation methods used in electric vehicles.

Deng, Luh, and Che (2020):
The authors reviewed recent developments in Battery Management Systems for electric vehicles, focusing on intelligent monitoring, battery diagnostics, thermal protection, cloud connectivity, and future research directions. The study highlighted the importance of integrating IoT technology with advanced BMS for safer and more efficient electric transportation.

Hannan, Hoque, Mohamed, and Ayob (2017):
The authors reviewed various energy storage technologies used in electric vehicles and emphasized the importance of battery safety, efficient charging, thermal management, and intelligent monitoring systems. Their work demonstrated that advanced Battery Management Systems play a crucial role in improving battery performance, vehicle reliability, and user safety.

III.EXISTING SYSTEM

The existing Battery Management Systems (BMS) used in many electric vehicles primarily focus on basic battery monitoring and protection functions, such as measuring battery voltage, current, and temperature during charging and discharging. While these systems provide essential protection against overcharging, over-discharging, and short circuits, many conventional BMS implementations have limited capabilities for real-time remote monitoring and intelligent fault detection. In most cases, battery information is available only through the vehicle's onboard display, making it difficult for users or maintenance personnel to continuously monitor battery health from remote locations. Furthermore, several existing systems lack integrated fire detection and automatic emergency response mechanisms, increasing the risk of battery damage or thermal runaway under abnormal operating conditions. Although advanced Battery Management Systems are available in premium electric vehicles, they are often expensive and rely on complex hardware and software architectures, making them unsuitable for low-cost or small-scale EV applications. Additionally, many traditional systems do not provide cloud connectivity, instant mobile notifications, predictive maintenance, or automatic isolation of the battery during hazardous situations. These limitations reduce overall battery safety, operational reliability, and user convenience. Therefore, there is a need for an intelligent, IoT-enabled Battery Management System that integrates real-time charge monitoring, thermal protection, fire detection, automatic safety control, and remote monitoring into a single cost-effective platform to improve battery performance and ensure safe operation of electric vehicles.

IV.PROPOSED SYSTEM

The proposed IoT-Enabled Smart Battery Management System (BMS) with Charge Monitoring and Fire Protection is an intelligent embedded solution designed to improve the safety, reliability, and performance of electric vehicle battery systems. The system continuously monitors important battery parameters such as voltage, current, temperature, and State of Charge (SOC) using suitable sensors connected to a microcontroller. The collected data is processed in real time and transmitted to a cloud-based IoT platform through a Wi-Fi communication module, enabling users to remotely monitor battery status using a smartphone or web application. To enhance battery safety, the system incorporates temperature and smoke/flame sensors that continuously detect abnormal conditions such as overheating, smoke generation, or fire. If any unsafe condition is identified, the microcontroller immediately disconnects the battery from the charging or load circuit using a relay module, activates a buzzer or alarm, and sends instant notifications to the user through the IoT platform. The proposed system also provides protection against overcharging, over-discharging, overcurrent, and short-circuit conditions, thereby extending battery life and improving operational efficiency. By integrating intelligent battery monitoring, IoT-based remote supervision, automatic fault detection, and emergency fire protection into a single embedded platform, the proposed system offers a cost-effective, reliable, and scalable solution for modern electric vehicles. It significantly improves user safety, minimizes battery failures, reduces maintenance costs, and supports the development of smart and connected electric mobility systems.

V.BLOCK DIAGRAM

The block diagram of the IoT-Based EV Battery Management System (BMS) with Charge Monitor and Fire Protection illustrates the complete architecture and operation of the proposed intelligent battery safety and monitoring system. The system is designed to continuously monitor the condition of the lithium-ion battery pack, protect it from hazardous situations, and provide real-time battery information to users through an IoT platform. It consists of several functional blocks, including the Power Supply, Battery Pack, Voltage Sensor, Current Sensor, Temperature Sensor, Smoke Sensor, Flame Sensor, Safety and Protection Unit, Microcontroller (Arduino/ESP32), LCD Display, Relay Module, Buzzer/Alarm, Cooling Fan, Fire Extinguisher (DC Pump), LED Indicators, Wi-Fi Module (ESP8266), IoT Cloud, and Mobile Application. These blocks work together to provide intelligent battery monitoring, automatic fault detection, remote supervision, and emergency protection.

The system is powered by a regulated power supply, which provides the required operating voltage to the microcontroller, sensors, communication modules, and output devices. The Lithium-ion Battery Pack serves as the primary energy source for the electric vehicle. The battery is continuously monitored to ensure that it operates within safe voltage, current, and temperature limits. Since lithium-ion batteries are highly sensitive to abnormal operating conditions, continuous monitoring is essential to prevent battery degradation and improve operational safety.

A set of sensors is connected to the battery pack to monitor its operating condition in real time. The Voltage Sensor continuously measures the battery voltage and detects conditions such as over-voltage and under-voltage. The Current Sensor measures the charging and discharging current flowing through the battery, helping detect overcurrent conditions and enabling accurate charge monitoring. The Temperature Sensor monitors battery temperature continuously to identify overheating conditions that may lead to thermal runaway. To further improve safety, the system includes both Smoke Sensor and Flame Sensor, which detect smoke generation and fire around the battery compartment. These sensors provide early warning of battery failures and significantly reduce the possibility of fire accidents.

