

# MATLAB-Based Simulation and Design of Electric Vehicle Battery Pack: SOC and SOH Estimation

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**Abstract**—This study thoroughly explores the design, modelling, and simulation of battery packs in the context of their critical role in electric vehicles (EVs). The project involved creating a battery model using a 7s2p configuration in Simulink, utilizing a table-based battery approach. Moreover, a thorough battery model was developed with the Battery Builder app in MATLAB to simulate key characteristics. Through graphical simulations, the state of charge (SOC) and state of health (SOH) were analysed across charging and discharging cycles. To guarantee peak performance, various battery pack attributes, including voltage, current, and capacity are calculated. By exploring battery pack design and performance optimization, this research contributes to EV technology advancements.

**Index Terms**— Battery pack design, performance testing, battery pack modelling, SOC, SOH, Simulink, MATLAB.

## I. INTRODUCTION

EVs have become increasingly popular as a sustainable option to traditional gas-powered vehicles [5]. Battery packs, serving as the primary energy storage units, play a key role in determining EV performance through their design, efficiency, and durability. Nonetheless, managing battery packs brings unique obstacles, such as maintaining cell equilibrium to avoid performance decline and ensuring safety by preventing excessive voltage or temperature [9].

Uneven cell balancing results in premature aging, reduced capacity, and shortened lifespans, harming the reliability of electric vehicles. This has led to the critical need for effective modeling and simulation of battery packs in the design of efficient battery management systems (BMS) for electric vehicles. This research uses a table-based battery design in Simulink to simulate the realistic behaviour of a 7s2p battery configuration [14]. Additionally, the MATLAB Battery Builder app is utilized to create detailed battery models for performance evaluation. Using graphical representations, the study analyzes charging and discharging patterns by simulating key parameters like SOC and SOH. Evaluating battery performance and optimizing its design relies on calculations of fundamental parameters such as voltage, current, and capacity. This research explores methods for modeling and testing battery packs, emphasizing the need for precise state of charge (SOC) and state of health (SOH) estimations, along with effective balancing techniques. The results of this study contribute to the ongoing development of EV battery systems, ensuring long-term performance and advancing sustainable transportation technologies [5].

The paper is organized as follows: Section I introduces battery pack importance in EVs and simulation tools. Section II reviews literature on battery modeling and key metrics like SOC and SOH. Section III details the modeling process with Simulink and MATLAB. Section IV covers SOC, SOH, and parameter calculations. Section V presents simulation results and insights. Section VI concludes with findings and future recommendations for EV battery optimization.

## II. LITERATURE REVIEW

The pursuit of improved energy density, efficiency, cost-effectiveness, and safety has driven significant efforts in the academic and industrial communities towards the design and optimization of battery packs for electric vehicles (EVs). This review presents a thorough examination of critical literature concerning the selection of battery chemistry, series-parallel configurations, thermal management, and the performance-influencing factors of battery packs in electric vehicles [1].

Due to their high energy density, light weight, and extended cycle life, lithium-ion (Li-ion) batteries are the dominant battery chemistry used in electric vehicles (EVs).

According to Armand and Tarascon, lithium-ion batteries are considered to stand out as compared to nickel-metal hydride (NiMH) and lead-acid batteries in terms of energy density and efficiency, which is why they play a significant role in increasing the range of electric vehicles. Zhang et al. also pointed out that their ability to charge quickly and retain energy with minimum loss makes them particularly more suited for EVs [8]. Moreover, as these batteries are highly sensitive to temperature and can experience thermal runaway, a well-designed battery management system (BMS) is required for safety [10]. Research by Yoshio et al. tells that the way battery cells are arranged, whether in series or in parallel—significantly impacts both energy storage and power delivery in EVs. Park et al. argue that this configuration should be customized and must be based on the vehicle's specific requirements [12]. Moreover, the lightweight nature and higher charge retention contribute to improving vehicle performance. Additionally, lithium-ion batteries live longer than traditional ones, thereby reducing the long-term maintenance costs and increasing sustainability of the EVs.

