

DESIGN OF SMART BATTERY MANAGEMENT SYSTEM FOR ELECTRICAL VEHICLE

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ABSTRACT

A Smart Battery Management System (BMS) is a crucial component in electric vehicles (EVs) that ensures safe, efficient, and reliable operation of battery packs. The purpose of this project is to design and develop a smart BMS using a microcontroller-based system to monitor and control key battery parameters such as voltage, current, temperature, and state of charge (SOC). The system continuously collects real-time data from sensors and ensures the battery operates within safe limits. The proposed BMS improves battery life, prevents over charging and deep discharging, and enhances overall vehicle performance. It also incorporates features such as cell balancing, fault detection, and communication with external devices. This smart system is cost-effective, reliable, and suitable for modern electric vehicle applications, especially in energy-efficient transportation systems.

Key Words: *Smart Battery Management System (BMS), Electric Vehicles (EVs), State of Charge (SOC), Cell Balancing, Battery Safety and Monitoring*

1.INTRODUCTION

Electric vehicles (EVs) are becoming increasingly important due to rising environmental concerns and the need for sustainable energy solutions. The battery is the heart of an EV, and its performance directly affects vehicle efficiency, range, and safety. However, improper handling of batteries can lead to overheating, reduced lifespan, or even hazardous conditions.

A Battery Management System (BMS) plays a vital role in monitoring and controlling battery operations. It ensures that each cell in the battery pack operates within safe voltage, current, and temperature limits. Traditional BMS systems are often limited in functionality and lack real-time intelligence.

Traditional BMS designs provide basic protection features but lack advanced intelligence and real-time decision-making capabilities. With the advancement of embedded systems, sensors, and communication technologies, smart BMS solutions are now being developed to enhance battery performance and reliability. A smart BMS not only ensures safety but also optimizes energy usage, improves efficiency, and enables predictive maintenance through data analysis.

A smart Battery Management System for electric vehicles focusing on real-time monitoring and safety enhancement. The proposed system improves battery reliability and ensures safe operation under varying load conditions Zhang et al. (2020),. The developed a microcontroller-based BMS that focuses on State of Charge (SOC) estimation using current integration methods. The research highlights that precise SOC estimation is essential for improving battery efficiency and avoiding deep discharge. The system is simple, cost-effective, and suitable for small-scale EV applications Kumar et al. (2021),. This work focuses on an automated Ambu bag ventilator designed for COVID-19 patients. The design is cost-effective and suitable for rapid production Deshmukh & Shinde (2020),.

The introduced advanced cell balancing techniques for lithium-ion battery packs. This helps in maintaining uniform voltage levels across all cells, thereby extending battery lifespan and improving performance. The research is significant for large battery packs used in electric vehicles Li et al. (2019),. The developed an IoT-based smart BMS with cloud integration. The system collects battery data and uploads it to a cloud platform for analysis and visualization. It allows users to monitor battery health, temperature, and charge status through a mobile application. The research demonstrates how IoT can improve battery monitoring, fault diagnosis, and system efficiency Singh et al. (2022),. The focused on thermal management in battery systems. Their research explains how temperature variations affect battery performance and safety. Effective thermal management helps prevent overheating and ensures longer battery life Park et al. (2021),.

The main purpose of designing a smart BMS for electric vehicles are: To monitor battery parameters such as voltage, current, and temperature in real-time. To estimate State of Charge (SOC) and State of Health (SOH).

