

# EV-BMS-X1: A Smart IoT-Based Battery Management System with Real-Time Monitoring and Interactive User Interface for Electric Vehicles Deployment

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**Abstract:** The growing demand for electric vehicles has made battery safety, reliability, and performance monitoring a critical area of research. This paper presents the design and development of EV-BMS-X1, an intelligent battery management system that integrates embedded protection mechanisms with IoT-based real-time monitoring. The system is built using an ESP32 microcontroller and incorporates multiple sensors to continuously track key battery parameters such as voltage, current, temperature, and environmental conditions. Unlike conventional systems, the proposed solution introduces an adaptive web-based interface that allows users to monitor data and modify system parameters wirelessly without firmware reprogramming. To ensure measurement stability in noisy environments, filtering and smoothing techniques are applied to sensor data. Additionally, the system estimates battery usage through cycle counting and energy throughput analysis, providing insights into battery health. Experimental validation demonstrates that the system responds effectively to abnormal conditions such as over-voltage, over-current, and thermal hazards. The proposed design offers a practical, scalable, and user-friendly solution for next-generation electric vehicle battery management systems.

**Keywords:** Battery Management System, Electric Vehicles, IoT, ESP32, Smart Monitoring, Embedded Systems.

## I. INTRODUCTION

The shift toward electric mobility has significantly increased the importance of efficient and reliable battery management systems. Lithium-ion batteries, widely used in electric vehicles, require precise monitoring to operate safely within defined limits. Any deviation in voltage, current, or temperature can lead to performance degradation, reduced lifespan, or hazardous failures.

Traditional battery management systems mainly focus on protection by disconnecting the battery during

unsafe conditions. While effective, these systems often lack advanced features such as real-time monitoring, data visualization, and user interaction. This creates challenges in understanding battery performance and performing maintenance.

To address these limitations, this work proposes EV-BMS-X1, a smart battery management system that combines hardware protection with IoT-based monitoring and control. The system enables users to access real-time battery data and adjust parameters wirelessly through an interactive interface. This approach not only enhances safety but also improves usability and system transparency.

## II. LITERATURE REVIEW

Battery management systems have evolved significantly with the integration of intelligent algorithms and communication technologies. Various approaches have been proposed for estimating battery parameters such as State of Charge (SOC) and State of Health (SOH).

Previous studies emphasize the importance of filtering techniques to improve measurement accuracy, especially in noisy environments. Temperature monitoring has also been identified as a critical factor affecting battery lifespan and safety. IoT-based systems further enhance usability by enabling remote monitoring and data access.

However, most existing systems lack flexibility in configuration and require technical expertise for calibration. Additionally, many systems do not provide intuitive interfaces for end users. The proposed system addresses these challenges by integrating a user-friendly interface with real-time wireless control and dynamic parameter adjustment.

## III. METHODOLOGY

### System Architecture

The system follows a layered architecture consisting of sensing, processing, protection, and communication units. Sensors collect real-time data, which is processed by the microcontroller to detect abnormal conditions. The processed data is then transmitted to a user interface for visualization.

### Hardware Design

The hardware setup is designed to ensure accurate sensing and reliable protection. It includes:

- ESP32 microcontroller for computation and communication
- Current sensor for load measurement

- Temperature and humidity sensor for thermal monitoring
- Smoke sensor for hazard detection
- Relay/MOSFET for protection control

The protection circuit is triggered whenever the measured parameters exceed predefined safety thresholds.

### Signal Conditioning and Filtering

Sensor readings in practical environments often contain noise and fluctuations. To improve stability, a smoothing algorithm is applied to the measured values.

$$v_{filtered} = (1 - \alpha)v_{previous} + \alpha v_{current}$$

This filtering approach reduces sudden variations and ensures consistent output

### Battery Parameter Estimation

The system estimates the State of Charge using voltage-based mapping combined with smoothing techniques. In addition, energy throughput is calculated to estimate battery usage cycles which helps in analyzing long-term battery health.

