

Simulation of Battery Management System in Heavy Electric Vehicle

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Abstract As the automotive industry shifts toward sustainable transport, the efficiency and safety of Energy Storage Systems (ESS) have become paramount. This paper presents the development of a robust Battery Management System (BMS) designed for a 12-series connected Lithium-ion battery pack. Utilizing the LTC6804-2 multicell battery stack monitor, the system provides precise monitoring of overvoltage, undervoltage, overcurrent, and thermal irregularities. The hardware architecture, designed via Eagle CAD, integrates a PIC microcontroller for data processing and a custom balance board to ensure cell longevity. Preliminary results indicate high reliability in fault detection and cell equalization, addressing the critical requirements of safety and autonomy in modern Electric Vehicles (EVs).

Keywords: BMS, LTC6804-2, PIC Microcontroller, Cell Balancing, LiFePO₄, Electric Vehicles, Thermal Management.

1. INTRODUCTION

The global automotive industry is undergoing a transformative shift toward clean mobility, driven by the urgent need to mitigate carbon emissions and transition to sustainable energy systems. Electric Vehicles (EVs) have emerged as the primary solution in this roadmap. Central to the success of the EV is the battery pack—the most expensive and sensitive component of the drivetrain. While Lithium-ion chemistries such as Lithium Iron Phosphate (LiFePO_4) and Lithium Manganate (LiMn_2O_4) are preferred for their high energy density and efficiency, they are inherently sensitive to electrical, thermal, and mechanical stresses.

The operational integrity of these cells depends entirely on the Battery Management System (BMS). A BMS is an electronic control unit designed to ensure that each cell in a multi-cell pack operates within its Safe Operating Area (SOA). Without precise management, Lithium-ion batteries are vulnerable to overcharging, deep discharge, and thermal runaway—conditions that not only cause

irreversible capacity loss but also pose significant safety risks, including fire and explosion.

Beyond basic protection, a sophisticated BMS optimizes performance by managing charging cycles and performing cell balancing. In high-power applications, such as those involving fast charging and regenerative braking, the BMS must communicate seamlessly with motor controllers and cooling systems. Research indicates that a well-engineered BMS can extend the functional lifespan of a battery pack by 20% to 40%, making it an indispensable technology for the economic and technical viability of electric transportation.

This paper details the design and implementation of a modular BMS prototype developed for a 12-cell series-connected battery pack. The project utilizes the LTC6804-2 multicell battery stack monitor in conjunction with a PIC Microcontroller to provide a robust monitoring and protection framework. By integrating custom-designed balance boards and a centralized control circuit via Eagle CAD, this research provides an educational and functional prototype for real-time monitoring of voltage, current, and temperature. The system aims to demonstrate how precise hardware-software integration can enhance the durability and safety of the energy storage systems shaping the future of clean mobility.

2. Body of Paper

2.1 Methodology

A battery management system directly influences the safety, System Definition and Requirement Analysis Cell Characterization: Select chemistry (LFP is common for heavy duty due to cycle life). BMS Functions: Define which functions to simulate (SOC estimation, SOH monitoring, cell balancing, thermal management).

2. Plant Model Development (The Battery Pack). The "Plant" is the physical system the BMS controls. In heavy vehicles, you need high-fidelity models. Equivalent Circuit Model (ECM). Use a 2RC or 3RC (Resistor-Capacitor) network to represent the cell's dynamic behaviour. $V_t =$

$V_{oc}(SOC) = I R_0 - V_1 - V_2$ Where V_{oc} is the open-circuit voltage and R_0 is internal resistance.

Thermal Model Heavy vehicles generate significant heat. Implement a lumped-parameter thermal model to simulate temperature distribution across the pack.

3. BMS Control Logic Design This is the "brain" of your simulation. It is typically divided into three main algorithms: State of Charge (SOC) Estimation: Use an Extended Kalman Filter (EKF) or Unscented Kalman Filter (UKF). These are superior to simple Coulomb counting for heavy vehicles because they account for sensor noise and voltage fluctuations under high loads.

