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Research Paper

SMART BMS FOR ELECTRIC VEHICLES USING NODEMCU WITH CLOUD INTEGRATION

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Abstract: The rapid growth of electric vehicles and renewable energy systems has increased the need for efficient battery monitoring and management solutions. This paper presents the design and implementation of an IoT-based Smart Battery Management System (BMS) using the NodeMCU ESP8266 microcontroller. The proposed system continuously monitors key battery parameters such as voltage, temperature, State of Charge (SOC), and State of Health (SOH) to ensure safe and efficient operation.

A voltage sensing circuit is used to measure battery voltage, while an LM35 temperature sensor monitors thermal conditions. The NodeMCU processes these inputs and calculates SOC and SOH for performance evaluation. An automatic charging mechanism is implemented using a relay module, which activates when the battery voltage falls below a predefined threshold. A buzzer alert system is incorporated to indicate overheating conditions, enhancing system safety.

The system also features an LCD display for real-time local monitoring of battery parameters. Furthermore, IoT integration is achieved using the ThingSpeak cloud platform, enabling remote monitoring and data visualization over the internet. This enhances accessibility and allows users to track battery performance from anywhere.

The proposed system is cost-effective, compact, and suitable for applications such as electric vehicles, solar energy systems, and backup power management. It significantly improves battery safety, lifespan, and operational efficiency through intelligent monitoring and control.

Keywords: Battery Management System (BMS), NodeMCU ESP8266, Internet of Things (IoT), State of Charge (SOC), State of Health (SOH), ThingSpeak Cloud, Voltage Monitoring, Temperature Monitoring.

I. INTRODUCTION

Battery technology plays a crucial role in modern electrical and electronic systems, especially with the rapid growth of electric vehicles, renewable energy systems, and portable electronic devices. Batteries serve as the primary energy storage units in these applications. However, improper battery usage and lack of proper monitoring can lead to serious issues such as overcharging, deep discharging, overheating, reduced efficiency, and shortened battery lifespan. These challenges highlight the need for an efficient and intelligent battery management system.

A Battery Management System (BMS) is designed to ensure the safe and efficient operation of batteries. It continuously monitors key battery parameters such as voltage, current, temperature, State of Charge (SOC), and State of Health (SOH). The State of Charge represents the remaining capacity of the battery, while the State of Health indicates the overall condition and performance capability of the battery over time. Monitoring these parameters helps in preventing battery failures, improving battery life, and ensuring optimal performance.

Traditional battery monitoring systems often lack real-time monitoring and remote accessibility features. With the advancement of Internet of Things (IoT) technology, battery monitoring systems have become more intelligent and efficient. IoT enables devices to communicate and exchange data over the internet, allowing users to monitor and control systems remotely. This technological advancement has opened new possibilities for smart battery management solutions.

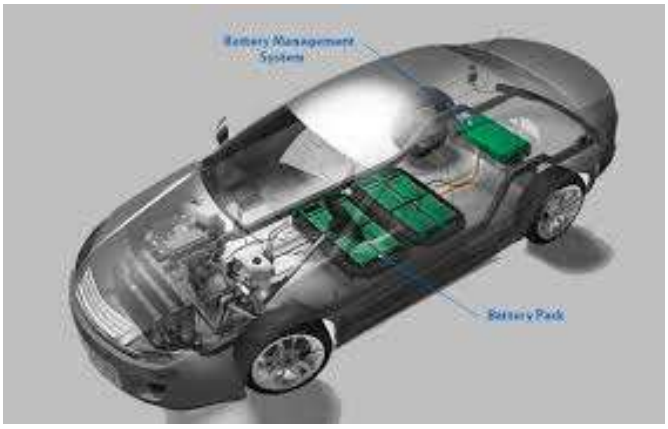


Fig 1 BMS management

In this work, an IoT-based smart battery monitoring and charging control system is proposed using the NodeMCU ESP8266 microcontroller. The NodeMCU is widely used due to its low cost, compact size, and built-in Wi-Fi capability, making it highly suitable for IoT applications. It acts as the central processing unit of the system, collecting data from sensors and controlling various components.

The system measures battery voltage using a voltage sensing circuit and monitors temperature using an LM35 temperature sensor. These sensors provide real-time data to the NodeMCU, which processes the information and calculates important battery parameters such as SOC and SOH. This enables accurate monitoring of battery performance and condition.