### IoT-Based Monitoring

The ESP32 hosts a local web server that enables wireless interaction. The system provides:

- Real-time parameter updates
- Adjustable safety limits
- Sensor calibration options

This eliminates the need for repeated firmware updates and improves system flexibility.

## IV. IMPLEMENTATION

### 1. Software Architecture

The software is designed using a modular approach, separating data acquisition, processing, communication, and safety control. This improves system reliability and makes future upgrades easier.

### 2. User Interface Design

A responsive web interface is developed to display real-time data in an intuitive format. The interface includes:

- Live parameter display
- Graphical indicators
- Alert notifications
- Configuration controls

### Data Storage and Logging

The system uses non-volatile memory to store important data such as energy usage and cycle count. This ensures that historical data is preserved even after power loss.

## V. RESULTS AND DISCUSSION

### System Performance

The system operates reliably under varying load conditions. Sensor readings remain stable due to the implemented filtering techniques.

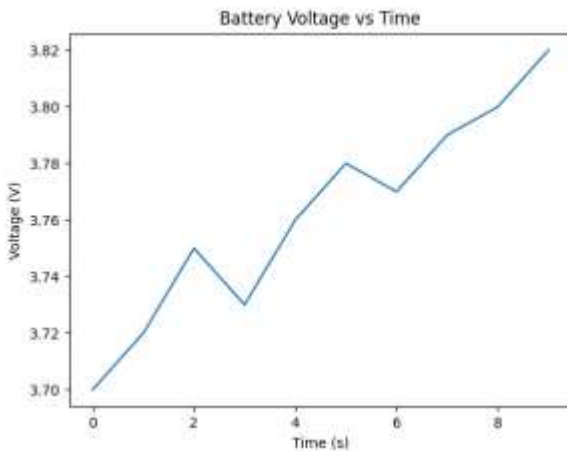


Fig. 1: Voltage graph

### Safety Evaluation

The protection mechanism successfully detects and responds to:

- Over-voltage conditions
- Excess current flow
- High temperature levels
- Smoke presence

The system disconnects the battery within a short response time, ensuring safety.

### 3. Accuracy and Stability

Sensor readings were compared with standard measurement tools, showing good agreement. The filtering technique significantly reduces noise and improves accuracy.

### 4. User Experience

The web interface provides smooth and responsive interaction. Users can easily monitor battery status and adjust settings without technical complexity.

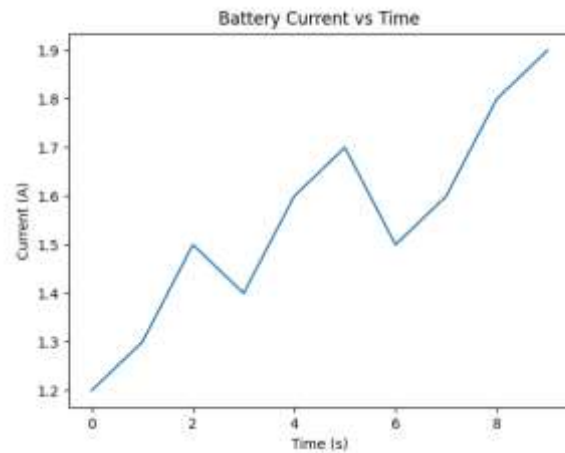


Fig. 2: Current graph



Fig. 3: Simulation Image

## IV. CONCLUSION

This paper presented the design and implementation of an IoT-enabled intelligent battery management system

for electric vehicles. The system integrates real-time monitoring, safety protection, and user interaction into a single platform.

The results demonstrate that the proposed system improves both safety and usability compared to traditional solutions. The ability to monitor and control the system wirelessly makes it highly practical for real-world applications.

Future work can focus on integrating machine learning algorithms for predictive maintenance, cloud connectivity for remote analytics, and advanced SOC/SOH estimation techniques.

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