

Design and implementation of Smart Battery Management System using ESP32

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Abstract: The rising use of rechargeable batteries in electric vehicles, renewable energy systems, portable electronics, and energy storage applications has created a demand for reliable battery monitoring and protection systems. This paper presents the design and implementation of a Smart Battery Management System using ESP32 for real-time monitoring, protection, and control of a rechargeable cell pack. The system designed uses a voltage sensor, current sensor, DS18B20 temperature sensor, and MQ-2 gas sensor to monitor important electrical and environmental parameters. The ESP32 processes sensor data and estimates the State of Charge (SOC) based on cell-pack voltage. The measured parameters and SOC are displayed on a 16×2 I2C LCD.

The system offers automatic protection against abnormal conditions such as undervoltage, overvoltage, overcurrent, high temperature, gas detection, and temperature sensor failure. A main relay disconnects the cell pack during fault conditions, while an exhaust fan provides automatic cooling when the temperature rises above the specified limit. Buzzer and LED indicators provide audible and visual fault and charging indications. In addition, the Blynk IoT platform is integrated through Wi-Fi for remote monitoring and selected control operations. The proposed system combines monitoring, SOC estimation, charging indication, protection, cooling, fault detection, and IoT connectivity into a single low-cost platform. The developed system demonstrates the suitability of ESP32 for smart and reliable battery management applications.

Keywords: Battery Management System, ESP32, State of Charge, Battery Monitoring, Battery Protection, IoT, Blynk, Temperature Monitoring, Gas Detection, Smart Battery.

INTRODUCTION

Rechargeable batteries have evolved into an essential part of modern energy systems and are widely used in electric vehicles (EVs), renewable energy storage systems, portable electronic devices, UPS systems, and other battery-powered applications. The increasing use of rechargeable batteries has led to the need for effective monitoring and management systems to ensure their safe, reliable, and efficient operation. Battery performance depends strongly on operating parameters such as voltage, current, temperature, and State of Charge (SOC). If these parameters are not properly monitored and controlled, conditions such as overcharging, over-discharge, excessive current, and overheating may occur, which can reduce battery performance, shorten its operating life, and create safety threats [1], [2].

A Battery Management System (BMS) is an important electronic system utilized to monitor and protect rechargeable batteries. A conventional BMS generally performs functions such as voltage and current monitoring, temperature measurement, charging control, and protection against abnormal operating conditions. However, basic battery protection systems may provide limited information to the user and may not support remote monitoring, intelligent control, or continuous fault identification. Therefore, the integration of microcontrollers, sensors, and Internet of Things (IoT) technology can improve the functionality of a conventional BMS and provide a more intelligent and connected solution. [2].

One of the important parameters in battery management is the State of Charge (SOC), which reflects the available charge level of the battery and is generally expressed as a percentage. Accurate SOC information is effective for understanding the remaining energy of the battery and for making appropriate charging and operating decisions. In the proposed system, SOC is estimated based on the measured cell-pack voltage and displayed to the user through a 16×2 I2C LCD. During charging, the charging condition is indicated using an LED, while the SOC is consistently monitored to provide information about the charging status[3].

The proposed work demonstrates a Smart Battery Management System using ESP32 for real-time monitoring, protection, and control of a rechargeable cell pack. The ESP32 Dev Module serve as the central processing and control unit. A voltage sensor and current sensor are used to monitor the electrical parameters of the cell pack. A DS18B20 temperature sensor is used to measure temperature, while an MQ-2 gas sensor is incorporated to detect abnormal gas or smoke conditions. The sensor readings are continuously acquired by the ESP32 and processed to determine the operating condition of the cell pack [4].

The system incorporates several automatic protection mechanisms to enhance battery safety. The measured parameters are compared with predefined safety limits. Conditions such as low voltage, high voltage, overcurrent, high temperature, gas detection, and temperature sensor failure are treated as abnormal conditions. When a fault condition is detected, the main relay can disconnect the cell pack, and the buzzer offers an audible warning. LED's provide visual indications of charging and fault conditions. In addition, an exhaust fan is controlled through a separate relay and is automatically activated when the temperature rises above the specified limit, providing additional thermal management. [5].

The proposed system also combines IoT-based monitoring using the Blynk platform. The ESP32 communicates with Blynk through Wi-Fi and transmits important battery parameters such as voltage, current, temperature, SOC, and system status. This allows the user to monitor the condition of the cell pack

remotely. Selected control functions, such as relay, buzzer, and LED control, can also be performed through the Blynk application. Thus, the system combines local monitoring through the LCD with remote monitoring and control through IoT technology [4].

