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Battery Supervision and Control System

Prashik Hatkar[1], Zanish Hussain[2], Vedant Nankar[3], S. D. Raut[4]
BTech Students, Department of Electronics Engineering[1-3]
Assistant Professor, Department of Electronics Engineering[4]
K.K Wagh Institute of Engineering Education and Research, Nashik, India

Abstract: *The Battery Supervision and Control System (BSCS) is an advanced embedded solution designed for real-time monitoring, protection, and optimization of lithium-ion battery packs in electric vehicles. The system employs an STM32 microcontroller to continuously monitor critical parameters such as cell voltage, current, temperature, and State of Charge (SoC), while estimating the State of Health (SoH) for predictive maintenance. The BSCS incorporates smart auto-cutoff mechanisms to prevent overcharging, cell balancing circuits to maintain voltage uniformity, and robust protection circuits against overvoltage, overcurrent, deep discharge, and short-circuit conditions. Additionally, an integrated thermal management subsystem regulates battery temperature, and IoT-based remote monitoring enables users to track performance metrics and receive safety alerts. By combining efficient circuit design, intelligent control algorithms, and robust safety protocols, the BSCS enhances energy utilization, operational reliability, and battery lifespan, contributing to the advancement of safer and more sustainable electric transportation technologies.*

Keywords*:* Battery Management System (BMS), Lithium-ion Battery State of Charge (SoC) State of Health (SoH) Cell Balancing, Electric Vehicle (EV), Overcharge Protection, Overcurrent Protection, Deep Discharge Protection, Short Circuit Protection

I. INTRODUCTION

In the rapidly evolving era of electric mobility, batteries serve as the core energy source for electric vehicles (EVs) and hybrid systems. Ensuring their safe operation, efficiency, and longevity is critical to the advancement of sustainable transportation. The Battery Supervision and Control System (BSCS) plays a vital role in monitoring, protecting, and managing the performance of battery packs under varying load and environmental conditions. As EV technology continues to expand globally, the demand for intelligent and reliable battery management and control systems has become increasingly significant to enhance both performance and safety. This project focuses on the design and implementation of a BSCS using the STM32 microcontroller. The system continuously monitors essential parameters such as cell voltage, current, temperature, and State of Charge (SoC) to ensure the battery operates within safe and efficient limits. It also estimates the State of Health (SoH) to evaluate the long-term condition of the battery pack.

The BSCS incorporates a smart auto-cutoff mechanism that automatically disconnects the charger when the battery voltage reaches a predefined threshold, preventing overcharging, overheating, and potential damage to the cells. Additionally, a cell balancing circuit redistributes charge among cells to maintain voltage uniformity, improving overall performance and extending the battery's lifespan. Protection circuits safeguard the battery against overvoltage, overcurrent, deep discharge, and short-circuit conditions, ensuring maximum reliability during operation.

The integration of IoT-based monitoring allows users to remotely observe battery parameters, receive alerts, and analyze real-time data. The system is also equipped with temperature sensors and a thermal management subsystem to regulate temperature and prevent thermal runaway. By combining efficient circuit design, precise control logic, and robust safety features, the BSCS provides a comprehensive solution for electric vehicle battery management. This project demonstrates how embedded technology can effectively enhance the safety, dependability, and sustainability of EV battery systems, marking a step forward in advancing clean and intelligent transportation solutions.

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II. LITERATURE REVIEW

Both papers review advanced Battery Management Systems (BMS) for electric vehicles, focusing on state estimation, thermal management, and safety optimization. They emphasize intelligent control, sustainable design, and strategies to enhance efficiency, longevity, and environmental performance of Li-ion batteries.[1][2]

Explored advanced Battery Management System (BMS) and Battery Energy Storage System (BESS) technologies for electric vehicles and grid-scale applications, emphasizing modeling, monitoring, and control for improved efficiency and reliability. They highlight state estimation, safety mechanisms, and integration strategies that drive sustainable and high-performance energy storage solutions.[3][4][5]

Battery Management Systems (BMS) in electric vehicles are critical electronic systems that monitor and control battery parameters such as voltage, current, temperature, and state of charge (SOC) to ensure safety, longevity, and optimal performance. They provide essential functions including cell balancing, fault detection, thermal management, and state estimation (SOC, SOH, RUL), protecting against overcharging, overheating, and other risks while optimizing energy use and extending battery life. Advanced architectures like distributed BMS enhance reliability and enable real-time monitoring and diagnostics for better vehicle performance and user safety.[6][7][8]