Cell Balancing: Simulate passive (resistive) or active (inductive/capacitive) balancing. For heavy vehicles, active balancing is often studied to reduce energy waste across large packs. Fault Detection: Implement logic for over-voltage, under-voltage, and over-temperature protection.

4. Driving Cycle Integration To validate the simulation, you must apply a realistic load. Standard light-vehicle cycles (like WLTP) aren't sufficient. Use WHVC (World Harmonized Vehicle Cycle): Specifically for heavy-duty vehicles. Custom Grade Cycles: Simulate uphill/downhill towing to test thermal limits and regenerative braking limits.

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2.2 Working of Battery Management System

The primary functions of a battery management system are monitoring, state estimation, cell balancing, power management, thermal management, protection, and communications.



The primary functions of a battery management system. Monitoring

A battery management system monitors voltage, current, and temperature to ensure the battery operates within its safe operating area.

State Estimation

One major function of a battery management system is state estimation, including state of charge (SOC), state of health (SOH), state of energy (SOE), and state of power (SOP) estimation. SOC is a normalized quantity that indicates how much charge is left in the battery, defined as the ratio between the maximum amount of charge extractable from the cell at a specific point in time and the total capacity. Methods to estimate SOC range from simple current integration (Coulomb counting) and voltage monitoring to sophisticated model-based and data-driven methods such as Kalman filters and neural networks.

SOH refers to the battery's overall health condition (internal resistance and capacity) relative to its

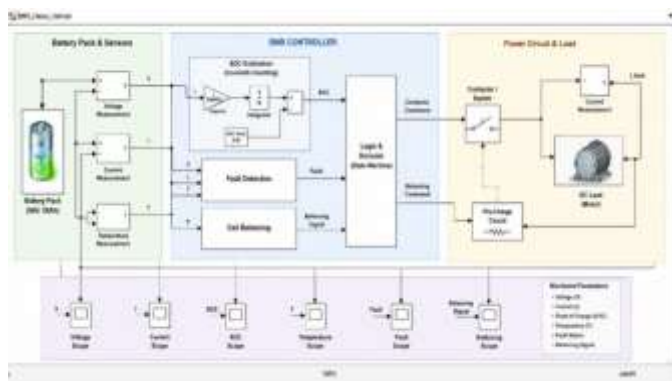
performance at the beginning of life (BOL). The SOH definition is more subjective than the SOC definition; there is no universal agreement on how SOH is to be defined. Because SOH can be defined based on capacity or internal resistance, each organization may have its own specific method for quantifying an SOH estimate in the battery management system, making it less desirable to create a general-purpose, off-the-shelf solution. Using Simscape Battery™, you can develop and simulate custom SOH estimation algorithms in your battery management system implementation that are in line with your organization's specific interpretation of battery health.

Cell Balancing

Over time, individual cells within a battery pack may exhibit different charge levels due to variations in manufacturing, usage, or temperature conditions. A battery management system balances the charge across cells to ensure they all have the same charge level, thereby maximizing the battery's capacity and lifespan. Two common approaches for cell balancing are passive balancing and active balancing.

Passive Balancing

A battery management system drains charge from high-SOC cells using bleeding resistors. In this case, energy is dissipated as heat. Simscape Battery allows you to have both a built-in passive balancing circuit in the battery pack and an external balancing strategy in the battery management system.



Modelling a passive cell balancing circuit in a battery management system using the Pack object in Simscape Battery. (See example.)

You can plot the resulting SOC of two cells connected in series using a passive balancing algorithm.

State of charge for two cells connected in series using a passive balancing algorithm. (See Simscape Battery example.)

Simscape Battery enables you to test your passive cell balancing algorithms in the battery management system

on a battery emulation hardware-in-the-loop (HIL) system using the Passive Balancing Interface block.

The Passive Balancing Interface block used for battery management system HIL testing.

Active Balancing

A battery management system moves charge from high-SOC cells to low-SOC cells using devices such as capacitors and inductors. In this case, energy is moved around within different cells inside the battery pack.

Model of the switched capacitor method for balancing battery cells. (See Simscape Battery example.)

