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Battery Management System for Electric Vehicles

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Abstract: *The integration of battery management with automation plays a crucial role in optimizing electric vehicle (EV) operations. This paper presents an advanced Battery Management System (BMS) designed to monitor and control key battery parameters, including voltage, current, temperature, and state of charge, in real-time. The system leverages embedded technology with the ESP32, enabling seamless data acquisition and automated control mechanisms for enhanced battery performance and safety [2]. This integration enhances user interaction by providing real-time insights and intelligent control over the battery's health, ensuring improved efficiency, reliability, and longevity [4]. Additionally, the system aids in cost reduction by preventing battery failures, optimizing charging cycles, and supporting informed decision-making [3]. The paper discusses the technical architecture and key benefits of implementing this system in electric vehicles. Furthermore, various applications of this technology are explored, including its role in energy management, safety enhancements, and sustainable transportation [5]. The findings highlight the potential of embedded-driven battery management systems in transforming EV operations by improving performance, ensuring safety compliance, and extending battery life [1].*

Keywords: Battery Management System (BMS), ESP32, Lithium-ion Battery, Embedded Systems, Power Management, Thermal Management

I. INTRODUCTION

Electric vehicle (EV) performance and safety are highly influenced by battery parameters such as voltage, current, and temperature. Effective monitoring and control of these parameters are essential for optimizing efficiency, ensuring safety, and reducing operational costs [3]. The Battery Management System (BMS) is an embedded system designed to provide real-time measurement and automated control of battery conditions. It integrates high-precision sensors with an Esp-32 microcontroller, enabling seamless monitoring and adjustments [2]. This system enhances EV battery performance by improving accuracy, efficiency, and decision-making. The paper discusses the system's design, implementation, and benefits in electric vehicle applications [1]

One key aspect of BMS is SoC estimation, which provides real-time data on battery charge levels, supporting energy optimization and efficient power distribution within the EV. Moreover, the BMS conducts thermal management to prevent overheating, which is critical for battery longevity and vehicle safety. Advanced BMS systems offer predictive maintenance by estimating the state of health (SoH) of the battery, allowing users and manufacturers to track battery degradation over time.

II. LITERATURE SURVEY

SR.NO	RESEARCH PAPER NAME	AUTHOR	METHODOLOGY
[1]	Optimization of Energy Storage in EV Battery Management Systems	Patel, S., & Zhang, W.	This paper explores strategies for improving the energy storage efficiency of BMS in electric vehicles, with a focus on algorithms for better charge management and battery lifespan extension.
[2]	Energy Storage Optimization in	Mehta, P., &	The authors discuss optimization techniques

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	EV Battery Management Systems in India	Gupta, R.	specific to India's climate and infrastructure, addressing challenges
[3]	Enhancing the Cyber-Security of BMS for Energy Storage	Williams, A., & Chen, X.	The paper covers the importance of cyber-security measures in BMS, focusing on data integrity and protection
[4]	Advances in State of Charge and State of Health Estimations for BMS	Yadav, M., & Singh, R.	This research highlights recent advancements in SOC and SOH estimations, crucial for the accurate tracking of battery health
[5]	Modelling and Simulation of BMS in EV Applications	Lee, H., & Wang, Y.	The authors present a simulation-based study that models thermal management in BMS

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III. EXISTING SYSTEM

The advent of the Internet of Things (IoT) has revolutionized smart systems by enabling real-time data exchange and intelligent control between devices. This transformation has made a significant impact across various sectors, especially in electric mobility, where monitoring the health and safety of battery packs is a critical requirement. Electric Vehicles (EVs) rely heavily on battery systems, which need to operate under optimal conditions to ensure safety, performance, and lifespan. However, issues such as overcharging, deep discharging, temperature rise, or uneven cell behavior can lead to performance degradation, safety risks, or even thermal runaway. Most modern EVs rely on embedded BMS solutions, but these are often expensive or not scalable for prototyping and academic use. Currently, many low-cost EV systems use manual methods for inspecting battery health, including visual checks or the use of handheld measurement devices. This makes it difficult to detect real-time issues such as sudden overheating, overcurrent, or short circuits that can severely affect the reliability and safety of the vehicle. Additionally, basic battery protection circuits focus only on voltage or current limits, lacking multi-parameter monitoring, data logging, and predictive diagnostics.

