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Electric Vehicle Battery Management System with Charge Monitor and Fire Protection

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Abstract: *The increasing demand for environmentally friendly and energy-efficient refrigeration systems has led to the exploration of alternative cooling technologies powered by renewable energy sources. This paper presents the design and development of a solar-powered refrigeration system using thermoelectric Peltier modules. The system operates based on the Peltier effect, where electrical energy is converted into a temperature difference across semiconductor junctions to produce cooling without the use of conventional compressors or refrigerants. Solar photovoltaic panels are used to generate electrical energy, which is stored in a battery and regulated through a digital temperature controller for precise temperature control. The proposed system is compact, portable, noiseless, and suitable for off-grid and remote areas. Experimental results demonstrate that the system can maintain temperatures in the range of 5 °C to 25 °C, making it suitable for food preservation and medical storage applications. Although the coefficient of performance of thermoelectric refrigeration is lower than conventional systems, the advantages of sustainability, low maintenance, and environmental safety make it a viable solution for small-scale cooling needs.*

Keywords*:* Lithium-ion Battery, Charge Monitoring, Fire Protection, Voltage Sensor, Current Sensor, Temperature Sensor, State of Charge (SoC), Battery Safety

I. INTRODUCTION

In recent years, the demand for electric vehicles (EVs) has increased rapidly across the world due to the growing awareness of environmental pollution, the need to reduce carbon emissions, and the depletion of fossil fuels. Electric vehicles are considered a key technology for achieving sustainable and green transportation. At the heart of every electric vehicle lies the battery pack, which stores electrical energy and provides power to the electric motor. The performance, safety, and lifetime of the EV heavily depend on the proper management of this battery system. This is where the Battery Management System (BMS) plays a vital role.

A Battery Management System is an electronic control unit that ensures the safe and efficient operation of rechargeable batteries. It continuously monitors various battery parameters such as voltage, current, temperature, and state of charge (SOC). The main purpose of the BMS is to protect the battery cells from operating outside their safe limits, to maximize their lifespan, and to provide accurate data for optimal vehicle performance. Without an effective BMS, the battery could suffer from overcharging, deep discharge, overheating, or cell imbalance, all of which can lead to reduced efficiency, shorter life, or even dangerous situations such as fire or explosion.

II. PROBLEM STATEMENT

Electric vehicles (EVs) are increasingly being adopted worldwide due to their environmental benefits and energy efficiency. At the core of every EV is the battery pack, which stores and supplies energy to the vehicle's electric motor. However, despite advancements in battery technology, safety, reliability, and efficient energy management remain critical challenges. Lithium-ion batteries, which are commonly used in EVs, are sensitive to overcharging, deep discharge, high temperatures, and mechanical damage. These conditions can lead to reduced battery life,

III. LITRATURE REVIEW

emphasized the critical importance of accurately estimating the State of Charge (SOC) and State of Health (SOH) in electric vehicle battery systems. SOC refers to the remaining usable capacity of the battery, while SOH reflects the overall condition and degradation level of the battery over time. Accurate estimation of these parameters is essential for ensuring safe operation, reliable performance, and prolonged battery life. In their research, Kumar et al. demonstrated that improper monitoring of SOC can lead to overcharging or deep discharge of battery cells, which not only reduces efficiency but also increases the risk of thermal runaway and safety hazards

The study concluded that implementing proper cell balancing techniques is essential for maximizing battery efficiency, extending life, and ensuring safe operation. Zhang and Lee emphasized that integrating these techniques within the Battery Management System (BMS) allows real-time monitoring and dynamic adjustment of individual cell voltages, making modern electric vehicles more reliable and safer for users. Their work remains foundational in the design of intelligent, high-performance battery systems.

IV. METHODOLOGY

The methodology begins with selecting suitable lithium-ion cells based on the required voltage, capacity, and safety standards. Voltage, current, and temperature sensors are interfaced with the microcontroller to continuously monitor battery parameters. The BMS control unit is programmed to calculate State of Charge (SoC) and detect abnormal conditions. Charging and discharging control logic is implemented to prevent overvoltage, overcurrent, and deep discharge. Temperature thresholds are defined to identify overheating and trigger protection actions. A fire detection and protection mechanism is integrated to respond to thermal faults. Audible alerts using a buzzer are activated during critical conditions. Finally, the complete system is tested under normal and fault conditions to verify safety, accuracy, and reliability.

