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A NOVEL THERMO-ELECTRIC COUPLING MODEL OF BATTERIES FOR ELECTRIC VEHICLES APPLICATION

Shanshan Guo, Rui Xiong*, Fengchun Sun, Hongwen He

National Engineering Laboratory for Electric Vehicles, School of Mechanical Engineering, Beijing Institute of Technology, Beijing 100081, China

(*Corresponding Author)

ABSTRACT

To improve the performance of power batteries at low temperature and reduce the dependence on the offline measurement equipment in obtaining the battery resistance, a novel thermoelectric coupling model has been employed for accurately calculating the resistance of the battery at different currents and temperatures. The Butler-Volmer(BV) equation has been proposed to describe the electrochemical reaction process of the battery. Compared with the traditional method, theoretical results show that the proposed model can accurately calculate the battery resistance and maintain the maximum calculation error less than 2mΩ. The proposed method has the potential to calculate the impedance timely and accurately.

Keywords: Batteries, low temperatures, thermoelectric coupling model.

1. INTRODUCTION

The power battery, which plays a critical role in electric vehicles, is also the significant bottleneck of electric vehicles[1,2]. It is highly sensitive to many factors. Especially, the resistant of the battery is easily influenced by different temperatures and currents.

1.1 *literature review*

Conventionally, the battery resistance are calculated by the electrochemical impedance spectroscopy (EIS) measurement and direct current internal resistance test [3–8]. A measurement system for impedance is proposed at a range of frequencies using the existing power electronics[7]. An impedance measurement is adopted to detect and analyze faults in battery packs [8].The online method presented in [9] requires no signal injection and complicated circuits, however, the measurement of impedance spectrum which includes different frequencies needs to be done sequentially[10]. Although the two traditional methods have been widely employed in the laboratory, the equipment are relatively costly and bulky to gain available results[11]. Meantime, the internal resistance of the battery cannot be measured in time, and many efficient models and algorithms are based on the offline data, which result are susceptible to the location, the length of the test instrument, the test idioms and so on.

1.2 *Contributions of the work*

Based on the previous research over obtaining the resistance, this study proposed a novel thermoelectric coupling model (TCM) which timely calculates the impedance of batteries: (i) The TCM can obtain the resistance at different temperatures and currents. (ii) The proposed method calculates the resistance online without equipment. (iii)The presented method can calculate the battery resistance continuously and accurately and maintain the maximum error within 2mΩ.

2. DESCRIPTION OF THERMO-ELECTRIC COUPLING MODEL

According to the circuit model based on the BV equation shown in Figure 1,

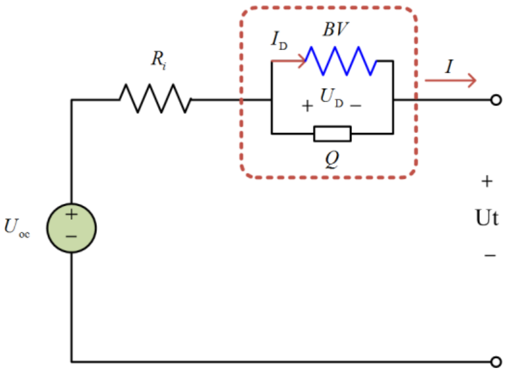

Fig.1 Butler-Volmer circuit model.

The polarization current I_D can be written as[12]:

$$I_{\mathrm{D}} = \mathrm{S}i_0 \left\{ \exp(\frac{\alpha_{\mathrm{a}} F \eta}{R_{\mathrm{g}} T}) - \exp(-\frac{\alpha_{\mathrm{c}} F \eta}{R_{\mathrm{g}} T}) \right\} \quad (1)$$

where, S is the active surface of the electrode, α_a and α_c are transfer coefficient of anode and cathode, $\alpha_a = \alpha_c = 0.5$, i_0 is exchange current density, R_g is the gas constant and η is the over-potential of the intercalation reaction, T is the temperature.