To ensure efficient charging, a relay module is used as an automatic switching device. When the battery voltage drops below a predefined threshold, the NodeMCU activates the relay to start the charging process. Once the battery reaches a safe voltage level, the system automatically disconnects the charger. This prevents overcharging and improves battery safety.

An LCD display is incorporated into the system to provide real-time local monitoring of battery parameters such as voltage, temperature, SOC, and SOH. Additionally, a buzzer is used as a safety alert mechanism. If the battery temperature exceeds the safe limit, the buzzer is activated to warn the user, thereby preventing potential hazards.

One of the key features of the proposed system is its IoT integration using the ThingSpeak cloud platform. The system uploads battery parameters to the cloud via Wi-Fi, enabling users to monitor battery performance remotely through a mobile phone or computer. This feature is particularly useful for applications where batteries are installed in remote or inaccessible locations.

The proposed system is cost-effective, compact, and easy to implement using readily available components. It is programmed using Embedded C in the Arduino IDE, making it simple for development and deployment. The system enhances battery safety, improves efficiency, and enables intelligent monitoring and control.

Furthermore, the system supports real-time decision-making by providing continuous updates of battery status. It can be extended by integrating additional sensors such as current sensors for more accurate analysis. Advanced features such as artificial intelligence-based battery life prediction can also be incorporated in future developments.

The proposed IoT-based battery management system finds applications in electric vehicles, renewable energy storage systems, uninterruptible power supplies, and industrial backup systems. In

conclusion, the integration of IoT with battery management provides a powerful solution for ensuring safe operation, improving performance, and enabling remote monitoring of battery systems.

II. METHODOLOGY

The proposed system is an IoT-based Battery Management System (BMS) designed to monitor battery parameters, estimate battery condition, and control the charging process automatically. The system is built around the NodeMCU ESP8266 microcontroller, which acts as the central processing unit. The methodology consists of data acquisition, signal processing, parameter estimation, decision-making, and IoT-based monitoring.

Initially, the battery voltage is measured using a voltage divider circuit. Since the NodeMCU analog pin can only accept low voltage (0–1V), the battery voltage is scaled down using resistors. The sensed analog voltage is then converted into digital form using the internal Analog-to-Digital Converter (ADC) of the NodeMCU. Similarly, the LM35 temperature sensor provides an analog output proportional to temperature, which is also converted into digital data through the ADC.

The NodeMCU continuously reads sensor data and processes it to determine battery parameters. Based on the measured voltage and temperature, the system calculates the State of Charge (SOC) and State of Health (SOH) of the battery. These parameters are essential for understanding battery performance and remaining useful life.

2.1 State of Charge (SOC) Estimation

The State of Charge (SOC) indicates the available capacity of the battery relative to its maximum capacity. In this system, SOC is estimated using the voltage-based method, which is simple and suitable for low-cost applications.

$$SOC(\%) = \frac{V_{measured} - V_{min}}{V_{max} - V_{min}} \times 100$$

Where:

- $V_{measured}$ = Measured battery voltage
- V_{min} = Minimum battery voltage (fully discharged condition)
- V_{max} = Maximum battery voltage (fully charged condition)

This method assumes a linear relationship between voltage and charge level. The SOC value helps in identifying whether the battery is fully charged, partially charged, or needs charging.

2.2 State of Health (SOH) Estimation

The State of Health (SOH) represents the overall condition of the battery and its ability to store and deliver energy compared to a new battery. It is calculated based on the ratio of current capacity to the rated (initial) capacity.

$$SOH(\%) = \frac{C_{current}}{C_{rated}} \times 100$$

Where:

- $C_{current}$ = Current available battery capacity
- C_{rated} = Rated (initial) battery capacity

In practical implementation, SOH can be estimated using voltage behavior, charge/discharge cycles, and temperature variations. A decrease in SOH indicates battery aging and degradation.

2.3 Charging Control Mechanism

The system implements an automatic charging control strategy using a relay module. The NodeMCU continuously monitors the battery voltage and compares it with predefined threshold values.

- If battery voltage < minimum threshold → Charging ON
- If battery voltage ≥ maximum threshold → Charging OFF

This prevents overcharging and deep discharging, thereby improving battery life and safety.

2.4 Temperature Monitoring and Protection

The LM35 sensor continuously monitors battery temperature. If the temperature exceeds a predefined safe limit, the NodeMCU activates a buzzer to alert the user.

- If temperature > threshold → Buzzer ON (Alert)
- Else → Normal operation

This ensures thermal protection and prevents damage due to overheating.

