Comparative study of Thevenin model and GNL simplified model based on kalman filter in SOC estimation

Jianhao Fang, Liankui Qiu, Xincheng Li

***Abstract*— To explore the importance of establishing battery models during the battery SOC estimation process. At present, the most commonly used Thevenin model and Gnl model, on the basis of the two models, the first comparison of the voltage waveform of the discharge two fitted with the actual static voltage waveform, the Gnl model in the process of fitting in voltage precision is higher than that of Thevenin model, have a stronger degree of simulation. With the extended Kalman filter algorithm, further confirm the use of the two model in SOC prediction model, the equation of state parameter identification by using the least square method, the relationship between calculation model and parameters of SOC cell, and obtained the simulation results and the actual conditions and results. After many experiments, found in the process of using the extended battery SOC estimation Kalman filter algorithm, battery model selection has an important influence on the experimental results, and the results show that Gnl model is better than the Thevenin model, the prediction error is reduced to 4%.**

***Index Terms*—Extended kalman filter; Thevenin model; Gnl model; SOC**

I. INTRODUCTION

In recent years, the research of vehicle power battery has a great development, but there still exist some problems, one of the most important problem is the battery state of charge (state of charge) estimation problem of SOC, and establish the precise model of the battery is basics of SOC estimated .There are many definitions of the battery SOC, and many researchers consider the remaining electricity and charged state (SOC) as a concept, but strictly speaking, there are differences between the them.The remaining power refers to the amount of charge released from all possible chemical reactions, while SOC refers to under certain conditions, the number of battery charge can release, SOC can accurately indicate that the battery more than remaining battery state of charge.There are many algorithms for SOC estimates , such as: open circuit voltage method, current time integral method, resistance method, Kalman filtering algorithm, neural network algorithm.However,these methods have their own shortcomings，For example, the open circuit voltage method requires the battery to remain stationary for a period of time before the open circuit voltage is measured；The current time integral method depends on theinitial value of SOC, If the initial value is not accurate, it will produce accumulative error；The Kalman filter algorithm can eliminate the accumulated error, but it has strong dependence on the battery model。From the research of these methods, it can be seen that either method can not be separated from the establishment of battery model，the accurate battery model is very important for the study of battery charging state。In this paper, the extended Kalman filtering algorithm is used to study two widely used battery models --Thevenin and GNL simplified models.Through simulation experiments, the advantages and disadvantages of the two methods in the research of battery SOC are compared, which lays a foundation for further research.Compared with traditional algorithms, such as open circuit voltage method, internal resistance method, current integration method and so on, extended kalman filtering method can make prediction achieve higher accuracy.

***Manuscript received Feb, 2013*.**

***Jianhao Fang**, College of Electrical engineering, Henan University of science and technology, Luoyang, China .*

***Liankui Qiu**, College of Electrical engineering, Henan University of science and technology, Luoyang,China .*

***Xincheng Li**, College of Electrical engineering, Henan University of science and technology, Luoyang, China .*

II. EXPERIMENTAL

A. *Equivalent Circuit Model*

The equivalent circuit models commonly used at home and abroad are: Rint model, Thevenin model, PNGV model, GNNL model, neural network model, etc.Considering the practicability of the battery model, the equivalent circuit model of the battery is neither simple nor too complex. The Thevenin model and the GNL model are widely used in these models,The following is the comparison of the two models.

B. *Thevenin Model*

The circuit diagram of the Thevenin model is shown in Figure 1. The model consists ofa constant voltage source, a capacitor and two resistors.The model describes the open circuit voltage of a battery with ideal constant voltage source Uoc,The resistance R0 represents the ohmic resistance of the battery,The resistanc R_P represents the polarization resistance of the battery,A network composed of a resistor R_P and a capacitor C_P can describe the planned function of the battery,The voltage at both ends represents the polarization voltage of the battery.