Power Management

A battery management system oversees and controls the power flow to and from a battery pack. During charging, the BMS prevents overcurrent and overvoltage. The constant-current, constant-voltage (CC-CV) algorithm is a common battery charging approach used in a battery management system. During the constant-current charging phase, the charging current is held constant and the battery voltage gradually increases. During the constant-voltage charging phase, the charging voltage is held constant and the battery current gradually decays.

Operation of the constant-current and constant-voltage charging modes in a battery management system. (See Simscape Battery example.)

Thermal Management

Controlling temperature is crucial in batteries because high temperatures significantly decrease battery life and low temperatures lower the usable capacity and energy as well as affect how fast batteries can be charged. It is important for a battery management system to activate heaters or coolers to keep the temperature within safe limits. With Simscape Battery, you can model a charging and discharging cycle on a battery module assembly while monitoring the cell temperature and enabling cooling.

Battery management system model showing charge and discharge battery module assembly with a Battery Coolant Control block. (See Simscape Battery example.)

The battery cells start at different temperatures, and the Battery Coolant Control block monitors the cell temperature and starts cooling the module assembly if the battery cells surpass a limit temperature. When the cell temperature goes below a threshold, the Battery Coolant Control block deactivates the coolant flow.

Temperature of cells inside the module assembly being regulated using the built-in Battery Coolant Control block.

With Simscape Battery, you can use built-in blocks to build battery thermal management control algorithms, such as battery coolant control and battery heater control. Protection

A battery management system provides safeguards against conditions that can harm the battery, such as overcharging, overdischarging, overcurrent, and overtemperature. Avoiding these conditions is crucial for preventing damage to the battery cells and ensuring user safety.

Simscape Battery provides several built-in battery protection algorithms for battery management system design:

- Battery Cell Contact Monitoring: Monitor for battery cell contact
- Battery Current Monitoring: Monitor for battery current
- Battery Temperature Monitoring: Monitor for battery temperature
- Battery Voltage Monitoring: Monitor for battery voltage
- Fault Qualification: Fault qualification algorithm

You can use a Battery Cell Contact Monitoring block in your battery management system to detect a disconnected cell based on the parallel assembly voltage.

Detecting a disconnected cell (parallel assembly #

1) using a Battery Cell Contact Monitoring block. (See Simscape Battery example.)

You can use built-in protection blocks in your battery management system to monitor the current and temperature of a battery for under temperature and overtemperature errors and overcurrent error (see Simscape Battery example).

Communications

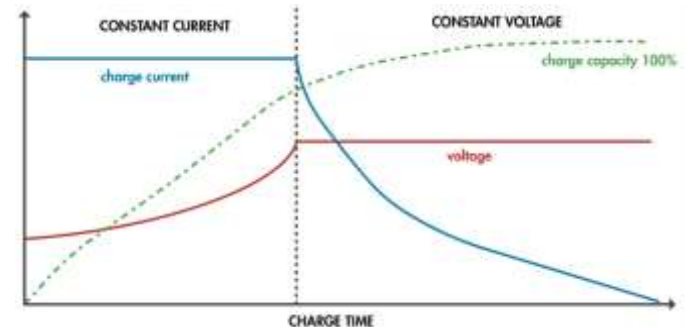
A battery management system communicates with external devices or systems, providing real-time information about the battery's status and receiving instructions for energy management.

By performing the primary functions above, a well-designed battery management system ensures maximum performance, safe operation, and optimal lifespan under diverse charge-discharge and environmental conditions.

