EVS30 Symposium
Stuttgart, Germany, October 9 - 11, 2017

The Simulation of Ni-MH Battery Based on Optimized Thevenin Model

Li Sun[1,2], Kezhen Xu[1,2], Peng Jin[1,2], Peng Lin[3]

[1]*North China University of Technology, No.5 Jinyuanzhuang Road, Shijingshan District, Beijing, China, sunli@ncut.edu.cn*

[2]*Collaborative Innovation Center of Electric Vehicles in Beijing, Beijing, China*

[3]*Beijing Institute of Technology, Beijing, China*

Summary

Ni-MH battery modeling and simulation is an important prerequisite for the study of battery characteristics and SOC estimation, so the establishment of accurate models on the battery itself and electric vehicle has important significance. The open circuit voltage is an important parameter of the battery modeling, which directly affects the accuracy of the battery model. Battery in the charge and discharge, the open circuit voltage is not the same, which is unfavorable to the modeling of the battery. So, based on the dynamic hysteresis characteristic of the open-circuit voltage of Ni-MH battery, the selection of Open-circuit voltage is optimized on the basis of the Thevenin simulation model, and the simulation model mainly optimizes the relationship between the open circuit voltage and the historical charge-discharge current direction. This paper using Hybrid Pulse Power Characterization(HPPC) test on Ni-MH power battery and Recursive Least Square method(RLS) for model parameter identification. Using Simulink to build classical Thevenin model and the optimized Thevenin model and then simulate with the input of variable current on the model. The simulation results show that the optimization model can better reflect the battery characteristics for the actual working condition of the electric vehicle and it has higher precision.

Keywords: open circuit voltage(OCV), dynamic hysteresis characteristics, optimized Thevenin model, simulation

1 Introduction

Ni-MH batteries as a little pollution, high specific energy and power, long cycle life and good safety performance in energy storage, and widely used in electric vehicles, it is the preferred object hybrid vehicle auxiliary energy. Modeling and simulation of batteries is an important prerequisite for studying the characteristics of all batteries and the SOC (State of Charge) estimation. Establishing an accurate model is of great significance for the development of BMS(Battery Management System) and improvement of the performance of electric vehicle[1].

In the paper [8], Xiuzhi Hu et al, used the hybrid pulse power characteristic test (HPPC)[2] to simulate the Thevenin battery model with an average of 12.5mV error. The simulation model did not take into account the dynamic hysteresis characteristics of the open circuit voltage(OCV) of the battery. This paper optimizes the battery model based on OCV, which improves the precision of the model and is more suitable for the complicated working condition of the current change.

This paper build the Thevenin model[3-4] in Simulink, and simulate the Ni-MH battery. The model parameters are identified by the recursive least square (RLS)[5] used HPPC test of Ni-MH battery. According to hysteresis characteristics of the OCV in Ni-MH battery, the OCV in Simulink battery model is modified by current direction, and obtained a good result. This optimized method also applies to other batteries, such as Lithium-ion battery.

2 Battery Model

2.1 Thevenin model

Thevenin model is commonly used in battery model[6], which can well describe the volt-ampere characteristics of the voltage and current during the operation of the battery, as shown in Fig. 1.

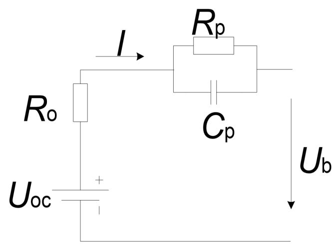


Figure 1: Thevenin model

U_b is the battery terminal voltage and can be obtained by measuring instrument, U_{oc} is the OCV, R_o is the battery ohmic resistance, R_p is the battery polarization resistance, C_p is the battery polarization capacitance, I is the battery current, the direction of the battery discharge current is the positive direction of the current.

2.2 Parameter Identification of the Thevenin Model

According to the model of Fig. 1 and the Kirchhoff law, the relationship of them can be obtained as:

$$\mathrm{U_{oc}} = U_b + U_o + U_p \tag{1}$$

$$\mathrm{U_o} = IR_o \tag{2}$$

$$\dot{\mathrm{U}}_p = -\frac{U_p}{C_p R_p} + \frac{I}{C_p} \tag{3}$$

$$\mathrm{U} = -\mathrm{U_b} + U_{oc} \tag{4}$$

Current I is the input of the battery model and U is the output of the battery model.

