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Simulation of Battery Management System using MATLAB Simulink

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***Abstract* - A Battery Management System (BMS) is a critical component for ensuring the safe and efficient operation of battery packs in electric vehicles and energy storage systems. This paper presents the design and simulation of a BMS using MATLAB/Simulink. The developed model incorporates key functions such as State of Charge (SOC) estimation, State of Health (SOH) estimation, and protection mechanisms against over-voltage, under-voltage, and over-current conditions. A basic cell balancing technique is also implemented to maintain uniform voltage across battery cells. The system is modeled using interconnected functional blocks in MATLAB/Simulink, with signal logging used to monitor parameters such as SOC, SOH, voltage, and current. Simulation results demonstrate the effectiveness of the proposed BMS in enhancing battery safety, performance, and reliability. The study highlights the importance of simulation tools in the development and validation of battery management systems.**

Keywords : Battery Management System, Electric Vehicle, MATALAB, Simulink.

I. INTRODUCTION

In recent years, the demand for efficient and reliable energy storage systems has increased due to the rapid growth of electric vehicles (EVs), hybrid electric vehicles (HEVs), and renewable energy applications. Among various energy storage technologies, lithium-ion (Li-ion) batteries are widely used because of their high energy density, high power capability, low self-discharge rate, and long cycle life.

However, Li-ion batteries are highly sensitive to operating conditions such as voltage, current, and temperature. Improper operation, including overcharging, deep discharging, and extreme temperature exposure, can lead to reduced performance, shortened lifespan, and safety risks. In practical applications, battery packs consist of multiple cells connected in series and parallel configurations, where variations among cells may cause imbalance, affecting overall efficiency and reliability.

To overcome these challenges, a Battery Management System (BMS) is employed to monitor and control battery operation. The BMS performs essential functions such as voltage and current monitoring, State of Charge (SOC) estimation, State of Health (SOH) estimation, fault detection, and cell balancing, thereby ensuring safe and efficient battery performance.

This paper presents the design and simulation of a Battery Management System using MATLAB/Simulink. The proposed model demonstrates key BMS functionalities, including monitoring, protection, and state estimation, to analyse battery behaviour under different operating conditions. The next section presents the literature review on the BMS.

II. LITERATURE REVIEW

Several researchers have contributed to the development and simulation of Battery Management Systems (BMS) using MATLAB/Simulink, focusing on improving battery performance, safety, and reliability.

A Verma and D. K. Joshi (2024) proposed a non-linear BMS model for lithium-ion batteries using MATLAB simulation. Their model captures the nonlinear characteristics of batteries during charging and discharging by incorporating parameters such as internal resistance, voltage variation, and temperature effects. The results showed improved accuracy in State of Charge (SOC) estimation and enhanced reliability of battery monitoring systems.

S. Kumar and V. Sindhu (2023) developed a MATLAB/Simulink-based model to analyze lithium-ion battery charging, discharging, and SOC estimation. Their work demonstrated the effectiveness of simulation tools in evaluating battery performance under varying load conditions, contributing to better battery monitoring strategies in electric vehicles and renewable energy systems.

K. Vijith, R. Rajesh, and P. Nair (2022) presented a simulation-based BMS architecture for electric vehicles. Their model focused on monitoring key parameters such as voltage, current, temperature, and SOC, along with protection mechanisms against overcharging, deep discharging, and overheating. The study concluded that an efficient BMS significantly enhances battery safety, lifespan, and overall system performance.

J. Zhang, L. Wang, and H. Li (2024) reviewed recent advancements in BMS using MATLAB-based simulation techniques. Their study covered important functions such as SOC estimation, State of Health (SOH) prediction, cell balancing, and thermal management. The authors emphasized that simulation-based design reduces development cost and improves system reliability.

MathWorks (2023) provided an application note on BMS modeling and simulation using MATLAB/Simulink. The document highlighted the capability of MATLAB tools in

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designing battery models, SOC estimation algorithms, and thermal management systems. It also demonstrated how simulation helps evaluate various operating conditions, including fault scenarios, making it a powerful tool for rapid prototyping and validation.

R. S. Kumar and P. Sharma (2020) designed and simulated a BMS using MATLAB/Simulink with features such as voltage monitoring, SOC estimation, and cell balancing. Their results indicated that simulation-based BMS effectively protects battery packs and improves operational efficiency.

M. Chen and G. Rincon-Mora (2006) introduced an accurate electrical battery model based on an equivalent circuit approach. Their model includes parameters such as open-circuit voltage, internal resistance, and transient response, providing a strong foundation for modern battery modeling and simulation techniques used in BMS development.

The extensive research in BMS using non-linear models for monitoring the performance of battery in EVs. There was research gap in using simulation of Battery Management System using MATLAB Simulink. Hence the methodology of BMS presented in next section.