To overcome these limitations, this project proposes an IoT-enabled BMS system using an ESP-32 microcontroller that integrates multiple sensors and real-time safety mechanisms. It monitors key battery parameters including voltage, current, temperature, and smoke detection, and controls output to load, fan, and buzzer using relays and GPIO control.

While some commercial BMS units are available, they often do not include cloud connectivity, live fault alerts, or data analytics capabilities. Some companies are exploring Machine Learning (ML) for battery fault prediction and life estimation, but no complete low-cost ML-integrated solution currently exists for academic or prototyping purposes. This project sets the foundation for real-time, multi-factor battery health monitoring, providing a platform that can later be enhanced with wireless data transmission, mobile integration, or ML-based predictive failure analysis.

IV. PROPOSED SYSTEM

Battery malfunction prediction has become an essential application of Machine Learning (ML) in the electric mobility domain, particularly within Battery Management Systems (BMS) for Electric Vehicles (EVs). Identifying battery issues in advance can help avoid sudden failures, extend battery lifespan, reduce maintenance costs, and improve both safety and reliability. Traditionally, BMS systems react to faults as they occur, but modern sensor technology and the growing availability of real-time battery data now support predictive approaches. ML models can process this sensor data to recognize degradation patterns, cell imbalance, overheating, and other early indicators of battery failure. By learning from historical battery performance and failure data, ML algorithms can estimate the Remaining Useful Life (RUL) of cells and modules, allowing targeted maintenance only when necessary. This reduces unnecessary interventions, avoids unexpected EV breakdowns, and optimizes energy usage. Real-time monitoring increases operational efficiency by enabling timely alerts and fault detection. Additionally, predictive maintenance minimizes the risk of hazardous battery incidents, such as thermal runaway or short circuits, which could otherwise jeopardize user safety.

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While IoT-based BMS platforms enable cloud-connected monitoring and remote diagnostics, they primarily focus on data acquisition and live alerts. In contrast, ML-based BMS systems go beyond by delivering intelligent analytics, forecasting potential failures before they impact system performance. The integration of ML with IoT enhances the overall decision-making process, supporting proactive strategies rather than reactive responses. As a result, predictive BMS frameworks can significantly improve the sustainability, safety, and efficiency of EV operations.

V. SYSTEM REQUIREMENTS

- Hardware Configuration

1. ESP-32 CONTROLLER
2. ZMPT101B Voltage Sensor
3. DHT11 Temperature Sensor
4. ACS712 Current Sensor
5. Transformer 12V-1A
6. DC or Servo Motor
7. Battery: 12V,9V
8. Relays
9. Cooling fan
10. Buzzer

