SMART BATTERY ADVISORY WITH CELL LEVEL MANAGEMENT

Dr. V. Anantha Lakshmi[1], G. Indumathi[2], Y. Rajeshwari[3]

Associate Professor, Dept of Electrical and Electronics Engineering, Andhra Loyola Institute of Engineering and Technology, Vijayawada, Andhra Pradesh, India[1]

Final Year Student, Dept of Electrical and Electronics Engineering, Andhra Loyola Institute of Engineering and Technology, Vijayawada, Andhra Pradesh, India[2,3]

Abstract: Battery management is essential for ensuring the safety, performance, and longevity of lithium-ion battery systems. This paper presents a low-cost smart battery advisory system with cell-level monitoring using a microcontroller-based architecture. The proposed system employs a three-cell lithium-ion battery and continuously monitors individual cell voltages, total voltage, current, and temperature using appropriate sensors. An Arduino Uno is used as the central controller, interfaced with voltage sensors, an INA219 current sensor, and a DHT11 temperature sensor. The system detects abnormal conditions such as cell undervoltage, overload due to excessive current, and high temperature, and provides advisory alerts through an LCD display and a buzzer. In addition, the system supports IoT-based remote monitoring using the ThingSpeak platform, enabling real-time graphical visualization of battery parameters on a mobile device. The proposed system offers a simple, scalable, and cost-effective solution for intelligent battery monitoring with enhanced safety and user awareness.

Keywords: Battery Management System, Lithium-ion Battery, Cell-Level Monitoring, Arduino Uno, Current Sensing, Temperature Monitoring, Smart Advisory System, IoT-Based Monitoring.

1. INTRODUCTION

Lithium-ion batteries are widely used in electric vehicles and energy storage systems due to their high energy density, long cycle life, and efficiency. However, variations among individual cells can lead to imbalance, performance degradation, and safety risks. Monitoring and managing these variations at the cell level is therefore essential for reliable battery operation. Recent studies *[1]–[3]* emphasize the importance of battery health monitoring and advanced Battery Management Systems (BMS) to improve performance and lifespan.

A typical BMS monitors key parameters such as voltage, current, and temperature. However, conventional systems often focus on pack-level measurements, which may fail to detect abnormalities in individual cells. Cell-level monitoring provides more accurate insight into battery behavior and enables early detection of faults.

With the integration of Internet of Things (IoT) technologies, real-time monitoring and remote access to battery data have become feasible. IoT-based systems enable continuous data transmission to cloud platforms for visualization and analysis. As presented in *[4]*, cloud-integrated battery monitoring improves accessibility, user awareness, and decision-making.

In this work, a Smart Battery Advisory and Cell-Level Monitoring System is proposed. The system monitors individual cell voltages, current, and temperature, and provides real-time advisory based on predefined thresholds. The data is transmitted using IoT and visualized in graphical form through the ThingSpeak platform, enabling efficient monitoring and analysis.

2. LITERATURE SURVEY

Recent advancements in battery management systems focus on improving monitoring accuracy, safety, and efficiency through cell-level analysis and IoT integration.

The study in *[1]* presents advanced techniques for battery health prognosis using data-driven approaches such as entropy-based analysis and predictive modeling. It emphasizes the importance of extracting internal battery characteristics to estimate degradation and remaining useful life. The work highlights that accurate monitoring of battery parameters is essential for improving reliability and preventing unexpected failures in lithium-ion batteries.

In *[2],* a comprehensive review of Battery Management Systems (BMS) is provided, covering key functions such as voltage, current, and temperature monitoring, state estimation, and protection mechanisms. The study discusses the limitations of conventional BMS architectures, particularly their focus on pack-level monitoring, which may overlook cell-level variations. It also outlines the need for improved sensing, control strategies, and real-time monitoring techniques.

The work in *[3]* discusses battery management systems in electric and hybrid vehicles, with emphasis on safety, performance optimization, and lifecycle management. It highlights the significance of cell-level monitoring in detecting abnormalities such as overvoltage, undervoltage, and thermal issues. The study also indicates that precise monitoring and control strategies can significantly enhance battery efficiency and lifespan.

