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Modeling and Simulation of Lithium-ion Battery Considering the Effect of Charge-Discharge State

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Modeling and Simulation of Lithium-ion Battery Considering the Effect of Charge-Discharge State

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Abstract. Establishing an accurate battery equivalent model is an important link in the development of battery management system (BMS). The second-order RC equivalent circuit model can accurately describe the dynamic characteristics of the battery. Considering the influence of state of charge (SOC) and battery charging and discharging state on the model parameters, the battery model parameters in charging state and discharging state are identified separately through battery performance test experiments. The equivalent circuit model of lithium ion battery with variable parameters is established by Simscape language, and simulation analysis is carried out. The results show that, considering the influence of battery charge and discharge state, the error of the model is small and the accuracy of the model is improved.

1. Introduction

Lithium-ion battery is one of the main energy storage components at present. In order to ensure the safe and reliable operation of the whole battery energy storage system, battery management system (BMS) is needed to estimate and predict the state of charge (SOC) and state of health (SOH) of lithium-ion battery [1]. In order to accurately estimate the state of lithium ion battery, it is necessary to establish an accurate battery model [2].

At present, there are three commonly used lithium ion battery models: electrochemical model, equivalent circuit model and neural network model [3]. Equivalent circuit model simulates the nonlinear operating characteristics of lithium ion batteries through circuit elements with variable parameters (resistance, capacitance and voltage source), which is widely used [4]. In order to establish an accurate battery equivalent circuit model, it is necessary to accurately identify the circuit component parameters in the equivalent circuit. Generally speaking, different SOC corresponds to different model parameters. In this paper, the second-order RC equivalent circuit model is selected, and the model parameters are identified by the test data of HPPC, with emphasis on the influence of battery charging and discharging state on the model parameters. And the simulation model with variable parameters is built by Simscape language in Matlab/Simulink [5], and the simulation results are compared and analyzed.

2. Battery performance test experiment

Taking a lithium-ion battery with rated capacity of 100Ah as the experimental object, the charge-discharge test and HPPC test of different rates of batteries were carried out at room temperature of 25℃.

2.1. Charge and discharge test
Under conditions at room temperature 25℃, the battery is charged to the cutoff voltage with a constant current of 0.5C(50A), 1C(100A), 2C(200A), and the charging curve at different magnification is shown in Figure 1(a). The battery is discharged to the cutoff voltage, and the discharge curve at different magnification is shown in Figure 1(b) with a constant current of 0.5C(50A), 1C(100A), 2C(200A).

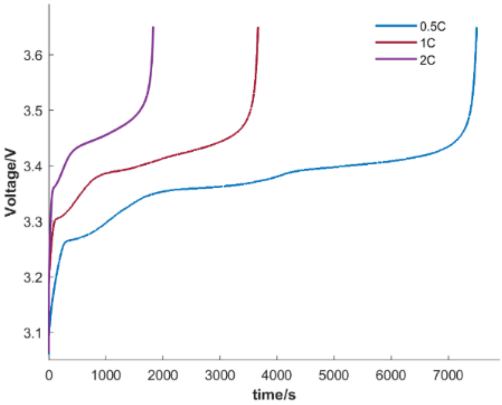

Figure 1(a). Charging curves of batteries at different multipliers

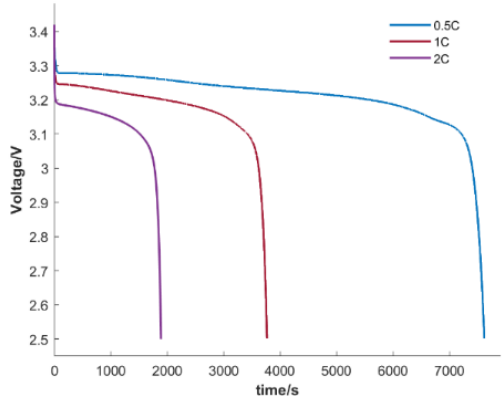

Figure 1(b). Discharging curves of batteries at different multipliers

Figure 1. Charging ang Discharging curves of batteries at different multipliers

By observing the charge-discharge curve of the battery, it can be found that the voltage changes rapidly in the initial and final stages of charge-discharge while the voltage changes smoothly in the intermediate process.

