A New Dynamic Parameters V-RC Model of Battery Parameter Identification

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Abstract. Different state of charge (SOC), batteries have different model parameters. This paper proposes a dynamic parameter identification method for battery models under different SOC. Firstly, dynamic parameter V-RC model of battery was designed according to the hysteresis loops characteristics and the polarization characteristics of the battery voltage during the charge-discharge process. Next, the test program was designed which can complete the lithium battery charge and discharge data acquisition, including identification of battery model parameters for AC signal injection. The relationship between OCV and SOC are obtained by using the least squares curve fitting method, which realizes the function fitting of the model’s parameters. Then, battery transient response experiment indicating that have different parameters under different SOC. Finally, test results can show that open-circuit voltage (OCV) error of the new model is lower than constant parameter model OCV error. The error of the fixed parameter model OCV is 2.6\%, while the OCV error of the dynamic parameter model is 1.6\%. Dynamic parameter V-RC model can more accurately reflect the actual state of the battery.

Keywords: Dynamic parameter V-RC model; Multi-frequency signal; SOC; Parameter identification.

1. Introduction
Power battery research requires an accurate model for analysis, whether it is for electric vehicles or emergency power supplies. The model should be able to represent the battery charge and discharge voltage and current, the battery capacity and working time, and the simulation of charge and discharge. At present, battery system modeling has become an important content in the development of vehicle power battery management systems. Scholars from all over the world have done extensive research on this issue and developed battery models with different levels of complexity and precision. The paper \cite{1} studies the electrochemical models, mathematical models and electrical models of batteries that are widely used at present, and analyzes their characteristics and limitations. Mentioned in paper \cite{2}, the model is consistently accurate for over ten polymer Li-ion batteries at 2\% runtime variation and 30-mV error voltage at 10\%-100\% SOC. The SOC and battery models are mentioned in the study \cite{3-9}, and the importance and necessity of the model for battery performance research can be seen. In literature \cite{10-13}, the lithium-ion battery has been deeply studied from the optimization of the battery model, the prediction of the model, the identification of the model parameters, as well as the new battery equivalent model design and development. This paper will analyze the current research status of the battery model, and propose a model suitable for simulating the dynamic change of the power battery based on the actual operation test of the power battery. A second-order variable parameters V-RC battery
equivalent circuit model is developed which can more accurately simulate battery operating characteristics.

2. Battery Dynamic Parameter Model and Parameter Identification

2.1. Battery Equivalent Physical Model

Fig.1 shows the battery second-order RC equivalent circuit, $U_{OC}$ is battery OCV, $R_0$ is the equivalent ohmic resistance of the battery, $R_1C_1$ network (concentration polarization) of the smaller time constant, which exhibits the impedance of the lithium ions during transmission between the electrodes, the $R_1C_1$ section of the larger time constant (diffusion polarization) describes the impedance of lithium ions as they diffuse in the electrode material. All parameters are related to temperature, current and other factors.

2.1.1. Description of battery characteristics. The lithium-ion battery OCV is related to the current SOC, and the relationship is shown in Fig.2. The same SOC, the different temperature, the voltage value will be different. Fig.2 is the OCV curve of Lithium polymer cell at room temperature through the test.

![Figure 1. Second-order RC equivalent circuit of the battery.](image)

![Figure 2. Battery charge and discharge curve Second order RC model.](image)

The blue line is the OCV at the time of discharge and the red line is the open-circuit voltage at the time of charging. It can be clearly seen in Fig.2 that under the same SOC, the open-circuit voltage during charging is different from the OCV at discharge, that is, under the same SOC, the OCV of the battery also depends on the charge-discharge state, which is the battery hysteresis characteristics. Define $U_{SOC}$ is the mean value of OCV charge and discharge, the corresponding curve with the black line to represent. Fig.2 shows the difference between the OCV of the charge and discharge, which is kept constant at $0% \leq SOC \leq 90\%$, as shown in Fig.2, the hysteresis voltage is set to $U_{h_{-min}}$ during discharging; Voltage is set to $U_{h_{-max}}$, it can be considered $U_{h_{-min}} = U_{h_{-max}}$. The hysteresis voltage satisfies the differential equation as follows:

$$
\begin{align*}
U_h &= I_t(U_{h_{-max}} - \text{sign}(I_t)U_h) \\
U_h &= U_0e^{-\beta I_t} + \text{sign}(I_t)U_{h_{-max}}(1 - e^{-\beta I_t})
\end{align*}
$$

Where, $I_t$ is the loop current, $U_0$ is the initial value, $U_{h_{-max}}$ is the maximum hysteresis voltage value, its value is constant, $\beta$ is a time constant which can be experimentally measured. $\text{sign}(I_t)$ is the current direction of the sign function, discharge is negative, charge is positive. So the OCV of the battery can be obtained:

$$
U_t = U_h + U_{SOC}
$$

Lithium battery has three polarization methods: electrochemical polarization, concentration difference polarization and ohmic polarization. It is known that the change of the ohmic resistance $R_0$ is small...
with the change of SOC, and the ohmic resistance of the discharge process is slightly greater than the charge process. While the electrochemical polarization and concentration polarization is more serious by the impact of battery SOC. Three kinds of polarization phenomena in the process of charge-discharge voltage changes shown in Fig.3.

