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Internal Resistance Identification in Vehicle Power Lithium-ion Battery and Application in Lifetime Evaluation

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***Abstract*—According to the characteristic analysis of lithium-ion power battery, battery accelerate life test is carried out to obtain the relevant conclusions such as the changing trend of battery ohmic resistance in different conditions. Battery ohmic resistance is consequently set up as the Evaluation Index of lifetime. Battery ohmic resistance equivalent model is established aiming at the real-time identification of lithium-ion battery ohmic resistance. Based on this model, the real-time identification is achieved by the experimental collected data and recursive least squares algorithm. The adoption of battery ohmic resistance identification algorithm can be applied to provide some useful reference for the battery life state estimation.**

Keywords: Lithium-ion battery; Internal resistance; Equivalent model; Lifetime evaluation

I. INTRODUCTION

Battery internal resistance is one of the most important characteristic parameters to measure performance and lifetime of the battery. Lithium-ion battery resistance is divided into ohmic resistance and polarization resistance. The ohmic resistance consists of electrode materials resistance, electrolytes resistance, separators resistance and contact resistance among various components. Polarized resistance is the resistance caused by polarization in electrochemical reaction, including the resistance caused by electrochemical polarization and concentration polarization. Internal resistance is affected by battery materials, manufacturing processes, battery structure and other factors.

The characteristics of lithium-ion battery internal resistance can be shown in Figure 1，when the current is loaded, battery voltage will have a jump-decline at first, and then the battery voltage slowly begins to decline; After the removal of the load current, voltage also will have a jump-rebound, and then begins to increase slowly. Line segment OR indicates battery voltage drop caused by ohmic resistance; line segment PR indicates battery voltage drop caused by polarization resistance. Clearly, according to Ohms Law, the voltage drop divided by the discharge current is equal to the corresponding resistance.

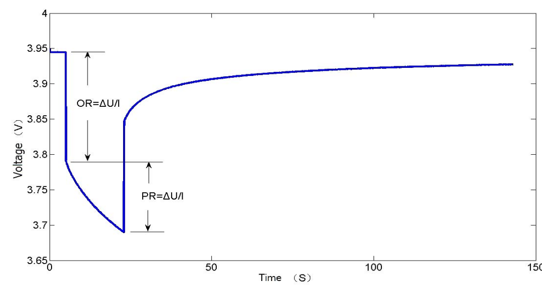

Figure.1 The pulse discharge response curve of lithium-ion battery

Increase of battery internal resistance would lower battery discharge voltage, shorten discharge time, and have a direct impact on the battery's power characteristics. And in the new energy vehicle application, such as" Oil-Electric hybrid program" and "Electric-Electric hybrid program ", battery works as auxiliary power, generally in a constantly changing working condition such as short-term high-current charge or discharge, it requires battery has high-power characteristics. Therefore, the internal resistance should be an important parameter to assess the performance of battery in the application of power battery, the real-time accurate examination of battery internal resistance in particular ohmic internal resistance should one of the fundamental tasks for battery management system.

In practice, through discharging to obtain information of battery capacity or loading pulse in order to obtain internal resistance information is very difficult to achieve, Whether standing pulse discharging or standards discharging will spend long time, can not meet the requirements of battery management system’s real-time detection and evaluation. Hence we need to access rapid evaluation method for automobile power battery lifetime. The power battery system can be simulated by battery equivalent circuit model, Based on this model, battery’s parameters in various stages of experiment can be accessed by the experimental

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collected data and identification algorithm, and according to the experimental decay tendency of battery lifetime, the battery lifetime can be evaluated accurately.

At present, related research work at this aspect is still relatively few, this paper makes an attempt to study on it.

II. Equivalent Model For Lithium-ion Battery Internal Resistance

In fact, the battery internal resistance can not be measured directly, it only can be obtain by measuring battery's voltage and current. Typical one is the pulse discharge method, that is, as shown in Figure 1, when current is being loaded, the battery interface resistance is equal to the corresponding loss of voltage divided by discharging current. The method is simple and accurate for the calibration of the internal resistance; but it needs the battery in a state of charge balance, can not meet the demand of on-line measurement and practical application. Based on the requirements of power battery for electric automobile, by the help of the establishment of equivalent model for battery resistance and the identification of related parameter, real-time measurement of resistance can be realized.