The overall system is designed as a low-cost and multifunctional battery management solution that combines sensing, SOC estimation, charging indication, fault detection, automatic cooling, relay-based protection, and IoT connectivity. The integration of these functions using the ESP32 provides continuous monitoring and automatic response to abnormal operating conditions. The proposed approach can be useful as a practical foundation for battery-based applications where safety, monitoring, and remote accessibility are important [5].

The main objective of this work is therefore to design and implement a Smart Battery Management System using ESP32 that provides continuous monitoring and protection of a rechargeable cell pack while offering SOC indication, charging-status monitoring, automatic cooling, fault alerts, and IoT-based remote monitoring. The developed system can be further extended for applications such as electric vehicles, solar energy storage, UPS systems, and other rechargeable energy-storage systems.

RELATED WORKS

Previous research on BMS has focused on battery monitoring, SOC/SOH estimation, thermal management, fault detection, and IoT-based communication.

Shrivastava et al. [4] reviewed model-based online SOC estimation techniques using the Kalman filter family for lithium-ion batteries. The study highlighted the importance of accurate battery modelling and estimation algorithms for reliable real-time SOC estimation.

Hannan et al. [2] presented a comprehensive review of battery modelling and state-estimation techniques for advanced BMS applications. The study discussed important battery states such as SOC, SOH, State of Energy, and State of Power, highlighting their importance in advanced battery management.

Research on IoT-based BMS has also increased in recent years. A cloud-based BMS study demonstrated the use of ESP32 for collecting battery data and transferring it to a cloud platform, enabling real-time visualization and remote monitoring [3].

Gozuoglu et al. [5] developed an IoT-enhanced battery management system using ESP-based microcontrollers for real-time SOC and SOH monitoring. The system demonstrated the potential of low-cost ESP32-based hardware for battery data logging, remote monitoring, and scalable battery applications.

Recent research has also investigated wireless BMS architectures. An IEEE study presented an ESP32-based wireless BMS for EV applications that monitors voltage, current, temperature, SOC, and SOH and transmits the information to a cloud server for real-time monitoring [6].

Another recent study developed an ESP32-based BMS using a hybrid OCV and Coulomb-counting approach for SOC estimation. The work demonstrated that a compact ESP32 platform can perform real-time voltage, current, and temperature sensing along with SOC estimation [7].

Recent work has also expanded BMS functionality beyond electrical measurements. An IoT-based battery thermal and management system incorporated cell-voltage monitoring, SOC/SOH estimation, temperature monitoring, smoke detection, flame detection, and ESP32-based IoT communication [8].

PROPOSED WORK

The proposed work focuses on the design and implementation of a Smart Battery Management System using ESP32 for real-time monitoring, protection, and control of a rechargeable cell pack. The system integrates multiple sensors and control devices to monitor important battery parameters such as voltage, current, temperature, gas level, and State of Charge (SOC). The ESP32 acts as the central processing unit and makes control decisions based on predefined safety conditions.

The proposed system provides SOC estimation, charging-status indication, automatic protection, temperature-based cooling, fault detection, and IoT-based monitoring. A 16×2 I2C LCD is used for local display, while the Blynk IoT platform enables remote monitoring and selected control functions through Wi-Fi. The main relay provides cell-pack protection, while the exhaust fan, buzzer, and LEDs are used for cooling and fault/status indication. The overall proposed system is designed as a low-cost and multifunctional solution for safe and reliable battery management.

3.1 System Design

The system design describes the overall hardware and functional architecture of the proposed Smart BMS. The ESP32 is used as the main controller and is connected to the voltage sensor, current sensor, DS18B20 temperature sensor, and MQ-2 gas sensor. The controller processes the sensor data and estimates the SOC of the cell pack.

The output section consists of a 16×2 I2C LCD, main relay, fan relay, exhaust fan, buzzer, and LEDs. The charging circuit is connected to the cell pack, while Blynk IoT provides remote monitoring and control through Wi-Fi.

3.2.1 Block Diagram

The block diagram illustrates the overall working of the proposed **Smart Battery Management System using ESP32. The cell pack parameters such as voltage, current, temperature, and gas level are measured using different sensors and provided to the ESP32 for processing. The ESP32 estimates the SOC and controls the relay, cooling fan, buzzer, and LEDs according to the detected conditions. The 16×2 I2C LCD displays the battery parameters and system status, while Blynk IoT enables remote monitoring and control through Wi-Fi.