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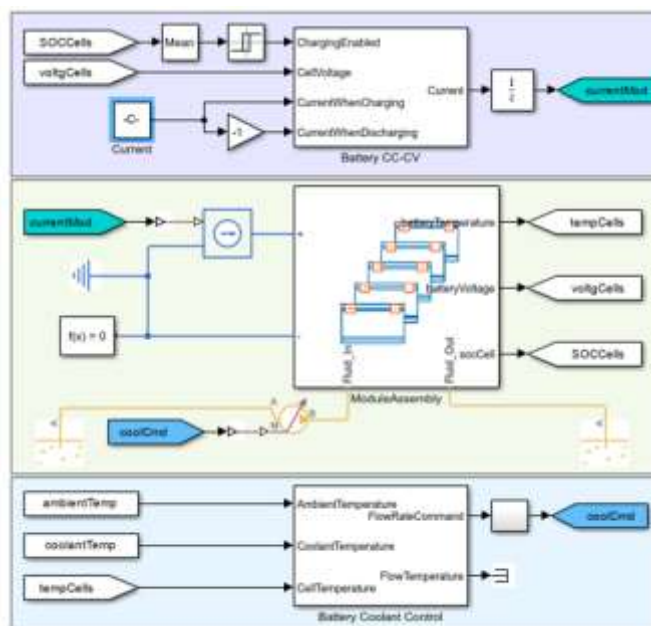


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In a BMS, thermal management is responsible for maintaining the battery pack within its safe operating temperature range, typically between 20 °C and 40 °C. This is achieved through a combination of temperature sensing, cooling, heating, and intelligent control algorithms. Sensors embedded at the cell and module levels continuously monitor temperature to detect hotspots or uneven thermal distribution. Cooling systems—either air-based, liquid-based, or hybrid—are activated when cells exceed threshold limits, with liquid cooling being the most effective for heavy-duty EV applications due to its higher heat transfer efficiency. In colder climates, heating elements such as resistive heaters or PTC devices are used to prevent lithium plating and ensure efficient charging. Control algorithms, often modelled in MATLAB/Simulink, regulate these thermal systems using hysteresis logic and predictive strategies, balancing energy consumption with safety. Advanced approaches also integrate phase-change materials (PCM) for passive heat absorption during peak loads, or hybrid cooling (liquid + PCM) to handle both steady-state and transient conditions. Importantly, thermal management is

not isolated—it works in tandem with SOC/SOH estimation and protection circuits, shutting down charging or discharging if overheating persists. Simulation environments allow engineers to test these strategies virtually, coupling electrical and thermal models to predict pack behaviour under stress, before validating them through Hardware-in-the-Loop (HIL) testing. Literature emphasizes that thermal imbalance between cells accelerates aging, so uniform temperature distribution is as vital as absolute temperature control. Overall, effective thermal management ensures safety, extends battery life, and supports reliable EV operation under diverse environmental conditions.



2.3 Advantages

- Enhanced Battery Safety
- Extended Battery Life
- Improved Reliability and Performance
- Efficient Energy Management
- Predictive Maintenance Capabilities
- Remote Monitoring and Data Logging
- Supports Fast Charging and Heavy Duty Operations
- Scalability and Modularity
- Cost Savings over Time

3. CONCLUSIONS

The project successfully developed a MATLAB/Simulink-based Battery Management System for electric vehicles. It effectively monitors battery parameters like voltage, current, temperature,

SOC, and SOH, ensuring safe and reliable operation. The simulation demonstrates battery protection, fault detection, and performance monitoring without hardware complexity. This model serves as a strong foundation for learning and future enhancements. With features like hardware implementation, CAN communication, and advanced algorithms, the system can be extended for real-time EV applications, improving battery efficiency and lifespan.

ACKNOWLEDGEMENT

The authors would like to acknowledge the guidance and support provided by faculty members and collaborators who contributed to the development of the simulation of battery management system in heavy electric vehicle.

Reference

1. Pragya Raghav & Khalil Ur Rehman, "A review of Battery Management System for EV: Estimation and Types," *IJIREEICE*, 2025.
2. M. T. M. N. et al., "Evaluation of Battery Management Systems for Electric Vehicles Using Traditional and Modern Estimation Methods," *MDPI*, 2025.
3. Yuan Xueqing et al., "Battery Management System for Electric Vehicle and the Study of SOC Estimation," *AASRI Conference*, 2015.
4. Ming Jiang et al., "Advances in Battery State Estimation of Battery Management System in Electric Vehicles," *Journal of Power Sources*, 2024..
5. A Systematic Literature Review of State of Health and State of Charge Estimation Methods for Batteries Used in Electric Vehicle Applications," *MDPI World Elect. Veh. J.*, 2023.