The sensor outputs are transmitted to the Arduino/ESP32 Microcontroller, which acts as the central processing unit of the entire Battery Management System. The microcontroller continuously processes sensor data and compares the measured values with predefined safety thresholds. If all parameters remain within the safe operating range, the battery continues to operate normally. However, if any abnormal condition such as excessive temperature, smoke detection, fire detection, over-voltage, under-voltage, or overcurrent occurs, the microcontroller immediately initiates appropriate protective actions.

The Safety and Protection Unit implements multiple battery protection mechanisms, including over-voltage protection, under-voltage protection, overcurrent protection, short-circuit protection, over-temperature protection, and fire detection and protection. These protective features ensure safe battery operation and significantly extend battery life by preventing damage caused by abnormal electrical or thermal conditions.

The Relay Module receives control signals from the microcontroller and automatically disconnects the battery from the charging circuit or vehicle load whenever unsafe operating conditions are detected. This immediate isolation of the battery minimizes further damage and prevents dangerous situations. Simultaneously, the Buzzer/Alarm is activated to alert nearby users about the fault condition. The Cooling Fan automatically starts when excessive battery temperature is detected, helping reduce battery temperature and prevent overheating. If fire or severe thermal runaway is detected, the Fire Extinguisher (DC Pump) is activated automatically to suppress the fire before it spreads further. Additionally, LED Indicators provide visual information regarding charging status, battery health, fault conditions, and system operation.

The processed battery information is displayed locally on the 16×2 LCD Display, which continuously shows important parameters such as battery voltage, charging current, temperature, State of Charge (SOC), fault status, and system condition. This allows users to monitor battery performance directly from the hardware unit without requiring external devices.

For remote monitoring, the system incorporates a Wi-Fi Module (ESP8266), which transmits battery data to an IoT Cloud Platform such as Firebase or ThingSpeak. The cloud platform stores real-time battery information and enables continuous monitoring over the internet. Users can access battery status through a Mobile Application, where they can view charging progress, battery temperature, voltage, current, State of Charge, and receive instant notifications whenever abnormal operating conditions occur. This remote monitoring capability improves maintenance efficiency and allows users to respond quickly during emergency situations.

Overall, the proposed IoT-Based EV Battery Management System combines intelligent sensing, embedded processing, cloud connectivity, and automatic fire protection into a single integrated platform. The system continuously monitors battery health, detects hazardous conditions at an early stage, automatically performs protective actions, and provides real-time remote monitoring. This integrated approach significantly improves battery safety, extends battery lifespan, enhances operational reliability, minimizes maintenance requirements, and contributes to the development of safer, smarter, and

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more efficient electric vehicle energy management systems.

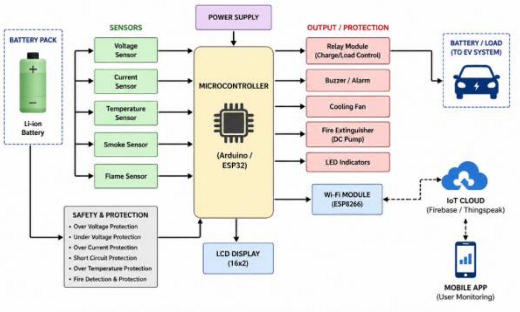

Fig 5.1 Block Diagram

VI.IMPLEMENTATION

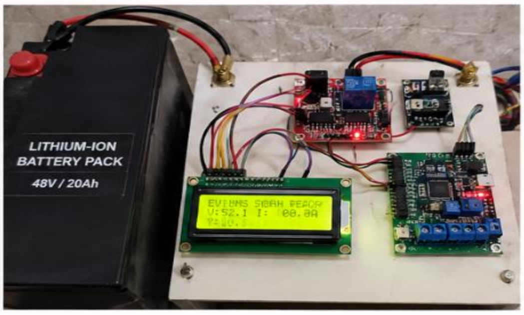

Fig. 6.1: Overall System Setup

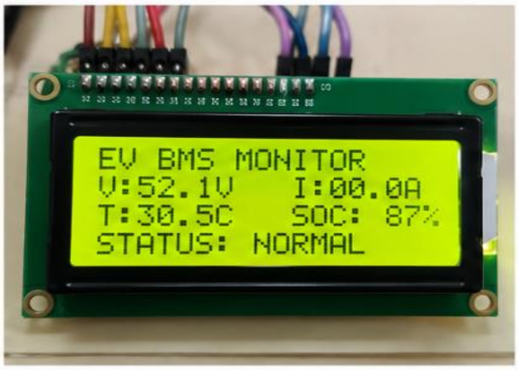

Fig. 6.2: LCD Display Showing Battery Monitoring Parameters

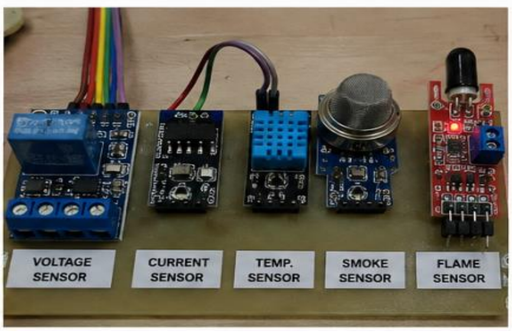

Fig. 6.3:Sensor Interface Unit (Voltage, Current, Temperature, Smoke, and Flame Sensors)