2.5 Display and User Interface

All measured and calculated parameters such as voltage, temperature, SOC, and SOH are displayed on an LCD module. This provides real-time local monitoring and enhances user interaction with the system.

2.6 IoT-Based Monitoring Using ThingSpeak

The NodeMCU connects to a Wi-Fi network and uploads battery data to the ThingSpeak cloud platform. The uploaded parameters include:

- Battery Voltage
- Temperature
- SOC
- SOH

This allows users to monitor battery performance remotely through mobile or web applications. The cloud platform also enables data logging and graphical visualization for analysis.

The system operates in a continuous loop where sensor data is acquired, processed, and transmitted. Based on real-time conditions, the system takes decisions such as enabling charging or triggering alerts. This closed-loop operation ensures efficient battery management, improved safety, and enhanced performance.

III. SYSTEM ARCHITECTURE

The proposed system is an IoT-based Battery Management System (BMS) designed to monitor battery parameters, control charging, and provide real-time as well as remote monitoring. The overall system architecture consists of several functional blocks, including power supply, sensing units, processing unit, control unit, display, alert system, and cloud communication.

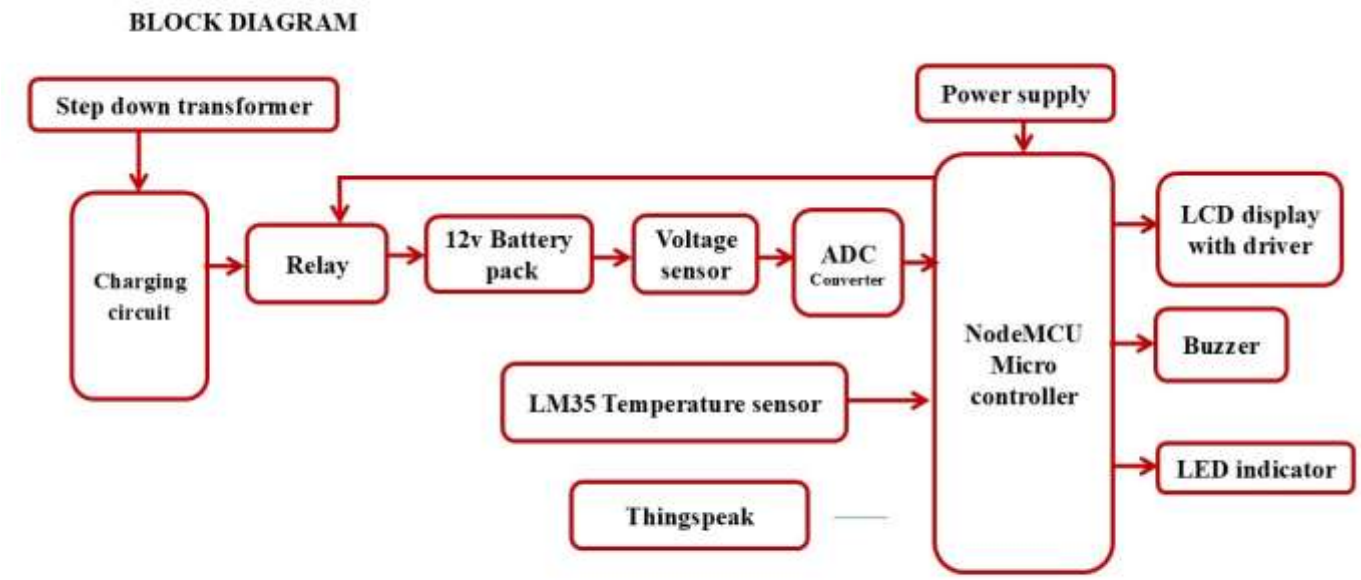


Fig 2 Proposed system

The system begins with a step-down transformer, which converts the high-voltage AC supply (230V) into a low-voltage AC signal suitable for electronic circuits. This output is then fed into a charging circuit, which consists of a rectifier, filter, and voltage regulator to convert AC into regulated DC voltage. This regulated power is used to charge the 12V battery pack and supply power to the system components.

A relay module is connected between the charging circuit and the battery. The relay acts as an automatic switching device controlled by the NodeMCU. Based on battery voltage conditions, the relay either connects or disconnects the charging circuit, enabling automatic charging control. This ensures that the battery is charged only when required and prevents overcharging.

