Parameter Identification of Lithium Iron Phosphate Battery Model for Battery Electric Vehicle

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Abstract. The third-order equivalent circuit model of battery electric vehicle lithium iron phosphate battery has been established. According to the characteristics of lithium iron phosphate battery in charging and discharging process, the data of open circuit voltage change during battery test were used to identify the third-order equivalent circuit model parameters. The joint simulation of lithium iron phosphate battery discharging based on NEDC operating condition was carried out by using MATLAB and ADVISOR software. The lithium iron phosphate battery was tested on the power battery test platform. The results show that the maximum relative error between the value of simulation and test is small. The trend of the simulation and test curve is in good agreement. Moreover, the characteristics of the lithium iron phosphate battery are described well by the third-order equivalent circuit model. The results demonstrate that the third-order equivalent circuit model has high accuracy.

1. Introduction
In recent years, energy shortages and environmental problems have become more and more serious, so battery electric vehicles will become a major direction for future car development. Power battery is one of the key components of battery electric vehicles [1]. The aging mechanism and internal physical and chemical reactions of lithium-ion batteries are quite complicated [2]. Accurate modeling and parameter identification of lithium ion battery has become an urgent problem to be solved.

Common lithium-ion battery models mainly include electrochemical models, artificial neural network models and equivalent circuit models [3]. The electrochemical model mainly describes the electrochemical reaction process of the battery based on the reaction mechanism inside the battery. Due to the partial differential equation, the algorithm solving process is quite complicated, and the simulation time is long and the practicability is poor [4]. The artificial neural network model has strong learning ability. It is better to simulate the characteristics of the battery through the training of a large amount of test data of the battery [5, 6]. However, the large amount of battery test data required by the artificial neural network model learning process depends on the complex working condition test of the battery. The universality of the model is poor. The equivalent circuit model uses electrical
components such as capacitors, resistors, and constant voltage sources to simplify the complex physical and chemical reactions of the simulated battery [7]. It is relatively easy to implement the parameter identification test of the model. The general model of the model is better. It is not only simple but also a wide range of applications.

2. Parameter identification of lithium iron phosphate power battery

2.1. Battery model establishment

The equivalent circuit model uses electronic components to form a circuit network to describe the internal physicochemical working principle of the battery [8]. It is widely used in the field of electric vehicle power battery simulation. The RC loop has high accuracy in describing the polarization characteristics of the battery. If the number of RC loops is larger, the simulation effect of polarization characteristics is closer to the actual situation. It requires a high degree of computer processing data. Considering the simulation accuracy of the model and the requirements of computer data processing capability, the application of the third-order RC model in this paper is very wide.

![Figure 1. Third-order RC model of power battery.](image)

In the third-order RC model of the battery, $R_0$ is the ohmic internal resistance. The circuit composed of $R_{p1}C_{p1}$, $R_{p2}C_{p2}$ and $R_{p3}C_{p3}$ simulates the polarization effect inside the battery. $R_0$ and three RC networks are connected in series to form the equivalent impedance model of the battery. The basic electrical equation of the equivalent circuit is shown in equation (1):

$$
\begin{align*}
U_t &= U_{OCV} - I \cdot R_0 - U_{P1} - U_{P2} - U_{P3} \\
I &= \frac{U_{P1}}{R_{p1}} + C_{p1} \frac{dU_{P1}}{dt} \\
I &= \frac{U_{P2}}{R_{p2}} + C_{p2} \frac{dU_{P2}}{dt} \\
I &= \frac{U_{P3}}{R_{p3}} + C_{p3} \frac{dU_{P3}}{dt}
\end{align*}
$$

(1)

In the formula, $U_t$ is the battery terminal voltage, $U_{OCV}$ is the battery open circuit voltage, $I$ is the battery current. $U_{P1}$, $U_{P2}$ and $U_{P3}$ are the output values of the RC network voltage source. $U_{OCV}$ is the open circuit voltage after the battery has been fully settled. $U_{OCV}$ is related to the average SOC of the battery rather than the electromotive force corresponding to the particle surface SOC of the current state. Therefore, the voltage drop caused by solid phase diffusion requires special calculations. In the electrochemical process, the voltage drop corresponding to the positive and negative double layer effects can be represented by three first-order inertial links, so the equivalent circuit model can be characterized by three sets of polarization voltage drops $U_{P1}$, $U_{P2}$ and $U_{P3}$. 