2.2. HPPC test experiment
Under the conditions of 25 ° C at room temperature, the battery was tested [6], and the battery was applied once, and the battery was applied once, the specific steps were as follows:

Step 1: Align the battery 2H at 25 ° C for 2 hours, Reaching a thermal balance state;

Step 2: Discharge the battery at a current of 1C to the voltage, the battery is standing for 2 h;

Step 3: Charge the charging method of CC-CV, first charge the shut-off voltage with 1.0C constant current, then turn the constant pressure Charging to the cutoff current, the battery is standing for 2 h;

Step 4: Apply a charge and discharge pulse on the battery: discharge 20s at 0.5c, stand 40s, and stand at 0.5C;

Step 5: Discharged by 0.3c discharge to the next SOC point, stand 2 h;

Repeat steps 4 and 5 until SOC is 0.

3. Parameter identification of the model

3.1. Analysis of battery equivalent circuit model
The second-order RC equivalent circuit model is shown in Figure 2, which consists of a voltage source, a resistor and two RC links in series. U_{OC} is the battery open-circuit voltage, R_0 is the battery ohmic resistance, R_1 and R_2 are the polarization resistors, C_1 and C_2 are the polarization capacitors. Two RC networks are used to describe the electrochemical polarization characteristics and concentration polarization characteristics of the battery, respectively. I is the battery current, U is the battery voltage, and U_1 and U_2 are the terminal voltage of the two RC networks.

According to Kirchhoff's law, the basic relationship between the above variables is as follows:

$$U = U_{OC} - IR_0 - U_1 - U_2 \tag{1}$$

$$I = \frac{U_1}{R_1} + C_1\frac{\mathrm{dU}_1}{dt} = \frac{U_2}{R_2} + C_2\frac{dU_1}{dt} \tag{2}$$

According to the second-order RC equivalent circuit model in Figure 2, it can be seen that the parameters to be identified are U_{OC}, R_0, R_1, R_2, C_1 and C_2. Through the HPPC test above, the model characteristics corresponding to each SOC point can be obtained, which is the principle of parameter identification. The corresponding voltage and current curves of a certain SOC point under HPPC test are shown in Figure 3.

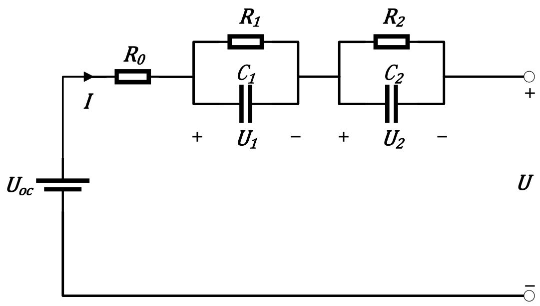

Figure 2. Second order RC equivalent circuit model

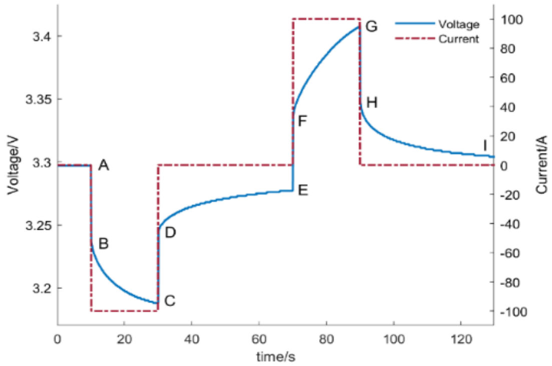

Figure 3. Schematic diagram of voltage and current for HPPC test

Before point A, the battery is in the static state for A long time, the current is 0, and the voltage is stable; the disc applied 100A is applied, and the voltage is drafted to the B point; during the discharge process of 20s, due to polarization effect, The change process of the voltage is shown in the curve BC; after the discharge is completed, the current is changed from 100a to 0, and the voltage is suddenly raised to the D point; during the standing process of 40s, due to the polarization effect, the voltage variation process such as curve de Indicated. The charging process is similar to the discharge process. In order to improve the accuracy of the battery model, this article applies a charge and discharge pulse every 5% SOC, and each model parameter corresponds to 21 identification points.