An IoT-based smart battery monitoring system is presented in *[4],* where real-time data acquisition and transmission are achieved through cloud-based platforms. The system enables remote monitoring, data visualization, and analysis, improving accessibility and user interaction. The study demonstrates how IoT integration enhances system scalability and allows continuous tracking of battery parameters in real time.

The research in *[5]* focuses on various cell balancing techniques used in battery management systems, including passive and active balancing methods. It explains how imbalance among cells can lead to reduced efficiency and uneven aging. The study highlights that proper balancing improves energy utilization, extends battery life, and ensures safe operation of multi-cell battery systems.

In *[6],* battery modeling and evaluation techniques are discussed for improving state-of-charge estimation and monitoring accuracy. The study compares different equivalent circuit models and their effectiveness in representing battery behavior under varying conditions. It shows that accurate modeling plays a crucial role in enhancing monitoring precision and overall system performance.

However, most existing works focus on analysis, modeling, and high-level system design, with limited emphasis on low-cost real-time implementation and IoT-based visualization using platforms such as ThingSpeak. This motivates the development of the proposed system.

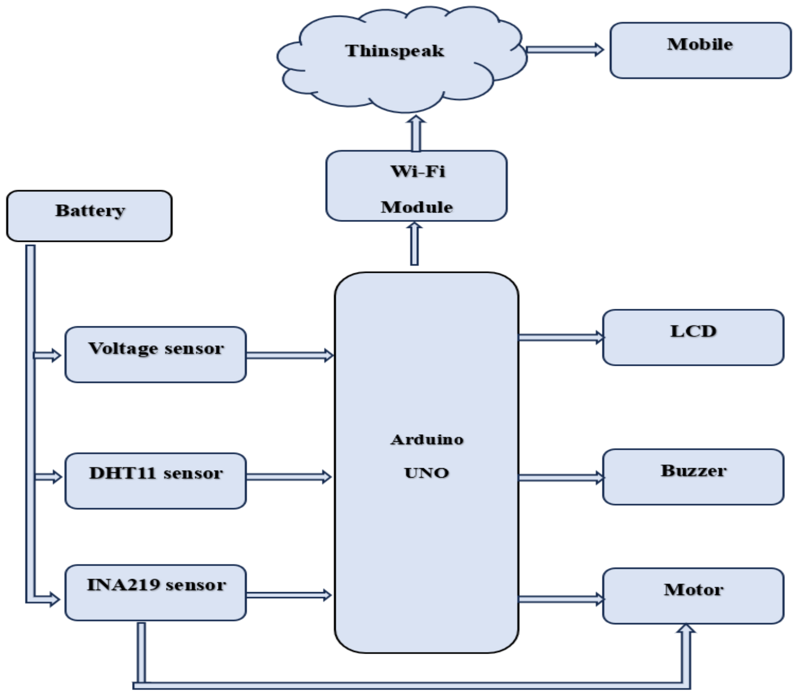

Fig 1. Block Diagram

3. PROPOSED SYSTEM

1)Proposed System Overview

The proposed system is a smart battery advisory system designed to monitor a three-cell lithium-ion battery pack at the cell level. It measures individual cell voltages, total battery voltage, current, and temperature to ensure safe and reliable operation. The system is implemented using an Arduino Uno microcontroller interfaced with voltage sensors, an INA219 current sensor, and a DHT11 temperature sensor.

The system performs real-time analysis to detect abnormal conditions such as undervoltage, overload, and high temperature. Alerts are provided through an LCD display and a buzzer. Additionally, a Wi-Fi module enables IoT-based monitoring by transmitting data to the ThingSpeak platform, where parameters are visualized in graphical form on a mobile device.

2)System Architecture and Block Diagram

The system consists of sensing, processing, and output units. Voltage sensors are connected across each lithium-ion cell to measure individual cell voltages. The INA219 sensor measures current and total voltage, while the DHT11 sensor monitors temperature.

All sensor data is acquired by the Arduino Uno, which processes the inputs and determines system status based on predefined thresholds. Output devices such as the LCD and buzzer provide local alerts. The Wi-Fi module enables communication with the ThingSpeak platform for remote monitoring and visualization.

3)System Design and Functional Description The system is designed to perform continuous monitoring and advisory based on multiple battery parameters. Individual cell voltages are analyzed to detect undervoltage and imbalance conditions. The current sensor measures load current to identify overload situations, and the temperature sensor ensures operation within safe thermal limits.

