ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr157

Simulation Based Battery Management System

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Publication Date: 2025/04/17

Abstract: In this paper, a Battery Management System (BMS) is developed using the ESP32 micro-controller integrated with voltage and current sensors to enhance the efficiency and lifespan of batteries in electric vehicles (EV). The primary objective is to continuously monitor key parameters such as voltage, current, State of Charge (SoC) and State of Health (SoH) to ensure optimal performance and safety. Pulse Width Modulation (PWM) techniques are employed to precisely regulate the charging and discharging processes, reducing energy losses and preventing battery degradation. The ESP32 micro-controller is known for its low power consumption and built-in Wi-Fi and Bluetooth capabilities, acts as the central processing unit, collecting real-time data and transmitting it to a cloud-based platform or local server for further analysis. Advanced algorithms and cell balancing techniques are integrated to provide accurate SoC and SoH estimation, ensuring uniform charge distribution across cells. Additionally, the BMS includes protection mechanisms against over-voltage, under-voltage and over-current conditions, enhancing safety and reliability.The proposed system offers a cost-effective and reliable solution for battery management in EV, focusing on efficient energy utilization, safety and extended battery life.

How to Cite: Dr. Archana Shirbhate; Mohd. Aasim Ameen; Mohd. Irshadalam; Ritik Satpute (2025). Simulation Based Battery Management System. *International Journal of Innovative Science and Research Technology*, 10(4), 339-344. https://doi.org/10.38124/ijisrt/25apr157

I. INTRODUCTION

The Battery Management System (BMS) is developed using the ESP32 micro-controller along with voltage and current sensors to enhance the efficiency and lifespan of batteries in electric vehicles (EV). The primary goal is to continuously monitor key parameters such as voltage, current, state of charge (SoC) and state of health (SoH) of the battery to ensure optimal performance and safety. The BMS employs Pulse Width Modulation (PWM) techniques to regulate the charging and discharging processes precisely. By adjusting the width of the pulses, PWM allows efficient control over power distribution, reducing energy losses and preventing battery degradation. The ESP32 micro-controller, known for its low power consumption and integrated Wi-Fi and Bluetooth capabilities, serves as the central processing unit, collecting real-time data from sensors and transmitting it to a cloud-based platform or local server for further analysis.The system also integrates cell balancing techniques and advanced algorithms for accurate SoC and SoH estimation, ensuring uniform charge distribution across battery cells. This BMS includes protection mechanisms to safeguard against over-voltage, under-voltage and over-current conditions, thereby enhancing the safety and reliability of the battery pack.This simulation demonstrates a cost-effective and reliable solution for battery management in EV, focusing on efficient energy utilization, safety, and extended battery life.

II. LITERATURE REVIEW

The development of BMS using PWM techniques has been extensively studied to enhance the efficiency, lifespan and safety of batteries, especially in EV. PWM is a control technique that regulates power delivery by adjusting the width of voltage pulses, enabling precise control over charging and discharging processes. Research indicates that integrating PWM in BMS allows for efficient power distribution, preventing issues such as overcharging, overheating and deep discharging of batteries. Studies have demonstrated that PWM based BMS significantly reduces energy losses during power conversion and ensures balanced power distribution across battery cells, which is essential for maintaining the health and performance of EV batteries. One of the prominent applications of PWM in BMS is in sensorless control techniques for Brushless DC (BLDC) motors. Digital PWM with back-EMF detection has proven effective in eliminating the need for physical sensors, thereby reducing system costs without compromising performance. Advanced algorithms such as Coulomb counting and Kalman filtering are often integrated into PWM based BMS to provide accurate real-time estimation of SoC and SoH. These methods not only optimize power management but also enhance the longevity of batteries by ensuring uniform charge distribution among cells and preventing voltage imbalances. However, challenges remain in refining PWM control strategies to handle varying load conditions efficiently. The literature suggests the need for

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further research to enhance the accuracy of control algorithms and integrate more advanced sensor technologies. Effective thermal management using PWM has been highlighted as a critical factor in preventing thermal runaway and ensuring the safe operation of batteries under diverse operating conditions. Overall, PWM based BMS presents a promising approach to advancing battery management technologies for electric vehicles by balancing efficiency, safety and cost-effectiveness.