3.2. Identification of open-circuit voltage U_{OC}

After each charge and discharge pulse, there will be 40s of standing time. In this process, the polarization effect gradually weakens and the polarization voltage gradually decreases. It can be considered that the polarization voltage of point E and point I is 0, and the voltages of point E and point I are respectively taken as the discharge U_{OC} and charge U_{OC} of corresponding SOC points. Different from the conventional identification method of U_{OC} [7], this paper does not take the average value of the two, but divides them into discharge and charge conditions to identify U_{OC} respectively.

3.3. Identification of ohmic internal resistance R_0

At the beginning and end of each charge and discharge, the voltage will suddenly change, which is caused by ohmic resistance R_0. According to Ohm's law, it can be obtained:

In case of discharge: $$R_0 = \frac{(U_A - U_B) + (U_D - U_C)}{2I} \tag{3}$$

In case of charge: $$R_0 = \frac{(U_F - U_E) + (U_G - U_H)}{2I} \tag{4}$$

3.4. Identification of polarization resistance R_1, R_2 and polarization capacitance C_1, C_2

According to the transformation of formula (1) and formula (2), it can be obtained:

$$U(\mathrm{t}) = U_{OC} - IR_0 - U_1(t) - U_2(t) \tag{5}$$

$$U_1(\mathrm{t}) = U_1(0)e^{-t/\tau_1} + IR_1\left(1 - e^{-t/\tau_1}\right) \tag{6}$$

$$U_2\left(\mathrm{t}\right)=U_2\left(0\right)e^{-t/\tau_2}+IR_2\left(1-e^{-t/\tau_2}\right) \tag{7}$$

Where τ_1 and τ_2 are the time constants of two RC links respectively, $\tau_1=R_1C_1, \tau_2=R_2C_2, U_1\left(0\right)$ and $U_2\left(0\right)$ are the initial voltages at both ends of the polarization capacitor in each stage.

Section *BC* is the zero-state response of RC link, and the voltages at both ends of polarization capacitor are:

$$U_1\left(\mathrm{t}\right)=IR_1\left(1-e^{-t/\tau_1}\right) \tag{8}$$

$$U_2\left(\mathrm{t}\right)=IR_2\left(1-e^{-t/\tau_2}\right) \tag{9}$$

At the instant from point *C* to point *D*, the polarization voltage is basically unchanged, so the initial voltage at both ends of the polarization capacitor in section *DE* can be obtained as follows:

$$U_1\left(0\right)=IR_1\left(1-e^{-T/\tau_1}\right) \tag{10}$$

$$U_2\left(0\right)=IR_2\left(1-e^{-T/\tau_2}\right) \tag{11}$$

T is the pulse duration of *BC* segment, which is 20s.

The input current of section *DE* is 0, which can be used as zero input response of RC link, and the terminal voltage is:

$$U\left(\mathrm{t}\right)=U_{OC}+U_1\left(0\right)e^{-t/\tau_1}+U_2\left(0\right)e^{-t/\tau_2} \tag{12}$$

According to formula (12), the values of $U_1\left(0\right)$, $U_2\left(0\right)$, τ_1 and τ_2 can be obtained by fitting the experimental data of *DE* section, and the values of R_1, R_2, C_1 and C_2 can be further obtained.

$$R_1=\frac{U_1\left(0\right)}{I\left(1-\mathrm{e}^{-T/\tau_1}\right)} \tag{13}$$

$$R_2=\frac{U_2\left(0\right)}{I\left(1-\mathrm{e}^{-T/\tau_2}\right)} \tag{14}$$

$$C_1=\frac{\tau_1}{R_1} \tag{15}$$

$$C_2=\frac{\tau_2}{R_2} \tag{16}$$

The parameter identification of the charging process is similar.

4. Modeling and simulation

The result of parameter identification is shown in Figure 4. By observing the result of parameter identification, it can be found that the model parameters identified by different SOC points are different, and at the same SOC point, the model parameters identified in charging state and in discharging state are also quite different.

Simscape language is used to write circuit elements with variable parameters, including voltage source, ohmic resistance, polarization resistance, polarization capacitance. All circuit components can realize parameter changes through automatic table lookup. Different SOC corresponds to different parameters, and different charging and discharging states correspond to different parameters.

