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Battery Management System

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Abstract: In today's rapidly advancing technological world, efficient battery management is essential for applications such as electric vehicles, renewable energy systems, and portable electronics. A Battery Management System (BMS) ensures safe and reliable operation by monitoring key parameters like voltage, current, and temperature; however, existing systems often lack features such as user-defined charging limits, real-time State of Charge (SoC) and State of Health (SoH) monitoring, and effective fault protection. This paper presents the design and implementation of an improved BMS that incorporates a smart charging limiter, real-time monitoring, and MOSFET-based protection mechanisms. The system utilizes an analog front-end and a microcontroller to continuously monitor battery parameters and automatically protect against over-voltage, under-voltage, over-current, and overheating conditions. Additionally, the system provides monitoring of key parameters such as voltage, current, temperature, SoC, and SoH through a mobile application using the Blynk platform. The proposed system enhances battery safety, improves performance, and extends battery lifespan, making it suitable for modern energy storage applications.

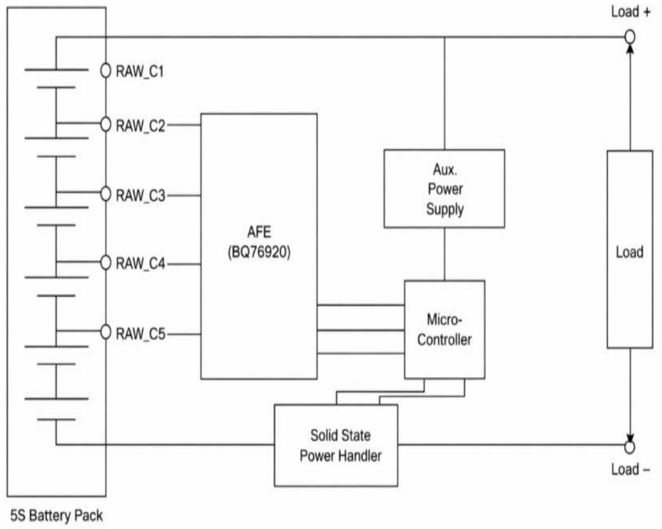
I. INTRODUCTION

In modern energy storage systems, the use of rechargeable batteries has significantly increased due to the growing demand in applications such as electric vehicles, renewable energy systems, and portable electronic devices. Ensuring the safe and efficient operation of these battery systems is a major challenge, as improper management can lead to reduced performance, overheating, and hazardous conditions. A Battery Management System (BMS) plays a crucial role in addressing these challenges by continuously monitoring key parameters such as voltage, current, and temperature, while also providing protection against faults like overcharging, deep discharge, and short circuits. However, conventional BMS solutions often lack advanced features such as user-defined charging limits, real-time monitoring of State of Charge (SoC) and State of Health (SoH), and efficient fault diagnosis mechanisms, which ultimately affect battery performance, lifespan, and reliability. Therefore there is a need to develop an advanced battery management system that integrates intelligent monitoring,adaptive control strategies and user friendly features to enhance battery efficiency and overall lifespan.

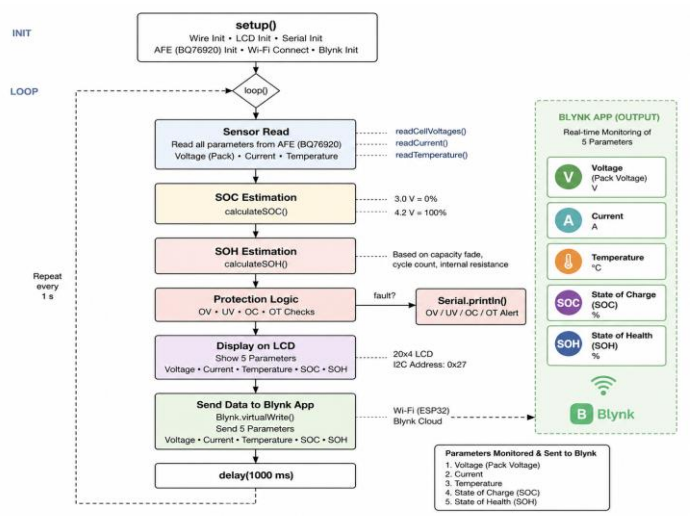
In this work, an advanced Battery Management System is proposed that incorporates a smart charging limiter, real-time monitoring, and enhanced protection mechanisms. The system is implemented using components such as the BQ76920 analog front-end, ESP32 microcontroller, MOSFETs, shunt resistor, resistors, capacitors, Schottky diodes, TVS diodes, Zener diodes, inductor, and MP4559 regulator. Additionally, the system enables monitoring of key parameters such as voltage, current, temperature, State of Charge (SoC), and State of Health (SoH) through a mobile application using the Blynk platform. The proposed system enhances battery safety, improves performance, and extends lifespan, making it suitable for modern energy applications.

