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Real-Time Charge Analytics And Autonomous Fire Suppression For Electric Vehicles

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Abstract--- Challenges connected with temperature regulation in electric vehicle (EV) battery management systems (BMS) include overheating, delayed cold charging, energy depletion, efficiency degradation, cell imbalance, and durability concerns. These difficulties can be addressed by the measurement of voltage, current, and temperature of individual cells, real-time data processing via microcontrollers, state of charge (SoC) and state of health (SoH) estimations, thermal modelling, and defect detection. This paper presents a comprehensive BMS that monitors the SoC) and SoH of the battery pack, while integrating advanced thermal management and fire prevention features to mitigate potential hazards. The charging and discharging circumstances of the suggested approach are evaluated using the MATLAB Simulink tool. The outcomes of the hardware implementation and testing indicate that the proposed method enhances battery longevity and electric vehicle safety while also resolving critical issues related to charging efficiency and fire safety and temperature management in electric vehicles. This concept facilitates the development of safer, more intelligent, and more dependable battery systems for electric vehicles.

Index Term : Electric Vehicle (EV) Battery Management System (BMS), Thermal Management, State of Charge (SoC), State of Health (SoH).

I. INTRODUCTION

The rapid growth of electric vehicles (EVs) has increased the demand for efficient, reliable, and safe battery systems. Lithium-ion batteries are widely used in EVs because of their high energy density, long cycle life, and superior performance. However, battery systems are highly sensitive to operating conditions such as temperature, charging rate, and load variations. Improper battery management can lead to overheating, reduced efficiency, cell imbalance, thermal runaway, fire hazards, and shortened battery lifespan. Therefore, an advanced Battery Management System (BMS) plays a crucial role in ensuring the safe and optimal operation of EV batteries.A Battery Management System is responsible for monitoring and controlling important battery parameters such as voltage, current, and temperature of individual cells. It also performs critical functions including State of Charge (SoC) estimation, State of Health (SoH) monitoring, thermal management, fault detection, and cell balancing. Among these, thermal management is one of the most important challenges because excessive heat generation during charging and discharging significantly affects battery performance, durability, and safety. Similarly, charging batteries under low-temperature conditions can reduce charging efficiency and damage battery cells. Hence, effective temperature regulation and safety mechanisms are essential for modern EV battery systems. In recent years, researchers have focused on developing intelligent BMS architectures integrated with real-time monitoring, thermal modelling, and fire prevention techniques to improve EV safety and battery reliability. Advanced microcontroller-based systems combined with sensors and simulation tools enable accurate monitoring and rapid response to abnormal operating conditions. Moreover, the integration of thermal protection and defect detection techniques helps prevent thermal runaway and enhances overall vehicle safety.

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II. EASE OF USE

The proposed Battery Management System (BMS) is designed with a user-friendly and intelligent architecture that simplifies battery monitoring and control in electric vehicles. It continuously measures important battery parameters such as voltage, current, and temperature without requiring manual intervention. The integration of real-time data processing, thermal management, and fault detection ensures smooth and safe operation during both charging and discharging conditions.The system automatically estimates the State of Charge (SoC) and State of Health (SoH), helping users and vehicle operators easily understand battery performance and remaining capacity. Advanced thermal regulation and fire prevention mechanisms improve operational safety and reduce the risk of battery failure. In addition, the use of MATLAB Simulink for simulation and hardware implementation enables accurate performance analysis and reliable system validation. The proposed approach reduces maintenance complexity, enhances charging efficiency, minimizes overheating issues, and improves battery lifespan. Its automated monitoring and protection features make the system highly suitable for modern electric vehicles, providing safer, smarter, and more dependable battery operation with minimal user effort.

III. OBJECTIVE

The main objective of this project is to design and develop a smart Battery Management and Thermal Safety System for Electric Vehicles (EVs) using an Arduino-based controller to improve battery safety, performance, and reliability. The system aims to continuously monitor important battery parameters such as temperature, voltage, and charging conditions to prevent overheating and fire hazards.Another objective is to implement real-time thermal management using heat/flame sensors and warning mechanisms such as a piezo buzzer and LCD display for early fault detection and user notification. The project also focuses on improving charging efficiency, battery lifespan, and operational safety through continuous monitoring and intelligent control.The proposed system further aims to provide an easy-to-use, low-cost, and efficient solution for electric vehicle battery protection by integrating sensor-based monitoring, alert systems, and real-time data display. Additionally, the project supports safer and smarter EV operation by reducing battery failures, maintaining optimal temperature conditions, and enhancing overall energy management.