The battery voltage is continuously monitored using a voltage sensor, which is typically implemented using a voltage divider circuit. Since the NodeMCU can only read low analog voltages, the sensor scales down the battery voltage to a safe range. The analog signal is then passed through an ADC (Analog-to-Digital Converter), which converts it into a digital value that can be processed by the microcontroller.

In addition to voltage monitoring, the system also includes an LM35 temperature sensor to measure the battery temperature. The LM35 provides an analog output proportional to temperature in degrees Celsius. This data is essential for detecting overheating conditions and ensuring safe battery operation.

The core of the system is the NodeMCU ESP8266 microcontroller, which acts as the central processing and control unit. It receives input data from the voltage sensor and temperature sensor, processes the data, and calculates important battery parameters such as State of Charge (SOC) and State

of Health (SOH). Based on these values, the NodeMCU makes decisions regarding charging control and safety alerts.

A regulated power supply is provided to the NodeMCU and other components to ensure stable operation. The microcontroller operates at 3.3V, and proper voltage regulation is essential for reliable performance.

For user interaction, an LCD display with driver is connected to the NodeMCU. It displays real-time information such as battery voltage, temperature, SOC, and SOH. This allows users to monitor system performance locally without requiring external devices.

To enhance safety, a buzzer is included in the system. If the battery temperature exceeds a predefined safe threshold, the NodeMCU activates the buzzer to alert the user. Additionally, an LED indicator is used to provide visual status indications such as charging ON/OFF or normal/fault conditions.

One of the key features of the system is its IoT capability. The NodeMCU uses its built-in Wi-Fi module to connect to the internet and send data to the ThingSpeak cloud platform. The transmitted data includes voltage, temperature, SOC, and SOH values. This enables remote monitoring of battery performance through a web interface or mobile application.

The overall system operates in a continuous loop where sensor data is acquired, processed, displayed, and transmitted to the cloud. Based on real-time conditions, the system automatically controls charging and generates alerts when necessary. This integrated architecture ensures efficient battery management, improved safety, and enhanced monitoring capabilities.

IV. RESULTS AND DISCUSSION

The proposed IoT-based Battery Management System (BMS) was successfully implemented and tested under different operating conditions. The system continuously monitored battery voltage, temperature, State of Charge (SOC), and State of Health (SOH), and transmitted the data to the cloud using the ThingSpeak IoT Analytics Platform. The experimental results confirm the accuracy, reliability, and real-time performance of the system.

During operation, the NodeMCU collected sensor data at regular intervals and uploaded it to the ThingSpeak server via Wi-Fi. The platform displayed the data in graphical form, enabling easy visualization and analysis of battery performance over time.