2.1.2. Dynamic parameter V-RC equivalent circuit model of battery. The hysteresis voltage characteristics of the battery are analyzed in the charge-discharge process. As is show in Fig.3, there is polarization effect of the battery, a fixed value of the RC parallel circuit can only work under a specific SOC. In practice, the RC parameter varies with SOC. In order to reflect the battery polarization characteristics and hysteresis voltage characteristics through the model, integrated battery characteristics, the V-RC model of the battery equivalent dynamic circuit is established, as shown in Fig.4.

\[ \eta = \frac{U_{OC}}{i} \]

\[ U_{OC} = k_1 e^{k_0 S_c} + k_2 + k_3 S_c + k_4 S_c^2 + k_5 S_c^3 \]

Where \( S_c \) stands for the SOC, \( k_i (i = 0,1,2,3,4,5) \) are to meet the SOC-OCV curve equation fitting coefficient obtained through the test.

2.1.3. Battery transient response. Fig.5 shows the transient response characteristics of a constant parametric model. The transient response characteristics of a dynamic parametric model are described by multiple curve segments. In the case of different SOC, the values of the RC network parameters are different, and the trends of concentration polarization and diffusion polarization are also different. The dynamic parameter V-RC model can well simulate the operating characteristics of the power battery, and provides an ideal model solution for the simulation research and theoretical research of the power battery.
2.2. Battery Test and Parameter Identification

2.2.1. Power battery test. According to the parameter identification model Fig.6, the battery charge-discharge test circuit and the detection circuit are to be established. The experimental platform is shown in Fig.7. It includes a battery tester, used for battery constant current constant voltage charge and discharge, complete charge and discharge control. It also includes a thermostat for controlling battery temperature, a computer for user interface and data storage, and a battery unit for detection. During charge/discharge, the battery voltage, current, capacity and temperature are measured and recorded in the host.

2.2.2. Parameter identification method. The parameters of the battery V-RC model need to be realized by experimental data and identification method, battery model parameters identification based on multi-frequency AC signal injection which can be realized by test of Fig.6. The specific identification process is shown in Fig.6.

Battery charge and discharge test can be obtained open circuit voltage data values, according to the method of Fig.6, we can get the data of $U_{DC}(S_C)$, $R_{ohm}(S_C)$, $R_1(S_C)$, $C_1(S_C)$, $R_2(S_C)$, $C_2(S_C)$, $S_C$ stands for SOC.

![Figure 5. Constant parameters Battery transient response.](image)

![Figure 6. Flow chart of battery parameter identification.](image)
2.2.3. Determination of open - circuit voltage function fitting parameters. The experiment adopts SenDe power polymer lithium battery: the nominal voltage is 3.7V, the standard capacity is 3200mAh, the maximum discharge rate is 30C, the internal resistance is 2.5mΩ to 3mΩ, the operating voltage is 2.7V to 4.2V, the charging temperature is 0℃ to 45℃ and the discharge temperature is -20℃ to 60℃. According to the test principle of Fig. 5, using constant current and constant voltage charging, the standard charging current is 1C (3.2A), charging to 4.2V using constant voltage charging to cut-off current of 0.05C (0.16A). Discharge with different discharge rate, discharge cutoff voltage setting at 3V. Use the battery at 0℃, 14℃, 23℃, 35℃ of discharge data to draw the curve, as shown in Fig.8. The discharge characteristics of the battery at 14 degrees can basically describe the discharge characteristics. Therefore, the average value of the charge-discharge test data at 14 degrees is used as the fitting data. The fitting results are shown in Fig.9.

The fitting function uses the formula (3), the least squares function fitting method can obtain the parameters of the fitting function: $k_0 = -23.8536$, $k_1 = -0.6518$, $k_2 = 3.8707$, $k_3 = -0.8062$, $k_4 = 2.6068$, $k_5 = -1.4523$, the fitting function curve is shown in Fig.9. The fitting parameters can be used as model data for SOC estimation.

3. Test and Discussion

3.1. Battery Dynamic Parameters V-RC Model Steady-state Response Test

The test uses a polymer lithium battery with a standard capacity of 3200mAh, nominal voltage is 3.7V, a maximum discharge rate of 30C, an internal resistance of 2.5mΩ to 3mΩ, an operating voltage of 2.7V.
to 4.2V and a charging temperature of 0°C to 46°C. The discharge temperature is -20°C to 61°C. Shown in Fig.10 is the battery tester test different transient SOC transient response test data, the test battery capacity is 3.2Ah. The curve drawn after the test data is processed. Fig.10 shows that the battery has different transient response time constants under different SOC, indicating that the batteries have different parameters under different SOC. Therefore, it is reasonable to adopt the dynamic parameter V-RC model.

3.2. Comparison of Constant Circuit and Variable Parameter Equivalent Circuit

The experiment adopts Lithium iron phosphate battery: the standard capacity is 15Ah, the maximum discharge rate is 5C, the nominal voltage is 3.2V, the operating voltage is 2.7V to 3.65V, the charging temperature is 0°C to 45°C and the discharge temperature is -20°C to 60°C. Discharge with 0.3C rate, discharge cut off voltage setting at 2.7V. Using constant parameter circuit and variable parameter circuit simulation respectively, the simulation results shown in Fig.11.

Fig. 11 shows the Voltage-SOC curve of the variable parameter circuit model has a better simulation effect. The constant parameter model is only close to the experimental value under a specific SOC. The maximum error of the fixed parameter model is 2.6%, while the maximum error of the variable parameter model is 1.6%. With the battery discharge, SOC is constantly changing, then V-RC model parameters are also changing, \( U_t \) affects the output voltage, to better simulate the internal changes in the battery, the variable parameter model with better simulation characteristics should be selected.

4. Conclusion

The dynamic parameter V-RC model proposed in this paper can simulate the actual operating characteristics of the power battery, and the model is verified by the excitation response under different and electrical states, Compared with the constant parameter model, the simulation accuracy is higher and the adaptability is better. Through the parameter identification of the dynamic parameter model and the improvement of the accuracy of the curve fitting result, the model is suitable for the performance analysis and simulation of the power battery, and is suitable for the estimation of the state of charge.
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