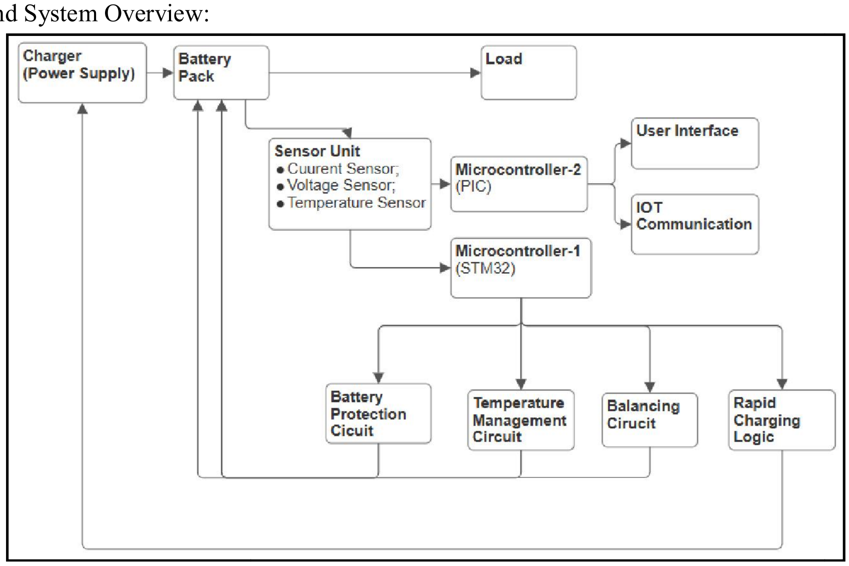
III. PROBLEM STATEMENT

Electric vehicles (EVs) rely heavily on lithium-ion battery packs as their primary energy source, whose safe, efficient, and reliable operation is critical to the performance and adoption of EV technology. However, existing battery management architectures face significant challenges including accurate real-time monitoring of battery parameters (voltage, current, temperature), precise estimation of State of Charge (SoC) and State of Health (SoH), prevention of hazardous conditions such as overcharging, deep discharge, overcurrent, and thermal runaway, as well as balancing individual cell voltages to maximize battery lifespan. Moreover, conventional systems often lack efficient thermal management and real-time remote monitoring capabilities, limiting operational safety and predictive maintenance.

These limitations can lead to performance degradation, reduced battery life, costly maintenance, and safety risks such as fires or explosions. Therefore, there is a critical need for an intelligent, integrated Battery Supervision and Control System that combines robust hardware interfacing, efficient control algorithms, active protection circuits, thermal management, and IoT-enabled monitoring to optimize battery usage, enhance safety, and extend battery service life in electric vehicles.

IV. METHODOLOGY

Block Diagram and System Overview:



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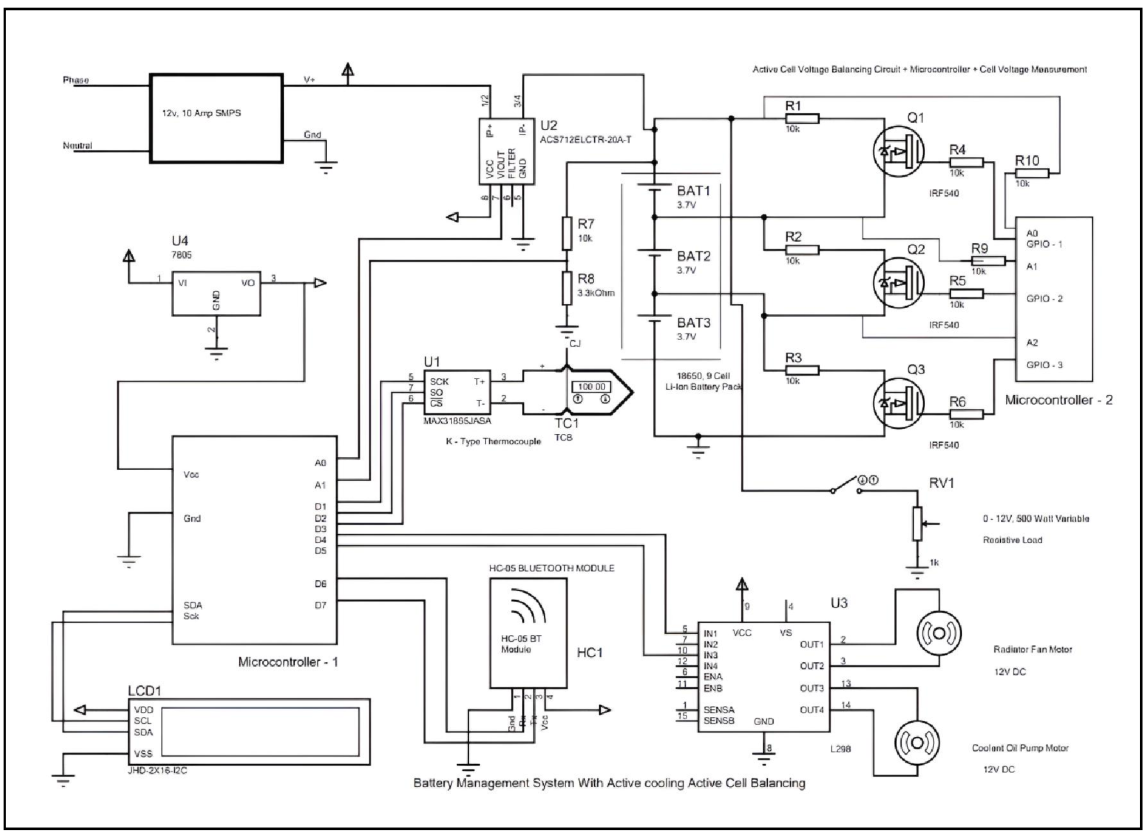
The methodology for the Battery Supervision and Control System (BSCS) is designed as an integrated hardware and software framework aimed at real-time monitoring, control, and protection of lithium-ion battery packs used in electric vehicles. The system architecture begins with a charger power supply that converts AC mains into a regulated DC voltage and current, suitable for the battery's chemistry, supplying power to a 9-series lithium-ion battery pack. A sensor unit continuously collects critical data on individual cell voltages, pack current, and battery temperature using precision sensors such as the ACS758 current sensor and K-type thermocouples.

