Parameter Identification Method for Lithium-Ion Battery Model with Multi Frequency AC Signal Injection

Linguo Zhang¹², Manfeng Dou¹, Jing Gao²

¹Northwestern Polytechnical University, Xi’an 710072, China
²Northeast Petroleum University, Qinhuangdao 066004, China

Abstract
In order to obtain the parameters of the lithium-ion power battery of electric vehicle, a method of parameter identification for multi frequency AC signal injection battery is presented. The method is based on the exact model of the battery model and the theory of solving equations. Firstly, the battery model is adopted, which can meet the analysis of the running time, the steady state characteristics and the transient response of the battery. Next, charge-discharge of the battery and parameter identification test circuit are built. Then, the theory of parameter identification method for the battery model with multi frequency signal injection is analyzed. Finally, the least square curve fitting was used to obtain the relationship between the identified data and state of charge (SOC). The fitting results show that the parameter identification method is effective, and the improved model has a great influence on the identification results. The fitting function can be chosen to approximate the parameter identification data, which is easy to achieve by using the accurate battery model, and the parameters of the equivalent model of the battery can be more realistic.

Key words: Method Of Multi Frequency AC Signal Injection; Battery Parameter Identification; Least Square Curve Fitting.

1. INTRODUCTION

Pure electric cars lithium-ion power battery is the vehicle dynamic security, understand the real-time status of the lithium-ion battery is to assess the capacity of storage battery, the most direct way is evaluated by the equivalent model of the lithium ion power battery. Therefore, lithium ion power battery model parameter identification is the most effective way to understand the internal characteristics of the battery. Use of accurate battery models are easy to achieve high estimation accuracy, and can more real reaction battery internal state.

At present, the method of parameter identification of battery model is more (Luo, 2012; Gao, Zhang and He, 2015; Xiong, He and Ding, 2011; Bi, Kang and Shao, 2015; Hu, Sun and Zou, 2011; Rahimi, Baronti and Chow, 2014; Lass and Volkwein, 2015; Rahman, Ashiqur, Anwar, Sohel, Izadian and Afshin, 2016). Literature (Wei, Sun and Tian, 2008) proposed zero input and zero state response analysis, and to identify the model parameters using least squares method. Literature (Zhang, Guo and Liu, 2013) the genetic factor recursive least squares algorithm to identify the model parameters, model parameters identification results can be provided, including resistance and battery open circuit voltage and other parameters estimation. In literature (Rui, He and Xu, 2012), the online and offline parameter identification methods are established by using the extended Calman filter and the least square algorithm, and the parameter identification method can simulate the dynamic voltage characteristics of the dynamic battery. In literature (Guo, 2012), a method of continuous excitation is designed, and the M sequence is used as an excitation parameter identification method to ensure the validity of parameter identification. The model parameters identification of lithium ion battery by using subspace method is proposed in the paper (Remmlinger, Buchholz and Dietmayer, 2013), using variable parameter model. Model parameter identification based on battery operating voltage, current detection. There are two limitations in the parameter identification of the existing battery model. One is the majority of the traditional models (such as Rint, Thevenin, PNGV, GNL, etc.). The model needs to be improved. The other is whether the method is scalable and can only be applied to a certain type of battery.

In this paper, proposed a multi frequency signal injection of lithium battery model parameter identification method with improved battery equivalent circuit. The method combined with online real time data detecting multi parameter equations of the theory of the reconciliation, applicable to a variety of battery model parameter identification.
2. MODEL PARAMETER IDENTIFICATION METHOD FOR LITHIUM ION BATTERY

2.1. Battery Equivalent Physical Model

To simulate the transient response time \( v \) shown in the literature (Chen and Rincon, 2006) proposed the improved equivalent circuit model, as shown in Figure 1. The model of the key parameters for the battery available capacity, expressed in \( Q_c \). Open circuit voltage \( U_{oc} \) and transient response network (RC network). The left part of the model is used for reference to the idea of running time model. Capacitance \( Q_c \) and flow control current sources were used to characterize the battery capacity, SOC and running time. The right part of the model is similar in GNL model, for the response of the cell to simulate the transient. The model also uses a voltage controlled voltage source to simulate the open circuit voltage and s nonlinear relationship. This model can meet the operation time of battery, steady-state characteristics, transient response the accuracy of the analysis of the various aspects of requirements.