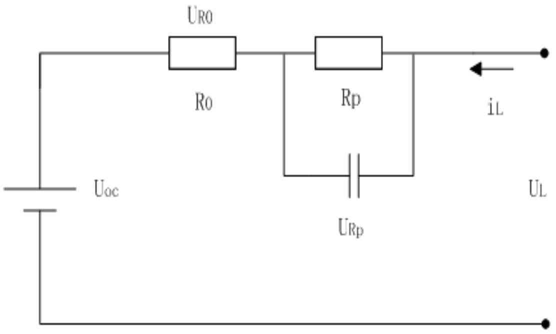

Fig.1.Thevenin model

Assuming that the charging current is positive direction, the state space equation of the model can be obtained according to the Kirchhoff voltage and current law:

State equation

$$U_p = -\frac{U_p}{C_p R_p} + \frac{i_l}{C_p} \qquad (1)$$

Output equation

$$U_L = U_P + U_{OC} + R_0 i_L \qquad (2)$$

For (1) and (2) two type discretization can be obtained (3) and (4)

$$U_p(K+1) = U_p(K)e^{-T/\tau_p} + i_L(k)R_p(1-e^{-T/\tau_p}) \qquad (3)$$

$$U_L(k) = U_{oc} + U_P(k) + i_L(k)R_0 \qquad (4)$$

C. General Nonlincar(GNL)Model

The circuit diagram of the simplified model of GNL is shown in Figure 2，The model consists of a constant voltage source, two capacitors and four resistors.The ideal voltage source Uoc for the model represents the open circuit voltage，The resistance *R0* is the ohm internal resistance of the battery，The resistance Rpp represents the internal resistance of the battery's concentration plan，A network consisting of a resistor *Rpp* and a capacitor *Cpp* can describe the concentration polarization of a battery.This is a simplified GNL model without considering the energy storage capacity.

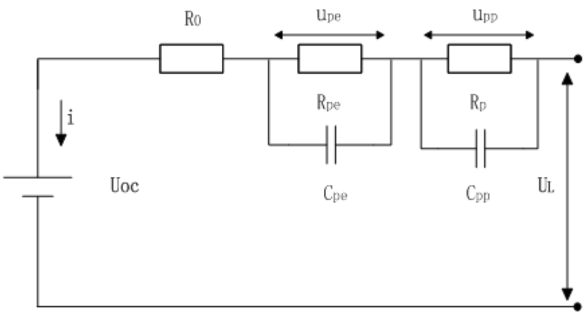

Fig.2. GNL model

State equation：

$$\begin{bmatrix} \dot{U}_{pe} \\ \dot{U}_{pp} \end{bmatrix} = \begin{bmatrix} -\frac{1}{C_{pe}R_{pe}} & 0 \\ 0 & -\frac{1}{C_{pp}R_{pp}} \end{bmatrix} \begin{bmatrix} U_{pe} \\ U_{pp} \end{bmatrix} + \begin{bmatrix} \frac{1}{C_{pe}} \\ \frac{1}{C_{pp}} \end{bmatrix} i_L$$

(5)

Output equation:

$$U_L = \begin{bmatrix} 1 & 1 \end{bmatrix} \begin{bmatrix} U_{pe} \\ U_{pp} \end{bmatrix} + R_0 i_L + U_{oc} \qquad (6)$$

Discretization of state equation and output equation：

$$U_{PP}(k+1) = U_p(k)e^{-T/\tau_p} + i_L(k)R_{PP}(1-e^{-T/\tau_p}) \qquad (7)$$

$$U_{Pe}(k+1) = U_{pe}(k)e^{-T/\tau_{pe}} + i_L(k)R_{Pe}(1-e^{-T/\tau_{pe}}) \qquad (8)$$

$$U_L(k) = U_{oc} + U_{PP}(k) + U_{Pe}(k) + i_L(k)R_0 \qquad (9)$$

Both the Thevenin model and the GNL simplified model take the charging current as the forward current.

D. Parameter Identification of Model

In the Thevenvin model and the GNL simplified model, the parameters need to be identified are the internal resistance and time constant of the battery.The parameters that the thevenvin model needs to identify are ohmic resistance R_0 ,Polarization internal resistance R_p ,time constant τ_p .GNL simplified model needs to identify parameters with ohmic resistance R_0 ,Polarization internal resistance R_{pp} ,time constant τ_{pp} , τ_{pe} .A method of stationary discharge or charging static discharge of the battery is presented in this paper to get parameters of battery model.

The battery was discharged 600s after 1000mA and placed 3H, and the voltage characteristics of the battery are shown in the diagram .