The system design starts with creating a block diagram to define the interaction between the battery pack, sensors, and BMS controller. Hardware components are assembled on a suitable PCB to ensure reliable electrical connections. Sensor data is sampled at regular intervals for accurate real-time monitoring. Software algorithms are developed to analyze voltage balance between cells and detect faults. Protection logic is programmed to isolate the battery during unsafe conditions. Fire protection triggers are linked with automatic power cut-off and warning systems. Data is displayed or logged for performance evaluation and diagnostics. The system is validated through repeated charging, discharging, and stress testing scenarios.

V. WORKING

The proposed Battery Management System (BMS) with charge monitoring and fire protection operates on the principle of continuous measurement, control, and protection of the electric vehicle's battery pack. The system ensures that all battery cells function within their safe operating limits to maintain efficiency, performance, and safety.

The Arduino Uno acts as the brain of the system. It continuously collects real-time data from various sensors—voltage, current, and temperature sensors—connected to each battery cell. This data is processed to calculate key parameters such as State of Charge (SOC) and State of Health (SOH). Based on these values, the controller regulates charging and discharging operations to prevent overcharge, deep discharge, or excessive current flow.

The fire protection system plays a vital safety role. Temperature sensors continuously monitor the battery pack for abnormal heat. If overheating or a short circuit is detected, the ARDUINO UNO controller triggers protective actions such as disconnecting the power supply, isolating the affected cell, or activating a cutoff switch to prevent thermal runaway or fire.

When the system is initiated, the Arduino Uno begins gathering inputs from multiple sensors connected to individual battery cells. These sensors measure voltage, current, and temperature in real time. The ARDUINO UNO processes this data to calculate the State of Charge (SOC), which indicates the remaining battery capacity, and the State of Health (SOH), which reflects the battery's aging and overall condition. These calculations are critical for maintaining battery performance and predicting maintenance requirements.

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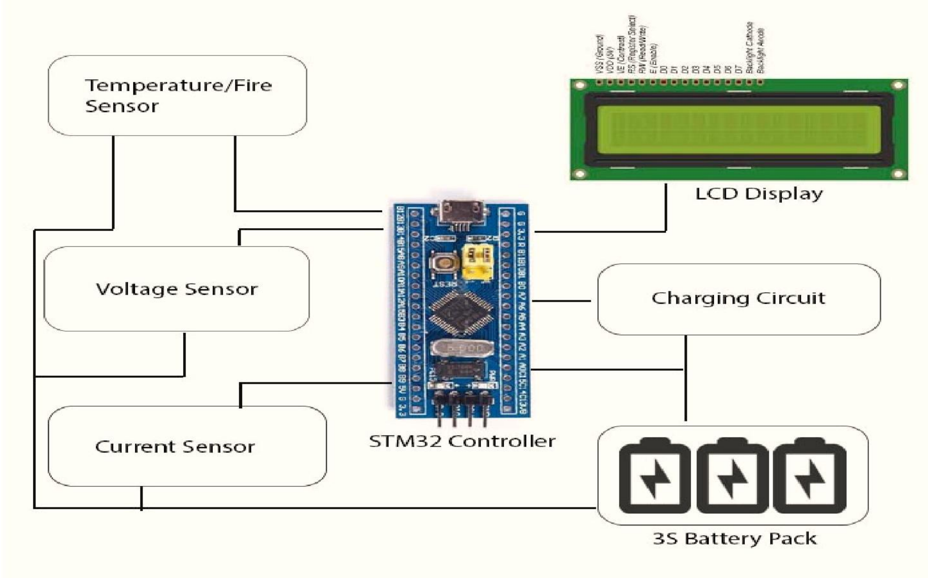
VI .BLOCK DIAGRAM



HARDWARE REQUIREMENT

- Battery Pack (Lithium-ion Cells)
- Voltage and Current Sensors
- Temperature Sensors (Thermistors or RTDs)
- Fire Protection System
- Buzzer
- Microcontroller / BMS Control Unit

VII. COMPONENTS DESCRIPTION

Battery Pack (Lithium-ion Cells):

The battery pack consists of lithium-ion cells connected in series and parallel to achieve the required voltage and capacity. It provides high energy density, long cycle life, and stable power supply for efficient electric vehicle operation.