Battery Voltage Graph Analysis

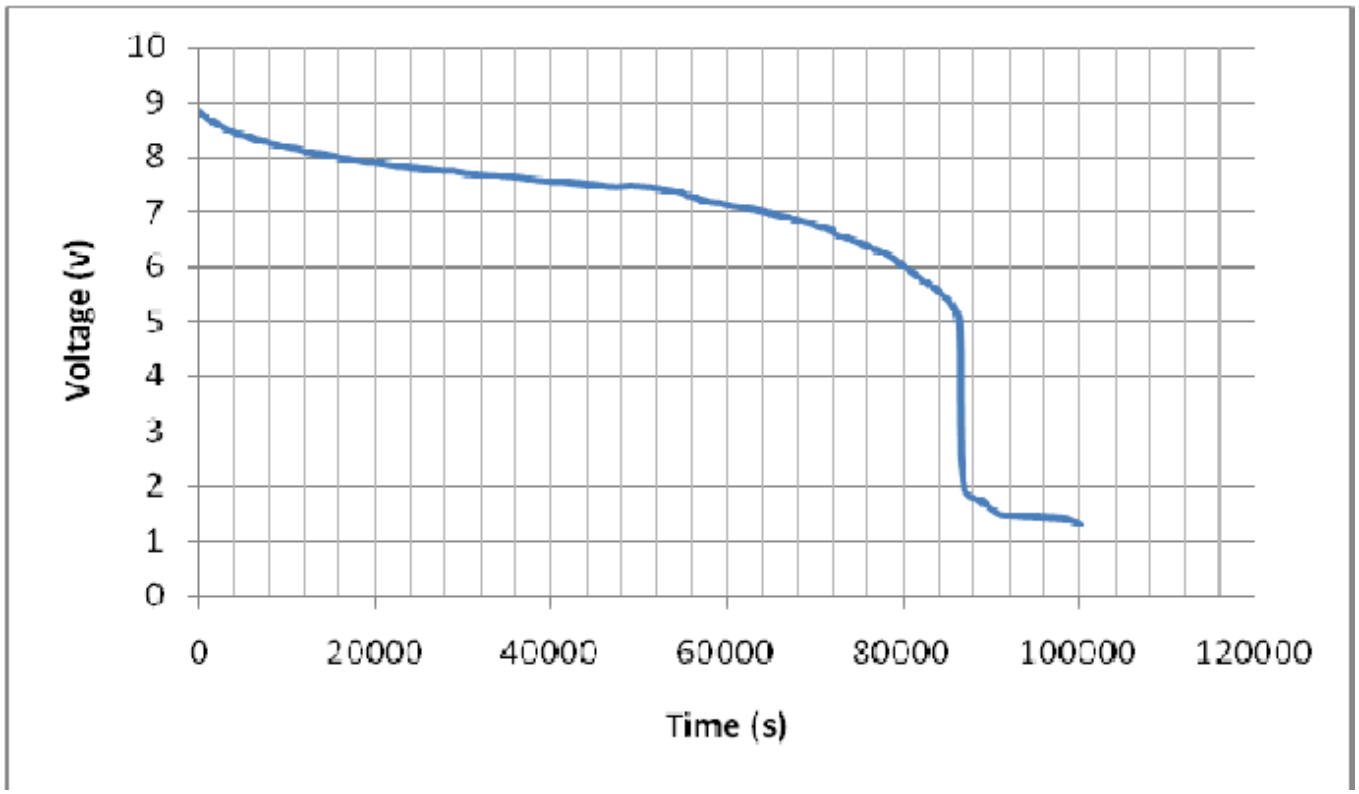


Fig 3 Battery Voltage

The voltage graph represents the variation of battery voltage with respect to time. Initially, when the battery is in a discharged condition, the voltage remains low. Once the charging process is activated, the voltage gradually increases.

During testing, it was observed that:

- The voltage rises steadily during charging
- The system disconnects charging when the voltage reaches the maximum threshold
- A stable region is observed when the battery is fully charged

This confirms that the automatic charging control using the relay is functioning correctly.

Temperature Graph Analysis

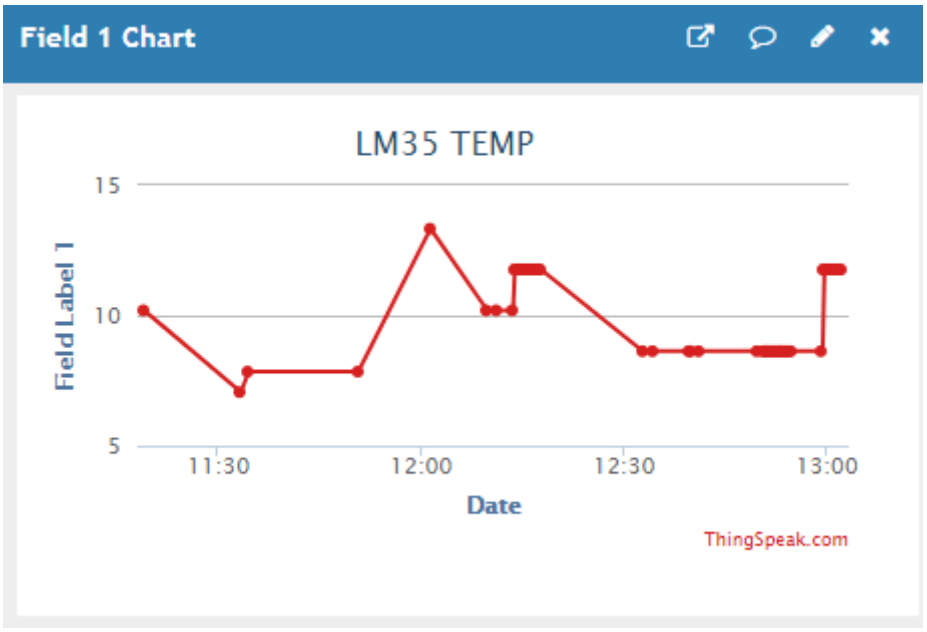


Fig 4 Temperature Graph Analysis

The temperature graph shows the variation of battery temperature over time. Under normal conditions, the temperature remains within a safe range.

