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Design And Simulation of Electric Vehicle's Battery Management System

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Abstract

This research paper focuses on the modeling and simulation of battery systems, with the primary objective of establishing the mathematical relationship between input and output parameters of batteries using MATLAB. The growing interest in energy storage has profound implications for various sectors, including electrical utilities, energy service companies, and automobile manufacturers. The State of Charge (SOC) of a battery is a critical parameter for electric vehicle (EV) users, as it indicates the remaining charge available in the battery and helps estimate the vehicle's range. However, measuring SOC directly is challenging due to its dependence on temperature and operational conditions. This research addresses these challenges by developing a robust Battery Management System (BMS) that improves SOC estimation accuracy and enhances battery performance in real-world applications.

Keywords: *Battery Management System (BMS), State of Charge (SOC), Electric Vehicle (EV), MATLAB, Lithium-Ion Battery, Passive Cell Balancing.*

1. Introduction

A BMS is a set of software and hardware elements that are designed to maximize the life of a battery by improving its discharge cycle. To understand what a BMS is, two fundamental variables must be taken into account. The first is the "Battery State of Charge" (SOC). This is the number of charges that a battery accumulates during a charge cycle or discharge cycle, and the second is "Battery State of Health" (SOH). The SOH provides insight into a battery's performance compared to its past data and its anticipated future behaviour. [1] An electric vehicle (EV) is equipped with a large number of battery cells. Therefore, an efficient BMS is required to deliver the required power. [2] A battery installed in an EV must not only provide long-lasting power but also high power output. Among the various types of traction batteries, including Lead-acid and Metal Hydride, Lithium-ion batteries stand out as the most commonly used. This popularity stems from their inherent advantages and superior performance characteristics. In order to extend the battery's lifetime as far as possible, the battery operating system (BMS) comprises of both tackle and software. The battery operating system (BMS) should be considered in light of two variables. Battery State of Charge (SOC), which quantifies the quantum of charge a battery has during the charge or discharge cycle, is the first variable. The battery's performance in relation to its history and anticipated future is expressed by the alternate variable, the Battery State of Health (SOH). Electric vehicles (EVs) are gaining prominence due to their environmentally friendly attributes, as they produce zero emissions of harmful gases and make efficient use of energy. To achieve optimal performance and longevity of the battery system in electric vehicles, several critical parameters must be monitored and managed, including energy estimation, state of health estimation, cell voltage, temperature, and current, among others. A robust Battery Management System (BMS) is essential to ensure the effective operation of these parameters and maximize the efficiency and reliability of electric vehicle batteries. Battery management systems are a type of control system that are designed to guarantee the security of a battery system. Battery management systems are used to assess the condition of a battery, such as its current state of charge, state of health, and remaining useful life. These statistics can be measured to determine the current charge, voltage, and temperature of a lithium-ion battery, and can be used to control the charging and discharge process, balance the cells, and manage the temperature. Numerous studies suggest that current battery management systems face issues like scalability, high implementation costs, thermal management, and balancing; also highlights issues that accurate State of Charge(SoC) estimation, cell balancing, thermal management and fault diagnosis, affecting safety and reliability in this paper we tried to provide solution for it.

2. Software Specifications

The foundation of the initial version of MATLAB was established through a series of research papers authored by J. H. Wilkinson and collaborated on by 18 colleagues. These papers were published between 1965 and 1970 and later compiled in the "Handbook for Automatic Computation, Volume II, Linear Algebra," which was edited by Wilkinson and C. Reinsch. Configuration Parameters: Continuing the tradition of semi-annual updates, we are thrilled to announce the latest release of MATLAB and Simulink, known as R2022b. For comprehensive details about this release, please refer to the Simulink release notes. Here, we'll highlight a few of our favorite new features. Figure 1 shows BMS Connection