The equation (1) can be transformed as following equation by the change of trigonometric function $\sinh x = \frac{1}{2}[\exp(x) - \exp(-x)]$.

$$I_{\mathrm{D}} = 2Si_0 \sinh(\frac{\alpha_{\mathrm{a}} F}{R_{\mathrm{g}} T} \eta) \quad (2)$$

According to the hyperbolic sin function transformation[13],the equation(2) can be rewritten as:

$$\eta = \ln \left\{ \frac{1}{2Si_0} I_{\mathrm{D}} + \left[\left(\frac{1}{2Si_0} I_{\mathrm{D}} \right)^2 + 1 \right]^{1/2} \right\} \frac{R_{\mathrm{g}} T}{\alpha_{\mathrm{a}} F} \quad (3)$$

The relationship between the polarization resistance R_D and over-potential η can be described as:

$$\eta = I_{\mathrm{D}} \cdot R_{\mathrm{D}} \quad (4)$$

The Equations (3) and (4) can be combined as:

$$R_{\mathrm{D}}(I) = \frac{\ln \left\{ \frac{1}{2Si_0} I_{\mathrm{D}} + [(\frac{1}{2Si_0} I_{\mathrm{D}})^2 + 1]^{1/2} \right\}}{\frac{\alpha_{\mathrm{a}} F}{R_{\mathrm{g}} T} I_{\mathrm{D}}} \quad (5)$$

According to Arrhenius equation [14] $R_{\mathrm{D}}(T) = \mathrm{A}\exp(\frac{E_{\mathrm{a}}}{T})$, R_D can be rewritten as:

$$R_{\mathrm{D}}(T,I) = \mathrm{A}\exp(\frac{E_{\mathrm{a}}}{T}) \times \frac{\ln \left\{ \frac{1}{2Si_0} I_{\mathrm{D}} + [(\frac{1}{2Si_0} I_{\mathrm{D}})^2 + 1]^{1/2} \right\}}{\frac{\alpha_{\mathrm{a}} F}{R_{\mathrm{g}} T} I_{\mathrm{D}}} \quad (6)$$

where, E_a is the activation energy, A is constant.

The total resistance can be depicted as:

$$R(T,I,f) = R_{\mathrm{i}}(T) + \frac{\mathrm{A}\exp(\frac{E_{\mathrm{a}}}{T}) \frac{\ln \left\{ \frac{1}{2Si_0} I_{\mathrm{D}} + [(\frac{1}{2Si_0} I_{\mathrm{D}})^2 + 1]^{1/2} \right\}}{\frac{\alpha_{\mathrm{a}} F}{R_{\mathrm{g}} T} I_D}}{1 + (2\pi f)^2 (\mathrm{A}\exp(\frac{E_{\mathrm{a}}}{T}) \times \frac{\ln \left\{ \frac{1}{2Si_0} I_{\mathrm{D}} + [(\frac{1}{2Si_0} \cdot I_{\mathrm{D}})^2 + 1]^{1/2} \right\}}{\frac{\alpha_a \cdot F}{R_{\mathrm{g}} \cdot T} \cdot I_{\mathrm{D}}})^2 C_{\mathrm{D}}^2} \quad (7)$$

Subjected to the AC heating[12], the T can be described as:

$$T = T_0 + \frac{1}{hS}(hS(T_{amb} - \mathrm{T}_0) + (1 - \exp(-\frac{hS\tau}{mV})) \frac{\mathrm{A}\exp(\frac{E_{\mathrm{a}}}{T}) \frac{\ln \left\{ \frac{1}{2Si_0} I_{\mathrm{D}} + [(\frac{1}{2Si_0} I_{\mathrm{D}})^2 + 1]^{1/2} \right\}}{\frac{\alpha_{\mathrm{a}} F}{R_{\mathrm{g}} T} I_D}}{1 + (2\pi f)^2 (\mathrm{A}\exp(\frac{E_{\mathrm{a}}}{T}) \frac{\ln \left\{ \frac{1}{2Si_0} I_{\mathrm{D}} + [(\frac{1}{2Si_0} \cdot I_{\mathrm{D}})^2 + 1]^{1/2} \right\}}{\frac{\alpha_a \cdot F}{R_{\mathrm{g}} \cdot T} \cdot I_{\mathrm{D}}})^2 C_{\mathrm{D}}^2}) \quad (8)$$

3. THE EXPERIMENT

All test cells were the commercial 2.4 Ah NMC lithium-ion batteries. All tests were carried out by a battery test system (Arbin BT2000). The environmental temperature was controlled by a thermal chamber (RGD500), human-machine interaction and experimental data collections were accomplished by a host computer, as shown in Fig2.

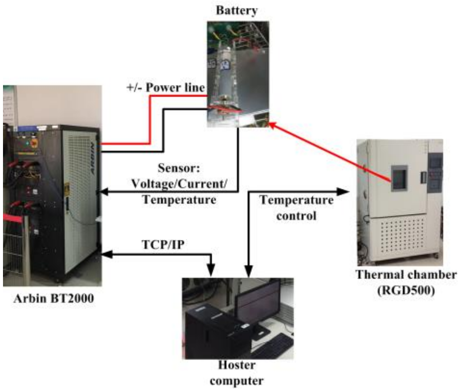

Fig.2 The configuration of the experiment.