Voltage and Current Sensors:

Voltage sensors monitor individual cell and pack voltage to prevent overcharging and deep discharge. Current sensors measure charge and discharge current, enabling accurate power management and protection of the battery system.I prefer this response

Temperature Sensors (Thermistors or RTDs):

These sensors measure the temperature of the battery cells to prevent overheating and thermal runaway. They provide real-time data to the BMS for activating cooling or protection mechanisms when temperature limits are exceeded.

Fire Protection System:

The fire protection system detects abnormal conditions such as overheating or short circuits and responds quickly to reduce fire risk. It may include automatic cut-off, alarms, and suppression mechanisms to ensure battery and user safety.

Buzzer:
The buzzer provides audible alerts during fault conditions such as overvoltage, overheating, or fire detection. It helps in immediately warning the user to take necessary safety actions.

Microcontroller / BMS Control Unit:
The microcontroller acts as the core of the BMS, processing sensor data and executing control algorithms. It manages battery monitoring, protection functions, and communication to ensure safe and reliable system operation.

SMPS
A switched-mode power supply (SMPS) is used to convert and regulate electrical power with high efficiency. It provides a stable and reliable voltage supply to the system components, ensuring safe and consistent operation.

VIII. ADVANTAGES

Enhanced Battery Safety:
The BMS continuously monitors voltage, current, and temperature to prevent unsafe operating conditions. Fire protection features reduce the risk of thermal runaway and battery-related accidents.Compact and Portable

Accurate Charge Monitoring:
The charge monitor provides precise State of Charge (SoC) information to the user. This helps in better trip planning and avoids unexpected battery depletion. No Moving Parts

Extended Battery Life:
By preventing overcharging, deep discharging, and overheating, the BMS improves battery health. This significantly increases the overall lifespan of lithium-ion cells

Fire Risk Prevention:
Early detection of abnormal temperature rise or faults enables timely protective actions. Automatic cut-off and alerts help in minimizing fire hazards.

Improved Energy Efficiency:
Optimized charging and discharging control reduce energy losses. This ensures efficient utilization of stored energy in the battery pack.

Real-Time Fault Detection:
The system quickly identifies issues such as overcurrent, short circuits, or sensor failures. Immediate warnings allow corrective action before major damage occurs.

User Safety and Awareness:
Audible and visual alerts inform the user about critical battery conditions. This improves user awareness and ensures safer vehicle operation.

Reliable and Stable Vehicle Performance:
Maintaining battery parameters within safe limits ensures consistent power delivery. This results in smoother vehicle performance and higher reliability.

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IX. LIMITATIONS

• Advanced sensors, microcontrollers, and fire protection components increase system cost. This can raise the overall price of the electric vehicle.
• Integration of multiple sensors and control algorithms makes the BMS design complex. This increases development time and chances of design errors.
• Sensors and electronic components may degrade over time. Regular calibration and maintenance are required for accurate operation.
• Fire protection systems can detect and respond to early faults. However, they may not fully suppress severe battery fires once thermal runaway occurs.
• Incorrect readings from voltage, current, or temperature sensors can lead to wrong decisions. This may affect safety and battery performance.
• Continuous monitoring and control consume a small amount of battery power. This slightly reduces overall energy efficiency.
• Extreme temperatures, moisture, or vibrations can affect BMS components. Harsh operating conditions may reduce system reliability.
• Adapting the same BMS design to different battery sizes and chemistries is difficult. Customization is often required for different EV models.

X. CONCLUSION

The Electric Vehicle Battery Management System with charge monitoring and fire protection plays a vital role in ensuring battery safety and reliability. By continuously monitoring voltage, current, and temperature, the system protects the battery from unsafe operating conditions. Accurate charge monitoring improves user awareness and efficient energy usage. Fire detection and protection mechanisms significantly reduce the risk of battery-related accidents. Overall, the BMS enhances battery life, vehicle performance, and user safety, making it an essential component of modern electric vehicles.

XI. FUTURE SCOPE

Future advancements in Electric Vehicle BMS can include the use of AI and machine learning for predictive fault detection and battery health estimation. Integration with cloud and IoT platforms will enable remote monitoring and real-time diagnostics. Enhanced fire suppression technologies and support for fast-charging and solid-state batteries will further improve safety and performance.

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