By the formula (1) - (4) according to Laplace transform and bilinear transformation, the difference equation of the system is obtained as follows:

$$\mathrm{U}(k) = -\alpha_1 U(k-1) + \beta_0 I(k) + \beta_1 I(k-1) \tag{5}$$

According to the formulas (1) - (5), the relationship between the difference equation parameters and the model parameters are:

$$\mathrm{R_o} = \frac{\beta_0 - \beta_1}{1-\alpha_1} \tag{6}$$

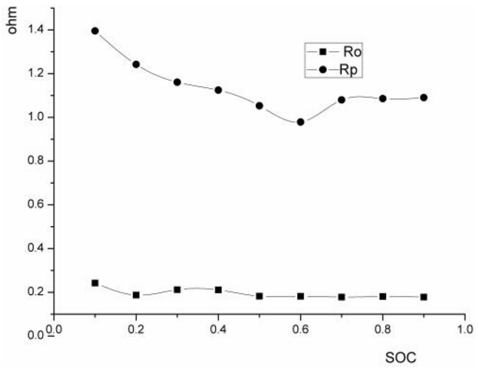
$$R_p = \frac{2(\beta_1 - \alpha_1\beta_0)}{1-\alpha_1^2} \quad (7)$$

$$C_p = \frac{T(1-\alpha_1)^2}{4(\beta_1 - \alpha_1\beta_0)} \quad (8)$$

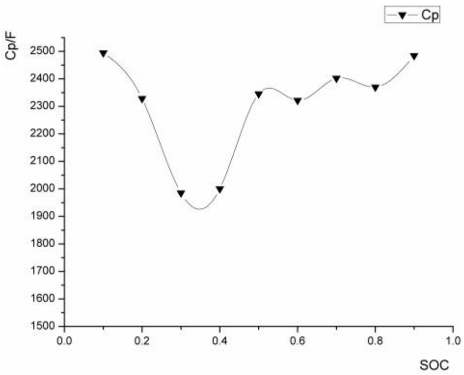
The experimental object is Ni-MH battery with 40Ah/1.2 V, and the test temperature is 25±1 ℃, based on the HPPC experiment (reference to the paper[2] — FreedomCAR Battery Test Manual For Power-Assist "Hybrid Electric Vehicles"), and the parameters of Thevenin model were identified by RLS method[7-8].

The whole experiment contains 9 HPPC tests, the concrete process are: 1) put the battery to the cut-off voltage 1.0V with 1C and pause 1 h(hour); 2) charge the battery to 40Ah with 1C, that is SOC=1.0, then pause 1 h; 3) discharge 4.0Ah with 1C and pause 1 h, then do HPPC tests; 4) repeat 3) step 8 times, put the battery to the cut-off voltage 1.0V with 1C, and pause 1 h, until complete the experiment.

The specific method of parameter identification is RLS method. The results of R_o, R_p and C_p with the SOC shown in Fig. 2. From Fig. 2, it can be seen that R_o and R_p are relatively stable in the whole process of SOC, but the C_p is higher at the both ends of SOC, that is, the battery is suitable for working in the middle of the SOC value. These parameters vary with SOC and given in the way of table in the simulation model.



(a)



(b)

Figure 2: The relationship of Ro, Rp, Cp and SOC

3 The Open Circuit Voltage of Ni-MH Battery

The open circuit voltage(OCV) of a battery refers to the terminal voltage of the battery in open circuit without polarization. Theoretically, there is a one-to-one relationship between the open circuit voltage and SOC. But in fact, for all batteries, due to the difference polarization direction of charge and discharge, the same SOC charging and discharging have a different open circuit voltage. For Ni-MH batteries, according to the charge and discharge of HPPC test, the OCV and the SOC's curve are shown in Fig. 3.

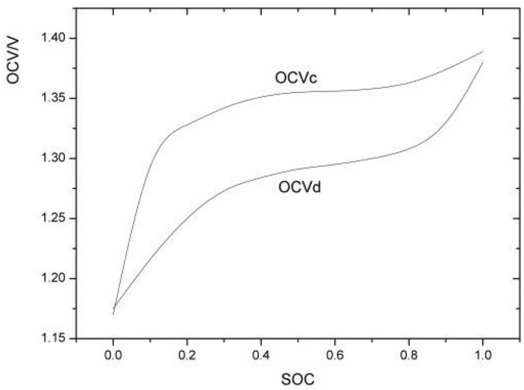


Figure 3: The relationship of OCV and SOC

Fig.3 is the dynamic hysteresis characteristics of the battery. The dynamic hysteresis characteristic means that when the pause time is limited, at the same SOC and the same pause time of the battery, charge and discharge are different form each other. The reason is that the partial polarization of the battery does not completely disappear, and the polarization direction of charge and discharge is different, too.