Despite the mentioned advantages, lithium-ion batteries are highly sensitive to temperature variations which can lead to safety hazards if not properly worked out. This is why a battery management system (BMS) is required to monitor charge levels, temperature fluctuations, and overall health of the battery. A BMS not only helps to prevent overheating but also optimizes energy distribution across cells, hence improving the overall battery efficiency.

The correct cell configuration helps to ensure that the battery pack can provide a stable energy supply which prevents various performance inconsistencies. A large number of series-connected cells increases the voltage output, ensuring sufficient power for acceleration and operation. Here, parallel connections play an important role in maintaining necessary current levels. The balance between series and parallel arrangements influences factors such as heat generation, charging time, and overall lifespan of the EV battery.

## III. METHODOLOGY

With the growing market of electric vehicles, the need for efficient, and reliable battery packs has become more critical [16]. The direct influence of the overall performance, driving range, and safety of an EV affects its battery pack design. The main aim is to develop and analyze battery packs that optimize factors like voltage, capacity, thermal regulation, etc. and to maintain cost efficiency [7]. This study highlights the ideal series and parallel configuration of lithium-ion cells to mark the required voltage and capacity, map out the charging and discharging characteristics, as well as manage the heat dissipation precisely.

Moreover, to this, the research aims to analyze how different configurations impact the battery pack's energy efficiency and safety. One of the majorly used EV battery pack design consists of 7 cells in series and 2 in parallel (which is a total of 14 cells), configured to balance voltage and the energy requirements of the vehicle [23]. For an instance, the arrangement is selected to ensure a compact, cost-effective, and energy-efficient solution which meets performance expectations. When cells are connected in series, the total battery voltage is the addition of each individual cell voltages. Here, given that a single lithium-ion cell has a nominal voltage of 3.6V, a series connection of 7 cells results in a total output voltage of:

$$V_{\text{total}} = 7 \times 3.6V = 25.2V \quad (1)$$

This voltage works well for powering many lower-to mid-power electric vehicle systems like smaller EVs, electric bikes, or scooters, providing enough power for the motor while not exceeding the requirements of these vehicles. This 25.2V output supplies sufficient voltage for motor operation while remaining compatible with other system elements including controllers and inverters. The battery pack's capacity, influenced by the parallel

configuration, dictates its charge storage ability. The total capacity of a battery pack in a parallel connection increase as the current capacity of each cell is added together. When 2 cells, each with a 3Ah capacity, are connected in parallel, the total capacity becomes:

$$C_{total} = 2 \times 3Ah = 6Ah \quad (2)$$

With a larger capacity, the vehicle can store more energy, increasing its range and allowing for longer journeys between charges. A parallel configuration of two cells delivers sufficient energy to meet standard usage, while keeping the battery pack compact and lightweight [23]. For compact EVs, the 7 series, 2 parallel (14 cells) configuration offers a practical balance of voltage and capacity due to space and weight limitations. While series connections raise the voltage, they do not affect the battery's capacity to store energy. The battery's capacity might be raised by adding greater number of parallel cells, but doing so could make the battery pack bigger, heavier, and more expensive [19]. For mid-range EV applications, this arrangement provides a well-rounded solution by selecting to use two cells in parallel to boost capacity and seven cells in series to get an adequate voltage. Efficiency and cost-effectiveness are crucial factors when selecting the 7 series, 2 parallel arrangement. It has only fourteen cells in total, which reduces manufacturing and material costs.

. This still allows for sufficient voltage and energy to power the vehicle efficiently. It also helps in simplifying the Battery Management System (BMS), which monitors and regulates the battery pack. Managing 14 cells is less complex and less costly than managing larger battery configurations [23]. Overall, the choice of 7 series and 2 parallel cells balances voltage, capacity, energy efficiency, and cost to create a compact and effective battery pack for smaller or medium-sized electric vehicles. It meets the necessary power and energy demands without over-complicating the design or significantly increasing costs.