III. PROPOSED METHODOLOGY OF BMS

A. System Overview

The proposed Battery Management System (BMS) is designed to monitor, control, and protect a lithium-ion battery pack using MATLAB/Simulink. The system consists of multiple functional blocks including the battery pack, measurement unit, estimation modules, protection system, and output visualization. These components are interconnected through signal lines to ensure proper flow of information and real-time processing of battery parameters as shown in **Fig. 1**.

B. Simulink Model Implementation

The Battery Management System (BMS) is implemented using MATLAB Simulink, where each block performs a specific function for monitoring and protecting a lithium-ion battery pack used in electric vehicles.

The model includes key components such as the battery pack, voltage and current sensors, protection block, State of Charge (SOC) estimator, State of Health (SOH) estimator, and cell balancing block. A 4-series (4S) battery pack is used as the energy source, with sensors continuously measuring voltage and current.

The protection block ensures safety by detecting over-voltage, under-voltage, and over-current conditions. If limits are exceeded, a fault signal is generated. SOC is estimated using the coulomb counting method, SOH is determined based on capacity comparison, and cell balancing maintains equal voltage across all cells by correcting voltage differences.

All the blocks are connected using signal lines to ensure proper flow of data throughout the system. Additionally, signal logging is enabled to capture important outputs such as SOC, voltage, and current for analysis. The complete Simulink model allows real-time simulation and analysis of battery behavior under different operating conditions.

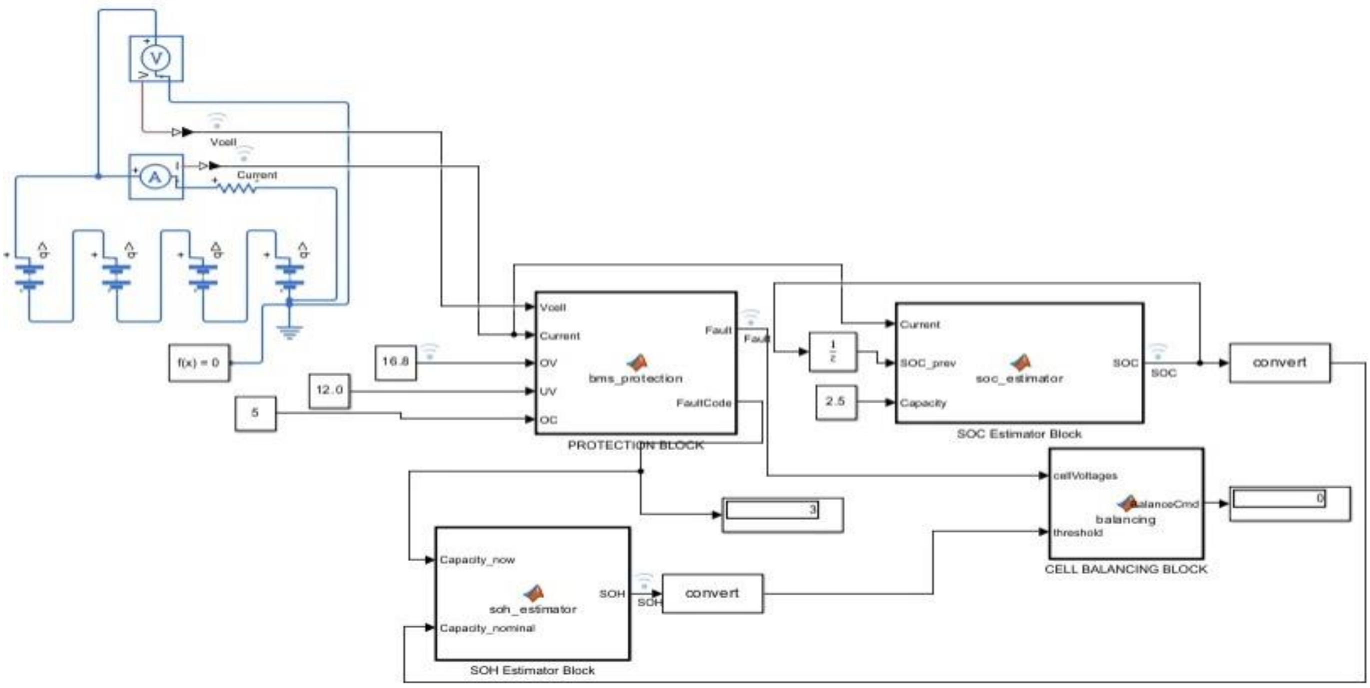

Fig.1 Simulink Model of Proposed BMS

The simulation model enables real-time analysis of battery behaviour under different operating conditions. Signal logging were incorporated to store system outputs for further analysis using MATLAB.

