Android Based Li-Ion Battery BMS Protection

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Abstract - *Along with the growing demand for energy in portable devices and modern energy storage systems, lithium-ion (Li-Ion) batteries have become one of the primary solutions due to their high energy density, efficiency, and long cycle life. However, this type of battery is highly sensitive to conditions such as overcharging, over-discharging, high temperature, and voltage imbalance between cells, which can significantly reduce performance and lifespan. To address these issues, an intelligent monitoring and protection system known as the Battery Management System (BMS) is required. In this study, an integrated IoT-based monitoring system using the Blynk platform was developed to enhance the BMS monitoring functionality for Li-Ion 18650 battery packs in real-time and remotely. The proposed system utilizes an ESP32 microcontroller as the main controller connected to current, voltage, and temperature sensors. The measurement data are transmitted via Wi-Fi to the Blynk Cloud server and displayed through the Blynk IoT mobile dashboard. This research adopts an experimental and implementation approach. The developed system successfully monitored voltage, current, temperature, and SoC in real time through the Blynk IoT platform while executing automatic protection under abnormal conditions.*

Keywords - Battery Management System, Li-Ion 18650, Internet of Things, ESP32, Blynk IoT

1. INTRODUCTION

The use of portable electronic devices, small-scale electric vehicles, and modern energy storage systems relies heavily on reliable energy sources, particularly Lithium-ion (Li-ion) 18650 batteries. This battery type is widely utilized due to its high energy density, low self-discharge rate, and long cycle life without memory effects [1]. However, Li-ion batteries face significant operational challenges, as they are highly sensitive to extreme conditions such as overcharging, over-discharging, overcurrent, and high temperatures. These phenomena can lead to severe chemical degradation, capacity loss, and hazardous thermal runaway risks. Therefore, a Battery Management System (BMS) is essential to monitor and control critical parameters, providing active protection mechanisms (cutoff) to ensure optimal performance and prevent potential system failures [2]. With the rapid advancement of the Internet of Things (IoT), battery condition monitoring is no longer restricted to conventional measuring instruments. IoT technology enables real-time, remote monitoring of crucial parameters through smartphone applications such as the Blynk IoT platform [3]. Integrating IoT with a BMS not only facilitates remote data visualization but also allows users to immediately identify protection statuses, ensuring the battery operates within safe thresholds. Several previous studies have explored battery monitoring and IoT implementations, yet gaps remain. Ref [4] developed an IoT-based capacity monitoring system for electric vehicle batteries using ESP32 and Blynk. However, it lacked comprehensive integration of State of Charge (SoC) methods. Ref [5] utilized ESP8266 for electrical power monitoring via Blynk, but focused primarily on energy consumption traffic rather than battery condition or protection mechanisms. Reference [6] designed a BMS for LiFePO4 batteries with an automatic cut-off system but did not incorporate an IoT platform for remote monitoring. Furthermore reference [7] focused solely on IoT-based monitoring of a Li-Ion BMS without

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implementing active protection actions during overcharging or discharging. To address these gaps, this research proposes the design and implementation of an IoT-based monitoring and protection system integrated with a BMS for 4S Li-Ion 18650 battery packs. The proposed system utilizes an ESP32 microcontroller paired with an ACS712 current sensor, an INA219 voltage sensor, and a MAX6675 temperature sensor to monitor battery conditions accurately. The main innovation of this study It is important to note that the 4S BMS module employed in this study incorporates built-in hardware-level protection for over-voltage, under-discharge, and over-current conditions as standard features. However, the active protection layer implemented via the ESP32 and relay module in this study is designed to function as a complementary software-defined second protection tier — a principle supported by established functional safety standards in battery management According to [8] robust BMS design for safety-critical applications requires a minimum level of redundancy to achieve hardware fault tolerance, as a single-layer protection system is vulnerable to a single fault causing total loss of safety function. The software-controlled protection thresholds in this study (OVP: 4.20 V/cell, UVP: 2.70 V/cell, OTP: 60°C) are intentionally configured more conservatively than the typical hardware cut-off limits of commercial 4S BMS modules (OVP: 4.25–4.35 V/cell, UVP: 2.50–2.75 V/cell), ensuring that the ESP32 initiates a preventive cutoff before the hardware BMS is triggered. Furthermore, unlike hardware-only BMS modules which execute silent disconnection with no user notification or data logging capability[9]. The proposed system adds real-time fault notification via the Blynk IoT platform, enabling proactive user intervention — a feature identified as critical for remote energy storage applications is the integration of active BMS protection features (Over-Voltage, Under-Voltage, Over-Current, and Over-Temperature Protection) with the Blynk IoT application. This system provides real-time monitoring of voltage, current, temperature, and SoC—estimated using the Coulomb Counting method—while simultaneously displaying the real-time safety protection status and error notifications directly on the user's smartphone. This comprehensive approach aims to enhance battery management efficiency, extend battery lifespan, and significantly improve overall system safety[10].