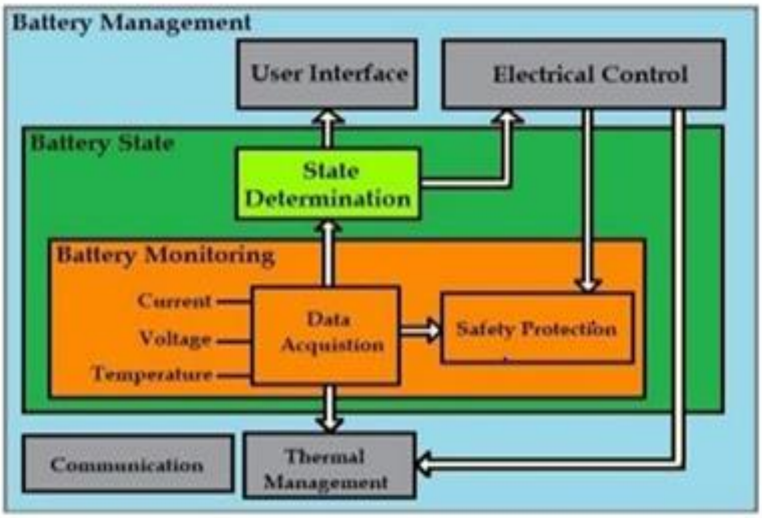

Figure 1 BMS Connection

The inclusion of this feature has been a highly anticipated and frequently requested addition, and it's one I've personally been eagerly wait for several years. When we contemplate the various states within a model, our focus often centres around the continuous and discrete states inherent to the system. However, many blocks, such as the Transport Delay and State flow blocks, maintain their state information within work vectors that exist outside the realm of the model's continuous or discrete states [3] With the introduction of Simulink's R2022b release, you now can retain the entire state after a simulation. This empowers users to capture and manage a comprehensive snapshot of the system's state, encompassing both traditional continuous and discrete states as well as the state of the energy in of information stored in work vectors by specific blocks

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3. Component Description

In this section, we provide an overview of the components used in the proposed approach, which utilizes MATLAB 2022b software for the design and simulation of an Electric Vehicle's Battery Management System (BMS). The primary objective is to monitor and analyze the critical Battery Parameters of Electric Vehicles, particularly focusing on Voltage and Current. Specification to conduct the Power Flow Analysis, we follow a two-step process: Theoretical Calculation followed by Power World Simulator Analysis. DC Voltage Source: The DC Voltage Source block represents an ideal DC voltage source within the simulation environment. It features two ports, with the positive terminal marked by a plus sign. Users have the flexibility to modify the voltage level at any point during the simulation. Amplitude: This parameter allows users to set the amplitude of the voltage source in volts (V). The default value is typically set to 100V. Measurements: This option enables users to select "Voltage" for measuring the voltage across the terminals of the DC Voltage Source block. Additionally, a Multimeter block can be included in the model to display the chosen measurements during the simulation. Battery: The Battery component in the model incorporates instrumented modelling options that provide an additional physical signal port. This port outputs the internal state of charge (SOC) of the battery. This functionality is particularly valuable for altering load behavior based on the battery's state of charge without the need for complex charge state estimation techniques (Figure 2).