At present, a lot of equivalent circuit models for vehicle power battery have been built, typical one is the standard battery model from "PNGV battery test manual", it was also used in 2003 "FreedomCAR battery test manual"[2]. The experiments show that the model can simulate the complex reaction in battery charge and discharge process, but the complexity of this model also brings difficulty to transplanting of model-based algorithm. For the consideration of cost, the model needs further simplification.

Considering that the battery's internal resistance model should focus on the transient response and the lithium-ion battery's pulse characteristic which shown in Figure 1 ,at the same time combine with the typical model of PNGV, the equivalent model can be got for lithium-ion battery internal resistance as shown in Figure 2. In this model, ideal voltage source U_{oc} simulates open-circuit voltage of the battery, reflects the DC bias of the battery; R_O is the battery internal ohmic resistance, manifests the sudden falling of battery's voltage under current excitation; capacitors C_p and resistors R_p in parallel describe the polarization of the battery and represent the internal polarized resistance.

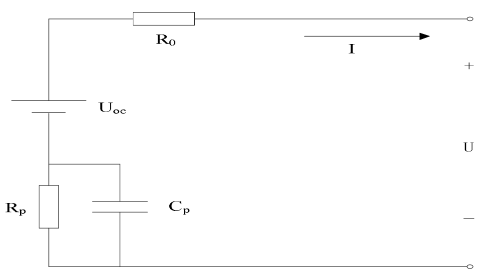

Figure.2 Simplified equivalent circuit model for lithium-ion battery

III. Evaluation Method For Lifetime Of Lithium-ion Battery

Taking a certain type 8Ah lithium manganate power battery as test sample, the experiment of accelerating battery life is carried out [5] [6]. Figure 3 describes the trend that battery available capacity 、 polarization resistance and ohmic resistance change along with attenuation of the battery (this battery works in the condition of 40 ℃, with the current rate of 4C for full charge and discharge). In order to facilitate comparison, normalization processing and exponential fitting method have been taken. Obviously the battery available capacity decreases along with the unceasing increase of battery operating cycle, the battery internal resistance manifests the overall tendency which increases along with the weakness of battery lifetime, but increased range of polarization internal resistance obvious much smaller than ohmic internal resistance, therefore the major part of battery internal resistance increase is caused by ohm internal resistance. At the same time, the battery available capacity can only obtain through complete discharging, it is unable to meat the requirement of real-time measurement in practice. Therefore, in the application of actual vehicle, when evaluate power battery performance what should pay most attention is the ohmic internal resistance. In battery resistance equivalent model shown in Figure 2, the identification of ohmic interface resistance R_O is very important.

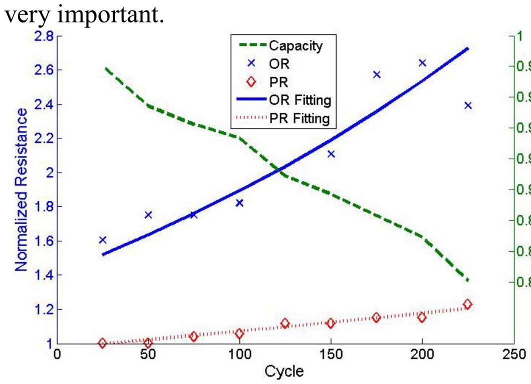

Figure.3.The changing trend of battery resistances

At the same time, battery lifetime experiment indicated that discharge current, electric discharge depth and ambient temperature all have influence on ohmic internal resistance. In order to remove the disturbance of stochastic noise and measuring error, experimental results are processed through exponential fitting method; In order to remove influence of inconsistency among batteries, the experimental data is carried on normalized processing.

As the lithium-ion battery accelerated life experiment (under constant temperature 40℃ for full charging and discharging) shown in Figure 4, the change of ohmic internal resistance under the different current for charging and discharging. Obviously, the battery ohmic internal resistance increases faster along with the enhancement of charging and discharging current.