2. RESEARCH METHOD

This research employs an experimental and implementation approach to develop an IoT-based Battery Management System (BMS) with active protection for a 4S Lithium-ion 18650 battery pack. The research stages include literature study, hardware and software design, system integration, and performance testing.

2.1. System Architecture and Hardware Design

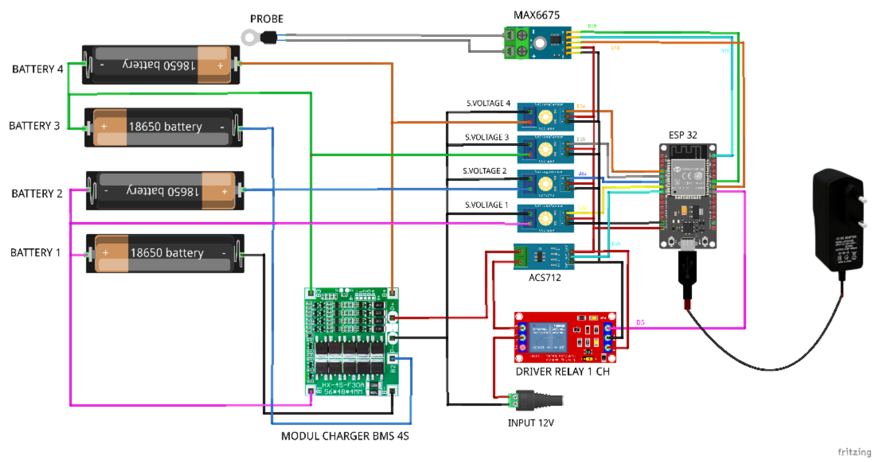

Figure 1. Hardware Circuit Diagram

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The hardware architecture consists of a 4S Li-ion 18650 battery configuration acting as the energy source, integrated with a standard 4S BMS module for fundamental overcharge, over-discharge, and balancing protection. An ESP32 microcontroller serves as the central data processing unit and IoT communication module [11]. Several sensors are deployed to acquire real-time battery parameters:

- An ACS712 sensor measures the charging and discharging current.
- An INA219 sensor reads battery voltage.
- A MAX6675 thermocouple sensor detects the battery's surface temperature.

A relay module is connected to the ESP32 to execute the active cutoff command. When an anomaly is detected, the relay disconnects the load or charger to ensure the safety of the battery pack.