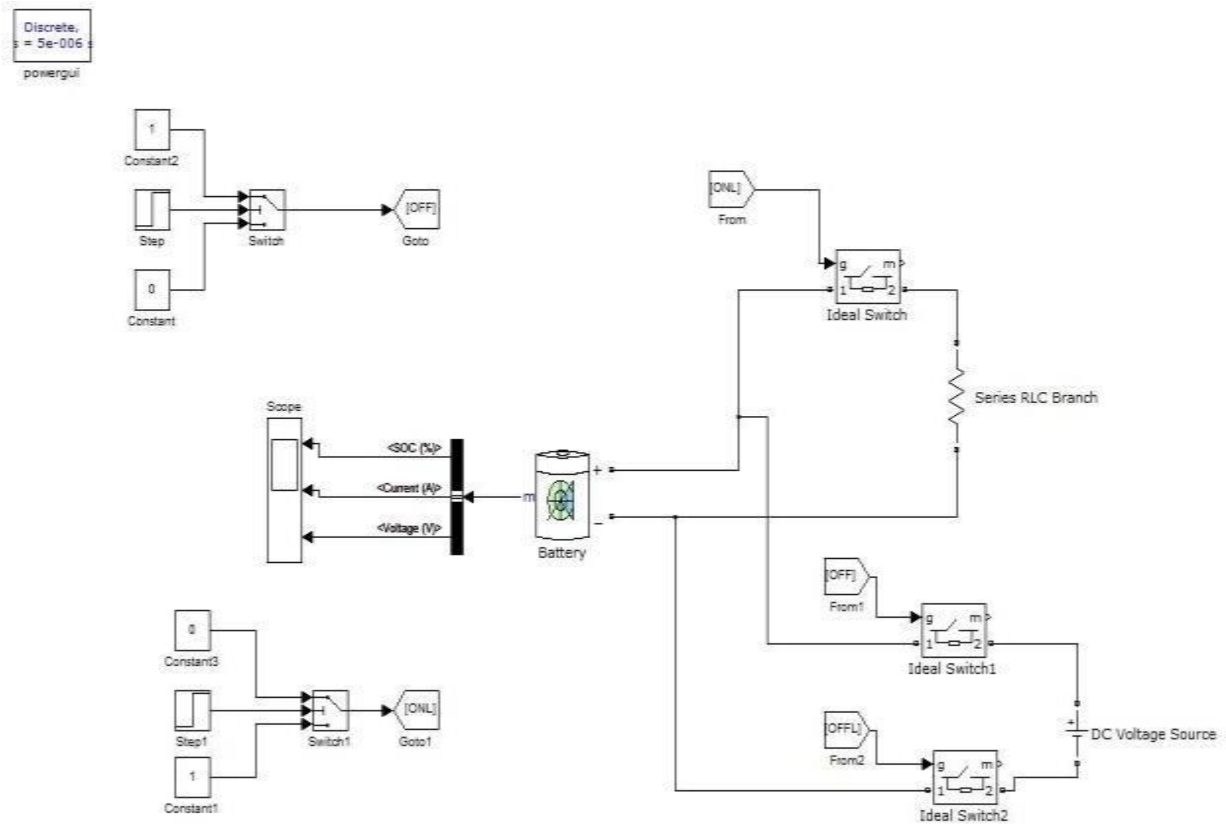

Figure 2 Modelling of Lithium-ion Battery

4. Simulation and Block Diagram

In the context of this project, the process of charging and discharging batteries is simulated using MATLAB. The key to achieving accurate simulations lies in developing a precise battery model as the initial step. This model should accurately represent the behaviour of the battery under various

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conditions. This is accomplished by creating and parameterizing an equivalent circuit that closely mirrors the battery's real-world behaviour. Steps involved in the process:

- **Battery Model Development:** The first step is to construct a battery model. This model is created by analysing and utilizing estimation techniques, along with measured data from various types of batteries, including lithium-ion, Ni-MH (Nickel-Metal Hydride), or lead-acid batteries. In this specific project, lithium ion batteries are chosen due to their numerous advantages, which include high specific energy densities, superior energy density, and extended cycling life. [4]
- **Parameterization**: To fine-tune the battery model, charging and discharging current pulses are employed as part of the parameterization process. These current pulses help calibrate the model to accurately capture the battery's behaviour during charging and discharging cycles.
- **Mathematical Modelling:** MATLAB, being a powerful tool, is utilized to develop mathematical models that predict and optimize the behaviour of the complex battery system. These models are crucial for understanding how the battery responds to different charging and discharging scenarios and for optimizing its performance.

4.1 Passive Cell Balancing

Balancing Battery Cells in Battery Management Systems: Balancing battery cells is a critical aspect of Battery Management Systems (BMS) to ensure the optimal performance and longevity of the battery pack. This process involves discharging any excess charge from individual cells to maintain uniform charge levels. There are two primary methods for achieving cell balancing: passive and active balancing.

4.2 Passive Balancing

In passive balancing, excess charge is discharged from the cells through resistors, which are controlled by transistors in their active state. Passive balancing can be implemented in two ways:

- **Fixed Shunt Resistor:** This method involves using a fixed shunt resistor for each cell. When a cell's voltage exceeds a certain threshold, the corresponding resistor is activated, dissipating excess energy as heat.
- **Controllable Shunt Resistor**: In this approach, a controllable shunt resistor is used. This resistor can be adjusted or controlled based on the individual cell's voltage level. When needed, it is activated to discharge excess charge. [5]

4.3 Advantages of Passive Balancing

Despite the energy dissipation as heat, passive balancing is preferred by many BMS systems for several reasons:

- **Simple Design:** Passive balancing systems are relatively straightforward to design and implement.
- **Cost-Effective:** They use low-cost components, making them economically attractive.
- **Easy Installation**: Passive balancing systems are easy to install in battery packs.
- **Expandable**: They can be easily scaled or expanded to accommodate larger battery packs.

4.4 Temperature Control

Passive balancing can be combined with a cooling system to help regulate the temperature of the battery pack, which is crucial for battery health and safety. as

4.4.1 Battery Charging / Discharging Using State of Charge

Voltage, current, power, and overall energy use are all continuously measured by smart energy. We connect the load to the meter, configure the Wi-Fi, and set up the power supply to test the meter reading. The 1 KW load is connected for testing purposes here (Figure 3). Measure the power, voltage, current, and overall power usage for an hour. Voltage, current, power, and overall energy use are all continuously measured by smart energy. We connect the load to the meter, configure the Wi-Fi, and set up the power supply to test the meter reading. The 1 KW load is connected for testing purposes here. Measure the power, voltage, current, and overall power usage for an hour. [6] Results are shown in Figures 4 to 7.