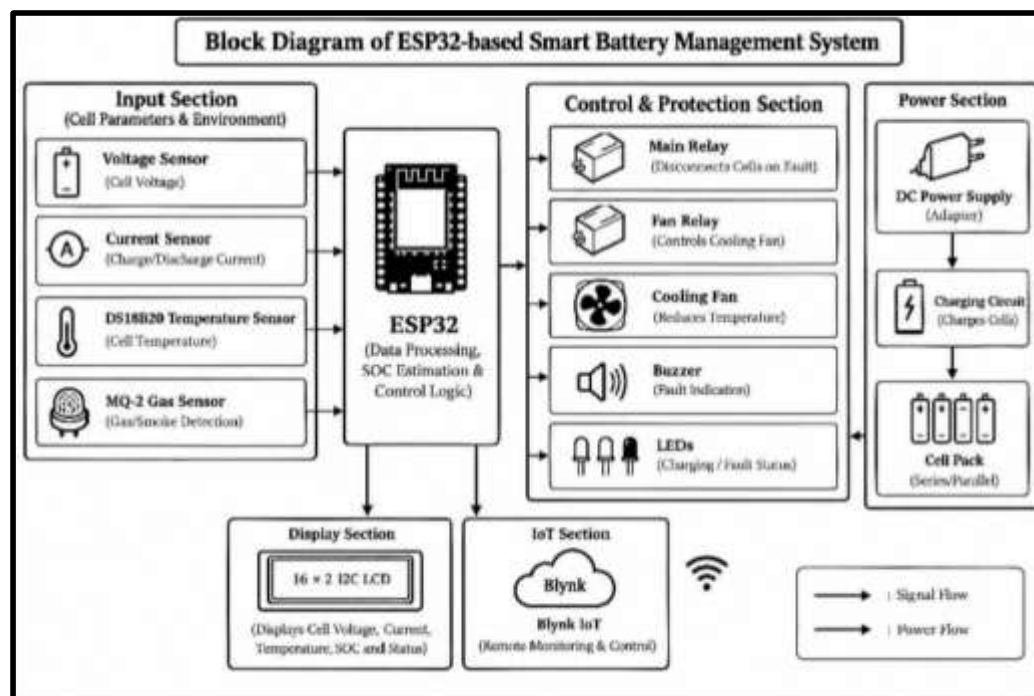


Figure.1. Block Diagram of the Proposed System

3.3 Working Principle

The system starts by initializing the ESP32, sensors, LCD, relays, Wi-Fi, and Blynk IoT. The voltage, current, temperature, and gas level are continuously measured from the cell pack. The ESP32 processes these values and calculates the SOC based on the measured voltage.

The SOC and other battery parameters are displayed on the LCD and transmitted to Blynk for remote monitoring. During charging, the charging LED indicates the charging condition.

The ESP32 continuously checks the measured parameters against predefined safety limits. When the temperature exceeds 38°C, the exhaust fan is switched ON. If low voltage, high voltage, overcurrent, high temperature, gas detection, or temperature sensor failure occurs, the main relay is switched OFF and the buzzer is activated. Under normal conditions, the system continues monitoring and controlling the cell pack.

3.4 System Flowchart

The system flowchart represents the sequential operation of the proposed Smart BMS. It starts with initialization of the ESP32, sensors, LCD, Wi-Fi, Blynk, and GPIO pins. The controller then reads the cell-pack voltage, current, temperature, and gas level and calculates the SOC.

The system checks the temperature and safety conditions continuously. If the temperature exceeds 38°C, the exhaust fan is activated. If any fault condition is detected, the main relay disconnects the cell pack and the buzzer provides an alert. If no fault is detected, the system operates normally.

The measured parameters, SOC, and system status are displayed on the LCD and transmitted to Blynk. After a short delay, the complete process is repeated continuously.