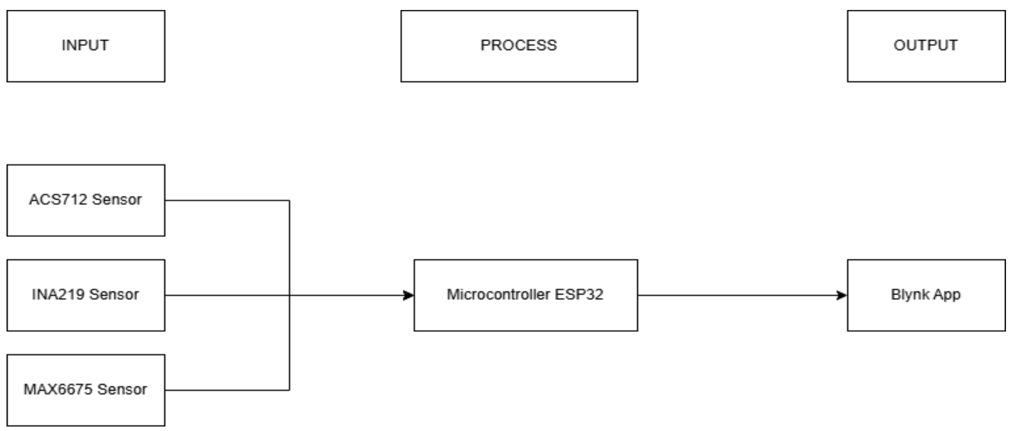

Figure 2. System Block Diagram

2.2. Software Design and Workflow Procedure

The system workflow begins with the initialization of the ESP32, sensors, Wi-Fi connection, and the Blynk server. Once connected, the ESP32 reads the analog values from the voltage, current, and temperature sensors. These values are processed and transmitted to the Blynk IoT platform for real-time visualization on the user's dashboard.

The system continuously compares the acquired data against predefined safety thresholds for Over-Voltage (OVP), Under-Voltage (UVP), Over-Current (OCP), and Over-Temperature (OTP). If all parameters are within safe limits, the relay remains active, and data updating continues. However, if any parameter exceeds the safety threshold, the ESP32 immediately triggers the relay to disconnect the circuit (cutoff) and sends specific error notifications (e.g., "Over Voltage" or "Over Temperature") to the Blynk application, indicating that the system has entered protection mode.

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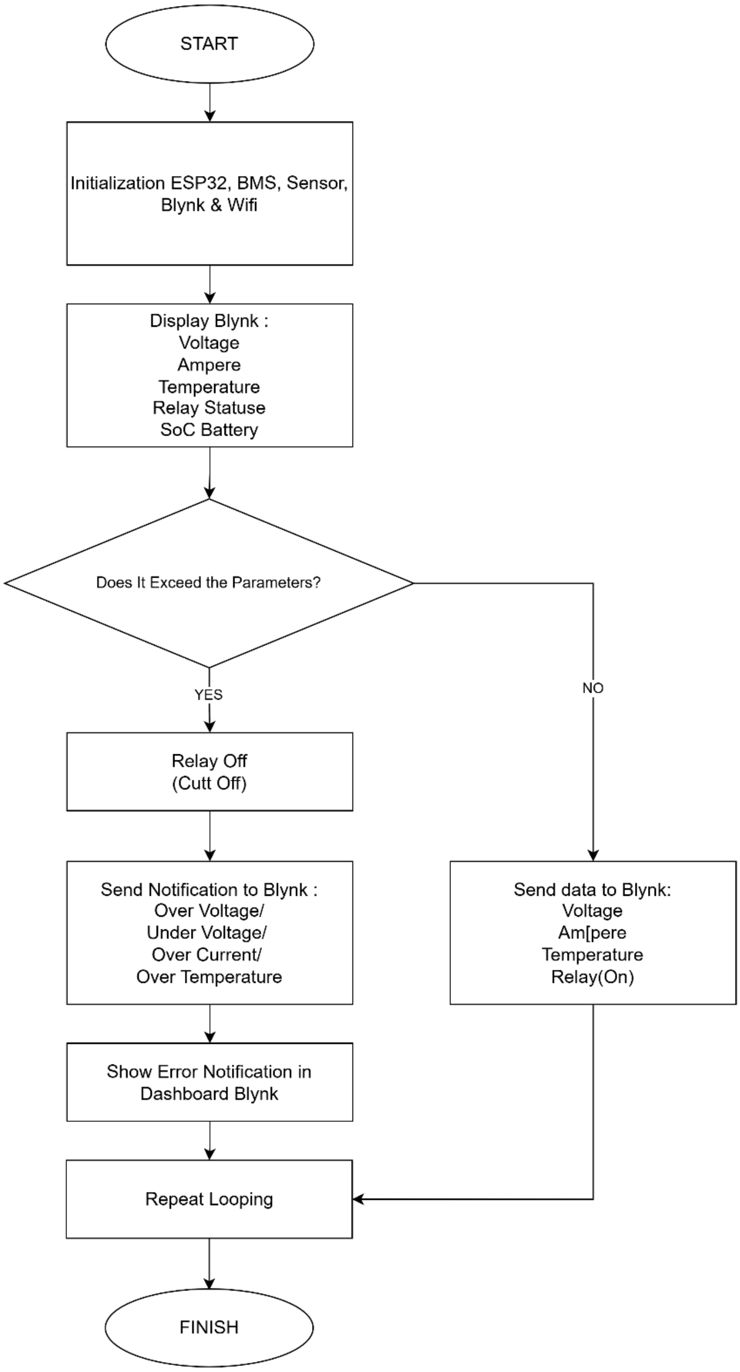