- Software Configuration

1. IDE: Arduino IDE
2. Language: C, C++
3. VS Code Editor

VI. METHODOLOGY

BLOCK DIAGRAM

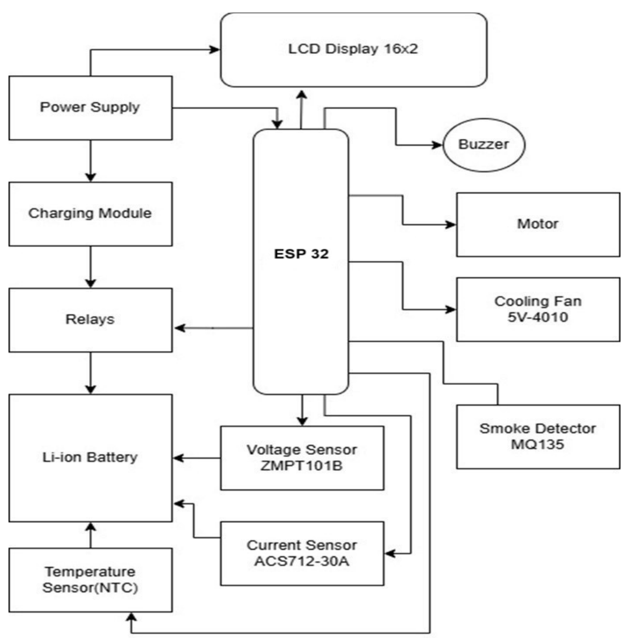

Fig 1: Block Diagram Of Battery Management System In Electric Vehicles

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In order to power the various components, the system begins with a power supply that converts AC mains into a regulated DC voltage. This powers the ESP32 microcontroller along with peripheral modules. The system employs several sensors such as the NTC temperature sensor, ZMPT101B voltage sensor, ACS712-30A current sensor, and MQ135 gas sensor to collect vital operational data. These sensors continuously monitor the battery's temperature, voltage, current, and air quality, ensuring real-time detection of anomalies or unsafe conditions.
The ESP32 microcontroller acts as the brain of the system, receiving analog inputs from the sensors and converting them into digital signals for processing. It uses the collected data to evaluate the state of the Li-ion battery and control connected components such as a cooling fan (5V-4010), a motor, a buzzer, and relays. If unsafe conditions like overcurrent, overheating, or gas leakage are detected, the microcontroller instantly takes protective actions such as shutting down the motor or activating the cooling fan or buzzer. It also displays the system status and alerts on a LCD for real-time human supervision.
For advanced diagnostics, the ESP32 transmits the sensor data to a laptop via serial communication. A machine learning model is deployed on the laptop to perform predictive analytics.

- Supervised Learning is used by training the model with historical labelled sensor data to recognize fault conditions.
- Random Forest is chosen for its robustness in handling non-linear sensor data with mixed types.
- Support Vector Machine (SVM) is applied for accurate classification of operational states.

Once trained, the model analyse new incoming data to detect patterns that indicate potential faults before they happen. If an abnormality is detected, the system instantly reflects it on the LCD screen and can also initiate protective actions. By integrating IoT with ML, the system enables early fault detection, enhanced battery protection, reduced downtime, smarter maintenance schedules, and extended component lifespan. Overall, this smart BMS achieves improved reliability, safety, and real-time operational awareness essential for modern energy systems and electric vehicles.

Simulation-PCB of hardware

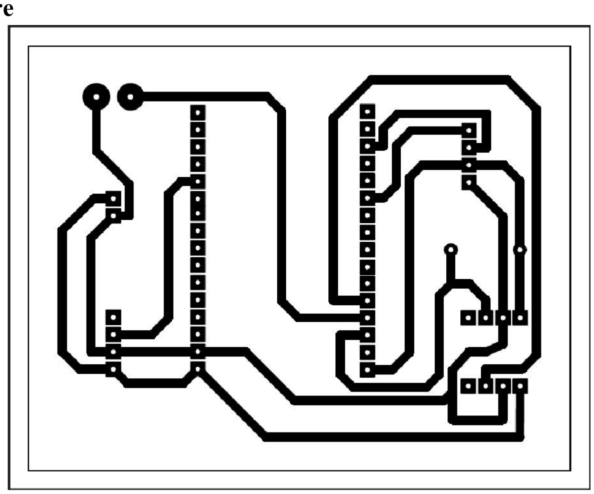

Fig 2: PCB Layout Of Battery Management System In Electric Vehicles

VII. RESULTS AND DISCUSSION

The table presents experimental data showing how **voltage** impacts both **current draw** and **temperature rise** in a Battery Management System (BMS) for an electric vehicle. It includes safety indicators for motor operation and buzzer alerts. As the voltage increases from 11V to 23.5V, the current rises steadily from 2.1A to 6.3A, indicating a proportional load demand with higher charging voltage. Similarly, temperature increases with voltage due to increased electrical activity and component heating.

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SN	Voltage	Current	Temperature	Motor Status	Buzzer Status
1	13.5	2.9	29	ON	OFF
2	16.5	4.2	31.5	ON	OFF
3	19.5	5.5	38	ON	OFF
4	21.0	6.0	44	ON	OFF
5	23.5	6.3	51	OFF	ON

Table 1. Voltage vs Current and Temperature Analysis

The **graph** visualizes this relationship using two y-axes:

- The **left y-axis** (blue line) shows the increase in current with voltage.
- The **right y-axis** (red line) shows the rise in temperature with voltage.

Two critical safety thresholds are highlighted:

- A **vertical dashed line at 22V** marks the limit where the **motor is programmed to stop** operation to prevent overvoltage damage.
- A **horizontal dashed line at 50°C** indicates the point where the **buzzer is activated**, warning of overheating conditions.

This graphical analysis confirms that:

- Current and temperature increase with voltage.
- The BMS system appropriately handles fault detection via automatic motor cutoff and buzzer activation beyond safe limits.