III. AIM AND OBJECTIVES

➢ *Aim*

The aim of this paper is to develop an efficient BMS using PWM techniques to optimize power distribution, enhance battery lifespan and ensure the safety and reliability of batteries in EV. The system seeks to achieve accurate monitoring and control of key battery parameters, including voltage, current, SoC and SoH.

➢ *Objectives*

- *To Design a PWM Based Control System:*

Develop a control strategy utilizing PWM techniques to regulate the charging and discharging processes of batteries efficiently.

- *To Implement Real-Time Monitoring:*

Integrate sensors to continuously monitor voltage, current, SoC and SoH of the battery and transmit this data for analysis.

- *To Enhance Safety Mechanisms:*

Incorporate protection features against over-voltage, under-voltage and over-current conditions to prevent battery damage and ensure safe operation.

- *To Improve Energy Efficiency:*

Optimize power distribution and minimize energy losses using PWM to extend the battery life and enhance overall efficiency.

- *To Validate System Performance:*

Test the BMS under various load conditions to ensure reliability, robustness and effectiveness of the proposed solution.

IV. PROPOSED METHODOLOGY

The methodology for developing a BMS using PWM techniques involves a systematic approach divided into key phases are system design, control strategy implementation, real-time monitoring, safety mechanisms and testing. This structured process ensures efficient power management, enhanced safety and extended battery lifespan for EV.

➢ *System Design and Component Selection:*

The first step is to design the overall architecture of the BMS and select appropriate components. An ESP32 micro-controller is chosen for its low power consumption and integrated Wi-Fi and Bluetooth capabilities, enabling real-time data transmission. Voltage, current, and temperature sensors are integrated to monitor critical battery parameters. A power management circuit is designed using MOSFET to control the charging and discharging processes efficiently. This phase focuses on ensuring that all hardware components work seamlessly to gather accurate data and execute control commands effectively.

➢ *PWM Control Strategy Implementation:*

In this phase, PWM techniques are implemented to manage the energy flow within the battery system efficiently. PWM is used to adjust the duty cycle of the power supplied to the battery, controlling the charging and discharging rates. Cell balancing techniques, either passive or active are incorporated to maintain uniform charge distribution across all battery cells preventing issues like over-voltage and under-voltage. A closed-loop feedback control system is also developed, allowing real-time adjustments to PWM signals based on sensor data to optimize battery performance and efficiency.

➢ *Real-Time Monitoring and Data Processing:*

Real-time monitoring is achieved by collecting data from voltage, current and temperature sensors, which is processed by the ESP32 micro-controller. This data is then transmitted to a cloud-based platform or local server for continuous monitoring and analysis. Advanced algorithms such as Coulomb counting and Kalman filtering are employed for accurate estimation of SoC and SoH. These estimations help in making informed decisions about power management and battery maintenance, ensuring optimal performance.

➢ *Safety and Protection Mechanisms:*

Safety mechanisms are crucial to prevent battery damage and ensure reliable operation. Over-voltage, under-voltage, and over-current protection circuits are designed to disconnect the power supply when parameters exceed safe limits. Thermal management is integrated by using PWM to control cooling systems based on real-time temperature data, preventing thermal runaway. These protection features enhance the safety and longevity of the battery pack.