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2.2. Parameter identification

The battery test platform includes the model of the power battery test system, the main control host computer and the test battery [9]. The power battery test system is Xi'an Xunpai/EVB-670-200-2ISO, which can perform constant current, constant voltage and constant power charging and discharging on the battery. The test object is a lithium iron phosphate power battery for battery electric vehicles. The main parameters are shown in Table 1.

Table 1. Lithium-ion battery parameters for testing.

| Parameter                        | Specification                                  |
|----------------------------------|------------------------------------------------|
| Nominal capacity (A·h)           | 120                                            |
| Battery positive and negative materials | Lithium iron phosphate/graphite                |
| Voltage operating range (V)      | 2.65~3.65                                      |
| Single cell nominal voltage (V)  | 3.2                                             |
| Overcharge protection (V)        | Any string of voltages is higher than 3.65±0.05|
| Over discharge protection (V)    | Any string of voltages is lower than 2.60±0.05  |
| Charge and discharge temperature (℃) | -25~65                                        |

The lithium iron phosphate battery was tested at an ambient temperature of 25°. The initial voltage value of the battery was first read for 300s. Next, the test was performed at a discharging rate of 1C (120A). The discharging time was 600s. After the discharge, the battery was allowed to stand for 1800s. The battery discharging static voltage rebound curve shown in Figure 2.

![Figure 2. Battery discharging static voltage rebound curve.](image)

In Figure 2, in order to read the initial voltage of the battery, it can be seen that the AB segment is the initial stationary zone. The BC segment discharging zone, the battery discharging test is completed. The CDE is the end of the stationary zone, the voltage will rebound. The rebound voltage of the battery is the difference between the voltage at point C and the voltage at point E. The rebound voltage includes two parts ΔU1 and ΔU2. ΔU1 is the voltage that was generated by the ohmic internal resistance of the battery. ΔU2 is the voltage that was generated by the internal polarization effect of the battery.

The battery voltage at any time in the BC area is shown in Eq.(2)

\[
U_{BC}(t) = U_{OCV} - I \cdot R_0 - I \cdot R_{p1} \left(1 - e^{-\frac{t}{\tau}}\right) - I \cdot R_{p2} \left(1 - e^{-\frac{t}{\tau}}\right) - I \cdot R_{p3} \left(1 - e^{-\frac{t}{\tau}}\right) \tag{2}
\]
Since the voltage of the RC network is \( U(t) = R_p(t)(1 - e^{-\frac{t}{RC}}) \), the discharging time is only 600s, the values of \( R_{p1}, R_{p2} \) and \( R_{p3} \) are between the order of \( 10^{-3} \) and \( 10^{-2} \), and the values of \( C_{p1}, C_{p2} \) and \( C_{p3} \) are between the order of \( 10^3 \) and \( 10^5 \). Therefore, the voltage at point \( C \) is \( e^{-\frac{t}{RC}} \approx 0 \), and the voltage at point \( C \) is shown in Eq.(3)

\[
U_C = U_{OCV} - I \cdot R_0 - I \cdot R_{p1} - I \cdot R_{p2} - I \cdot R_{p3} \tag{3}
\]

In the static zone of the CDE, after the C point, the battery is switched from the 1C discharging state to the stationary state, and the current is zero. The battery voltage is hopped due to the ohmic internal resistance. \( \Delta U1 \), ohmic internal resistance is shown in Eq.(4)

\[
R_0 = \frac{\Delta U1}{I} \tag{4}
\]