The Arduino Uno processes the acquired data and compares it with predefined threshold values. If any parameter exceeds safe limits, the system generates corresponding alerts. Simultaneously, the measured parameters are transmitted via the Wi-Fi module to the ThingSpeak platform, enabling real-time graphical monitoring. The design ensures simple, low-cost, and effective battery monitoring with both local and remote advisory features.

4. IMPLEMENTATION

1)Hardware Implementation

The hardware implementation consists of an Arduino Uno microcontroller interfaced with sensing and output components. A three-cell lithium-ion battery pack is used as the source. Voltage sensors are connected across each cell to measure individual voltages. The INA219 current sensor is connected in series with the load to measure current and total voltage. A DHT11 sensor is used for temperature monitoring.

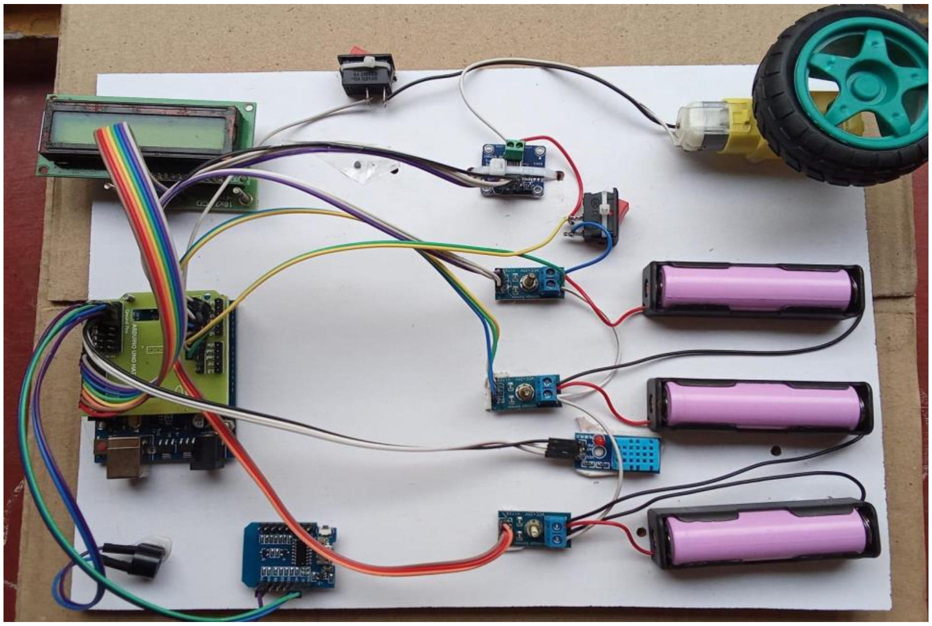

Fig 2. Hardware Implementation

A DC motor is used as a load to evaluate system performance. An LCD display provides real-time parameter values, and a buzzer is used for alert indication. A Wi-Fi module enables data transmission to the ThingSpeak platform for remote monitoring.

2)Circuit Configuration

The voltage sensors are connected across each lithium-ion cell to obtain individual cell voltages. The INA219 sensor is interfaced using I2C communication to measure current and total voltage. The DHT11 sensor is connected to a digital input pin of the Arduino.

The LCD display and buzzer are connected to the output pins of the Arduino for user notification. The Wi-Fi module is interfaced through serial communication for data transmission. Proper grounding and power connections are maintained to ensure stable system operation.

3)Software Implementation

The software is developed using the Arduino IDE. The program continuously reads data from the voltage sensors, INA219 current sensor, and DHT11 temperature sensor. The measured values are processed to obtain individual cell voltages, total voltage, current, and temperature.

Threshold limits are defined to detect undervoltage, overload, and high temperature conditions. When these conditions occur, the system generates alerts through the LCD and buzzer. The program also includes routines for transmitting data to the ThingSpeak platform via the Wi-Fi module for real-time monitoring.

4)Working Procedure

The system begins by initializing all sensors, communication modules, and output devices. It then continuously acquires data from the voltage sensors, current sensor, and temperature sensor at regular intervals.