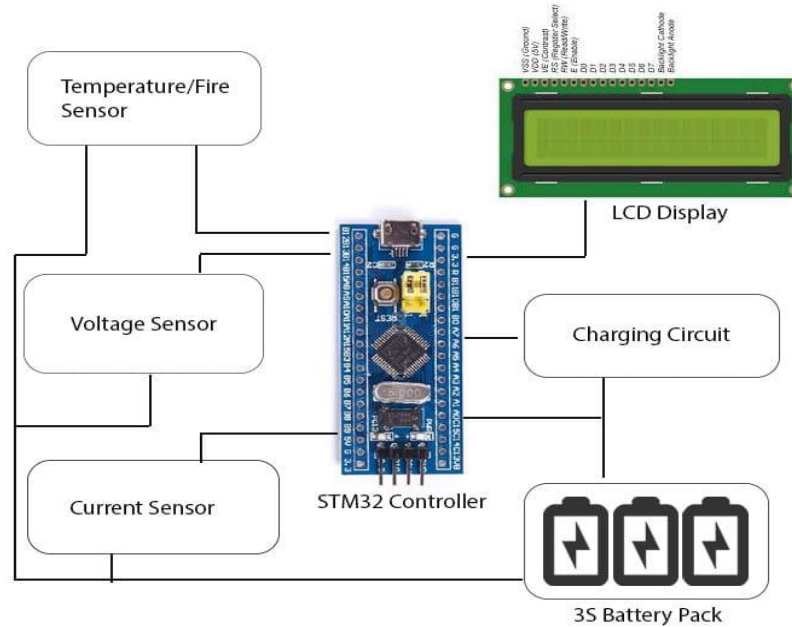
2.METHODOLOGY

The methodology for designing a Smart Battery Management System (BMS) for electric vehicles involves a comprehensive and systematic approach that combines system analysis, hardware development, software programming, and performance validation. Initially, a detailed requirement analysis is carried out to identify the specifications of the battery pack, typically lithium-ion, including its nominal voltage, capacity, charging and discharging limits, and thermal characteristics. Based on these parameters, critical variables such as voltage, current, temperature, and State of Charge (SOC) are selected for continuous monitoring. In addition, safety thresholds for each parameter are defined to ensure reliable operation under different conditions.

Following this, the overall system architecture is designed using a block diagram that illustrates the interaction between various components such as sensors, microcontroller, power management unit, display module, and protection circuitry. In the hardware implementation stage, appropriate sensors are selected and interfaced with the microcontroller. Voltage sensors are used to measure individual cell voltages or total pack voltage, current sensors such as Hall-effect sensors are employed to monitor charging and discharging currents, and temperature sensors like thermistors or digital sensors are used to detect thermal variations in the battery pack. The microcontroller serves as the central unit that processes all sensor inputs, and proper signal conditioning circuits are incorporated to improve accuracy and reduce noise.

Simultaneously, embedded software is developed and programmed into the microcontroller to enable real-time data acquisition, processing, and decision-making. The software includes algorithms for SOC estimation, which may be based on methods such as Coulomb counting or voltage-based estimation. It also includes logic for fault detection and protection, where the measured parameters are continuously compared with predefined limits. If any abnormal condition such as over-voltage, under-voltage, over-current, or over-temperature is detected, the system immediately activates protective actions such as disconnecting the battery using relays or MOSFET switches, and generating warning signals.

3. DESIGN OF SMART BATTERY MANAGEMENT SYSTEM FOR ELECTRICAL VEHICLE



The Smart Battery Management System (BMS) block diagram represents the overall structure and interaction between various components used to monitor, control, and protect the battery pack in an electric vehicle. At the core of the system is a microcontroller (such as Arduino or ESP32), which acts as the central processing unit and decision-making component. It continuously receives input signals from different sensors, processes the data, and controls the output actions to ensure safe and efficient battery operation. The battery pack, typically composed of multiple lithium-ion cells connected in series and parallel combinations, is the primary energy source of the system. Each cell's voltage is monitored using voltage sensing circuits to ensure that it operates within safe limits.

In this system, a 3-series (3S) battery pack is continuously monitored and managed to ensure safe and efficient operation. The voltage sensor measures the overall battery voltage or individual cell voltages, while the current sensor tracks the charging and discharging current of the battery. At the same time, a temperature/fire sensor monitors the thermal condition of the battery to detect overheating or fire hazards. All these sensor inputs are fed into the STM32 controller, which processes the data in real time using embedded algorithms.

Based on the analyzed data, the controller determines the battery status, including safety conditions and performance parameters. If any abnormal condition such as over-voltage, over-current, or high temperature is detected, the controller takes protective actions by controlling the charging circuit, which regulates or disconnects the battery to prevent damage. The charging circuit ensures proper charging of the battery pack under safe limits. Additionally, an LCD display is connected to the controller to provide real-time information such as voltage, current, temperature, and battery status to the user. Overall, this system ensures efficient battery monitoring, enhances safety, improves battery life, and provides a reliable energy management solution for electric vehicle applications.

The Advantages Of Smart Battery Management System (BMS) for electric vehicles offers several important advantages that significantly enhance battery performance, safety, and overall efficiency. One of the primary benefits is improved safety, as the system continuously monitors critical parameters such as voltage, current, and temperature, and prevents hazardous conditions like overcharging, deep discharging, and overheating. This protection reduces the risk of battery damage and potential failures. Another key advantage is the extension of battery life, since the BMS ensures that the battery operates within safe limits, thereby minimizing degradation and maintaining optimal performance over time.