II. SYSTEM ARCHITECTURE

The proposed Battery Management System (BMS) consists of a battery pack, sensing and monitoring unit, control unit, protection circuitry, auxiliary power supply, and a communication interface for displaying parameters. The system is designed based on a 5-series (5S) configuration using the BQ76920; however, one cell is removed and bypassed as shown in the circuit, resulting in an effective 4-cell (4S) operation. Each lithium-ion cell operates within a voltage range of approximately 3.0V to 4.2V, and the total battery pack voltage is obtained by summing the active cell voltages, which varies from approximately 12V (discharged condition) to 16.8V (fully charged condition).



Block Diagram



Flowchart

The battery pack is interfaced with the BQ76920 analog front-end (AFE), which monitors individual cell voltages through connections such as RAW_C1 to RAW_C5 as shown in the block diagram. The sensed data is transmitted to the ESP32 microcontroller, which acts as the central control unit. The system operates through an initialization phase followed by a continuous loop, where the ESP32 periodically reads parameters such as total voltage, individual cell voltages, current, and temperature using a shunt resistor and temperature sensing elements. Based on the acquired data, the system computes important parameters such as State of Charge (SoC) and State of Health (SoH), as represented in the flowchart.

The protection and control section consists of a solid-state power handler implemented using MOSFETs, which controls the charging and discharging paths of the battery and regulates power flow to the load. During operation, protection logic is continuously executed to detect abnormal conditions such as over-voltage, under-voltage, over-current, and over-temperature, ensuring safe battery operation. Passive components such as resistors and capacitors are used for voltage division, filtering, and balancing, while protection devices including Schottky diodes, TVS diodes, and Zener diodes ensure voltage clamping and circuit safety. The system also includes an auxiliary power supply block that provides regulated power for stable operation.

The processed data is displayed locally and transmitted to a mobile application using the ESP32, where parameters such as total voltage, individual cell voltages, current, temperature, State of Charge (SoC), and State of Health (SoH) are displayed in real time through the Blynk platform. The system operates continuously by integrating sensing, processing, protection, and communication, ensuring efficient and reliable battery management.