The core processing is managed by the STM32 microcontroller, which implements control algorithms to calculate the battery's State of Charge (SoC) and State of Health (SoH), executes cell balancing protocols, and manages thermal regulation by controlling coolant pumps and radiator fans. A secondary PIC microcontroller acts as a safety overseer, redundantly monitoring critical parameters and activating hardware protection circuits to discharge or isolate the battery during faults such as overvoltage, undervoltage, overcurrent, or short-circuits. Cell voltage uniformity is maintained via a passive balancing circuit controlled by MOSFET switches that dissipate excess voltage as heat in individual cells to prevent stress and extend battery lifespan.

Communication interfaces include a local alphanumeric LCD to display battery status and an HC-05 Bluetooth module enabling IoT-enabled remote monitoring and alerting. The embedded firmware integrates sensor data acquisition, decision-making for protection and balancing, and user interaction with IoT connectivity, ensuring an intelligent, safe, and efficient battery management solution for electric vehicle applications.

V. DESIGN & EXPERIMENTATION



The design and experimentation phase of the Battery Supervision and Control System (BSCS) focused on developing a comprehensive hardware-software integrated system to ensure real-time monitoring, protection, and optimization of a 9-cell lithium-ion battery pack. The design employed precise current, voltage, and temperature sensing using Hall-

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effect sensors, voltage dividers, and thermocouples interfaced with an STM32 microcontroller for advanced control, including State of Charge (SoC) and State of Health (SoH) calculations.

A secondary PIC microcontroller facilitated redundant safety management and battery protection. Experimentation included the implementation of cell balancing circuits using MOSFETs and resistors to equalize individual cell voltages, essential for extending pack longevity. Thermal management was experimentally verified by integrating coolant pumps and radiator fans controlled by the microcontroller based on sensor feedback, successfully preventing overheating. The system's user interface combined an alphanumeric LCD for local status indication and a Bluetooth HC-05 module supporting IoT-enabled remote monitoring. Functional testing involved validating sensor accuracy, protection mechanisms (overcharge, discharge, and short circuit), balancing efficiency, and cooling activation under controlled conditions.

Results demonstrated accurate measurement and effective fault response with balancing achieving uniform cell voltages around 3.7 V. The active cooling system responded promptly to temperature variations, confirming robust thermal regulation.

Overall, the design and experimentation phase validated the BSCS as a reliable, scalable, and intelligent solution for enhancing battery safety, performance, and lifespan in electric vehicle applications. This practical implementation underscores the integration of modern embedded control, sensor technologies, and IoT communication in advancing electric mobility.

VI. RESULTS

Experimental and simulation results of the Battery Supervision and Control System (BSCS) project demonstrate successful implementation and validation of comprehensive battery management functionality for a 9-cell lithium-ion battery pack. The balancing circuit effectively equalized individual cell voltages to approximately 3.7 V, confirming the ability to maintain uniform charge and extend pack lifespan. The monitoring circuit provided near-accurate readings of critical battery parameters including voltage, current, and temperature, with real-time display both on the local alphanumeric LCD and remotely via the IoT-enabled Bluetooth interface. Thermal management was experimentally validated as the system activated the coolant pump and radiator fan responsively in reaction to increased temperature signals, demonstrating effective control of battery temperature to prevent overheating. Safety mechanisms performed reliably by engaging protection circuits during fault simulations such as overvoltage, undervoltage, and short circuit, promptly disconnecting load or charger to avoid battery damage. The embedded STM32 and PIC microcontrollers efficiently coordinated sensor data acquisition, fault diagnosis, cell balancing, and cooling actuation under various test scenarios, validating the integration of hardware and firmware components. Overall, these results confirm that the BSCS meets design objectives by ensuring safety, optimizing performance, and facilitating remote monitoring, making it a robust solution for electric vehicle battery management. The project outcomes establish a strong foundation for further enhancements including AI-driven predictive diagnostics and expanded communication features