\[
Z = R_s + \frac{R_1}{1 + j\omega R_1 C_1} + \frac{R_2}{1 + j\omega R_2 C_2} = R_s + \frac{R_1}{1 + (\omega R_1 C_1)^2} + \frac{R_2}{1 + (\omega R_2 C_2)^2} - j\left(\frac{\omega R_1^2 C_1}{1 + (\omega R_1 C_1)^2} + \frac{\omega R_2^2 C_2}{1 + (\omega R_2 C_2)^2}\right) \tag{1}
\]

Where, \( Z \) is the resistance of the battery, the formula (1) shows that there are five parameters need identification, it need three different frequency signal can be identified.
From Figure 2, under the same battery charge state, the battery is injected into the low frequency AC sinusoidal signal $u_1(t), u_2(t), u_3(t)$, flow through the battery current are $i_1(t), i_2(t), i_3(t)$, the three signal frequency are $\omega_1, \omega_2, \omega_3$, meet $\omega_2 = 2\omega_1, \omega_3 = 2\omega_2$, the battery impedance can be expressed as,

$$\begin{align*}
Z_1 &= \frac{u_1(t)}{i_1(t)} = \frac{U_1}{I_1} (\cos \varphi_1 + j \sin \varphi_1) \\
Z_2 &= \frac{u_2(t)}{i_2(t)} = \frac{U_2}{I_2} (\cos \varphi_2 + j \sin \varphi_2) \\
Z_3 &= \frac{u_3(t)}{i_3(t)} = \frac{U_3}{I_3} (\cos \varphi_3 + j \sin \varphi_3)
\end{align*}$$

(2)

$\varphi_1, \varphi_2$ and $\varphi_3$ are the phase difference between the voltage and current of the battery, which can be obtained by the detection circuit and the data processing of MCU. From formula (1) and (2), order

$$\begin{align*}
X_1 &= \frac{U_1}{I_1} \cos \varphi_1, X_2 &= \frac{U_2}{I_2} \cos \varphi_2, X_3 &= \frac{U_3}{I_3} \cos \varphi_3 \\
Y_1 &= \frac{U_1}{I_1} \sin \varphi_1, Y_2 &= \frac{U_2}{I_2} \sin \varphi_2, Y_3 &= \frac{U_3}{I_3} \sin \varphi_3
\end{align*}$$

(3)

So the parameter identification equations are obtained,

$$\begin{align*}
R_s + \frac{R_1}{\sigma_1^2} + \frac{R_2}{1 + \sigma_2^2} &= X_1 \\
R_s + \frac{R_1}{1 + 4\sigma_1^2} + \frac{R_2}{1 + 4\sigma_2^2} &= X_2 \\
R_s + \frac{R_1}{1 + 16\sigma_1^2} + \frac{R_2}{1 + 16\sigma_2^2} &= X_3 \\
\frac{\sigma_1 R_1}{1 + \sigma_1^2} + \frac{\sigma_2 R_2}{1 + \sigma_2^2} &= Y_1 \\
\frac{2\sigma_1 R_1}{1 + 4\sigma_1^2} + \frac{2\sigma_2 R_2}{1 + 4\sigma_2^2} &= Y_2 \\
\frac{4\sigma_1 R_1}{1 + 16\sigma_1^2} + \frac{4\sigma_2 R_2}{1 + 16\sigma_2^2} &= Y_3
\end{align*}$$

(4)
The formula (4) can be solved,
\[
\begin{align*}
(1+16\sigma_1^2) &= (4X_2 - X_1)\sigma_1 - (2Y_2 - Y_1) \\
1 + \sigma_1^2 &= (4X_3 - X_2)\sigma_1 - \frac{1}{2}(2Y_3 - Y_2) \\
(1+16\sigma_2^2) &= (4X_2 - X_1)\sigma_2 - (2Y_2 - Y_1) \\
1 + \sigma_2^2 &= (4X_3 - X_2)\sigma_2 - \frac{1}{2}(2Y_3 - Y_2)
\end{align*}
\]
(5)