➢ *Testing and Validation:*

The final phase involves testing the BMS under various load conditions to validate its performance and reliability. Simulation tools are used to replicate real-world scenarios, focusing on parameters like energy efficiency, accuracy of SoC and SoH estimations, and the effectiveness of protection mechanisms. The test results are analyzed to refine the PWM control strategy and other system parameters. Iterative improvements are made to optimize efficiency and ensure that the BMS meets the desired performance standards.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr157

V. FLOW CHART

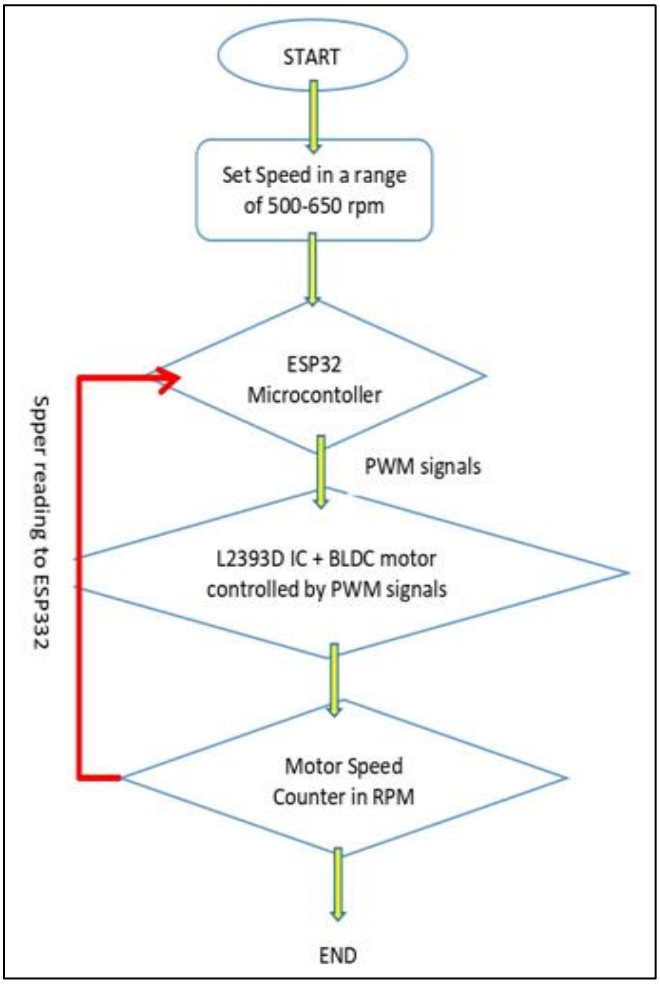


Fig 1 Flow of Power

From fig1. The algorithm for controlling a BLDC motor using an ESP32 micro-controller and PWM techniques begins with the collection of real-time data from sensors. A current sensor and a voltage sensor measure the motor's power consumption and supply, respectively. This information is sent to the ESP32 micro-controller, which acts as the central processing unit for the system. By analyzing this data, the micro-controller determines the appropriate PWM signals to regulate the motor speed and power. The use of PWM is crucial as it allows precise control over the amount of power delivered to the motor by adjusting the duty cycle, ensuring efficient power management. The PWM signals generated by the ESP32 are then sent to the L298N motor driver which serves as an intermediary between the micro-controller and the BLDC motor. The L298N driver interprets these signals to control the power and speed of the motor according to the requirements.

As the motor operates, an LM393 speed sensor continuously monitors its speed and feeds this information back to the ESP32 micro-controller. This feedback mechanism enables the system to assess if the actual speed matches the desired speed set by the control parameters. Based on the speed sensor feedback, the ESP32 adjusts the PWM signals dynamically to maintain the motor's speed within the desired range. This closed-loop control system ensures that any deviations in speed due to load variations or power supply fluctuations are corrected in real-time. By continuously optimizing the PWM signals based on feedback, the system achieves efficient and stable motor performance. This approach not only enhances energy efficiency but also ensures smooth and reliable operation of the motor.