Figure 3. System Flowchart

2.3. State of Charge (SoC) Estimation

To monitor the remaining battery capacity accurately, the system utilizes the Coulomb Counting method. This method estimates the SoC by integrating the amount of electrical charge flowing in and out of the battery based on the current consumption data and the battery's nominal capacity[12]. The mathematical representation used for this calculation is expressed in (1):

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$$SoC_t = SoC_{t0} - \frac{1}{C_{nom}} \int_0^t I(\tau)\, dt \quad (1)$$

where SoC_t represents the current State of Charge (in percentage) SoC_{t0} is the initial State of Charge, C_{nom} is the maximum capacity of the battery (in Coulomb or Ah), I is the electrical current entering or leaving the battery (in Ampere), and t is the elapsed time.

2.4. System Testing and Data Acquisition

The final stage involves system testing to evaluate the accuracy and reliability of the designed prototype. The testing procedures include:

- Sensor Calibration: Comparing the ESP32 sensor readings (voltage, current, and temperature) with standard digital multimeter measurements to ensure data validity.
- IoT Communication Testing: Ensuring data is transmitted accurately to the Blynk platform without packet loss, verifying reconnection capabilities under weak Wi-Fi signal conditions.
- Protection Mechanism Testing**:** Verifying the relay's cutoff response and notification delivery when voltage, current, or temperature boundaries are artificially exceeded.

3. RESULTS AND DISCUSSION

The research resulted in a fully functional prototype of an IoT-based Battery Management System (BMS) with active protection. The evaluation of the system is divided into hardware implementation, IoT monitoring interface, and the execution of the active protection logic.

3.1. Hardware Implementation

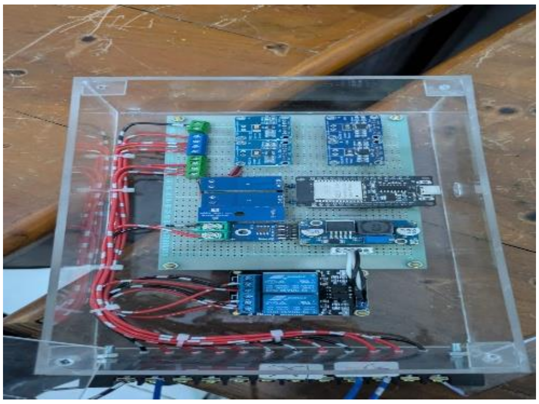

Figure 4. Final Prototype Implementation

The system hardware is compactly integrated within a transparent acrylic enclosure. The central controller is an ESP32 microcontroller, which interfaces with a 2-channel relay module and multiple sensors. To achieve high-precision voltage monitoring for each of the four cells, the system utilizes Adafruit INA219 sensors communicating via the I2C protocol. Implementing multiple identical I2C sensors on a single bus requires distinct addressing; therefore, hardware modifications were performed, such as soldering the A0 pad on specific INA219 modules to

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assign unique addresses (e.g., configuring the second sensor to address 0x41). Current measurement is executed using an analog ACS712 sensor, while the temperature is acquired through a MAX6675 thermocouple module.