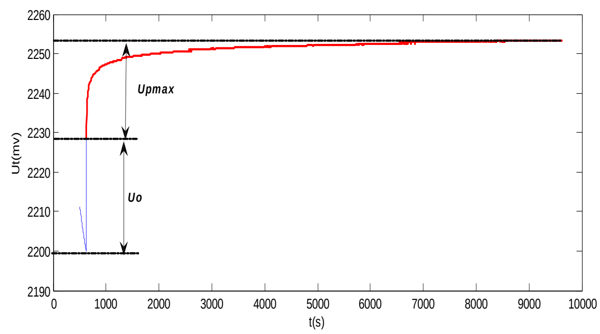

Fig.3.Voltage curve after discharging last 600s at 1A discharge current

The voltage will rise suddenly after the battery stops discharging and it will take some time to settle down，The reason is that the current suddenly ceases to be zero after discharge, and the ohmic resistance produced by ohmic resistance disappears instantaneously, but the polarization of the battery does not disappear immediately.The polarization voltage does not change to zero immediately. As the battery is stationary, the polarization voltage drops to zero，The

All Rights Reserved © 2017 IJARCET

voltage at both ends of the battery is the open circuit voltage of the current SOC.Therefore, the ohmic resistance and polarization resistance of the

This method is used in the Thevwnin model：

$$U_p(t) = U_{P\max} e^{-t/\tau_p} \tag{10}$$

$$u(t) = U_{P\max}(1-e^{-t/\tau_p}) \tag{11}$$

In the formula $u(t)$, $U_{p\max}$ can be obtained through experiments,Using the least square method to fit the experimental data $u(t)$, the value of time constant τ_p can be obtained.

It can be deduced from the simplified GNL model：

$$U_p(t) = U_{PP\max} e^{-t/\tau_{pp}} + U_{Pe\max} e^{-t/\tau_{pe}} \tag{12}$$

$$u(t) = U_{P\max}[\mu(1-e^{-t/\tau_{pe}}) + (1-\mu)(1-e^{-t/\tau_{pp}}) \tag{13}$$

$$R_{Pe} = \mu R_p \tag{14}$$

$$R_{PP} = (1-\mu) R_p \tag{15}$$

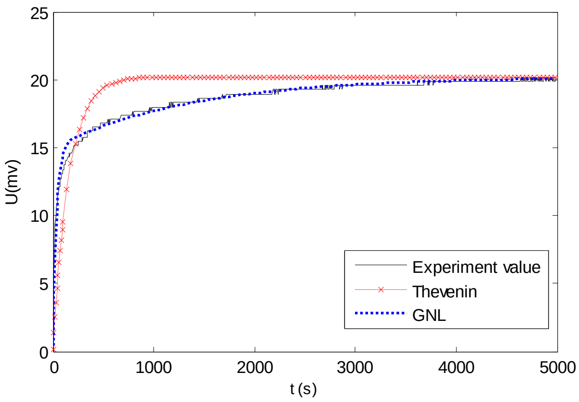

Fig.4.Comparison of the experiment value of Upmax-Up(t) and the value frome the model fitting

The parameters identified by this method are substituted into the model respectively.The simulation results of GNL simplified model and Thevenin model are compared in the graph.It can be seen that the simulation value of the GNL simplified model is very close to the experimental value,that illustrate the accuracy of GNL simplified model is higher than that of Thevenin model.The GNL model can accurately describe the battery system.In order to further verify this model, simulation analysis is carried out by combining the Kalman filtering algorithm.

III. LGORITHM VERIFICATION AND RESULT

A . Extended kalman Filtering

kalman is mainly used to deal with linear discrete systems.The extended kalman filtering algorithm used in this paper is an excellent algorithm to deal with nonlinear systems.The battery cell is a nonlinear dynamic system.The state value of this moment is estimated by using the estimated and observed values of the battery state at a previous moment.The equivalent discrete equation is as follows:

$$\begin{cases} x_{k+1} = f(x_k, u_k) + w_k \\ y = g(x_k, u_k) + v_k \end{cases} \tag{16}$$

Expanding the function $f(x_k, u_k)$ 、 $g(x_k, u_k)$ by Taylor formula to reach the purpose of linearization of nonlinear function：

$$f(x_k, u_k) \approx f(\hat{x}_k, u_k) + \frac{\partial f(x_k, u_k)}{\partial x_k}\Big|_{x_k=\hat{x}_k}(x_k - \hat{x}_k) \tag{17}$$

$$g(x_k, u_k) \approx g(\hat{x}_k, u_k) + \frac{\partial g(x_k, u_k)}{\partial x_k}\Big|_{x_k=\hat{x}_k}(x_k - \hat{x}_k) \tag{18}$$

$$A_k = \frac{\partial f(x_k, u_k)}{\partial x_k}\Big|_{x_k=\hat{x}_k} \quad C_k = \frac{\partial g(x_k, u_k)}{\partial x_k}\Big|_{x_k=\hat{x}_k} \tag{19}$$

B. Algorithm verification

Put the battery at room temperature (25℃).The working condition of the battery in actual use is simulated by experiment charging and discharging.Fig. 5 is the change of current and voltage under the experimental condition.From the diagram, the battery charge and discharge alternately.The SOC of the battery is calculated by collecting the capacity of the battery charging and discharging.