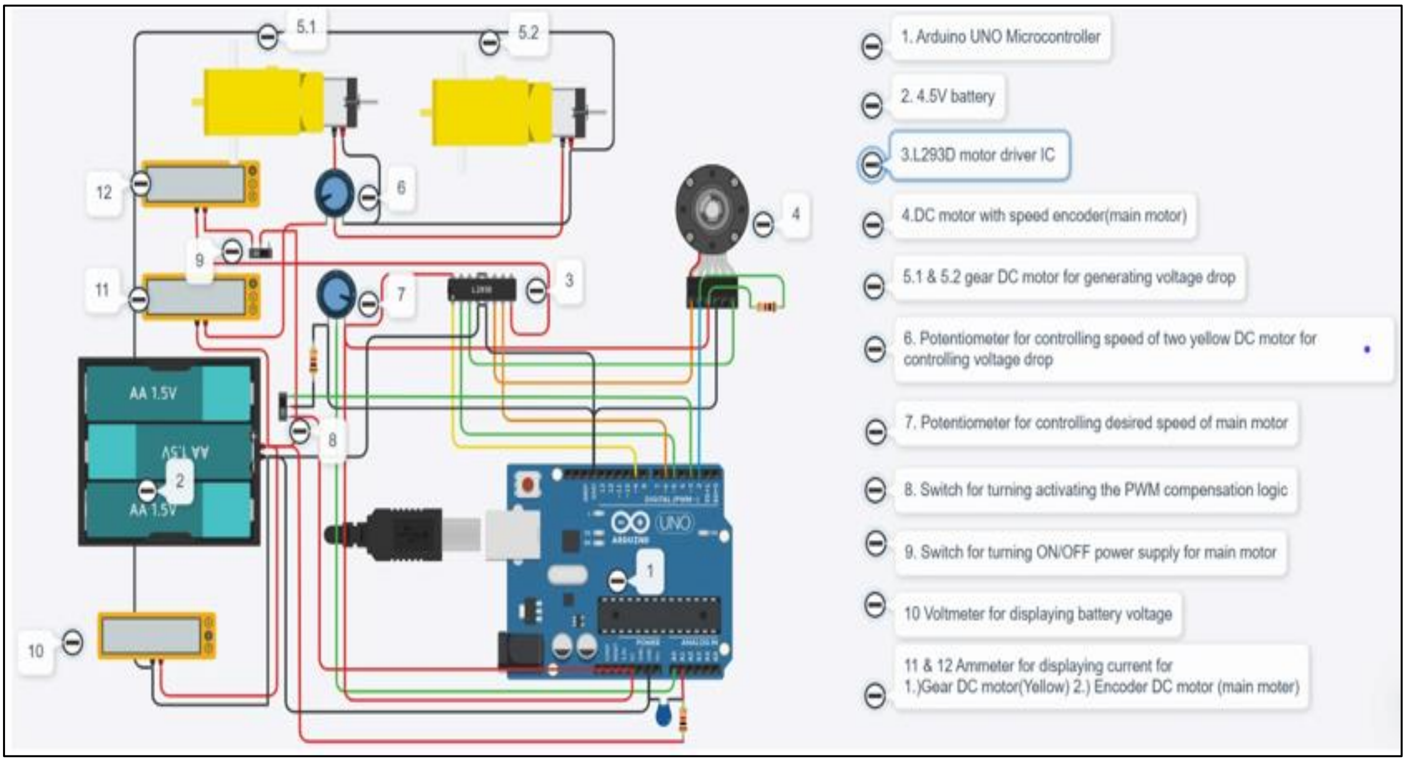


Fig 2 Simulation of BMS in TinkerCAD Software.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr157