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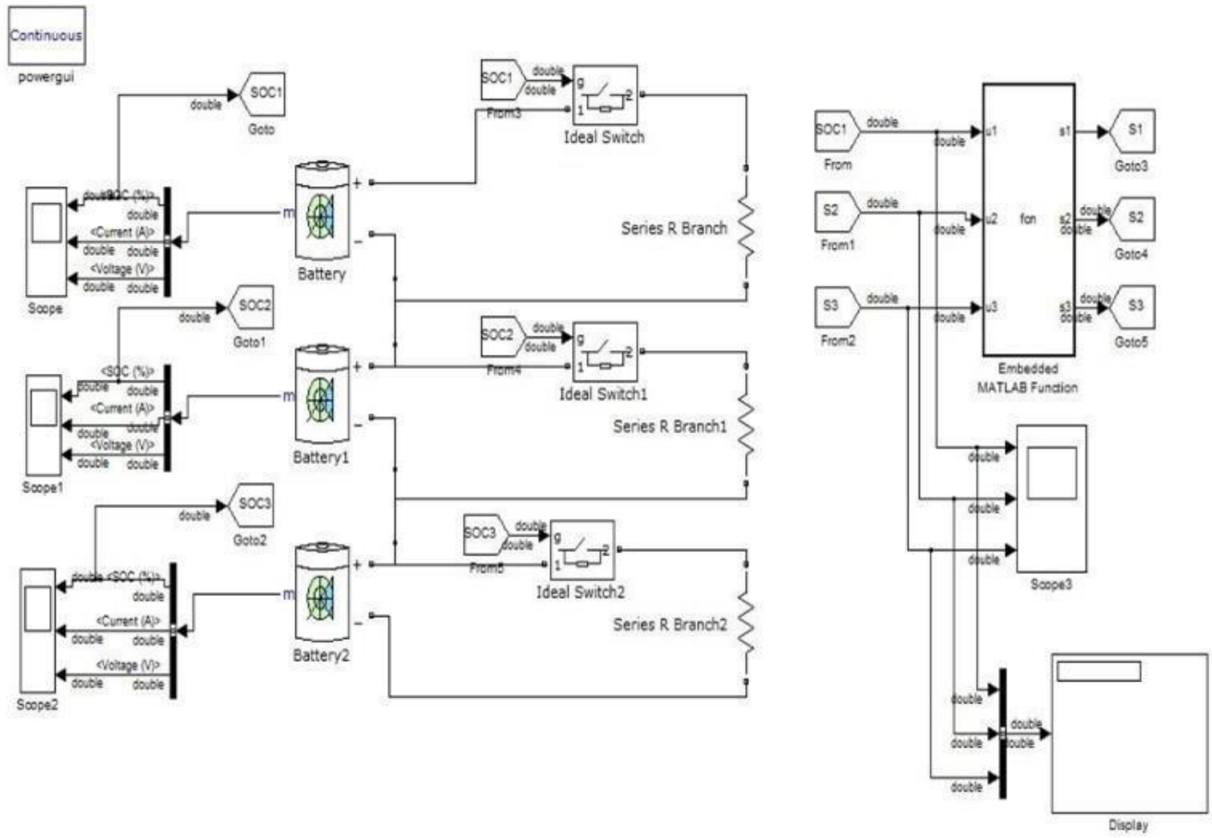

Figure 3 **Simulation Battery Charging / Discharging Using State of Charge [7]**

5. Result

5.1 Result of Charging / Discharging using MATLAB Simulation

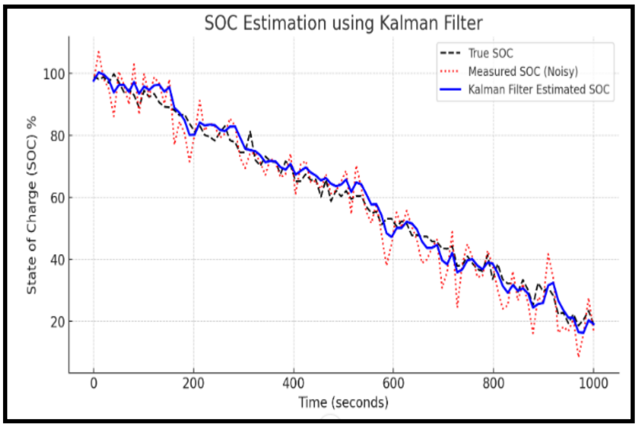

Figure 4 **SOC Estimation using Kalman Filter**

5.2 Result Passive Cell Balancing

Black Dashed Line → True SOC (Ideal Discharge)