C. Working Principle

The working of the proposed BMS, based on continuous monitoring and processing of battery parameters. The battery pack supplies energy, and the voltage and current measured

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using sensors. These signals were provided to the protection block, which checks for abnormal conditions such as over-voltage, under-voltage, and over-current. If any fault condition was detected, the system generates a fault signal.

Simultaneously, the State of Charge (SOC) estimated using the coulomb counting method, which calculates the remaining battery charge based on current flow. The State of Health (SOH) was determined by comparing the available battery capacity with the nominal capacity. The cell balancing block ensures uniform voltage distribution across cells by generating balancing commands when voltage differences exceed a predefined threshold.

All the output parameters, including SOC, SOH, voltage, current, and fault status were displayed and logged for analysis.

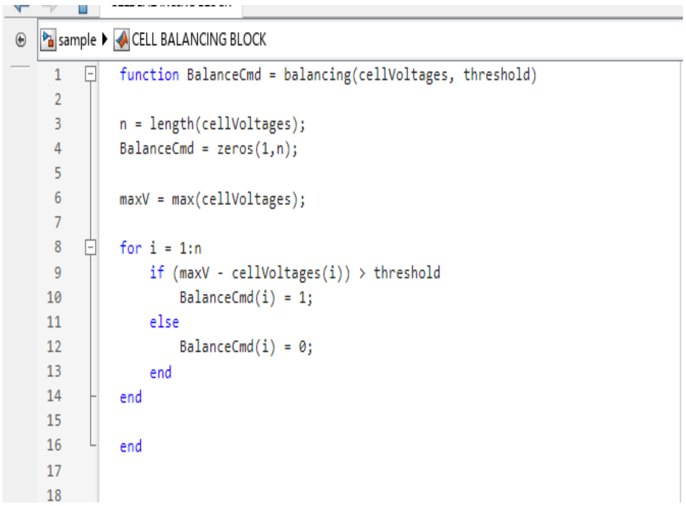
D. Functional Blocks Description

The major functional blocks of the proposed system are described as follows:

- **Battery Pack:** Represents multiple lithium-ion cells connected in series and/or parallel configuration to provide the required voltage and capacity.
- **Measurement Unit:** Measures battery voltage, current and provides input signals for further processing.
- **Protection Block:** Detects unsafe operating conditions such as over-voltage, under-voltage, and over-current, and generates fault signals.
- **SOC Estimator:** Calculates the remaining charge of the battery using current integration (coulomb counting method).
- **SOH Estimator:** Determines battery health based on capacity degradation.
- **Cell Balancing Block:** Maintains equal voltage across all cells to improve battery efficiency and lifespan.
- **Display and Logging:** Displays system outputs and stores signals for graphical analysis in MATLAB.

E. Cell Balancing Algorithm Implementation

The cell balancing function is implemented using a MATLAB function block in the Simulink model. The algorithm compares individual cell voltages with the maximum cell voltage and generates a balancing command based on a predefined threshold value.
If the voltage difference between a cell and the maximum voltage exceeds the threshold, the balancing command for that cell is activated. Otherwise, no balancing action is performed. This helps in maintaining uniform voltage across all cells and improves battery life and efficiency.




```
function BalanceCmd = balancing(cellVoltages, threshold)

n = length(cellVoltages);
BalanceCmd = zeros(1,n);

maxV = max(cellVoltages);

for i = 1:n
    if (maxV - cellVoltages(i)) > threshold
        BalanceCmd(i) = 1;
    else
        BalanceCmd(i) = 0;
    end
end

end
```

Fig. 2 MATLAB Function for Cell Balancing Algorithm

F. Data Logging and Analysis

Signal logging is enabled in the Simulink model to capture important parameters such as SOC, SOH, voltage, and current. These signals are exported to the MATLAB workspace and plotted to analyse system performance over time. The graphical results help in validating the effectiveness of the proposed BMS under different operating conditions. Next section presents the discussion on the results obtained.

IV. RESULTS AND DISCUSSION

The proposed Battery Management System (BMS) model was simulated using MATLAB Simulink to evaluate its performance under different operating conditions. Key parameters such as State of Charge (SOC) and battery voltage were continuously monitored and analyzed. In addition, various parameters of the battery pack, including current and temperature, were constantly monitored to ensure safe and efficient operation. The system response during fault conditions like over-voltage and over-current was also observed to verify the effectiveness of the protection circuit. Furthermore, output graphs can be generated as per requirement, which helps in analyzing and evaluating the performance of the battery under different operating conditions.

The variation of SOC with respect to time shown in **Fig. 3 predicts that** the SOC decreases gradually during the discharge process, indicating correct implementation of the coulomb counting method. The smooth decline in SOC confirms stable battery operation and proper estimation of remaining charge.