Key observations include:

- Gradual temperature increases during charging
- Stable temperature during idle conditions
- Sudden spikes when external heat or overcharging conditions occur

When the temperature exceeds the predefined threshold, the buzzer is activated. This behavior verifies the effectiveness of the thermal protection system.

State of Charge (SOC) Graph Analysis



12 Volt AGM Battery State of Charge	
Level	Voltage
100%	13.00 Volts
90%	12.75 Volts
80%	12.50 Volts
70%	12.30 Volts
60%	12.15 Volts
50%	12.05 Volts
40%	11.95 Volts
30%	11.81 Volts
20%	11.66 Volts
10%	11.51 Volts
0%	10.50 Volts

Fig 5 SOC

The SOC graph indicates the percentage of battery charge over time. It is directly related to the battery voltage.

From the results:

- SOC increases gradually during charging
- SOC decreases during battery discharge

- The curve shows a near-linear trend based on voltage estimation

This confirms that the SOC estimation method is working properly and provides a clear indication of battery status.

State of Health (SOH) Graph Analysis

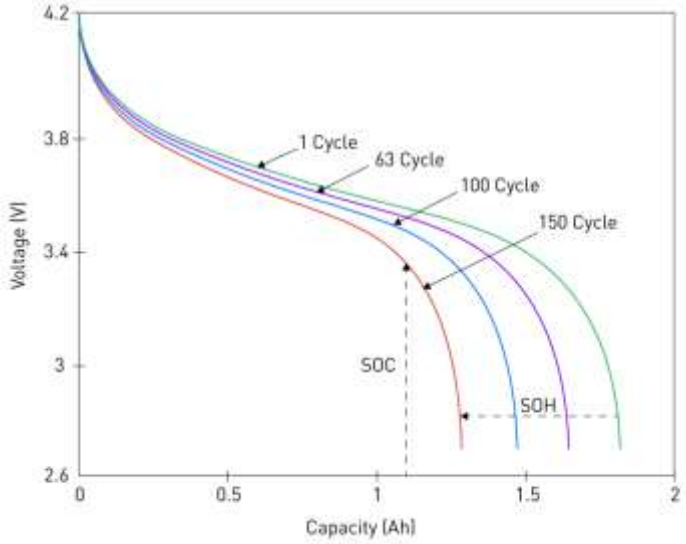


Fig 6 SOH

The SOH graph represents the health condition of the battery over time. Unlike SOC, SOH changes slowly and reflects long-term battery performance.

Observations:

- SOH remains close to 100% for a new battery
- Gradual decrease in SOH over multiple charge-discharge cycles
- Stable behavior indicates proper battery usage and control

This demonstrates that the system can effectively track battery aging and performance degradation.

Cloud Monitoring and Data Visualization

The integration with ThingSpeak enables real-time remote monitoring of battery parameters. The platform provides:

- Graphical visualization of all parameters
- Data logging for long-term analysis
- Easy access through web or mobile devices

Users can monitor battery performance from anywhere, making the system highly useful for remote applications such as solar systems and electric vehicles.

Overall Performance Evaluation

The experimental results show that:

- The system accurately measures voltage and temperature
- SOC and SOH are successfully estimated
- Automatic charging control works efficiently
- Over-temperature protection is reliable
- IoT-based monitoring provides real-time data access

The system operates continuously without significant delay, ensuring real-time performance.

The obtained results validate the effectiveness of the proposed IoT-based BMS. The ThingSpeak graphs clearly illustrate battery behavior under different conditions. The system improves battery safety, enhances monitoring capability, and enables intelligent decision-making through real-time data analysis.

CONCLUSION

The proposed IoT-based Battery Management System (BMS) using the NodeMCU ESP8266 has been successfully designed and implemented to monitor and control battery performance efficiently. The system continuously measures important parameters such as battery voltage and temperature and estimates key indicators like State of Charge (SOC) and State of Health (SOH). These parameters provide a clear understanding of battery condition and performance.

The integration of an automatic charging control mechanism using a relay ensures that the battery is charged only when required, thereby preventing overcharging and deep discharging. The inclusion of a temperature monitoring system with a buzzer alert enhances safety by detecting overheating conditions in real time.

The use of the ThingSpeak IoT Analytics Platform enables real-time remote monitoring of battery parameters. Users can visualize data through graphs and access battery information from anywhere via the internet. This feature significantly improves system usability and reliability, especially in remote or critical applications.

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