The second-order RC equivalent circuit model was built in Matlab/Simulink. The model parameters obtained from parameter identification were imported to compare the simulation output voltage curve of the model with the experimental charging-discharge curve. The comparison curve between the simulation results and the experimental results is shown in Figure 5, and the error curve is shown in Figure 6.

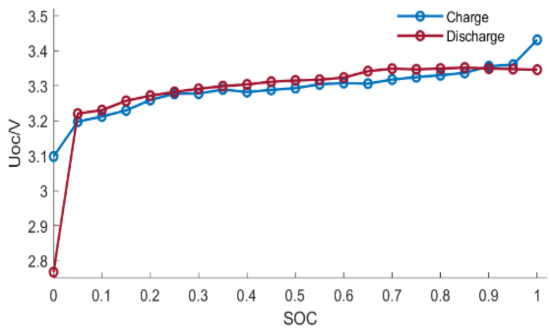

Figure 4(a). The identification results of U_{OC}

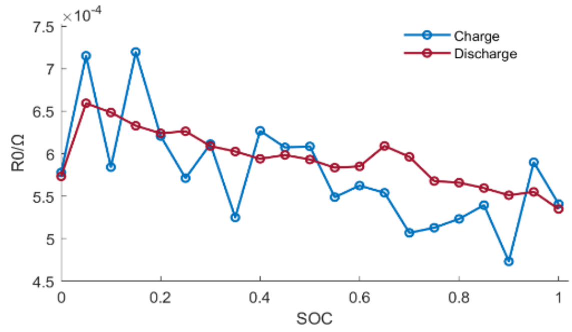

Figure 4(b). The identification results of R_0

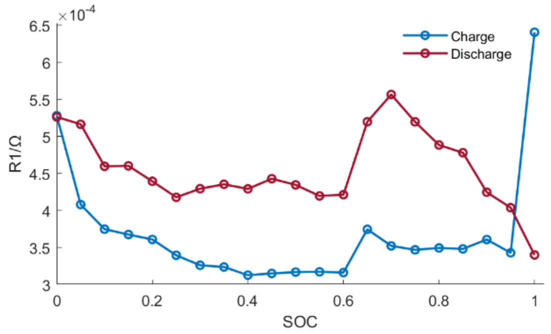

Figure 4(c). The identification results of R_1

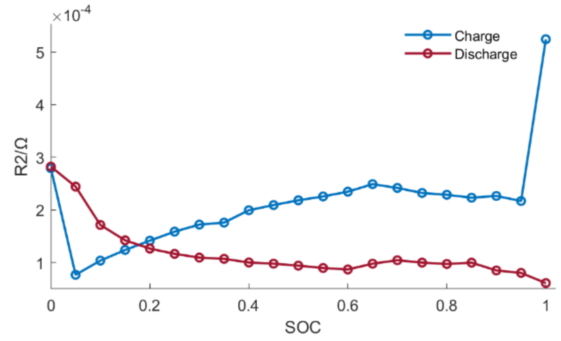

Figure 4(d). The identification results of R_2

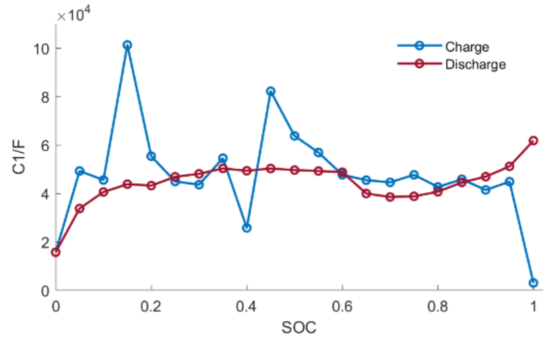

Figure 4(e). The identification results of C_1

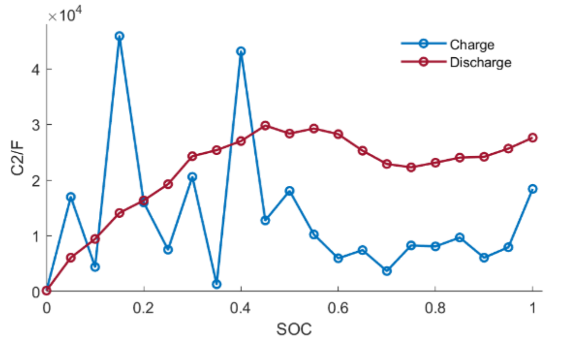

Figure 4(f). The identification results of C_2

Figure 4. The results of parameter identification

By analyzing the simulation and experimental results, it can be found that: under the charging state, the larger error occurs when the SOC is 0~0.15 and the SOC is 0.9~1, and the maximum error is 0.0147V;In the discharge state, the larger error occurs when the SOC is 0~0.05 and the SOC is 0.9~1, and the maximum error value is 0.0374V.Otherwise, the error remains within ±0.0001V.

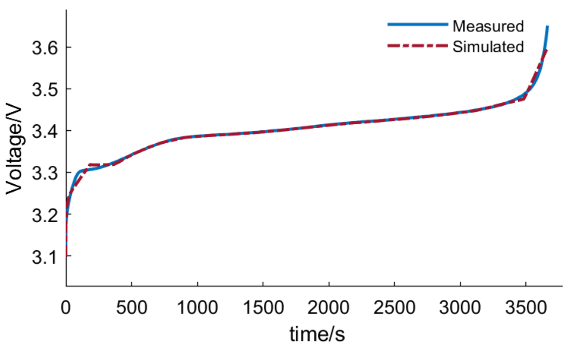

Figure 5(a). Voltage curve in charging state