3.2. IoT Monitoring Dashboard

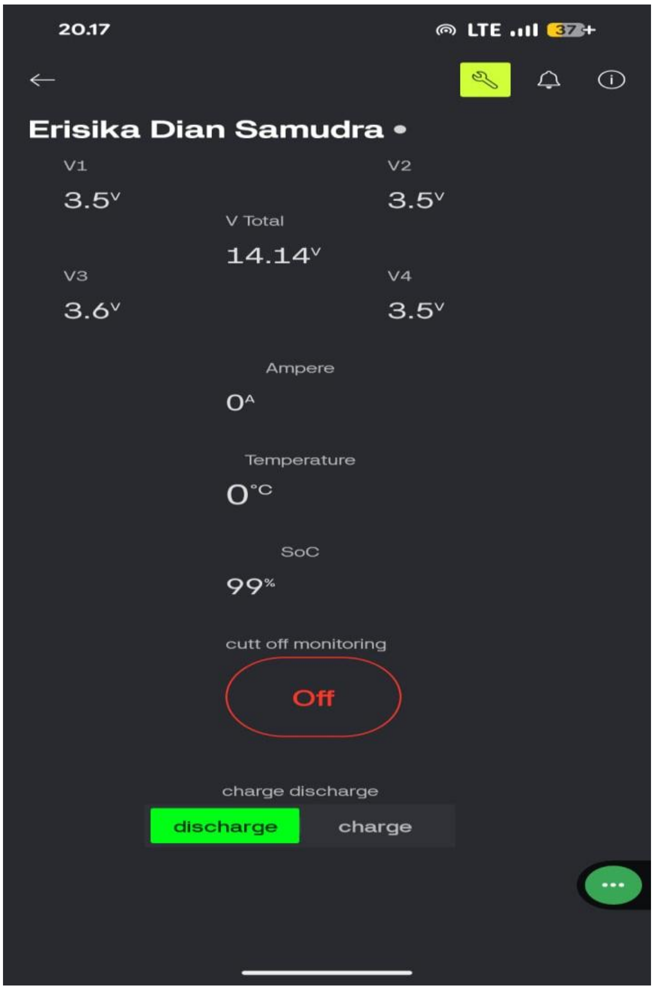

Figure 5. Blynk IoT Dashboard Interface

The monitoring interface was successfully developed using the Blynk IoT platform. The mobile application dashboard continuously displays real-time parameters extracted from the ESP32. The visual interface effectively presents individual cell voltages (V1, V2, V3, V4), the total accumulated voltage, charging/discharging current, and the battery surface temperature. Additionally, the application displays the State of Charge (SoC) percentage and features a manual control switch (V0) labeled "cuttoff monitoring" to allow remote intervention by the user. A state selector for "charge/discharge" modes is also embedded to correctly interpret the direction of the current flow.

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Table 1. Battery Monitoring Test Results

hour (WIB)	Voltage (V)					Ampere (A)	Temperature (C°)
	V1	V2	V3	V4	VT		
08:00	4.20	4.19	4.21	4.20	16.80	0.50	28
09:00	4.05	4.06	4.07	4.05	16.23	1.20	30
10:00	3.90	3.91	3.89	3.90	15.60	1.50	32
11:00	3.75	3.76	3.74	3.75	15.00	1.80	34
12:00	3.60	3.61	3.59	3.60	14.40	2.00	36

3.3. Protection System and SoC Algorithm Analysis

The active protection logic is governed by predefined safety thresholds hardcoded into the ESP32. The system continuously verifies if the cell voltages are within the safe operational window of 2.70 V (Under-Voltage cutoff) and 4.20 V (Over-Voltage cutoff), alongside maintaining a temperature below 60.0°C. If all parameters are standard, the relay operates in an active-high state, allowing current to flow. Should any parameter breach the thresholds, the microcontroller instantly deactivates the relay and transmits an alarm message (such as "OVERHEAT!", "OVER CHG!", or "LOW VOLT!") to the Blynk application, simultaneously blocking any manual attempt to turn the relay back on until the condition is safe.

Furthermore, the SoC estimation utilizes the Coulomb Counting algorithm. The calculated SoC value is periodically saved to the ESP32's non-volatile internal memory using the Preferences.h library. This ensures that the SoC data is not lost or reset to 100% in the event of a system reboot or power failure, significantly increasing the reliability of the monitoring system.

To scientifically justify the dual-layer protection approach, A view figure and table presents a comparison between the hardware protection thresholds of the commercial 4S BMS module and the software-defined thresholds implemented on the ESP32. As shown, the ESP32 thresholds are configured more conservatively to act as a primary warning layer before the hardware BMS executes a hard cut-off