The simulation setup shown in fig.2. illustrates the control and monitoring of multiple DC motors using an Arduino UNO microcontroller, an L293D motor driver IC, and various sensors and components for speed and voltage regulation. The system is powered by a 4.5V battery pack. The L293D motor driver receives control signals from the Arduino UNO to manage the speed and direction of the motors. The primary DC motor with a speed encoder is used for precise speed measurement, while two additional gear DC motors generate a voltage drop to simulate varying load conditions. Speed control is achieved through potentiometer. Potentiometer adjusts the speed of the yellow gear DC motors, influencing the voltage drop, while potentiometer sets the desired speed for the main motor. A switch activates the PWM compensation logic, allowing the system to adjust motor speed based on feedback from the speed encoder. Another switch controls the main motor power supply. This setup enables real-time speed adjustments, ensuring stable performance under different load conditions. To monitor the system performance, a voltmeter displays the battery voltage, and ammeters measure the current for the yellow gear DC motor and the main motor, respectively. By integrating these sensors, the simulation can effectively demonstrate how PWM and real-time feedback maintain motor speed despite voltage variations and load changes. This assembly is valuable for testing control algorithms and power management strategies for DC motors in practical applications.

VI. MAJOR COMPONENTS

BMS consists of the three major groups of components are as explained in below as follows;

- *Arduino UNO Microcontroller and L293D Motor Driver IC*

The Arduino UNO micro-controller acts as the central control unit of the simulation, responsible for generating and managing PWM signals based on user inputs and sensor feedback. It processes data from potentiometer and speed sensors to adjust the motor speed accordingly. The L293D motor driver IC serves as an interface between the Arduino and the DC motors, providing sufficient power and enabling bidirectional control. It receives control signals from the Arduino and manages the power flow to the motors, ensuring they operate smoothly at the desired speed and direction. The combination of Arduino and L293D allows precise control of the motors, making it possible to test different speed and load conditions effectively.

- *DC Motors, Speed Encoder, and Potentiometer*

The simulation includes a main DC motor equipped with a speed encoder and two additional gear DC motors to create voltage drops and simulate various load conditions. The speed encoder generates pulses proportional to the motor's speed, which are sent to the Arduino as feedback. This feedback mechanism enables the Arduino to adjust PWM signals dynamically, ensuring the motor maintains a steady speed despite changes in load or power supply. Potentiometer play a crucial role in this system: one controls the speed of the yellow gear DC motors, influencing the voltage drop, while the other directly adjusts the desired speed of the main motor. This setup allows users to manually test and observe how different voltage levels and load conditions impact motor performance.

- *Sensors, Switches, and Monitoring Instruments*

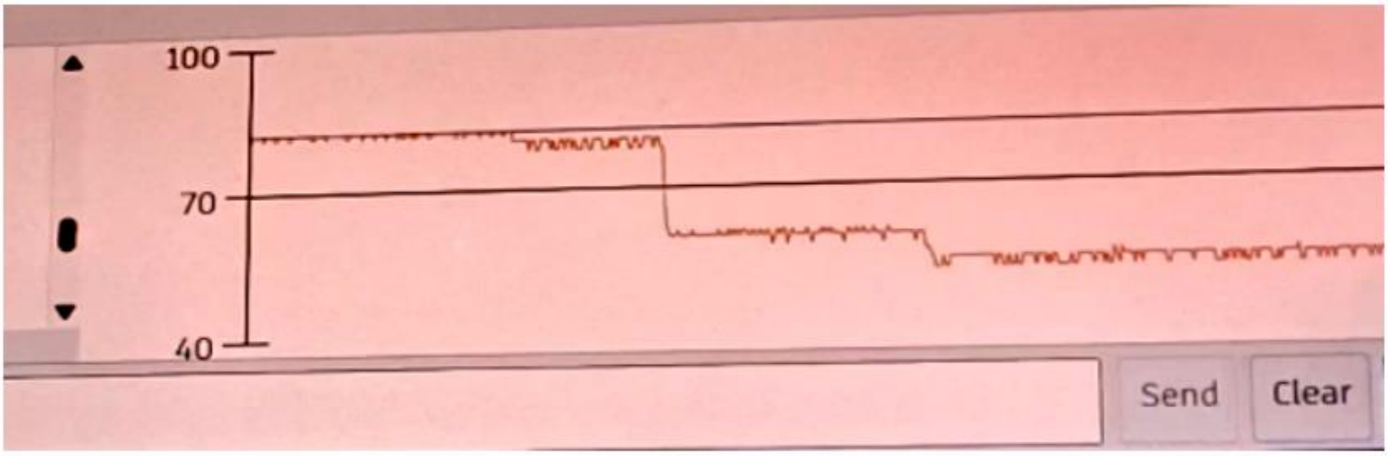
The simulation is equipped with various sensors and monitoring instruments, including voltmeters and ammeters, to provide real-time data about the system's performance. The voltmeter displays the battery voltage, ensuring the power supply is within operational limits. Ammeters measure the current drawn by both the main motor and the yellow gear DC motors, helping users analyze power consumption under different conditions. Additionally, the system features two critical switches: one activates or deactivates the PWM compensation logic, allowing the Arduino to adjust speed based on feedback, while the other serves as a main power switch for the motor. These components not only facilitate precise control over the simulation but also enable detailed analysis of motor performance under varying loads and power conditions, making the setup an effective tool for testing motor control strategies.