The DE region is due to the voltage difference \( \Delta U2 \) generated by the internal polarization internal resistance of the battery. Since the C point and the D point are almost at the same time, the voltage at any DE time is shown in Eq.(5)

\[
U_{DE}(t) = U_{OCV} - I \cdot R_{p1} \cdot e^{-\frac{t}{RC}} - I \cdot R_{p2} \cdot e^{-\frac{t}{RC}} - I \cdot R_{p3} \cdot e^{-\frac{t}{RC}} \tag{5}
\]

\( R_{p1}, R_{p2}, R_{p3}, C_{p1}, C_{p2}, \) and \( C_{p3} \) can be identified by exponential fitting the DE region test data, as shown in Table 2:

**Table 2.** Equivalent circuit parameter value table.

| \( R_0/\Omega \) | \( R_{p1}/\Omega \) | \( R_{p2}/\Omega \) | \( R_{p3}/\Omega \) | \( C_1/F \) | \( C_2/F \) | \( C_3/F \) |
|-----------------|------------------|------------------|------------------|-------------|-------------|-------------|
| 0.02203         | 0.03021          | 0.01511          | 0.00755          | 330.97      | 13238.83    | 264776.53   |

3. Model verification in combination with NEDC operating condition

The MATLAB and ADVISOR joint simulation results are compared with the test to verify the accuracy of the third-order equivalent circuit model established in Figure 2. The new European driving cycle condition (NEDC operating condition) was adopted in the test. The NEDC operating condition includes four urban operating conditions (ECE working condition) and one suburban operating condition (EUDC working condition). The operating time of one urban operating condition is 195s. The operating time of one suburban operating condition is 400s. The average driving speed of one NEDC operating condition is 33.6km/h. The operating time of one NEDC operating condition is 1180s, and the driving distance of one NEDC operating condition is 11.2km [10].

The parameters of the battery electric vehicle for the test are shown in Table 3. The parameters of the whole vehicle are input into ADVISOR. The model of electric vehicle was established by ADVISOR which is shown in Figure 3.

**Table 3.** Test vehicle battery electric vehicle parameters.

| Vehicle parameters | Curb quality (m/kg) | Wheel radius (r/m) | Frontal area (A/m²) | Air resistance coefficient (C_L) | Rolling drag coefficient (f) |
|--------------------|---------------------|--------------------|---------------------|---------------------------------|-----------------------------|
| Numerical value    | 900                 | 0.28               | 1.6                 | 0.4                             | 0.015                       |
The NEDC working condition and the test electric vehicle parameters are imported through ADVISOR, and the third-order equivalent circuit model is co-simulated of ADVISOR and MATLAB. The NEDC operating condition battery voltage simulation value is compared with the experimental value as shown in Figure 4.

In Figure 3, the maximum relative error between the voltage simulation value and the experimental value of the third-order equivalent circuit model is 3%. At the same time, the curve is more consistent, and most of the curves have the same trend. Therefore, the third-order equivalent circuit model of the battery electric vehicle lithium iron phosphate power battery has high accuracy. It has certain engineering application value. However, the polarization effect and aging mechanism inside the battery are quite complicated. In particular, the internal parameters of the battery will change as the battery is aging.

4. Conclusion
According to the characteristic of lithium iron phosphate battery during charging and discharging process, a third-order equivalent circuit model of battery electric vehicle lithium iron phosphate power battery was established. During the battery test process, the battery will generate a trip voltage after standing at a high discharging rate. The battery discharging will be partitioned by different voltage
changes. According to the change data of open circuit voltage during battery test, the third-order equivalent circuit model parameters are identified. Using MATLAB and ADVISOR joint simulation and experimental results, the maximum relative error between the voltage simulation value and the experimental value of the third-order equivalent circuit model is only 3%. The coincidence degree between the simulation and the test curve trend is better, indicating that the third-order equivalent circuit model has high accuracy. The characteristics of the lithium iron phosphate battery are well described by the third-order equivalent circuit model. The model has better engineering application value.

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