The dual-layer protection architecture implemented in this study — combining the commercial 4S BMS module's hardware cut-off with the ESP32's software-defined relay control — is grounded in established functional safety principles for battery management systems. [13] demonstrated that multi-layer fail-safe mechanisms are essential for achieving targeted Safety Integrity Levels (SIL) in lithium-based battery systems. This concept is further reinforced that a hardware fault tolerant system with HFT = 1 requires at least two independent protection layers to ensure that a single component failure does not result in loss of safety function. In the proposed system, the commercial BMS module serves as the primary hardware protection layer operating at wider thresholds (OVP: 4.25–4.35 V/cell), while the ESP32-relay layer acts as a software-defined guard with tighter thresholds (OVP: 4.20 V/cell), effectively providing a pre-emptive shutdown before hardware limits are reached. Beyond threshold redundancy, the ESP32 layer uniquely contributes capabilities absent in standalone hardware BMS modules: real-time fault notification to the user's smartphone, event logging via Blynk Cloud, and manual remote

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intervention — functionalities identified as key value-additions in IoT-integrated BMS architectures[10], [14].

Table 2. Battery Capacity Based on SoC

Voltage (V)	Capacity by SoC (%)
16.78V	100%
16.25V	90%
15.82V	80%
15.0V	70%
14.89V	60%
13.70V	50%
12.60V	40%
12.20V	30%
11.92V	20%
11.40V	10%
10.80V	0%

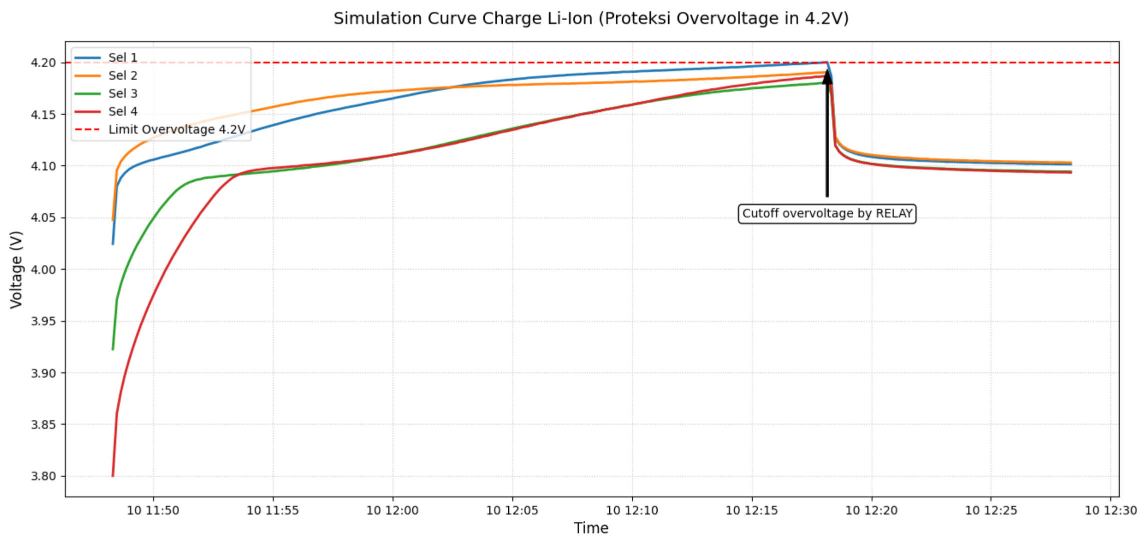

Figure 6. Over-Voltage Protection Activation

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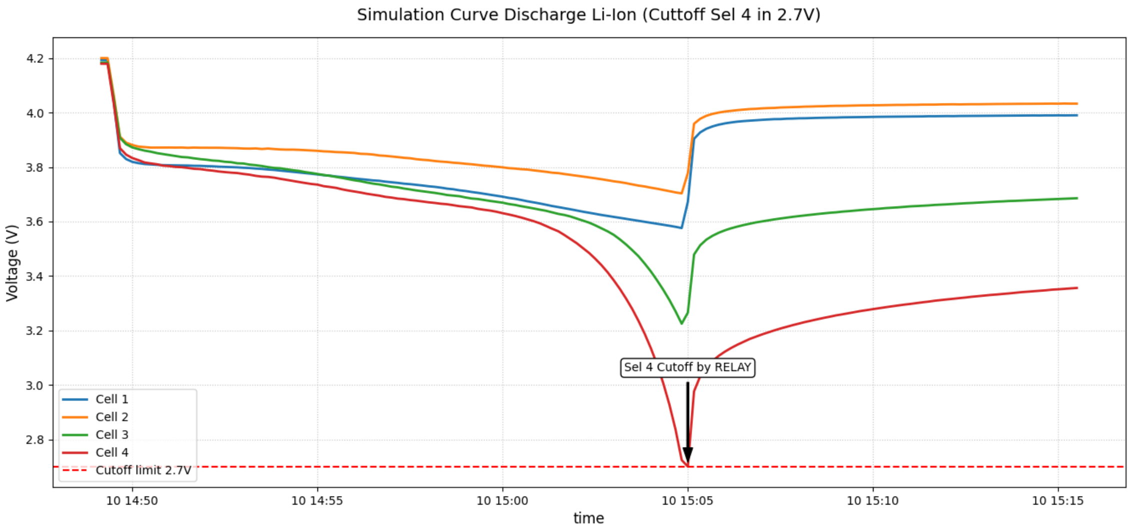