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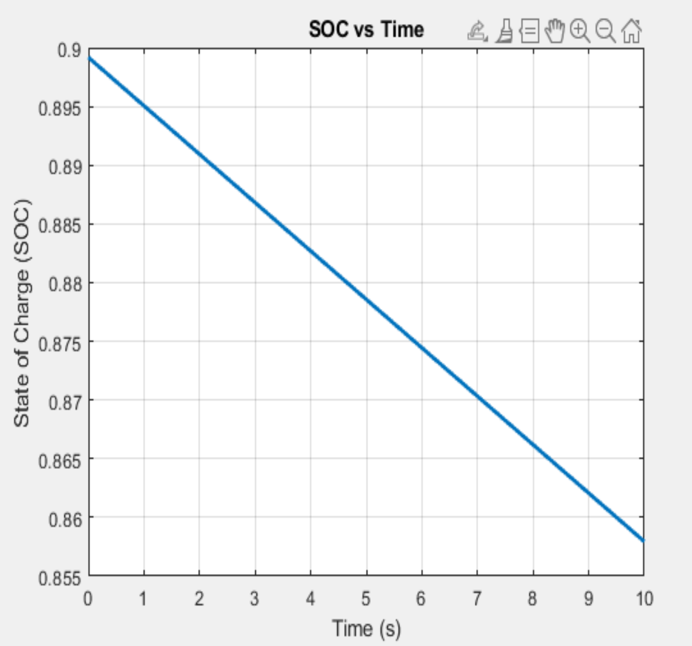

Fig. 3 SOC vs Time (Graph)

The battery voltage variation with time is illustrated in **Fig. 4**. The voltage remains within safe operating limits and follows expected discharge characteristics. This indicates that the battery model and measurement system are functioning correctly

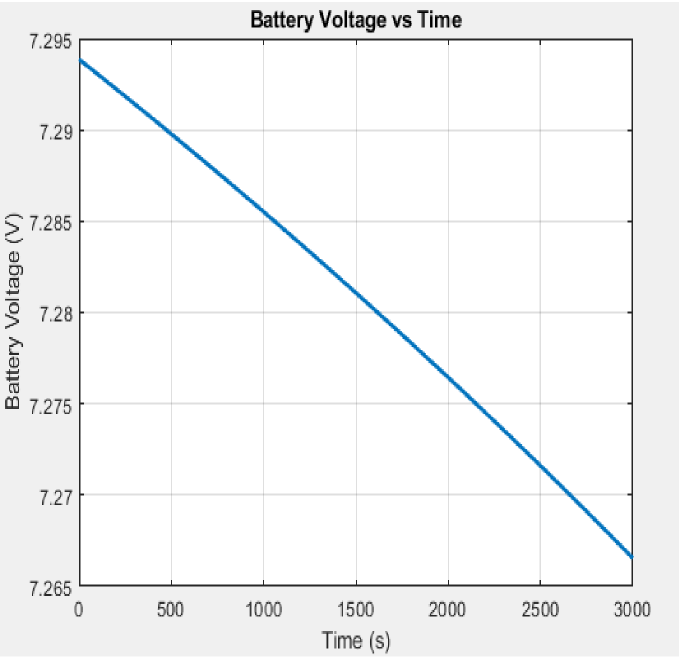

Fig. 4 Battery Voltage vs Time (Graph)

The results demonstrate that the proposed BMS model effectively monitors battery parameters and ensures reliable performance. The system provides accurate estimation and stable operation under simulated conditions. Next section presents the conclusion with future scope in research.

V. CONCLUSION AND FUTURE WORK

This paper presented the design and simulation of a Battery Management System (BMS) using MATLAB/Simulink. The developed model integrates essential BMS functionalities, including voltage and current monitoring, protection mechanisms, State of Charge (SOC) estimation, State of Health (SOH) estimation, and cell balancing.

The protection module effectively identifies abnormal operating conditions such as over-voltage, under-voltage, and over-current, ensuring safe battery operation. SOC estimation is performed using the coulomb counting method, providing continuous tracking of battery charge, while SOH estimation evaluates battery health based on capacity degradation. Additionally, the cell balancing mechanism maintains uniform voltage distribution among cells, thereby improving battery performance and lifespan.

Simulation results obtained through signal logging and MATLAB-based graphical analysis demonstrate the effectiveness of the proposed system in monitoring battery parameters and ensuring reliable operation. The developed model successfully validates the basic working principles of a Battery Management System.

Overall, the proposed simulation provides a simple and effective approach for understanding and analyzing BMS functionalities. The model can be further extended by incorporating advanced estimation techniques, thermal management, and real-time implementation for practical - applications in electric vehicles and energy storage systems.

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