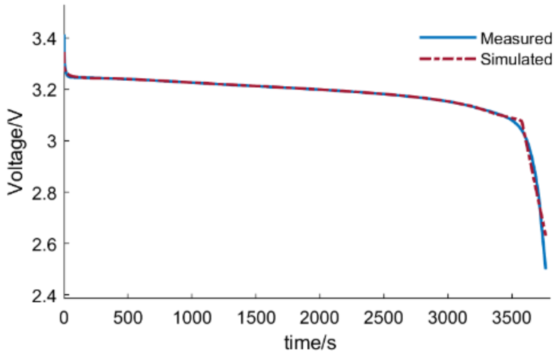

Figure 5(b). Voltage curve in discharging state

Figure 5. Comparison curve between simulation results and experimental results

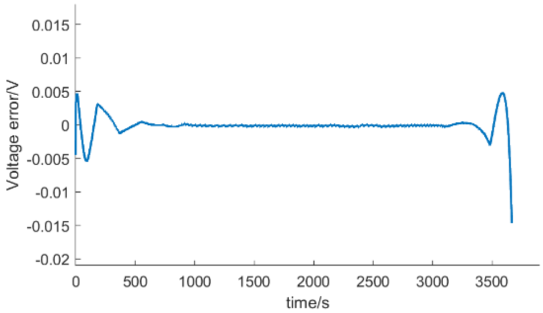

Figure 6(a). Error curve in charging state

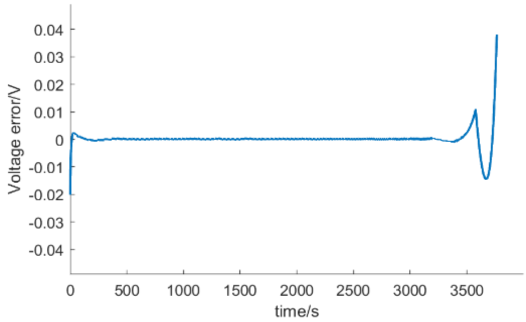

Figure 6(b). Error curve in discharging state

Figure 6. Error curve in charging and discharging state

5. Conclusion

This paper focuses on the influence of the different charge and discharge state of the battery on the identification of battery parameters. Taking the second-order RC equivalent circuit model as the research object, the model parameters of the battery are identified in charge-discharge state and discharge state respectively. It can be found that the model parameters in charge state and discharge state are quite different. The equivalent circuit model of the battery was built by Simscape language in Matlab/Simulink, and the simulation was verified. The results show that the error of the model is particularly small in the interval of SOC from 0.15 to 0.9, and the error is substantially in the range of ± 0.0001V, and the error in other intervals is slightly large, but no more than 0.0375V. The results show that considering the influence of different charging and discharging states of the battery, the error of the equivalent model is smaller and the accuracy of the model is higher.

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