A battery pack is simulated of 7s2p nominal voltage of 25V and 6A using Simulink. In Simulink, Simscape electrical and Simscape battery is used. A table-based battery is used and chose Panasonic NCR18650BD as the cell [5].

To make the model of the battery pack, the battery builder app of MATLAB is used. First of all, a 3D model of cell Panasonic NCR18650BD is to be created.

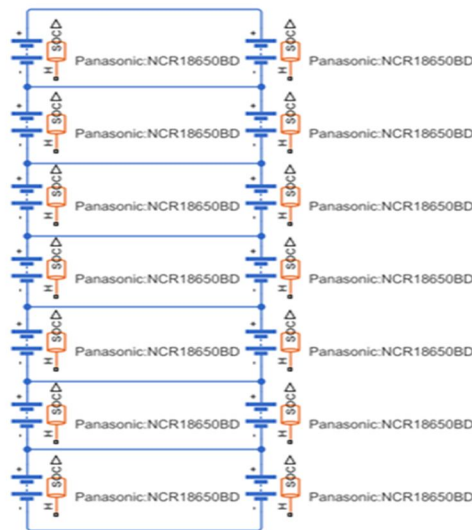


Fig.1 Simulation Diagram of 7S 2P battery Pack using NCR18650BD

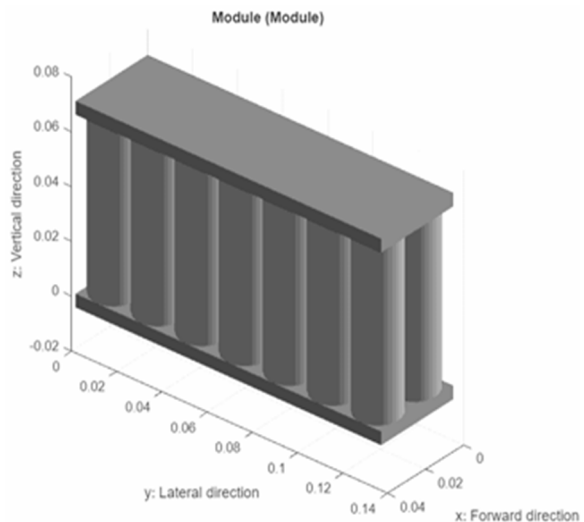


Fig.2 Design Model of 7S 2P Battery pack in Battery Builder App

#### IV. CALCULATION AND RESULTS

1. Max Temperature (before thermal runaway):

$$P_{loss} = I^2 \times R_{total} \quad (3)$$

$$P_{loss} = (16)^2 \times 0.28 = 71.68W$$

$$t \text{ (runtime)} = \text{Current} / \text{Capacity} = 6/16 = 0.375 \text{ hrs}$$

$$m \text{ (total battery mass)} = 46g \times 14 \text{ cell} = 644g = 0.644 \text{ kg}$$

$$C_p \text{ (specific heat capacity)} \approx 0.9 \text{ J/g } ^\circ\text{C}$$

$\Delta T$  = change in temperature

$$\Delta T = (P_{loss} \times t) / (m \times C_p) \quad (4)$$

$$\Delta T = (71.68W \times 1350s) / (0.644kg \times 900 J/g \text{ } ^\circ C)$$

$$\Delta T = 17^\circ C$$

Temperature of thermal runaway = room temperature + temperature rise =  $25^\circ C + 17^\circ C = 42^\circ C$

2. CC-CV (Total Charging Time)

Constant Current Phase (CC): 3A until voltage rise to 29.4V

Constant Voltage Phase (CV): hold the voltage on 29.4V until current tapers to 0.3A (0.1C rate)  $T_{\text{charge}} = 1.5$  hours (CC) + 0.5 hours (CV)