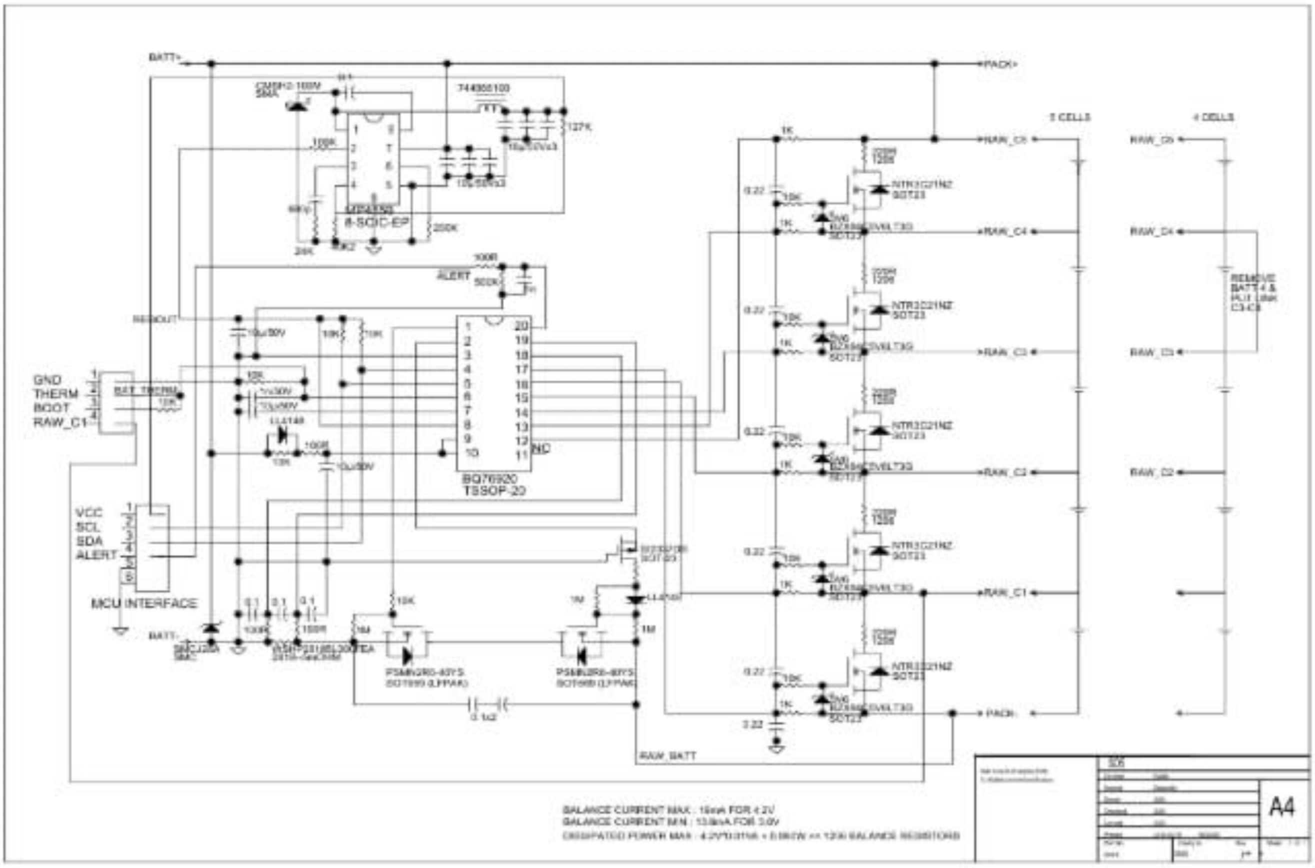
III. HARDWARE

♣ BQ76920 Analog Front-End (AFE)

The BQ76920 is a highly integrated analog front-end IC designed for monitoring multi-cell lithium-ion battery packs. It supports up to 5 series-connected cells and provides accurate measurement of individual cell voltages, pack voltage, and other critical parameters. The device includes built-in features such as cell balancing control, protection mechanisms, and communication interfaces. In this system, the BQ76920 is used to monitor the voltage of each cell through connections such as RAW_C1 to RAW_C5, ensuring safe and reliable operation of the battery pack.

♣ ESP32 Microcontroller

The ESP32 is a powerful microcontroller with integrated Wi-Fi and Bluetooth capabilities, making it suitable for IoT-based applications. It features multiple GPIO pins, ADC channels, and communication interfaces such as I2C, SPI, and UART. In this project, the ESP32 acts as the central control unit, processing data received from the BQ76920 and executing control logic. It also enables wireless communication with the Blynk application, allowing real-time monitoring of battery parameters.



Circuit diagram

♣ MOSFETs (Power Control Switches)
MOSFETs are used in the system to control the charging and discharging paths of the battery pack. These semiconductor devices act as electronic switches, allowing or blocking current flow based on control signals from the microcontroller. In the proposed design, MOSFETs form part of the solid-state power handler, ensuring safe operation by isolating the battery during fault conditions.

