Performance Evaluation of Lithium-ion Battery Second Order Thevenin Equivalent Circuit Model under Various Temperature Levels

Nour El Houda KORBAA*, Ahmed Wahid BELARBI, Nadir BOUCHETATA

Department of Electrical Engineering, University of Science and Technology of Oran MB, Algeria
*Corresponding author's e-mail: nourlhouda.korbaa@univ-usto.dz

ABSTRACT

This paper selected the second order Thevenin equivalent circuit model to simulate the dynamic behavior of lithium-ion battery. The relationship between the state of charge and the open circuit voltage of the battery was obtained via the incremental current open circuit voltage test. Then, the equivalent circuit model parameters were extracted appropriately. The model was established in MATLAB Simulink and was validated using constant current pulsed discharge and pulsed charged conditions. The performance of proposed model was later on tested under varying temperatures for different dynamic profiles. The simulation results showed that the model can precisely represent the static and dynamic behaviors of the battery and the parameters identified have high accuracy where it gives increased precision at higher temperatures.

Keywords: Lithium-ion battery, Second order Thevenin, State of charge

1 Introduction

Excessive gas and fossil fuel use has led to rapid climate change and high global temperatures. This problem, exemplified by their use in the automotive industry, has prompted a shift towards cleaner energy sources, particularly electric vehicles (EVs). These EVs primarily rely on lithium-ion batteries, considered superior due to their environmental benefits, recyclability, high power and energy density, high terminal voltage, lack of memory effect, and low self-discharge rates [1]. To ensure the optimal performance of these batteries in EVs, a battery management system (BMS) is crucial [2]. This system requires a precise and efficient battery model for accurate monitoring of both the battery pack and the vehicle's performance [3].

2 Methodology

Effective battery modeling for lithium-ion batteries involves a delicate balance between simulation accuracy, computational complexity, and parameterization effort. Complex models, while more accurate, pose greater challenges for testing and computation. Three primary modeling approaches include electrochemical, mathematical, and equivalent circuit models (ECM). Of these, ECM stands out for its simplicity, accuracy, and widespread use in electric vehicle control systems. The chosen ECM variant is Thevenin-based, enhanced with an RC network to model fast and medium-scale battery dynamics [4]. It considers factors like internal resistance, polarization resistance, polarization capacitance, concentration impedance, concentration capacitance, open circuit voltage, terminal voltages, and charge-discharge current. Experimental data from an INR 18650-20R battery at various temperatures was collected [5], with a focus on Open Circuit Voltage (OCV), which correlates closely with the battery's electromotive force. Relationships between OCV and State of Charge (SOC) were established using voltage curves. Relaxation periods allowed for the determination of steady-state OCV by eliminating polarization effects. Hysteresis, which leads to differing terminal voltages during charge and discharge, was also accounted for. Ultimately, OCV-SOC relationships were fitted using MATLAB's curve-fitting function. The pulsed discharge experiment provided additional insights into how terminal voltage behaves during changes in current. Extracted parameters for different SOC values were organized into a data matrix, and functional relationships between these parameters and SOC were established, contributing to improved battery

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modeling [6].

3 Results and Discussion

The voltage responses of real battery cells and the designed model on SIMULINK were compared to assess model performance at different temperatures. In contrast to lower temperatures like 0°C, the dynamic voltage response of both the model and the real battery is similar and nearly identical at temperatures of 25°C and 45°C. Using the RMSE formula, the difference between real and estimated values was calculated, and the results are shown in Table 1. The table shows that the proposed model fared better under the DST and FUDS tests than it did under the BJDST test, where it performed poorly and had a bigger error than a genuine battery cell. Due to the model's failure to accurately represent the complex battery behaviour at lower temperatures, its overall performance was best at higher temperatures of 25°C and 45°C and worst at lower temperatures of 0°C.

Table 1: *Root Mean Square Error of different dynamic testing profiles at different testing temperatures*

	RMSE-DST	**RMSE-FUDS**	**RMSE-US06**
0°C	0.0496	0.0446	0.1682
25°C	0.0113	0.0089	0.0092
50°C	0.0111	0.0082	0.0089

4 Conclusion

The study focuses on lithium-ion power batteries, using a second-order Thevenin equivalent circuit as the selected model. It involves extracting model parameters and establishing a MATLAB-based model that effectively adapts to State of Charge (SOC) variations. Validation is done through constant current pulsed discharge and charge tests, with the model exhibiting a low error rate (within 2%) and high accuracy. Dynamic tests, mirroring real-world conditions, reveal that the model performs exceptionally well at higher temperatures, achieving a Root Mean Square Error (RMSE) of less than 1%.

5 Competing Interests

The authors declared that no conflict of interest exists in this work.

How to Cite

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