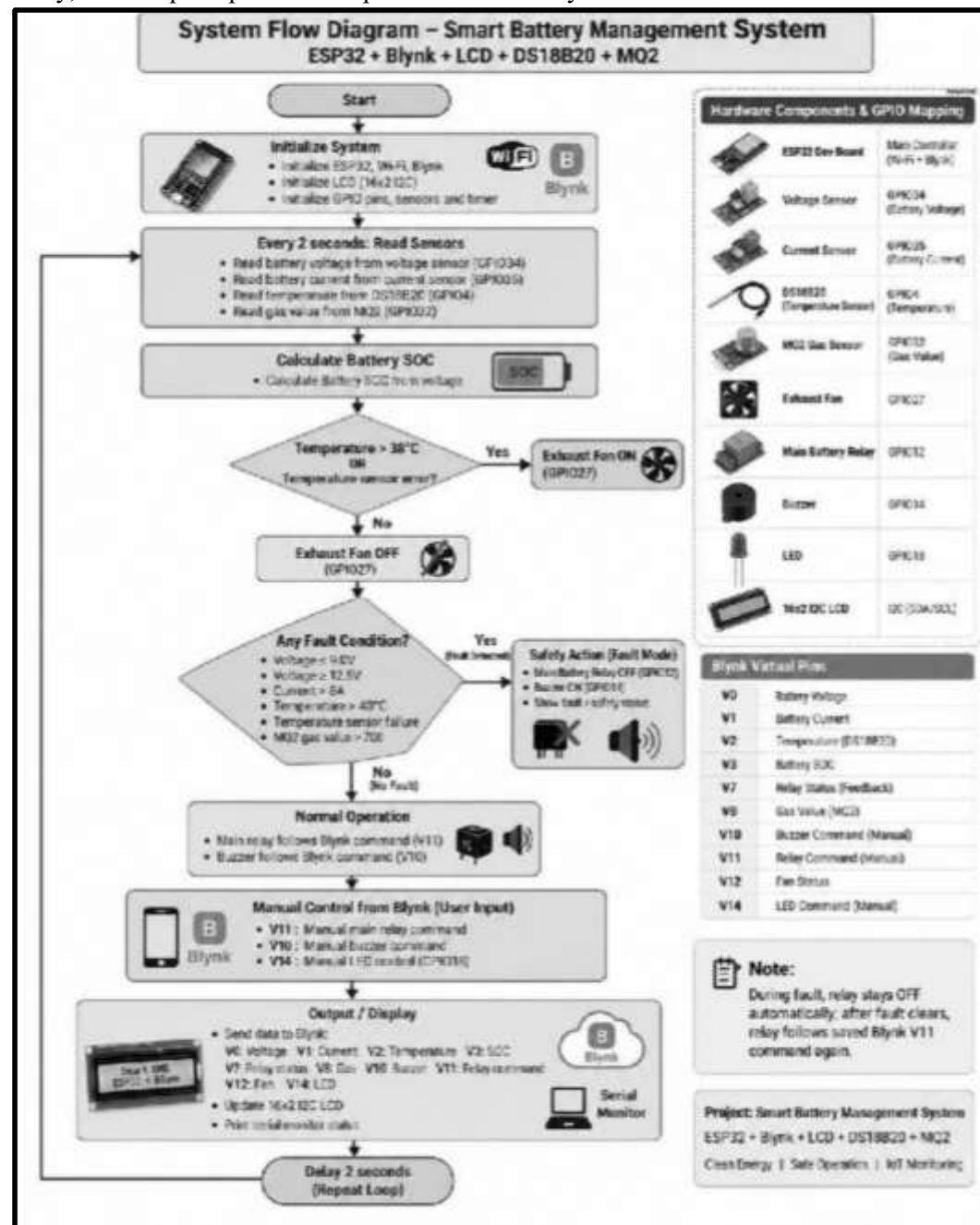


Figure.2.Flowchart of the Proposed Smart BMS

RESULT AND DISCUSSION

The developed Smart Battery Management System successfully integrates real-time monitoring, battery protection, SOC estimation, and IoT-based supervision using an ESP32. The system continuously measures battery voltage, current, temperature, and gas/smoke level through appropriate sensors, with the measured parameters displayed on a 16x2 I2C LCD and transmitted to the Blynk IoT platform. The voltage and current measurements are used to identify abnormal operating conditions, while the DS18B20 provides temperature monitoring for thermal protection. The system activates the cooling fan when the temperature exceeds 38°C and considers temperatures above 40°C as a fault condition. Similarly, an MQ-2 sensor is used for gas/smoke detection, and a value above the predefined threshold of 700 is treated as an unsafe condition. In case of over-voltage, under-voltage, over-current, excessive temperature, gas detection, or sensor failure, the main relay is switched OFF and the buzzer is activated, thereby disconnecting the load and improving battery safety.

The developed BMS also provides SOC estimation and remote monitoring through Blynk, allowing important parameters such as voltage, current, temperature, SOC, relay status, fan status, and gas level to be observed remotely. The system uses a 2-second monitoring interval, enabling continuous observation of changing battery conditions and rapid response to abnormal events. The integration of electrical, thermal, and gas protection provides a comprehensive safety mechanism compared with monitoring a single battery parameter. The experimental implementation demonstrates the feasibility of using an ESP32-based platform for a low-cost intelligent BMS with both local and IoT monitoring.