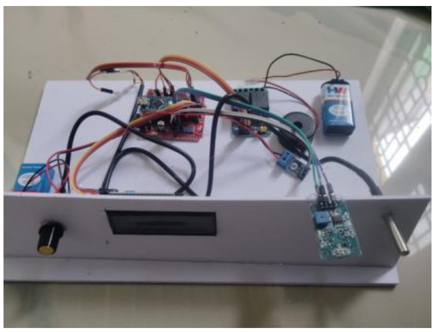
IV. METHODOLOGY

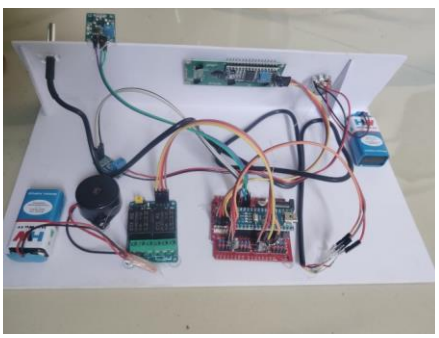
- A 5V power supply is provided to the Arduino UNO and all connected components.
- The LM35/temperature sensor continuously monitors battery temperature and heat conditions.
- Sensor data is sent to the Arduino UNO through analog input pins.
- The Arduino processes the received temperature data in real time.
- A potentiometer is used to adjust threshold values and simulate battery conditions.
- The I2C LCD display shows temperature values and system status continuously.
- If overheating or abnormal heat is detected, the Arduino activates the piezo buzzer.
- The buzzer provides an alert to prevent battery damage and fire hazards.
- MATLAB Simulink is used to analyze charging, discharging, and thermal performance.
- The complete system improves battery safety, efficiency, and lifespan in electric vehicles.
- The system continuously monitors battery conditions without manual supervision.
- Real-time thermal monitoring helps in preventing thermal runaway conditions.
- The Arduino UNO acts as the central processing and control unit of the system.
- Analog sensor signals are converted into digital values for accurate processing.
- The system provides quick response during abnormal temperature rise.

V. APPROACH

- Testing alternate methods to prevent and manage traditional and electrical fire hazard by:
- sensing and moving vehicle to safe distance
- extinguishing electric fire in battery region both without human intervention.

VI. TESTING





The proposed EV Battery Management and Thermal Safety System was tested under different temperature conditions to evaluate its performance and reliability. The LM35 sensor continuously monitored temperature and displayed real-time values on the LCD screen.When the temperature exceeded the safety limit, the Arduino activated the piezo buzzer successfully, providing an immediate warning alert. MATLAB Simulink analysis also confirmed stable charging, discharging, and thermal performance. The testing results show that the system effectively prevents overheating, improves battery safety, enhances charging efficiency, and increases battery lifespan in electric vehicles.

Testing alternate methods to prevent and manage traditional and electrical fire hazard by:

- sensing and moving vehicle to safe distance
- extinguishing electric fire in battery region both without human intervention

The goal is to design and build an autonomous Arduino-based robot capable of performing tasks like obstacle avoidance and line following using modular hardware (e.g., ultrasonic sensors, motors, motor drivers) and programmable logic. This project aims to provide hands-on experience in integrating hardware (sensors, actuators) with software (Arduino code), fostering skills in electronics, programming, and problem-solving, while creating a scalable platform for future upgrades like wireless control or advanced navigation algorithms.

VII. SCALABLITY

Challenges for Consumer Vehicle Implementation

- Real-time processing becomes complex when multiple battery cells are connected.
- Power consumption of monitoring circuits may increase in large-scale EV systems.
- Integration with different vehicle models and battery types requires additional design modifications.
- Ensuring reliable fault detection and fire prevention in high-capacity batteries is challenging.
- Cost optimization is necessary for large-scale commercial implementation. Maintaining accurate temperature monitoring in large battery packs can be difficult.

Hardware Scaling

- Additional temperature and voltage sensors can be integrated for larger battery packs.
- Higher-capacity microcontrollers or processors can be used for faster data handling.
- Wireless communication modules such as Wi-Fi or Bluetooth can be added for remote monitoring.
- Advanced cooling systems can be integrated for

improved thermal management.

- Multiple battery modules can be connected using modular hardware architecture.
- The LCD display can be upgraded to smart monitoring interfaces for detailed analysis.

Hardware Scalability

- The proposed system supports easy expansion by adding more sensing and protection modules.
- The Arduino-based design allows flexible integration with different EV battery configurations.
- Modular circuit architecture simplifies maintenance and future upgrades.
- The system can be adapted for two-wheelers, four-wheelers, and industrial EV applications.
- Additional safety features such as GPS tracking and IoT monitoring can be incorporated.
- The scalable design improves reliability, efficiency, and long-term usability in modern electric vehicles.

VIII. CONCLUSION

Some of key findings are:

The proposed Electric Vehicle Battery Management and Thermal Safety System provides an efficient, reliable, and low-cost solution for improving battery safety and performance in electric vehicles. The system successfully monitors important battery parameters such as temperature and heat conditions using sensors and real-time processing through the Arduino UNO.

The integration of thermal monitoring, warning alerts, and fault detection mechanisms helps prevent overheating, fire hazards, and battery damage during charging and discharging operations. The LCD display and buzzer system provide continuous monitoring and immediate user alerts, enhancing operational safety and ease of use.

Simulation and hardware testing results confirm that the proposed system improves charging efficiency, battery lifespan, thermal stability, and overall EV reliability. The scalable and modular design also allows future expansion for advanced battery management applications.

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3. Electric Vehicle Fire Staged to Study Environmental, Health Ramifications Researchers at the University of Miami conducted staged EV fires to assess environmental impacts and improve safety measures. The study utilized wearable sensors to monitor exposure levels, aiming to enhance safety protocols for firefighters and the public during EV fire incidents.
4. A Review on Fire Prevention and Suppression Solutions for EV Battery Packs - This paper reviews various strategies for preventing and suppressing fires in EV battery packs, focusing on technological advancements and best practices to enhance safety in battery design and management.
5. Approaches to Mitigate Electric Vehicle Fire Risks in Enclosed Spaces- This research discusses the unique challenges posed by EV fires in enclosed areas like parking garages. It explores measures to improve safety, including enhanced ventilation systems and firefighting strategies tailored for EV incidents.

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6. Fire Protection Materials for EV Batteries 2024-2034 This report analyzes trends in fire protection materials specifically designed for EV batteries, assessing their effectiveness in enhancing battery safety amid evolving regulations and technological advancements
7. Fire Safety of Battery Electric Vehicles: Hazard Identification, Detection, and Mitigation - This review provides a detailed overview of fire hazards associated with battery electric vehicles (BEVs), identifying key failure mechanisms and proposing detection.

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