Two schemes were used to select the open circuit voltage. 1) When the current is positive (discharging), select the discharge parameters, the current is negative (charge), select the charge parameters; 2) according to the specific gravity of the current to select the OCV.

This paper select the second one, and based on the test as follows: test 1, put the battery fully charged (greater than 40 Ah or 1.5 V), pause 2 h, and then discharge 16Ah out of the battery with 1 C, at this time the SOC is 0.6, then pause 2 h and measured the OCV—U_1; test 2, charge the battery to 28 Ah by 1 C, that is, the SOC is 0.7, immediately discharge 4.0 Ah out of the battery by 1 C, at this time the SOC is 0.6, pause 2 h, measured the OCV —U_2.

The test result is U_2 greater than U_1. In the condition of variable current, the OCV is between the charging OCV and the discharge OCV. So, they are relate to the current polarity and the relationship of them can be defined as:

$$\mathrm{U}_{\mathrm{oc}}^{'} = \alpha_k U_{oc,c} + (1-\alpha_k) U_{oc,d} \tag{9}$$

$$\alpha_{\mathrm{k}} = \frac{m-1}{m}\alpha_{\mathrm{k-1}} + \frac{D_k}{m} \tag{10}$$

In the formula (9) and (10): $\mathrm{U}_{\mathrm{oc}}^{'}$ is the selected OCV, α_{k} is specific gravity coefficient of the current, $\mathrm{U}_{\mathrm{oc},c}$ is the OCV in charging, $\mathrm{U}_{oc,d}$ is the OCV in discharging, m is the number of the current which is not 0 before the k time, D_{k} is the direction of the current in k time. Those relationship between them are used to optimize the system in the simulation model.

4 Simulation Results

Based on the parameters of the model identified in section 2.2, the battery model in Simulink as shown in Figure 4. In Figure 4, In1(that is I) is the input of the battery simulation model system; the terminal voltage U_b is the output of the battery simulation model system; and the In2 is the real terminal voltage. Subsystem and Subsystem1 are the relationship between the current and OCV, and the optimization of the model is mainly embodied in Subsystem1. In order to verify the simulation condition of the simulation model under the variable current condition, the battery was tested by the Gigatron battery test system(BNT-600)[9]. The current input of the battery model simulation is shown in Fig. 5.

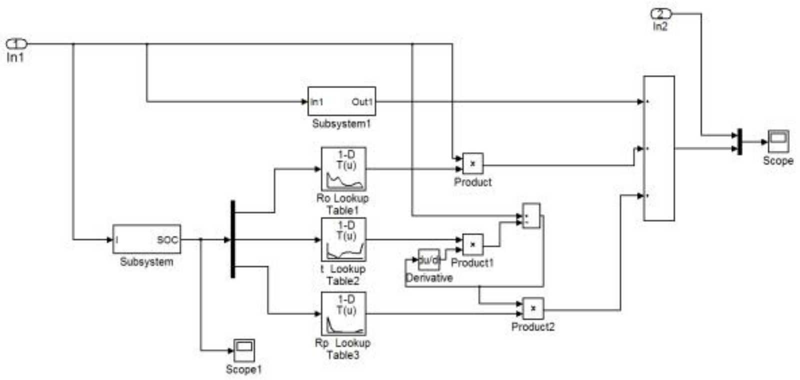


Figure 4: Simulation model of Ni-MH battery

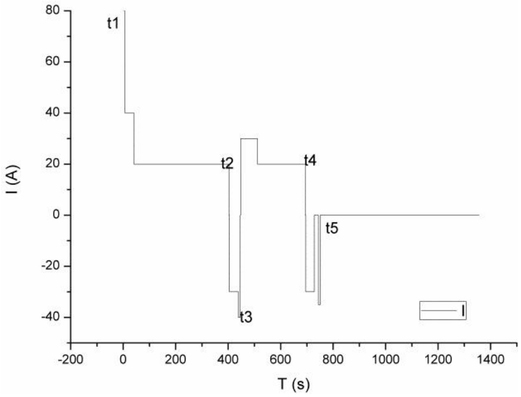


Fig.5 Test current of the battery model simulation

In the Figure 5, t1-t2 and t3-t4 are the discharge state, t2-t3 and t4-t5 are the charging state. Before the Subsystem1 is optimized, for the parameters of the OCV, in discharging state they were selected the discharge parameters and in charging state they were selected the charge parameters.