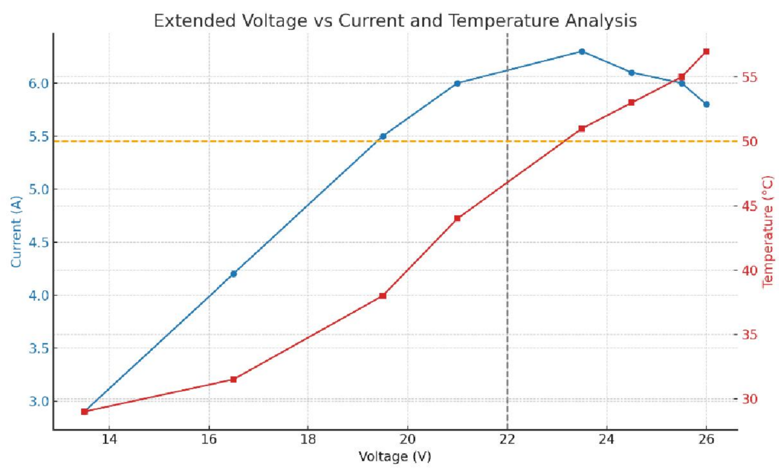

Fig 3: Voltage vs Current and Temperature for your BMS

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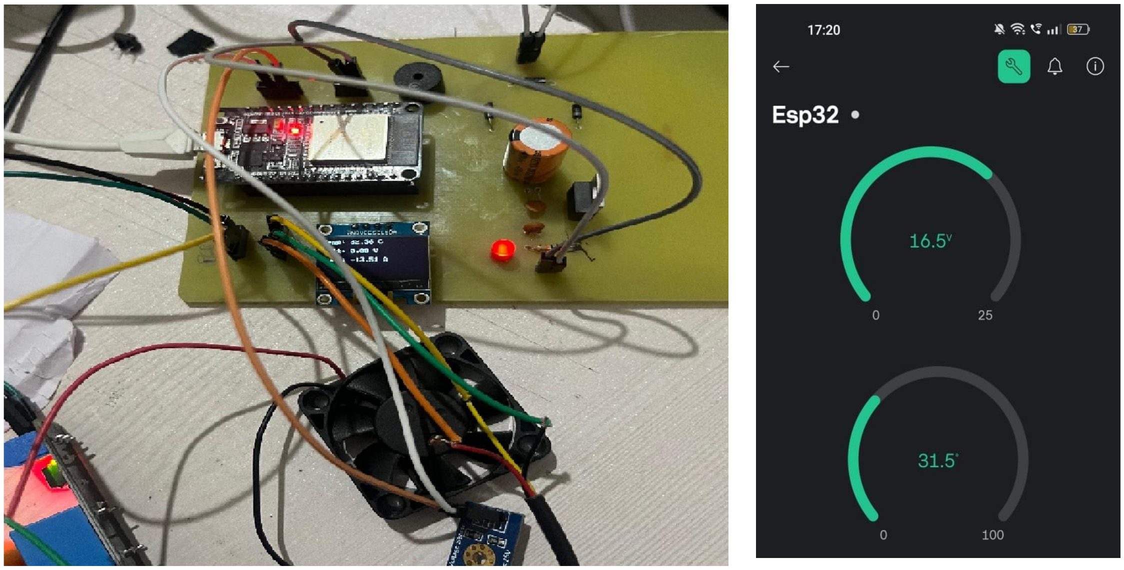

Fig 4: Hardware And Software Result Of BMS

VIII. CONCLUSION

All The development of the Battery Management System (BMS) for Electric Vehicles (EVs) represents a significant step forward in the integration of advanced technologies for managing and optimizing energy storage in electric vehicles. The project successfully combines efficient battery monitoring, power management, and safety protocols, ensuring that the battery system operates optimally throughout its lifecycle. This BMS serves as a critical component in enhancing the performance, reliability, and safety of EVs, particularly in managing smaller battery systems like AA cells for prototyping. It demonstrates how cutting-edge solutions in battery management can directly contribute to extending battery life, improving energy efficiency, and ensuring safe operation, even in challenging or dynamic environments. The project provides a foundation for future advancements in battery management, with an emphasis on scalability, cost-effectiveness, and ease of implementation. It highlights the increasing importance of effective energy management in the growing electric vehicle market, and serves as a stepping stone toward more sustainable and efficient electric transportation systems. As the BMS technology matures, it will play a vital role in the continued evolution of the EV industry, ensuring that electric vehicles become more accessible, reliable, and widely adopted across various sectors.

IX. ACKNOWLEDGMENT

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learning framework (SPCA, bat algorithm) for sensor fault detection in EV BMS

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