It can solve $\sigma_1$ and $\sigma_2$ at the same time can get $R_i, R_2, R_s, C_1, C_2$.

\[
\begin{align*}
R_i &= \frac{(1+\sigma_1^2)(1+4\sigma_1^2)}{\sigma_2 - \sigma_1} \times \frac{1}{3}[(4X_2 - X_1)\sigma_2 - (2Y_2 - Y_1)] \\
R_2 &= \frac{(1+\sigma_2^2)(1+4\sigma_2^2)}{\sigma_1 - \sigma_2} \times \frac{1}{3}[(4X_2 - X_1)\sigma_1 - (2Y_2 - Y_1)] \\
R_s &= \frac{X_1 - R_i^2}{1+\sigma_1^2} - \frac{R_2}{1+\sigma_2^2} \\
C_1 &= \sigma_1 / \omega R_1 , \quad C_2 = \sigma_2 / \omega R_2
\end{align*}
\]

Next, the test circuit built in Figure 3 can be measured by $X_1, X_2, X_3, Y_1, Y_2, Y_3$, the parameter identification problem is transformed into the solution of the equations.

3. BATTERY CHARGING AND DISCHARGING TEST AND PARAMETER FITTING

3.1. Test Data and Identification Data

Test using SENDE dynamic polymer lithium battery. Nominal voltage 3.7V, nominal capacity 3000mAh, standard charge current 0.5C (1.5A), discharge current 1C (3A), charging temperature (℃) 0~45, discharge temperature (℃) -20~60, charging cut-off voltage 4.2V, discharge cut-off voltage 2.75V. The charging and discharging processes are adopted 20℃.

Open circuit electromotive force $U_{oc}$ is generally considered to be a function of the battery SOC. $U_{oc}$ measurement method is to charge or discharge the battery to the default SOC value, static an hour, measuring the battery terminal voltage. This procedure is completed by the PC program, the data is processed and stored in the PC, which reduces the workload and is not limited by the storage space. We are based on the characteristics of $U_{oc}$ and SOC curves. 0 ≤ SOC ≤ 0.1, Every 1% of SOC for a sample. 0.1 ≤ SOC ≤ 1, Every 5% of SOC to make a sample. As shown in Figure 3, the specified SOC sample point voltage of the charge and discharge process.

![Figure 3. Voltage of sample in charge-discharge process](image1)

![Figure 4. Ohmic resistance identification data](image2)

Combined with the 2.3 section of the parameter identification method, the designated SOC sampling point identification data can be obtained, as shown in Figure 4, Figure 5 and Figure 6.
3.2. Model Parameters Fitting Curve of Lithium Battery

The lithium battery model parameters are fitted to the curve least squares (Zhou, 2005; Li, Chen and Lin, 2004; Deng and Lin, 2014; Morais, Cardoso and Mariotto, 2011) problem, which can be described as, based on known data \((x_k, y_k) (k = 1,2,\cdots, n)\), select an approximation of the function \(f(x)\), making the \(E_2(f)\) (root mean square error) minimum. In the curve fitting, only the most close to the true curve fitting function can obtain the best fitting effect. According to the relationship between the parameters of the lithium battery model and SOC, this paper uses the \(e\) exponential function and \(m\) order polynomial function combination.

\[
f(x) = b_0e^{b_1x} + a_0 + a_1x + a_2x^2 + \cdots + a_m x^m
\]

By finding the minimum value of the following expression, the value can be obtained.

\[
E(b_0, b_1, a_0, a_1, a_2, \cdots, a_m) = \sum_{k=1}^{n} (b_0e^{b_1x_k} + a_0 + a_1x_k + a_2x_k^2 + \cdots + a_m x_k^m - y_k)^2
\]

Let \(\partial E/b_0, \partial E/b_1, \partial E/a_0, \partial E/a_1, \partial E/a_2, \cdots, \partial E/a_m\) is zero, \(\{(x_k, y_k)\}_{k=1}^{n}\) has \(n\) points. It can be changed into linear equations as follows.