Put the battery fully charged and pause 1 h, then discharge 8Ah out of the battery with 1 C, at this time the SOC is 0.8, and the mechanism of the OCV selection is shown in Figure 6.

According to the method of selecting OCV in Fig. 6, t1-t2 and t3-t4 are the discharge state and selected the discharge parameters, t2-t3 and t4-t5 are the charging state and selected the charge parameters. The simulation results are shown in Figure 7.

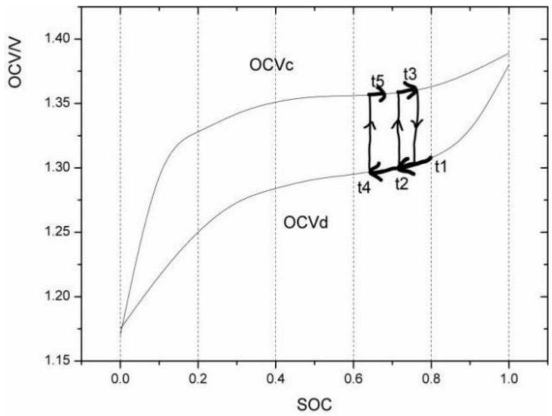


Fig.6: The selection of OCV before optimization

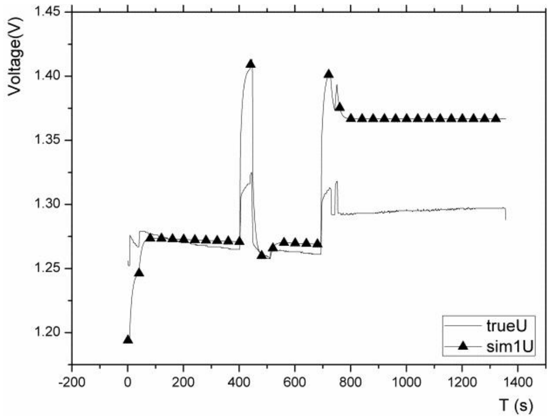


Fig.7: The comparison of simulation terminal voltage before optimization and measurement terminal voltage

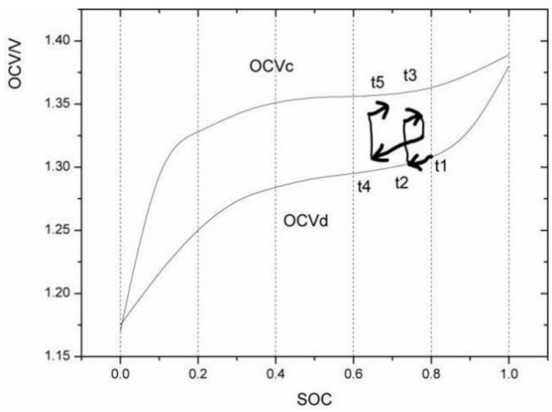


Fig.8: The selection of OCV after optimization

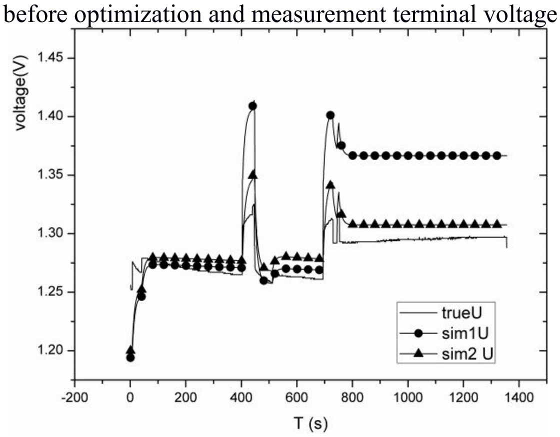


Fig.9: The comparison of simulation terminal voltage and measurement terminal voltage

As shown in the Figure 7, when the current direction is changed, the error between the terminal voltage of the simulation output and the real terminal voltage is very large, so the model needs to be optimized. According to the dynamic hysteresis characteristic of OCV in the Ni-MH battery, the Subsystem1 is optimized by the formula (9) and (10), as shown in Figure 8. In the optimized model, the simulation and measured results are shown in Figure 9.

It can be seen from Figure 9 that the optimized simulation results are more closer to the external characteristics of the real battery and it can well simulate the charging and discharging characteristics of the Ni-MH battery.