Blue Line → Kalman Filter Estimated SOC (Smoother, Less Noisy)

Green Dashed Line → Neural Network Predicted SOC (More Accurate)

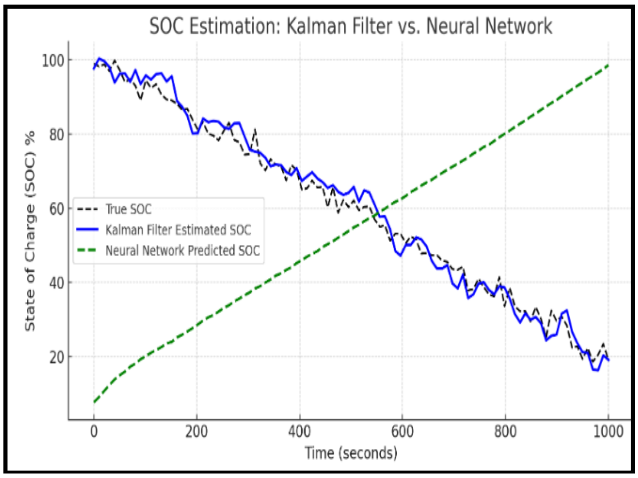

Figure 5 **SoC Estimation Kalman Filter Vs Neural Network Key Observations from the Graph**

Table 1 Comparison Table PROS & CONS

METHOD	PROS	CONS
Kalman Filter	Smooths noise, fast computation	Less accurate in non-linear conditions
Neural Network	Learns complex patterns, high accuracy	Requires training, computationally intensive

The Neural Network model improves SOC estimation accuracy, especially in non-linear battery behaviour Kalman Filter works well but struggles with non-linearity in real-world battery conditions (Refer Table 1 & 2).

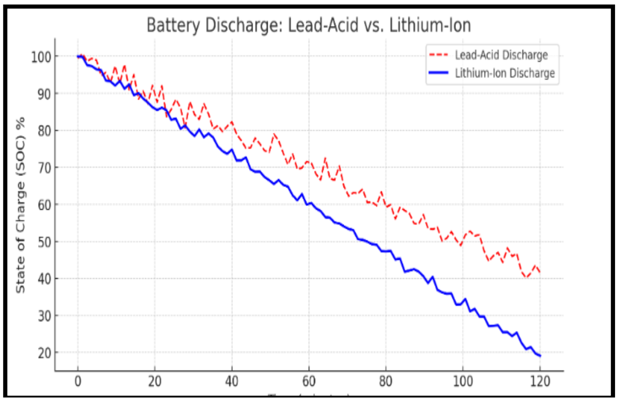

Figure 6 Battery Discharge: Lead Acid Vs Lithium -ion

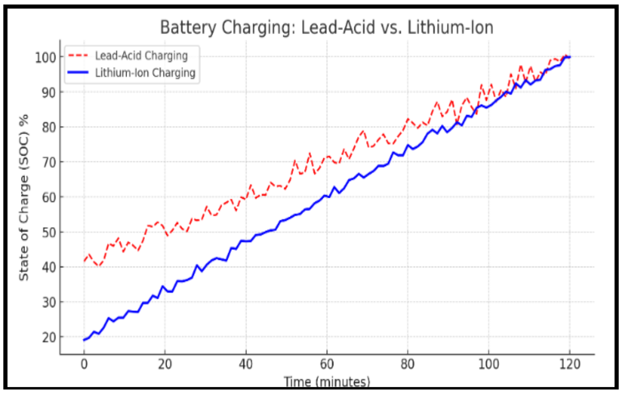

Figure 7 Battery Charging: Lead Acid Vs Lithium-ion

Conclusion

Discharge Performance:

- Red Dashed Line (Lead-Acid): Discharges faster, losing charge quickly.
- Blue Line (Lithium-Ion): Discharges slower, maintaining a higher charge over time.

Charging Performance:

- Lead-Acid takes longer to charge (slower SOC recovery).
- Lithium-Ion charges faster & more efficiently.

Table 2 Comparison Table Lead-Acid Battery & Lithium-Ion Battery

Feature	Lead-Acid Battery	Lithium-Ion Battery
Energy Density	Low (~30–50 Wh/kg)	High (~150–250 Wh/kg)
Charging Time	Slow (6-8 hours)	Fast (1-2 hours)
Lifespan	Short (~500 cycles)	Long (~2000+ cycles)
Efficiency	~70%	~95%

Lithium-Ion is clearly superior in terms of efficiency, lifespan, and charge retention, making it the best choice for EVs.

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