VII. RESULTS

The implementation of the BMS using the ESP32 micro-controller demonstrated significant improvements in monitoring and managing battery performance for EV. The system was able to accurately track key parameters such as voltage, current, SoC and SoH in real-time. The use of PWM techniques effectively regulated the charging and discharging processes, minimizing energy losses and preventing overcharging or deep discharge scenarios. This approach not only enhanced the efficiency of energy utilization but also contributed to extending the overall lifespan of the battery pack. The data collected by the ESP32 was successfully transmitted to a cloud-based platform, allowing for remote monitoring and analysis. Advanced algorithms for SoC and SoH estimation proved to be effective, providing precise information that enabled balanced charging across individual cells. The protective mechanisms integrated into the system, including safeguards against over-voltage, under-voltage, and over-current, performed reliably during testing, ensuring the safety and stability of the battery pack under various operational conditions.

ISSN No:-2456-2165
https://doi.org/10.38124/ijisrt/25apr157

(a)



(b)

Fig 3 Simulation Waveform

The graphs presented in fig.3. show a series of stepwise decreases in the measured parameter, starting from a stable baseline near 70 and progressively dropping to lower levels. The first graph exhibits a more irregular pattern in the descent, with multiple small oscillations and fluctuations, suggesting intermittent disturbances or adjustments. This pattern might indicate a system responding to incremental changes or facing intermittent disruptions. The stepwise nature of the graph implies discrete events causing the drops rather than a continuous decline. In contrast, the second graph shows a smoother transition between levels, with fewer oscillations compared to the first. The stepwise drops are more clearly defined and consistent, suggesting a controlled or less disturbed environment. The lower level, which appears to stabilize briefly before further declines, could indicate stages of equilibrium between each step. The smoothness of the transitions might point to a system that is adjusting more gradually to the changing conditions or inputs. The differences between the graphs could imply variations in the experimental conditions or the system's response to similar stimuli. The irregularities in the first graph might be due to noise, less precise control, or external influences, while the smoother transitions in the second graph suggest a more controlled or stable system. Further analysis would require understanding the specific parameters measured and the experimental context.

VIII. CONCLUSION

In conclusion, the ESP32-based BMS offers a cost-effective, reliable, and efficient solution for managing battery systems in electric vehicles. Its real-time monitoring capabilities, accurate parameter estimation, and comprehensive protection systems position it as a valuable contribution to the field of electric vehicle technology, paving the way for safer and more efficient energy management systems.

FUTURE SCOPE

➢ *Future Scope Regarding the Battery Management System is being Marked in the Following Points as Follows;*

- **Integration of Machine Learning:** Implement machine learning algorithms to predict battery degradation patterns and optimize charging cycles based on real-time data and historical usage trends.
- **Energy Harvesting and Efficiency:** Incorporate renewable energy sources for auxiliary power and optimize hardware and software to reduce power consumption.
- **Compact and Efficient Hardware Design:** Focus on designing smaller, energy-efficient hardware

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25apr157

components to enhance system efficiency and suitability for resource-constrained environments.

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