Figure 10 is the error diagram of OCV after optimized simulation and measurement, and the error between the simulated voltage and the real voltage is shown in table 1. As shown in Table 1, the maximum error rate of the optimized simulation is 0.925%, which indicates that the model has higher accuracy.

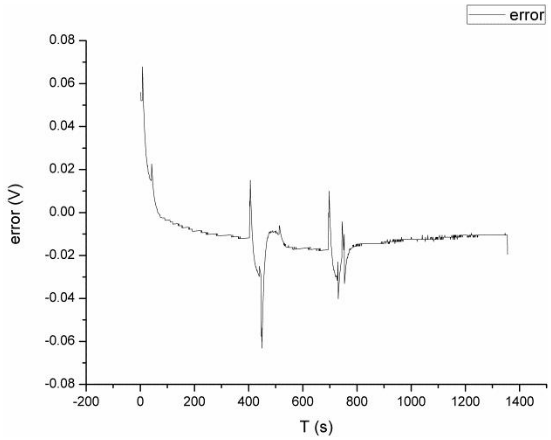


Fig.10: The error of simulation voltage and measurement voltage

Table1 The error between simulation voltage and real voltage

	Average voltage deviation (V)	Maximum deviation (V)	Maximum error rate
Un-optimized simulation results	0.0384	0.1166	3.200%
Optimized simulation results	0.0111	0.0678	0.925%

5 Conclusion

Based on the dynamic hysteresis characteristic of OCV, this paper optimizes the Thevenin model of the battery and verifies the complex dynamic characteristic of the battery — the current is changing with the times, and the simulation results show that the optimized model can better embody the characteristic of the battery and it has higher precision.

The test current of Figure 5 is very complex, if the current is relatively simple, the simulation error will be smaller.

The OCV is affected by the battery temperature, in order to verify the dynamic characteristics of the battery model, the OCV factor is mainly considered and the experimental temperature is set to 25 ℃. The simulation results show that the Thevenin model can basically describe the external characteristics of the battery at constant temperature. After optimizing the OCV, it can better meet the external characteristics of the Ni-MH battery when the current changes and verify the feasibility of the model.

This optimization method can be applied to other batteries, including lithium-ion batteries, and it will also get very good results.

Referencing

[1] Guoliang Wu, *Study on Estimation Method of Residual Electricity for Ni-MH Battery for Electric Vehicles,* Harbin Institute of Technology, 2010

[2] United States Idaho National Engineering & Environmental Laboratory, *Freedom CAR Battery Test Manual for Power-Assist Hybrid Electric Vehicles,* DOE/ID-11069, 2003

[3] Quanshi Chen et. Al., *A Review of Battery Performance Models for Electric Vehicles,* Automotive Technology, ISSN 1000-3703, 1(3), 2005,1-5

[4] Chengtao Lin et. Al., *Comparison of Equivalent Circuit Models for Current Input Electric Vehicle,* Journal of Mechanical Engineering, ISSN 0577-6686, 41(12), 2006, 76-81

[5] Hao Zhu et. Al., *Parameter identification of hybrid Ni-MH battery,* Journal of Hunan University(Natural Sciences, ISSN 1674-2974, 38(8), 2011, 19-23

[6] Xuyun Feng et. Al., *Research on MH / Ni Battery Equivalent Circuit Model,* Battery Bimonthly, ISSN 1001-1579, 37(4), 2007, 286-288

[7] Jiajia WU et. Al., *Parameter identification of hybrid Ni-MH battery based on Thevenin model,* Ageng Equipment & Vehicle Engineering, ISSN 1673-3142, 52 (1), 2014, 1-5

[8] Xiuzhi Hu et. Al., *Simulation of Hydrogen-Nickel Battery Based on Thevenin Model,* Chinese Journal of Power Sources, ISSN 1002-087X, 138(11), 2014, 2063-2065

[9] Digatron Technical Services, *Battery Test System BTS-600,* Digatron(Qingdao) Electronic Co.,LTD.

Authors

Li Sun is the professor of Northern University of Technology. Prof. Sun is currently the Secretary-General of the Electric Vehicle Professional Committee of China Electrotechnical Society and the Director of Collaborative Innovation Center of Electric Vehicles in Beijing. And he has long been engaged in the field of battery research, research comprising: modeling and application battery, battery management technology, electric vehicle power system optimization matching and control technology, CAN bus communication technology.

Kezhen XU is a postgraduate student in North China University of Technology, major in Electric Engineering. Mrs. Xu’s research direction is Electric vehicle technology and battery modeling and simulation.