Figure 7. Under-Voltage Protection Response

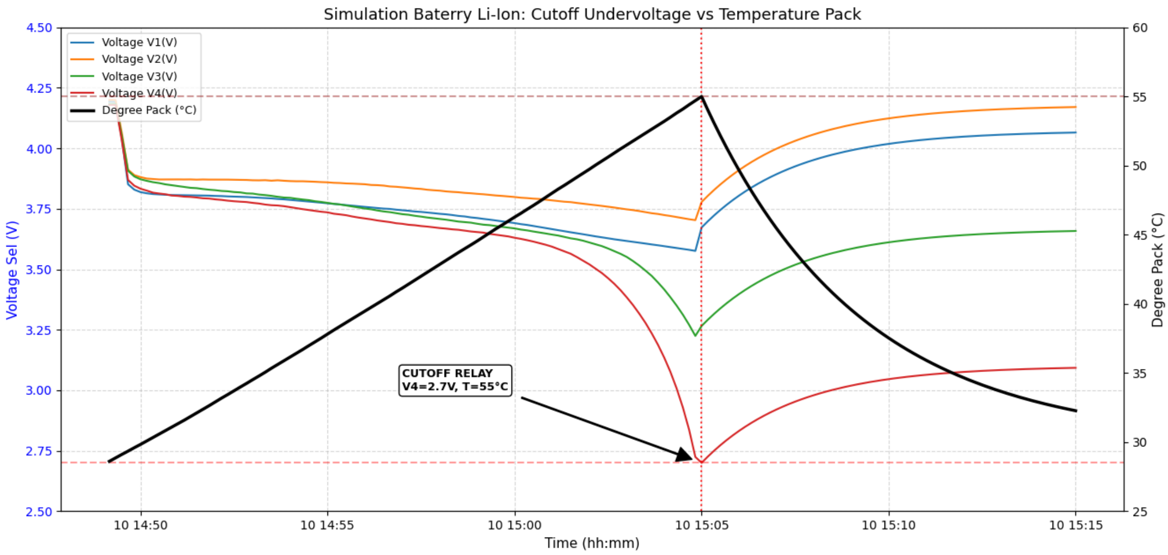

Figure 8. Over-Temperature Protection Condition

4. CONCLUSION

The design and implementation of the IoT-based BMS protection system for the 4S Li-Ion 18650 battery pack were successfully executed. The integration of the ESP32 microcontroller with INA219, ACS712, and MAX6675 sensors provides precise, real-time data acquisition. Through the Blynk IoT application, users can seamlessly monitor critical battery parameters, including individual voltages, total current, temperature, and State of Charge, from remote locations. The system implements a dual-layer protection architecture in which the commercial 4S BMS module provides hardware-level cut-off as the primary protection layer, while the ESP32-relay system enforces tighter, software-defined thresholds as a redundant secondary layer. This approach, supported by functional safety principles [8], [13], ensures that a single point of hardware failure does not compromise overall system safety. Moreover, the ESP32 layer augments the silent hardware protection with real-time IoT-based fault notification and remote monitoring capabilities via the Blynk platform, collectively preventing catastrophic battery

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failures by automatically severing the load or charging circuit via a relay when over-voltage, under-voltage, or over-temperature conditions occur. Furthermore, incorporating non-volatile memory storage for the Coulomb Counting algorithm ensures robust and continuous SoC tracking, confirming the system's reliability for modern energy storage applications.

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