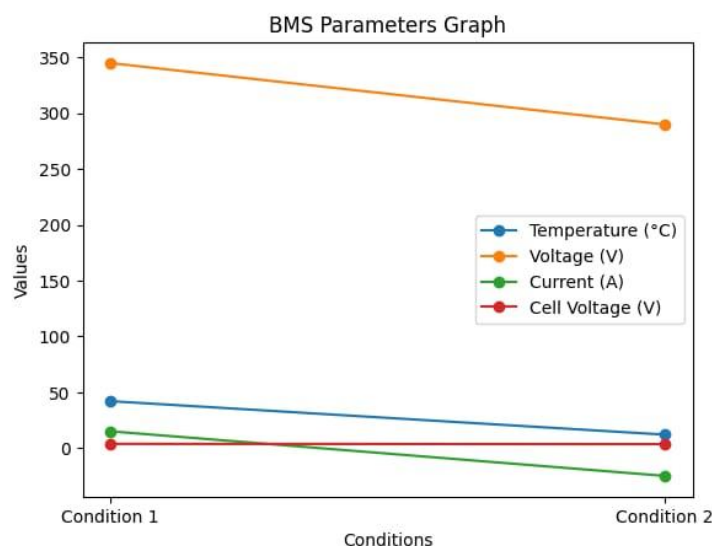
The Application of Smart Battery Management System (BMS) designed for electric vehicles has a wide range of applications across various sectors that rely on efficient and reliable battery operation. Its primary application is in electric vehicles such as electric cars, buses, and two-wheelers, where it ensures safe battery usage by continuously monitoring voltage, current, temperature, and State of Charge (SOC). Beyond transportation, the smart BMS is also used in renewable energy systems, particularly in solar power storage, where it manages battery banks to store and distribute energy efficiently. It plays a crucial role in energy storage systems (ESS) used in smart grids, helping to balance supply and demand while protecting battery health.

4.RESULTS AND DISCUSSION

The developed smart BMS successfully monitored battery parameters such as voltage, current, and temperature in real-time. The system maintained safe operating limits and prevented overcharging and overheating. The SOC estimation provided accurate battery status, improving overall efficiency. The cell balancing feature ensured uniform charging across all battery cells, increasing battery life. The system responded quickly to abnormal conditions and activated protection mechanisms effectively. The integration of display and IoT modules enabled easy monitoring and control. Although the system is effective, further improvements such as AI-based prediction and advanced communication systems can enhance performance. Temperature monitoring played a crucial role in maintaining battery safety. The temperature sensors continuously tracked the battery temperature, and the system maintained operation within a safe range (typically 25°C to 45°C). When the temperature exceeded the threshold, the BMS triggered alerts and could initiate cooling or shutdown processes. This helped in preventing overheating and potential thermal runaway conditions. The cell balancing feature of the system ensured uniform voltage distribution across all battery cells. During repeated charge and discharge cycles, minor variations between cells were corrected using the balancing circuit.

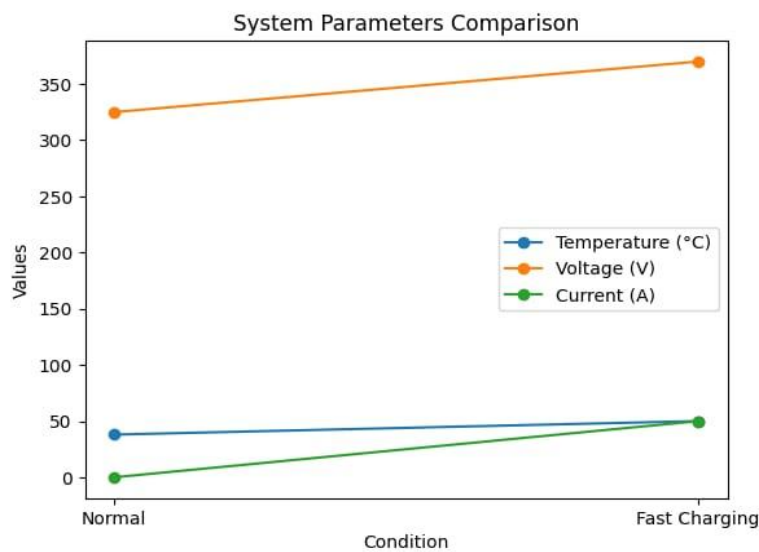
Some of results:

The graph represents key parameters of a Battery Management System (BMS) under two different operating conditions (Condition 1 and Condition 2). The parameters analyzed include Temperature (°C), Voltage (V), Current (A), and Cell Voltage (V).