The acquired data is processed and compared with predefined threshold limits. If any parameter exceeds safe limits, the system generates appropriate alerts and notifies the user through the LCD and buzzer. At the same time, the measured parameters are transmitted to the ThingSpeak platform via the Wi-Fi module.

The data is updated periodically and visualized in graphical form, enabling remote monitoring. This cycle of sensing, processing, alert generation, and data transmission continues continuously, ensuring real-time monitoring and advisory functionality.

5. RESULTS AND DISCUSSION

1)Observed Parameters

Fig 3. Cell Voltages

Fig 4. Total Voltage, Current & Temperature

The proposed system was tested using a three-cell lithium-ion battery under different operating conditions. During operation, the system continuously monitored individual cell voltages, total voltage, current, and temperature, and displayed these parameters on both the LCD and the ThingSpeak platform for real-time visualization. Under normal operating conditions, the observed cell voltages were approximately 3.5 V, 3.7 V, and 3.7 V for cells A, B, and C respectively, with a total voltage of about 11.2 V. The current was approximately 0 mA under no-load conditions, and the temperature was recorded around 29°C. All measured parameters were within the predefined safe limits, and the system status was indicated as “NORMAL,” confirming the stable and safe operation of the battery pack.

2)Fault Condition Analysis

Fig 5. Low Voltage Detection in Cell-C

Fig 6. Overload Condition

The system was evaluated under different abnormal conditions to verify its advisory functionality.

a. Low Voltage Condition:

When the voltage of cell C dropped below the threshold value of 3.0 V (observed ≈ 2.9 V), the system successfully detected the undervoltage condition and displayed the alert "C LOW" on the LCD. This confirms effective cell-level monitoring and fault identification.

b. Overload Condition:

When the load current exceeded the threshold of 70 mA (observed ≈ 111 mA), the system identified the condition as overload and displayed "OVERLOAD". This demonstrates proper current monitoring and protection capability.

3)IoT-Based Monitoring Results

Fig 7. Cell-A Voltage

Fig 8. Cell-B Voltage

The measured parameters were transmitted to the ThingSpeak platform using the Wi-Fi module, enabling real-time remote monitoring. The data was visualized in graphical form for each parameter.

Fig 9. Cell-C Voltage

Fig 10. Total Voltage

a.Cell Voltage Graphs:

The individual cell voltage graphs show stable values for cells A and B, while cell C exhibits a gradual decrease reaching approximately 2.9 V, clearly indicating the undervoltage condition.

b. Total Voltage Graph:

The total voltage remains around 11.2 V under normal conditions, showing consistent battery performance.

c. Current Graph:

Fig 11. Current

Fig 12. Temperature

The current graph shows a significant rise up to approximately 111 mA during overload conditions, validating accurate detection of high current

d. Temperature Graph:

The temperature remains within safe limits (below 37°C), with observed values around 28–35°C, indicating normal thermal operation during testing.

These graphs confirm that the system can effectively monitor and transmit real-time battery data for remote analysis.

4) Performance Evaluation

The results demonstrate that the proposed system accurately monitors battery parameters at the cell level and effectively identifies abnormal conditions. The use of predefined threshold values enables reliable detection of undervoltage, overload, and temperature variations.

Cell-level monitoring provides improved fault detection compared to conventional total voltage-based systems, as individual cell degradation can be identified early. The integration of IoT with ThingSpeak enhances system capability by enabling remote monitoring and graphical visualization of parameters.
The system shows consistent performance in both normal and fault conditions, making it a suitable low-cost solution for basic battery monitoring and advisory applications.

6. CONCLUSION

The proposed Smart Battery Advisory and Cell-Level Monitoring System was successfully designed and implemented to monitor key battery parameters, including individual cell voltages, current, and temperature. The system effectively identifies abnormal conditions such as undervoltage, overload, and high temperature using predefined threshold values, ensuring safe battery operation.

The integration of IoT technology enables real-time data transmission and visualization through the ThingSpeak platform, allowing continuous monitoring and analysis. Experimental results demonstrate that the system accurately detects battery conditions and provides appropriate status indications.

Overall, the proposed system offers a simple, low-cost, and efficient solution for real-time battery monitoring and advisory, making it suitable for small-scale energy storage and battery management applications.

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