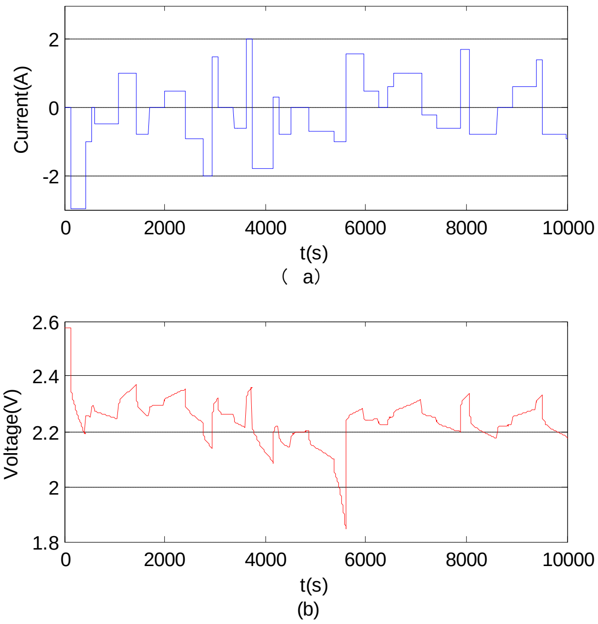

Fig.5.Current and voltage wave forms the test condition

C. Simulation Result

The results of simulation are compared in Figure 6 and Figure 7.The SOC simulation value is compared with the experimental value based on the Thevenin model and the GNL model.Figure 8 is the error comparison of simulation results.It can be seen from the diagram that the errors of the two models converge within 4%.However, the simplified GNL model results slightly higher than that of Thevenin results which can reach 3%.Results of synthesis graph 4,The GNL model is better than the Thevenin model in estimating the battery SOC by kalman filtering.

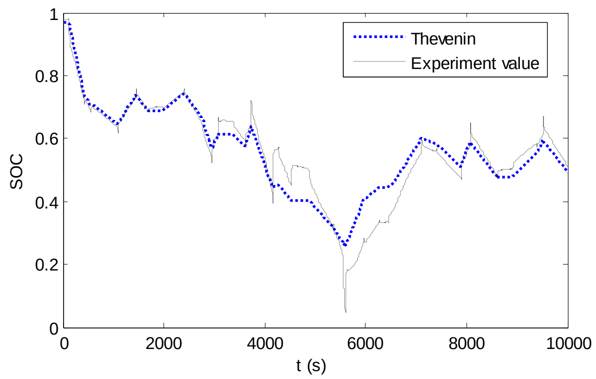

Fig.6.Comparison of the estimated SOC based on Thevenin model and the soc from experiment

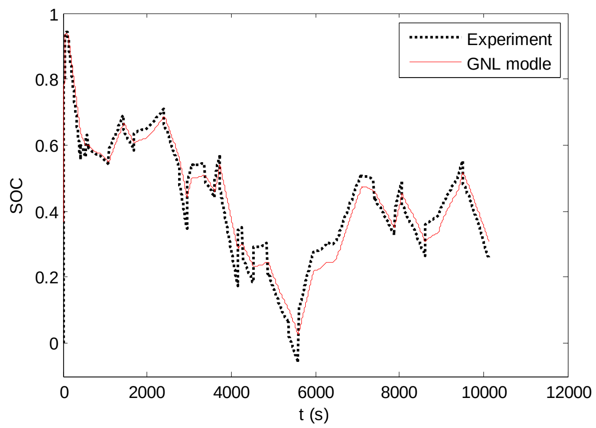

Fig.7.Comparison of the estimated SOC based on GNL model and the soc from experiment

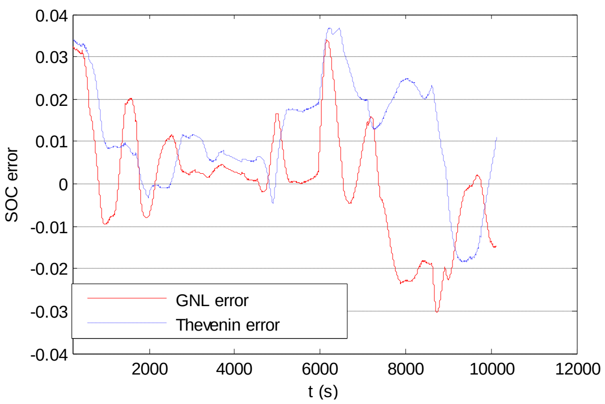

Fig.8.Comparison of the erroe of SOC estimated byThevenin model and the by GNL model