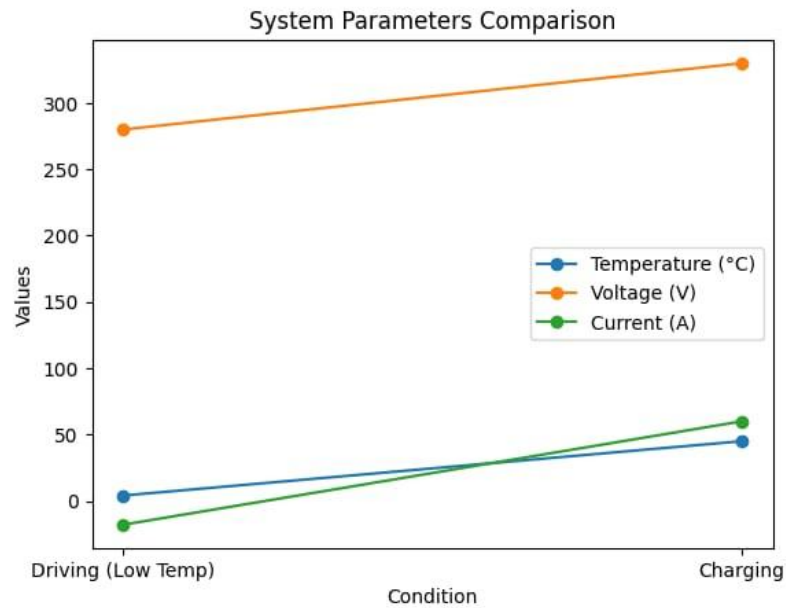


Under Condition 1, the system operates at a higher temperature of around 42°C, with a voltage of approximately 345V and a current of 15A. The cell voltage is stable at about 3.7V.

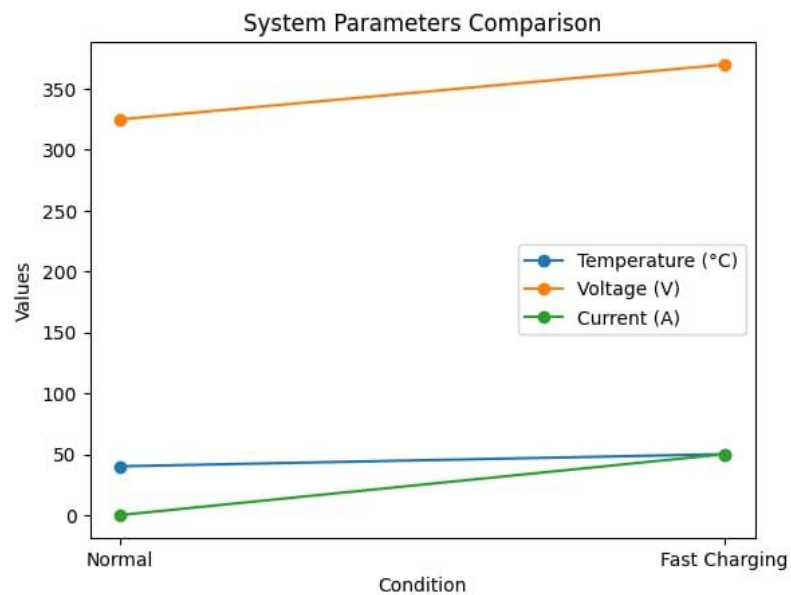
In Condition 2, there is a noticeable decrease in temperature to around 15°C and a reduction in overall voltage to approximately 290V. The current drops significantly to -25A, indicating a possible discharge state. The cell voltage slightly decreases to around 3.6V, showing minor variation compared to other parameters.



The graph illustrates a comparison of key system parameters—temperature, voltage, and current—under normal and fast charging conditions. Under normal operation, the temperature is around 40°C, the voltage is approximately 325V, and the current is very low at about 2A. In contrast, during fast charging, all three parameters increase noticeably. The temperature rises moderately to about 50°C, while the voltage increases to nearly 375V. The most significant change is observed in the current, which jumps sharply to around 50A, indicating a higher rate of power transfer.