To investigate the thermo-sensitivity and amplitude-sensitivity of battery resistance, the test batteries with 50% SOC (state of charge) are soaked in the chamber set and fixed at 0/10/20/30°C respectively for more than four hours. The Hybrid Pulse Power Characteristic (HPPC) is a sequence of the pulse cycles consisting of six different charge-discharge currents, considering that the typical current ranges of the battery in EVs are between 0-3C[15]. The sampling interval in the experiments is 1 s.

4. RESULTS AND DISCUSSION

The resistance of the traditional method is identified by genetic algorithm based on the experimental data. The results of the two methods at different temperatures are presented and discussed.

As shown in Fig.3, the reliability and validity of the proposed method are verified by the mathematical model and the traditional method. And the maximum error of TCM is lower than 2mΩ.

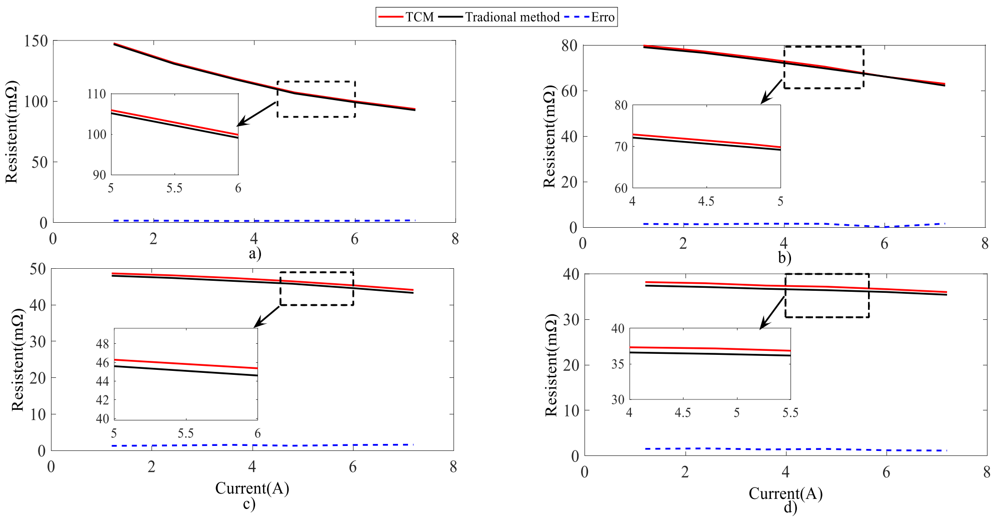

Fig.3 Results of two methods at different temperatures: a)T=0°C, b)T=10°C, c)T=20°C, d)T=30°C.

Based on the above discussion, the model-based temperature estimation during AC heating is conducted by the traditional method and the improved method. Both methods are used with different sample intervals and two different algorithms. Fig.4 shows the temperature estimation results of the traditional method and the proposed method. It is apparent that the results of the two methods are nearly identical. In contrast, the results of the traditional method are faster than the experiment, and the simulation error between the traditional method and the experiment is larger than the proposed one.

The results indicate that the new method can maintain good accuracy and reliability. Therefore, the proposed method is superior to the traditional method.

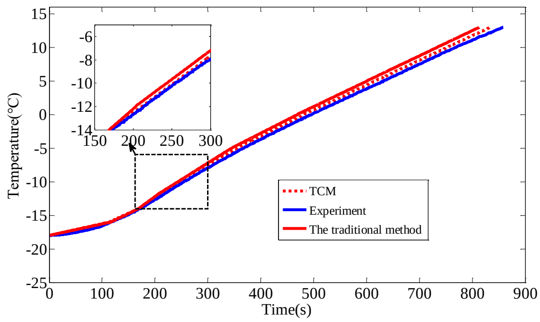

Fig.4 Simulation Results of two methods

5. CONCLUSION

In this study, a novel thermoelectric coupling model (TCM) has been developed to calculate the temperature and resistance of batteries at the different conditions, which has the following obviously advantages:

(i) The proposed method is suitable for different temperatures and currents. (ii) The presented method can calculate the battery resistance continuously and efficiently, which can maintain the maximum error within 2mΩ. (iii) The proposed method can also accurately estimate battery impedance in AC heating.

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