IV. CONCLUSIONS

In this paper, SOC estimation of power battery is studied based on extended Kalman filtering algorithm .We built the battery power model, Thevenin model and Gnl model.The advantages and disadvantages of the two models in the application of Kalman filter to predict the battery SOC are deeply studied and the simulation results are obtained.By comparing the experimental results, we can see that the accuracy of thevenin model in SOC estimation by Kalman filtering is lower than that of Gnl model.And The GNL model is more close to the actual battery performance and can reduce the error to less than 4%.

The method is mainly dependent on the application of Kalman filtering and the application of other algorithms in estimating battery SOC has not been studied deeply.The conclusions presented in this paper can lay the foundation for the follow-up research of battery work.

V REFERENCES

[1] Yuanqi Fang,Ximing Cheng,Yilin Yin et al. "SOC Estimation of Lit hium-ion Battery Packs Basedon Thevenin Model[C].//*Mechanical engineering, industrial electronics and informatization*.2013:201-205.

[2] Chen, Bing,Ma, Haodong,Fang, Hongzheng et al. "An approach for state of charge estimation of Li-ion battery based on Thevenin equival ent circuit model[C].//*IEEE 2014 Prognostics and SystemHealth Man agement Conference " : IEEE 2014 Prognostics and System Health M anagement Conference (PHM-2014 Hunan)*, 24-27 August 2014, Zha ngjiajie, China.2014:647-652.

[3] He, H.,Xiong, R.,Zhang, X. et al. "State-of-Charge Estimation of the Lithium-Ion Battery Using an Adaptive Extended Kalman Filter Base d on an Improved Thevenin Model" [J].*IEEE Transactions on Veh icular Technology*,2011,60(4):1461-1469.

[4] Jiani Du,Zhitao Liu,Youyi Wang et al. "State of charge estimation for Li-ion battery based on model from extreme learning machine " [J]. *Control engineering practice*,2014,26:11-19.

[5] Liang-Bi CHEN. "A System-Level Model of Design Space Explorati n for a Tile-Based 3D Graphics SoC Refinement" [J].*IEICE Transact ons on fundamentals of electronics, communications & com puter sciences*,2009, E92/A(12):3193-3202.

[6] Dai Haifeng,Wei Xuezhe,Sun Zechang et al. "Model based SOC estim ation for high-power Li-ion battery packs used on FCHV" [J]. *High Technology Letters*,2007,13(3):322-326.

[7] Yuanbin Yu,Zhou Cai,Kai Peng et al. "SOC Estimation Strategy and Its Accuracy Analysis" [C].//*Advanced Energy Technology*, Part 1: S elected, peer reviewed papers from the 2014 3rd International Confere nceon Energy and Environmental Protection(ICEEP 2014),April 26-2 8, 2014, Xi an, China.2014:790-795.

[8] Xiaopeng Chen,Weixiang Shen,Zhenwei Cao et al. "Adaptive gain sl iding mode observer for state of charge estimation based on combined battery equivalent circuit model" [J].*Computers &Chemica l Engineering: An International Journal of Computer Applications in Chemical Engineering*,2014,64:114-123.

[9] Wang, Wenguan,Chung, Henry Shu-Hung,Zhang, Jun et al. "Near-R eal-Time Parameter Estimation of an Electrical Battery Model With M ultiple Time Constants and SOC-Dependent Capacitance" [J].*IEEE T ransactions on Power Electronics*,2014,29(11):5905-5920.

[10] Novie Ayub Windarko,Jaeho Choi. "LiPB Battery SOC Estimation U sing Extended Kalman Filter Improved with Variation of Single Domi nant Parameter" [J].*Journal of power electronics: A publications of t he Korean Institute of Power Electronics*,2012,12(1):40-48.

[11] Xu Long,Wang Junping,Chen Quanshi et al. "Kalman filtering state of charge estimation for battery management system based on a stochasti ic fuzzy neural network battery model" [J].*Energy conversion & amp; management*,2012,53(1):33-39.

All Rights Reserved © 2017 IJARCET