3. Energy Density

$$\text{Total Weight} = 14 \times 46g = 644g \approx 0.644kg$$

$$\text{Energy Density} = 151.2Wh / 0.644kg$$

$$\text{Energy density} = 235 Wh/kg$$

4. Power Density (W/kg)

$$P_{\text{max}} = 25.2V \times 16A = 403.2W$$

$$\text{Weight} = 14 \text{ cells} \times 46g = 644g = 0.644kg$$

$$\text{Volume} = 14 \text{ cell} \times 16.4 \text{ cm}^3 = 229.6 \text{ cm}^3 = 0.2296L$$

$$\text{Gravimetric power density} = 0.644kg / 403.2W = 626.1W/kg$$

$$\text{Volumetric power density} = 0.2296L / 403.2W \approx 1755.8W/L$$

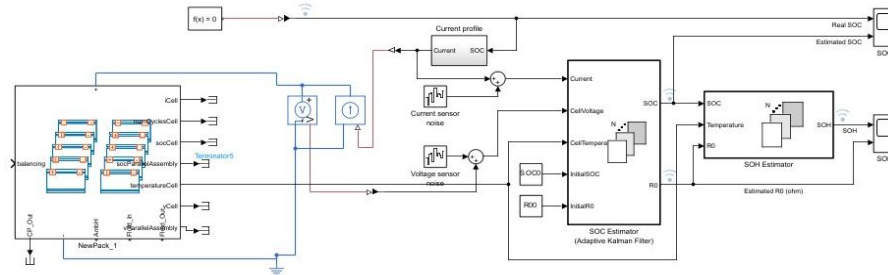


Fig.3 Simulink Model of SOH and R0 Finding Using Adaptive Kalman Filter

## V. OBSERVATION

Actual and Estimated SOC:

In Fig 3, the model used in the experiment involved observing the Actual State of Charge (SOC) alongside the Estimated SOC. In that a simple circuit using a controlled current source and a voltage sensor was used [7].

A probe was used to measure the actual SOC. The Estimated SOC calculation began with the sensor voltage, to which band-limited white noise have been added. Here a similar approach is followed for the current situation, combining the controlled current source and probe outputs after passing them through blocks like product, saturation, and relay [30]. Using current, voltage, temperature data, and the initial SOC value as inputs were then given to a Kalman filter to generate an Estimated SOC.

SOH and R0 estimator:

Similar to the prior model, this model includes a battery pack, a controlled current source, and a voltage sensor [18]. In this instance, an Adaptive Kalman Filter block. Band-limited white noise was added to the voltage supplied by the sensor to mimic real-world scenarios. For the data collection data probes were used. This collected data from the output of the controlled current source block (i.e. the output of SOC from adaptive Kalman's filter and value of internal resistance is the fed the SOH estimator block for further analysis. This output of SOH estimator and the internal resistance are simulation observed on the scope allowing us to analyze the battery's performance and health over time by monitoring the variation in SOH and internal resistance.

This real time monitoring allows us to identify the potential threats like battery degradation by which it can be indicated that there is a need for militance or replacement of battery pack [6]. To accurately represent these factors, our study used Simulink and MATLAB Battery Builder to simulate a 7s2p battery setup.

### A. State of Health (SOH):

Every cell regardless of the chemical composition is affected by the phenomenon of limiting of the lifetime of the cell ages. This causes the decrease in the cell capacity and increase in the cell impedance. The simulation performed determines the SOH by considering the capacity fade any cycle count. The continuous decrease in the health of the cell can be observed in the simulation.

### B. Internal Resistance (RO)

Internal resistance is one of the key parameters for determining the power efficiency and heat loss inside a cell[15]. In this simulation, the internal resistance of the cell was measured by calculating the energy difference between the charging and discharging process of the cell. Continuous increase of internal resistance is observed during the simulation [9].

Internal resistance caused more heat loss and reduces efficiency during the charging process. The increase in internal resistance during the discharge process cause the voltage drop which leads to power losses and reduction in runtime of battery [32].