\[
\sum_{k=1}^{n} (b_0e^{b_1x_k} + a_0 + a_1x_k + a_2x_k^2 + \cdots + a_m x_k^m)e^{b_1x_k} = \sum_{k=1}^{n} y_ke^{b_1x_k}
\]

\[
\sum_{k=1}^{n} (b_0e^{b_1x_k} + a_0 + a_1x_k + a_2x_k^2 + \cdots + a_m x_k^m)x_k e^{b_1x_k} = \sum_{k=1}^{n} y_kx_ke^{b_1x_k}
\]

\[
\sum_{k=1}^{n} (b_0e^{b_1x_k} + a_0 + a_1x_k + a_2x_k^2 + \cdots + a_m x_k^m)x_k^2 e^{b_1x_k} = \sum_{k=1}^{n} y_kx_k^2 e^{b_1x_k}
\]

\[
\cdots
\]

\[
\sum_{k=1}^{n} (b_0e^{b_1x_k} + a_0 + a_1x_k + a_2x_k^2 + \cdots + a_m x_k^m)x_k^m e^{b_1x_k} = \sum_{k=1}^{n} y_kx_k^m e^{b_1x_k}
\]

Figure 5. Short-time RC identification data

Figure 6. Long-time RC identification data

According to the 2.2 section, the open circuit voltage data are measured in different state of charge, and the parameters of the battery model are identified. It can get the least square fitting curve. The relationship between parameters and functions of Li ion power battery model is as follows. \(S_c\) stands for SOC.
\[ U_{oc}(S_c) = -1.0565e^{-33.44S_c} + 3.7123 - 0.0116 \cdot S_c + 0.4036 \cdot S_c^2 \] (10)

\[ R_s(S_c) = 24.1881e^{-16.17S_c} + 5.4513 - 2.3585 \cdot S_c \] (11)

\[ R_l(S_c) = 21.2943e^{-16.75S_c} + 5.3644 - 2.4744 \cdot S_c \] (12)

\[ C_1(S_c) = -713.9e^{-22.63S_c} + 330.0074 + 433.1054 \cdot S_c - 353.2458S_c^2 \] (13)

\[ R_2(S_c) = 50.3017e^{-17.39S_c} + 5.4726 - 1.1817 \cdot S_c \] (14)

\[ C_2(S_c) = 10^3 \times \left[ -1.4081e^{-3.33S_c} + 1.3827 - 3.7996 \cdot S_c + 4.0935 \cdot S_c^2 - 1.5788S_c^3 \right] \] (15)

**Figure 7.** Open circuit voltage fitting curve

**Figure 8.** Ohmic resistance fitting curve

**Figure 9.** Short-time RC fitting curve

**Figure 10.** Long-time RC fitting curve

The voltage curve fitting of Figure 7 is the average of the data. That is charging and discharging of two processes, in the same state of charge, the use of charging and discharging voltage sampling points, and then achieve data fitting. The results of this fitting can take into account the variation of the overall parameters of the battery operation. It can be obtained from figure 8. The ohmic resistance of battery is the main parameter to the internal characteristics of reaction cell. It has a certain nonlinear relationship with the battery capacity, and can
be used as a reference index of the battery capacity. Figure 9 is the short-time resistance capacity of the curve, figure 10 is a long-time resistance capacitance curve. It can be seen that they have the characteristics of similarity, but there is a difference in the number of capacitors, these two sets of curves for the study of the changes in the process of charging time to help.

4. CONCLUSIONS

In this paper, an improved model of lithium ion battery is used. The battery charging and discharging circuit and data acquisition circuit are established. The parameters of the battery model are identified by using the multi frequency AC signal injection method. The battery model parameter identification method is suitable for various battery models. This method has better portability and applicability. Least square curve fitting method is used in this paper, the test data and identification data were processed, experiments show that the method can meet the requirements of the performance analysis of the battery, and can get a better effect. On the basis of this parameter identification, the on-line identification of the parameters of the battery model can be further realized.

REFERENCES