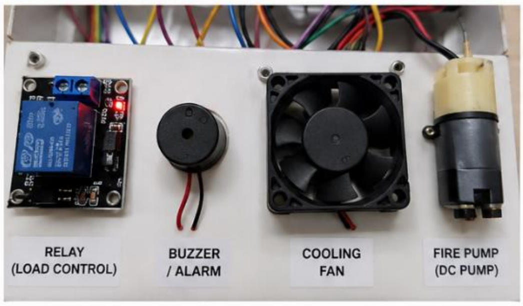

Fig. 6.4: Protection and Output Unit (Relay, Buzzer, Cooling Fan, and Fire Pump)

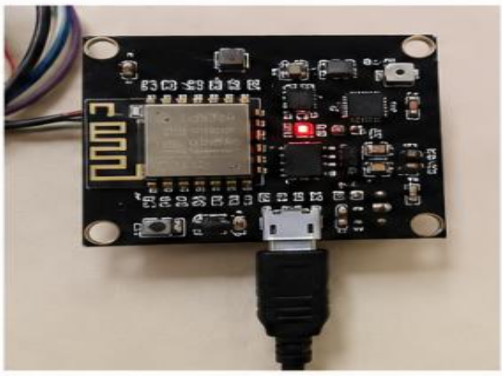

Fig. 6.5: Wi-Fi Module for IoT Connectivity

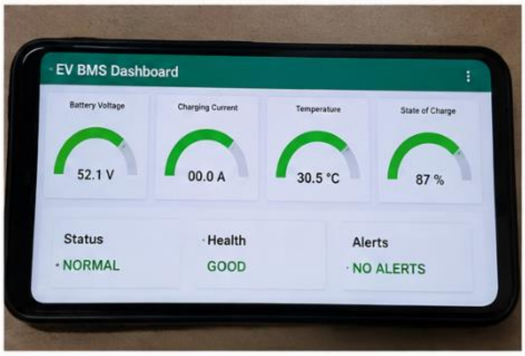

Fig. 6.6:IoT Dashboard for Real-Time Battery Monitoring (Mobile Application)

VII.CONCLUSION

The IoT-Based EV Battery Management System (BMS) with Charge Monitor and Fire Protection successfully demonstrates an intelligent and reliable solution for enhancing the safety, performance, and operational efficiency of electric vehicle battery systems. The proposed system continuously monitors critical battery parameters such as voltage, current,

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temperature, and State of Charge (SOC) using multiple sensors and processes the collected data through a microcontroller. By integrating IoT technology, the system enables real-time remote monitoring of battery status through a mobile application or cloud platform, allowing users to access battery information anytime and anywhere. The inclusion of smoke and flame sensors, along with automatic protection mechanisms such as relay-based battery isolation, buzzer alerts, cooling fan activation, and fire suppression, significantly improves battery safety by preventing hazardous situations caused by overheating or thermal runaway. In addition, the system provides protection against overcharging, over-discharging, overcurrent, and short-circuit conditions, thereby extending battery life and reducing maintenance costs. The developed system is cost-effective, scalable, and suitable for implementation in electric vehicles of different capacities. Overall, the proposed IoT-enabled Battery Management System offers an efficient approach to intelligent battery monitoring, charge management, and fire protection, contributing to safer, smarter, and more reliable electric mobility while supporting the future development of connected and autonomous electric transportation systems.

VIII.FUTURE SCOPE

The IoT-Based EV Battery Management System (BMS) with Charge Monitor and Fire Protection can be further enhanced by incorporating advanced technologies to improve battery intelligence, safety, and overall efficiency. In the future, Artificial Intelligence (AI) and Machine Learning (ML) algorithms can be integrated to predict battery health, estimate the remaining useful life (RUL), and identify potential faults before they occur through predictive maintenance techniques. Cloud-based data analytics can be employed to analyze long-term battery performance and optimize charging strategies for improved battery lifespan. The system can also be expanded to support fast-charging stations, wireless charging technologies, and advanced cell balancing methods to increase charging efficiency and battery reliability. GPS integration can enable location-based emergency alerts in case of battery overheating or fire incidents, while GSM/5G communication can provide faster and more reliable notifications to users and emergency services. Additional sensors such as gas leakage sensors, humidity sensors, and vibration sensors can further improve fault detection and battery safety. The proposed system can also be integrated with Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication to support intelligent transportation systems and smart city applications. Furthermore, compatibility with renewable energy sources, cloud-based fleet management, and autonomous electric vehicles will make the system more versatile and suitable for next-generation electric mobility. These advancements will enhance battery reliability, reduce maintenance costs, improve user safety, and contribute to the development of intelligent, connected, and sustainable electric vehicle ecosystems.

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