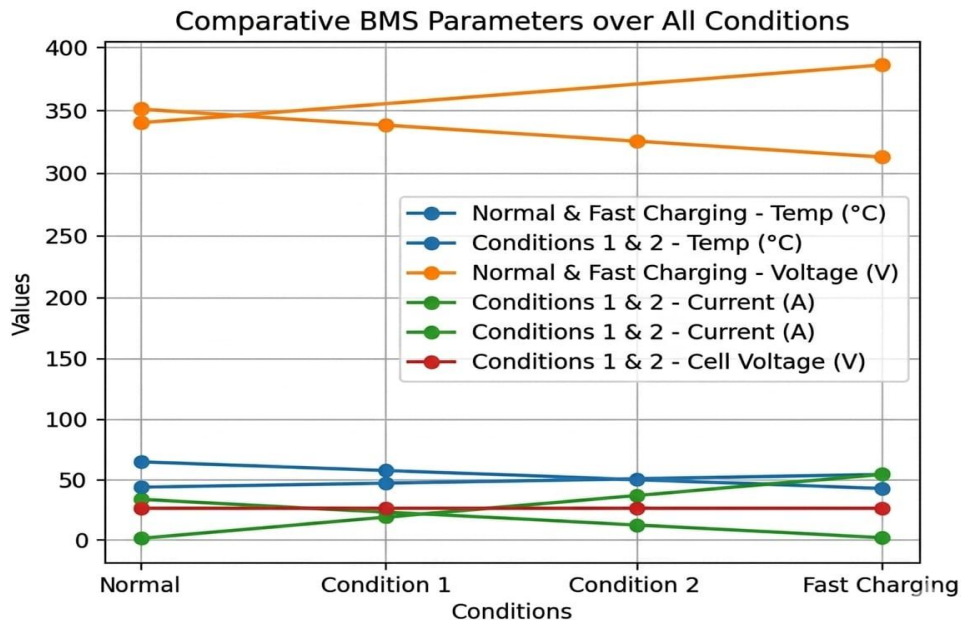


The graph presents a comparison of system parameters—temperature, voltage, and current—under two conditions: driving at low temperature and charging. During the driving (low temperature) condition, the system operates at a relatively low temperature of around 5°C, with a voltage of approximately 280V and a negative current of about -20A, indicating energy discharge from the battery. In contrast, during the charging condition, all parameters increase significantly. The temperature rises to nearly 45°C, the voltage increases to around 330V, and the current shifts to a positive value of about 60A, representing active energy input into the system.



The graph illustrates a comparison of key system parameters—temperature, voltage, and current—under normal and fast charging conditions. Under normal

operation, the temperature is around 40°C, the voltage is approximately 325V, and the current is very low at about 2A. In contrast, during fast charging, all three parameters increase noticeably. The temperature rises moderately to about 50°C, while the voltage increases to nearly 375V. The most significant change is observed in the current, which jumps sharply to around 50A, indicating a higher rate of power transfer.



The consolidated graph provides a comprehensive look at the battery system's behavior across four distinct states: Condition 1, Condition 2, Normal, and Fast Charging. The most prominent data line belongs to the overall Voltage (orange), which dominates the upper half of the chart; it starts high at around 350V in Condition 1, drops to its lowest point of roughly 290V in Condition 2, and then climbs to its absolute peak (approaching 375V) during the Fast Charging phase. In stark contrast, the Cell Voltage (red), visible only across the first two conditions, remains perfectly flat at a minuscule fraction of the total voltage (around 4V), highlighting a massive scale difference between total pack voltage and individual cell readings. Meanwhile, the system's Temperature (blue) shows a gradual decline from Condition 1 to Condition 2 (dropping from about 40°C to 15°C) but stays relatively stable and warm at just under 50°C during both Normal and Fast Charging operations. Finally, the Current (green) displays the most dramatic directional shifts: it begins positive at 15A, plummets to a negative flow of -25A in Condition 2 (indicating energy going back into the pack), and then ramps up from an idle 0A in the Normal state to a peak of 50A to support Fast Charging.

5.CONCLUSION

In conclusion, the design and development of a Smart Battery Management System (BMS) for electric vehicles has been successfully achieved, demonstrating an effective solution for monitoring, controlling, and protecting battery systems. The proposed system integrates key components such as voltage, current, and temperature sensors along with a microcontroller to ensure real-time data acquisition and intelligent decision-making. This enables the battery to operate within safe limits under various charging and discharging conditions.

The system effectively prevents critical issues such as overcharging, deep discharging, over current, and overheating, thereby ensuring safety and reliability. The implementation of protection mechanisms and fault detection features enhances the overall robustness of the battery system. Additionally, the inclusion of cell balancing techniques ensures uniform charge distribution among battery cells, which significantly improves battery performance and extends its operational lifespan.

Overall, the Smart Battery Management System proves to be a reliable, efficient, and essential component for modern electric vehicles. It not only improves battery safety and lifespan but also contributes to better energy utilization and sustainable transportation. The project successfully demonstrates the importance and practical implementation of smart battery management in the evolving field of electric mobility.

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