♣ Shunt Resistor
A low-value shunt resistor is used to measure the current flowing through the battery pack. The voltage drop across the resistor is proportional to the current, which is then sensed and processed by the system. This enables accurate monitoring of charging and discharging currents.

♣ Passive Components (Resistors and Capacitors)
Resistors and capacitors play a crucial role in the proper functioning of the circuit. Resistors are used for voltage division, biasing, and cell balancing, while capacitors are used for noise filtering and voltage stabilization. The values range from ohms to megaohms for resistors and from picofarads to microfarads for capacitors, depending on the application within the circuit.

♣ Protection Components (Diodes)
Various types of diodes such as Schottky, TVS, and Zener diodes are used in the system to provide protection against voltage spikes and reverse polarity conditions. These components help in voltage clamping and ensure the safety of sensitive electronic components.

♣ MP4559 Regulator and Inductor
The MP4559 is a switching regulator used to provide a stable and regulated power supply to the system. It works along with an inductor to efficiently step down the voltage and maintain consistent output, ensuring reliable operation of the microcontroller and associated circuitry.

♣ PCB, Connectors, and Wiring
The complete system is implemented on a printed circuit board (PCB), which provides mechanical support and proper electrical connections between components. Connectors and jumper wires are used for interfacing and testing purposes. Proper PCB design ensures minimal noise, efficient layout, and reliable system performance.

IV. SOFTWARE

The software implementation of the proposed Battery Management System (BMS) follows a structured flow consisting of an initialization phase followed by a continuous loop operation, as illustrated in the flowchart. During the setup phase, all required modules such as the analog front-end (BQ76920), I2C communication interface, and Wi-Fi connection for the Blynk application are initialized. This ensures proper configuration of both monitoring and communication systems before entering the main operation. After initialization, the system continuously reads sensor data including individual cell voltages, total pack voltage, current, and temperature. Based on these values, important battery parameters such as State of Charge (SoC) and State of Health (SoH) are calculated.