Hardware Design

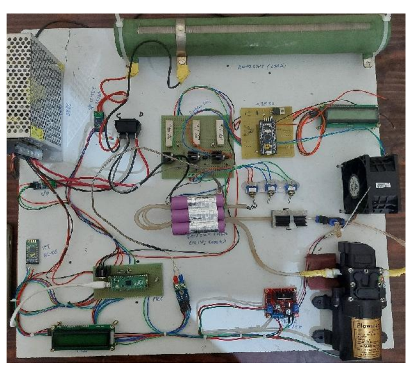

Figure 6.1 Hardware Design

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The hardware design of the Battery Supervision and Control System (BSCS) integrates several key components to achieve precise monitoring, protection, and control of a lithium-ion battery pack. The system centers around the STM32 microcontroller, responsible for collecting sensor data and executing control algorithms. Current sensing is implemented using the ACS758 Hall-effect sensor, while voltage sensing is done via resistor voltage dividers connected to individual battery cells. Temperature measurement is achieved through K-type thermocouples positioned strategically on the battery pack. Protection circuits include MOSFET-based switches that disconnect the battery during fault conditions such as overvoltage, undervoltage, or overcurrent. The cell balancing circuit uses MOSFETs to selectively discharge cells with higher voltage via resistors to equalize cell voltages. A thermal management subsystem controls a coolant pump and radiator fans through motor driver ICs (L298), activated based on temperature sensor inputs to prevent overheating. For user interaction and status indication, the system features an alphanumeric LCD and an HC-05 Bluetooth module for wireless IoT communication. Additionally, a secondary PIC microcontroller provides hardware-level monitoring and rapid fault detection with redundant protection. This hardware architecture ensures reliable, scalable, and intelligent battery management suitable for electric vehicle applications.

Results

Figure 6.2 Cell Ratings

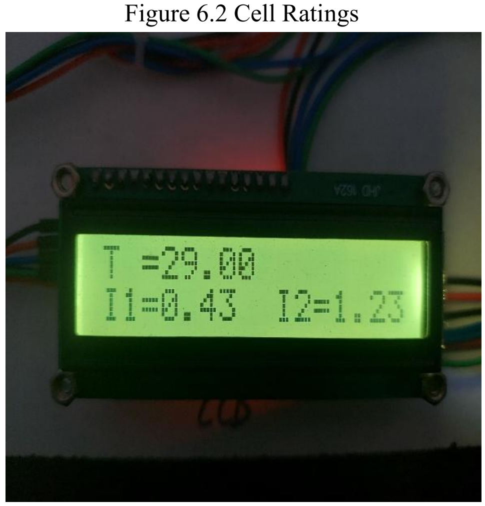

Figure 6.3 Battery Current & Temperature Parameters

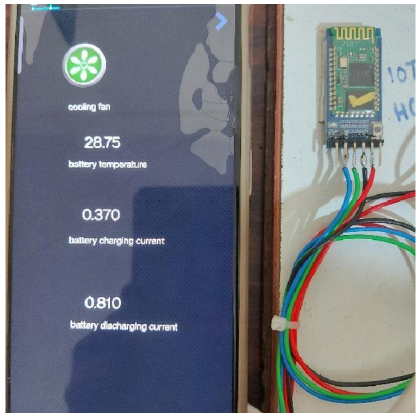

Figure 6.4 IoT & Web Interface Results

VII. CONCLUSION

The Battery Supervision & Control System (BSCS) with active cooling and cell balancing enhances the safety, reliability, and longevity of lithium-ion battery packs. It includes hardware and software subsystems that monitor critical parameters like cell voltages and temperatures, employing balancing circuits and cooling mechanisms to maintain optimal conditions. The BSCS protects against overcharge, deep discharge, and thermal runaway while enabling intelligent control of charging and discharging. Active cell balancing compensates for variations in cell capacity and state of charge, extending battery life and performance. The active cooling system manages temperature using real-time feedback, preventing overheating and ensuring stability. Additionally, wireless communication and visual interfaces provide real-time insights for remote diagnostics. This advanced BSCS design is crucial for the future of electric mobility and energy storage, promoting safer and more efficient battery applications for sustainable energy solutions.

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