### C. Actual SOC

It is used to represent the real time energy of the battery pack and also tells us about the current status. In the simulation we determined the SOC based on current and voltage parameters during charging and discharging process. This Actual Soc also helped us determine the Full charge, Deep discharge and the intermediate energy level of the simulated battery pack.

### D. Estimated SOC

It is used to predict the battery charge level based on the computational algorithm[39]. This algorithm used simple white gaussian noise as a random signal. To predict the SOC Coulomb counting Algorithm was used.

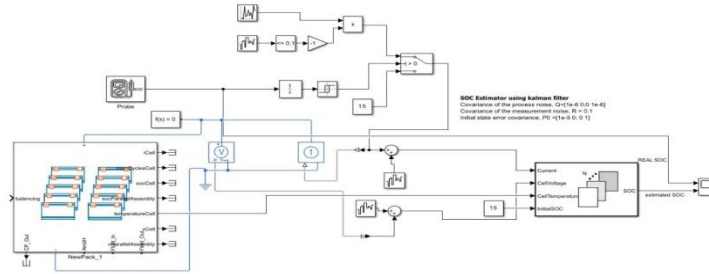


Fig.4. Simulink Model of SOC estimation using Kalman's filter

TABLE I: PARAMETERS OF BATTERY PACK

| Sr no. | Parameter (Battery Pack)               | Value   |
|--------|----------------------------------------|---------|
| 1      | Nominal voltage                        | 25.2V   |
| 2      | Capacity                               | 6Ah     |
| 3      | Max Continuous Discharge Current       | 16A     |
| 4      | Energy Storage                         | 151.2Wh |
| 5      | Charge Voltage                         | 29.4V   |
| 6      | Cutoff Voltage / Discharge end voltage | 17.5V   |
| 7      | Optimum Charging Time (CC-CV)          | ~2hr    |

TABLE II: PARAMETERS OF CELL

| Sr no. | Parameter (Cell: - NCR18650B)    | Value   |
|--------|----------------------------------|---------|
| 1      | Nominal Voltage                  | 3.6V    |
| 2      | Capacity                         | 3000mAh |
| 3      | Max Continuous Discharge Current | 8A      |
| 4      | Charge Voltage                   | 4.2V    |
| 5      | Discharge End Voltage            | 2.5V    |

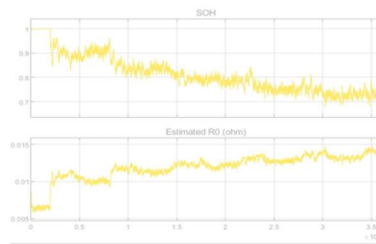


Fig.5. Graphical representation of SOH and RO

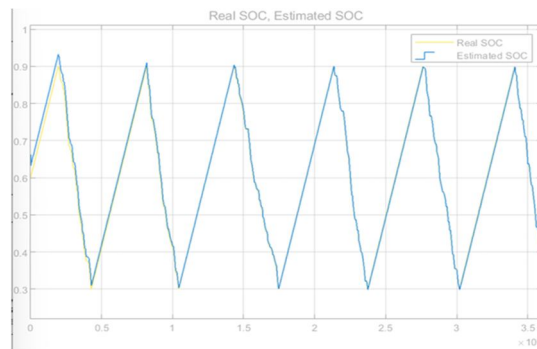


Fig.6.Graphical Representation of Actual and Estimated SOC

## VI. CONCLUSION

The 7s2p configuration battery model is developed in the battery builder app of MATLAB Simulink. To increase the performance and life span of the batteries. The essential simulation parameters like State of Charge (SOC), State of Health (SOH) and internal resistance (RO) of the battery pack were graphically analyzed. Along with that observation of various factors like temperature variations and load conditions on SOC, SOH and RO. The main focus of this research was to illustrate how these battery parameters evolve during the charging and discharging process and how to optimize the energy usage, battery health performance by using these parameters. Future work should focus on how to enhance the accuracy and reliability of the battery management systems by using the machine learning algorithms for more optimization of the process.

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