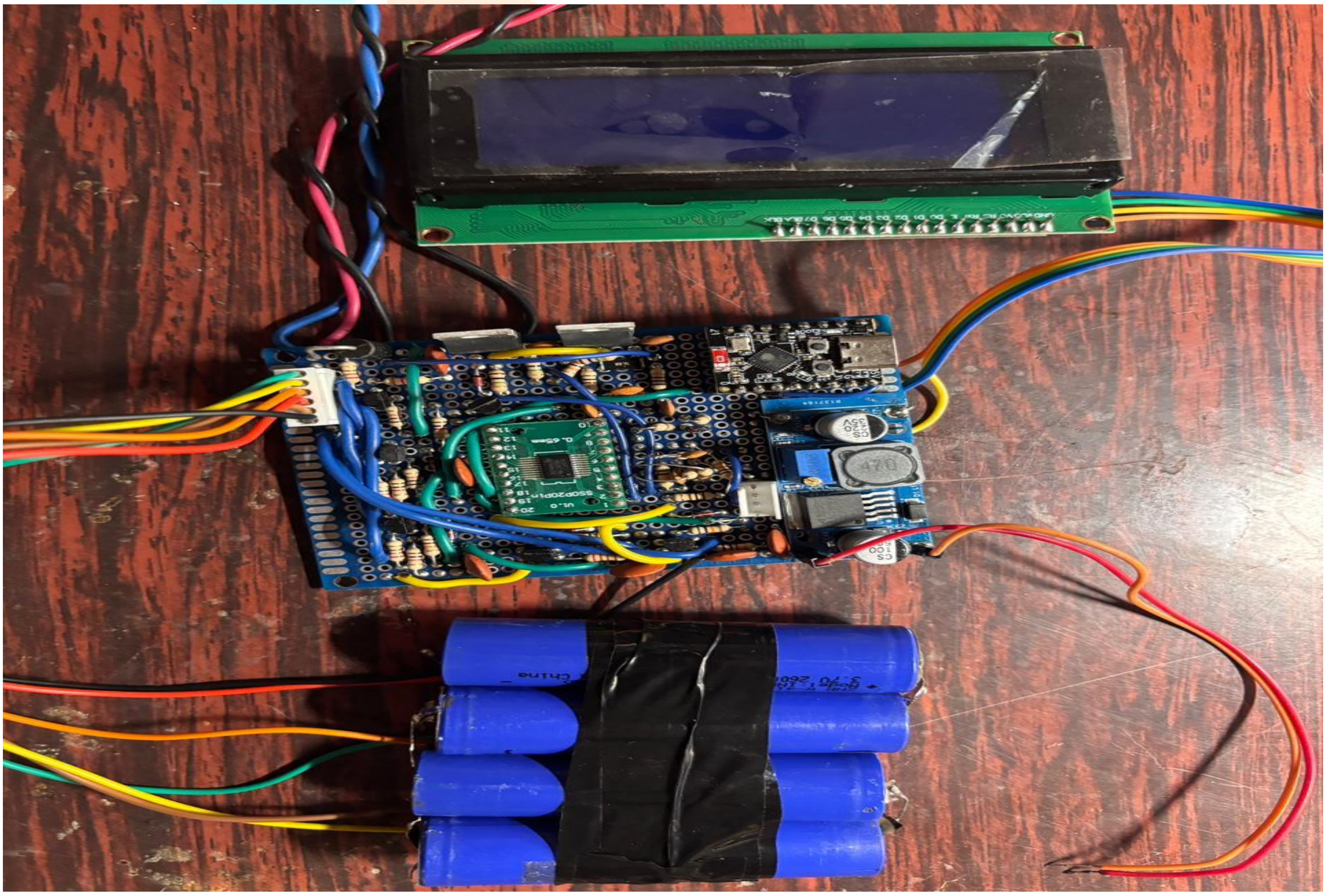
The processed data is transmitted through I2C communication for reliable internal data exchange, and simultaneously sent via Wi-Fi using the ESP32 to the Blynk application for real-time monitoring of voltage, current, temperature, SoC, and SoH. The system also executes protection logic to detect abnormal conditions such as over-voltage, under-voltage, over-current, and over-temperature, and takes necessary actions when required. The entire process runs continuously with periodic updates, ensuring efficient monitoring, communication, and safe operation of the battery system.

V. RESULTS AND DISCUSSION

The proposed Battery Management System (BMS) was implemented and tested under different operating conditions to evaluate its performance. The system successfully monitored key battery parameters such as total voltage, individual cell voltages, current, and temperature in real time. The calculated parameters including State of Charge (SoC) and State of Health (SoH) were also obtained based on the measured data. The monitoring results were transmitted using I2C communication for internal data exchange and displayed on a mobile application using the Blynk platform through Wi-Fi, providing a user-friendly interface for real-time observation.

The system demonstrated reliable performance in detecting abnormal conditions such as over-voltage, under-voltage, over-current, and over-temperature. The protection circuitry effectively responded to these conditions by controlling the charging and discharging paths through MOSFETs. The real-time data displayed on the Blynk application showed stable and accurate readings of voltage, current, temperature, SoC, and SoH, indicating proper functioning of both sensing and communication modules.

Overall, the proposed BMS achieved efficient monitoring, reliable protection, and effective communication. The integration of I2C communication ensured robust internal data transfer, while the Wi-Fi-based Blynk interface enabled convenient remote monitoring. The results confirm that the system is suitable for modern battery management applications requiring safety, reliability, and real-time performance.



Battery Management System

VI. CONCLUSION

An advanced Battery Management System (BMS) has been designed and implemented to ensure safe and efficient operation of a multi-cell lithium-ion battery pack. The system successfully monitors key parameters such as voltage, current, and temperature, along with calculated parameters including State of Charge (SoC) and State of Health (SoH). The developed system provides reliable performance and real-time monitoring of battery parameters, making it suitable for modern energy storage applications. The overall design improves battery safety, enhances performance, and extends battery lifespan. Future work can focus on improving system efficiency, enhancing balancing techniques, and implementing more advanced methods for accurate battery state estimation.

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