The system operates with a 2-second monitoring interval, allowing continuous observation of battery conditions. The predefined protection conditions and corresponding responses are summarized in Table 1.

Parameter	Protection Condition	System Response
Battery Voltage	< 9.0 V or > 12.5 V	Relay OFF, fault Indication
Battery Current	> 8 A	Relay OFF, fault indication
Temperature	> 38°C	Fan ON
Temperature	> 40°C	Relay OFF, Buzzer ON
MQ-2 Gas Level	> 700	Relay OFF, Buzzer ON
Temperature Sensor	Sensor error	Protective action

Table 1. Battery Monitoring and Protection Conditions of the Proposed BMS

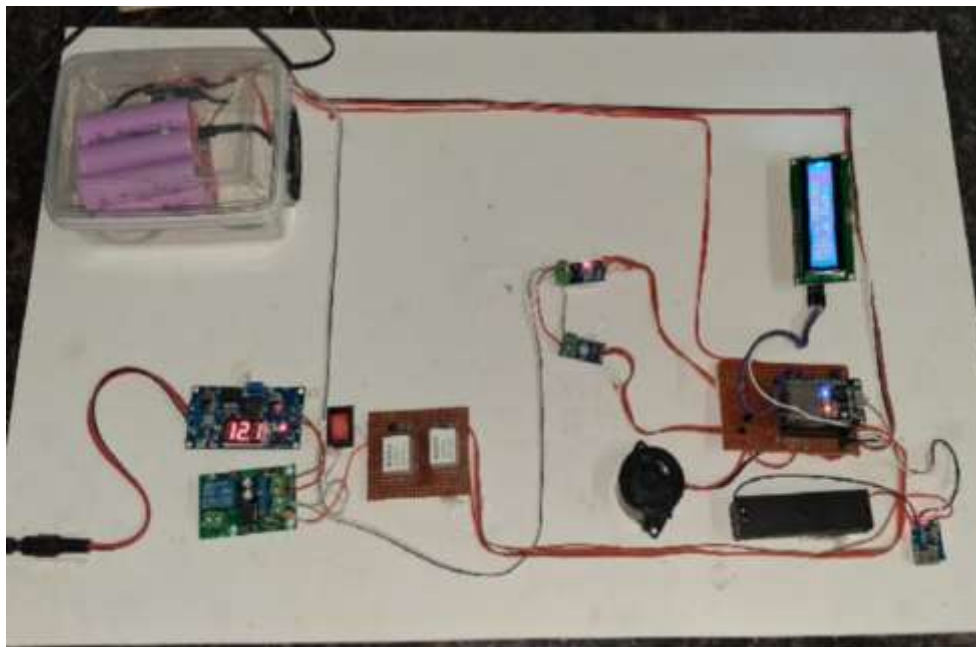


Fig3. Experimental hardware prototype of the proposed ESP32-based Smart Battery Management System.



Fig.4 IoT-based remote monitoring and control interface developed using Blynk.



Fig.5 Local monitoring of battery parameters using the 16x2 I2C LCD.

CONCLUSION

The proposed Smart Battery Management System using ESP32 provides an integrated solution for monitoring, protection, and management of a rechargeable cell pack. The system continuously monitors important parameters such as voltage, current, temperature, gas level, and State of Charge (SOC). ESP32 processes the sensor data and takes appropriate control actions according to the defined safety conditions.

The SOC of the cell pack is estimated and displayed on the 16×2 I2C LCD, allowing the user to easily observe the battery condition. During charging, the charging LED provides a visual indication of the charging process. The system also provides automatic protection against overvoltage, undervoltage, overcurrent, high temperature, gas detection, and sensor failure. When an unsafe condition occurs, the main relay disconnects the cell pack, and the buzzer provides an alert.

Temperature management is achieved by automatically operating the exhaust fan when the temperature exceeds the specified limit. In addition, the integration of Blynk IoT enables remote monitoring and selected control functions through Wi-Fi, making the system more convenient and intelligent.

Overall, the developed system demonstrates that an ESP32-based Smart BMS can provide low-cost, real-time, multifunctional battery monitoring and protection. The proposed system improves operational safety, reliability, and ease of battery management and can be extended for practical applications such as electric vehicles, solar energy storage, UPS systems, and other rechargeable energy-storage systems.

Conflict of Interest The authors declare that there is no conflict of interest regarding the publication of this research work.

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