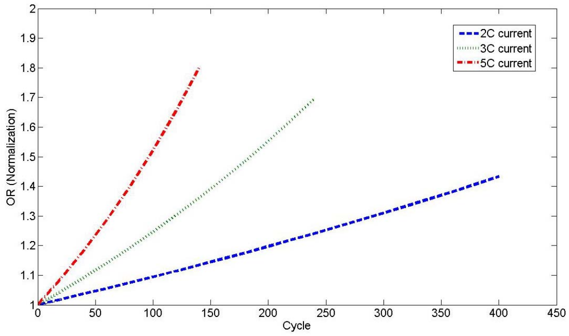

Figure.4. The changing trend of internal resistance under different current rate

Setting working conditions that different charging and discharging depth (DOD) (for example 20%DOD means that battery works from 100%SOC(battery's state of charge) to 80%SOC), the constant temperature (40℃), the constant current to charge and discharge circularly. Figure 5 shows changing trend of the lithium-ion battery internal resistance under different DOD. The battery ohmic internal resistance increases along with the enhancement of DOD.

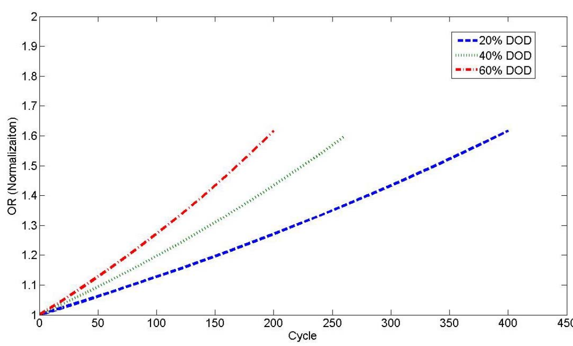

Fig.5. The changing trend of internal resistance under different DOD

Figure 6 shows the change of ohmic internal resistance, when the battery works in different ambient temperature but the same charge and discharge conditions. The rise of ohmic internal resistance has obvious difference along with temperature increasing.

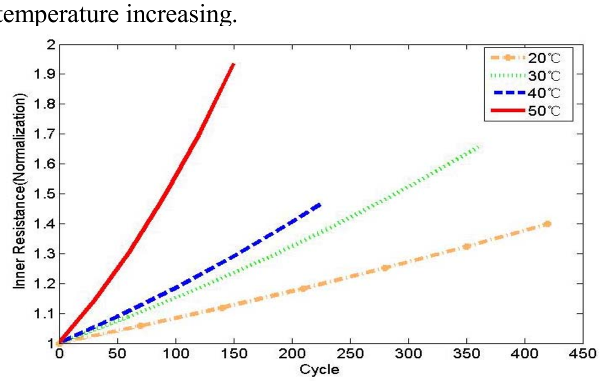

Figure.6. The changing trend of internal resistance under different ambient temperature

Moreover, the experiment discovers the relations between battery ohmic internal resistance and battery's state of charge (SOC) as shown in Figure 7, in lithium-ion battery voltage platform area (SOC is between 30% and 80%), ohmic internal resistance of battery basically maintains stable, battery's SOC condition has very small influence on it; and under the different current excitation, the ohmic internal resistance of lithium-ion battery almost has no change, that indicates the ohmic internal resistance is the embodiment of battery's own conditions.

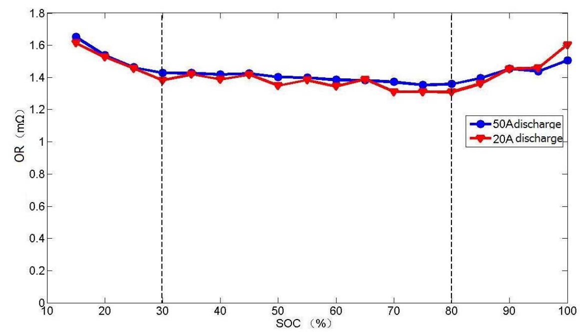

Figure.7. The relationship between ohmic resistance and SOC

In the synthesis, increase of battery ohmic internal resistance is the prominent performance of curtailment of electric automobile battery lifetime as well as weakness of performance, and the increasing range of battery ohmic internal resistance intensifies along with enhancement of operating condition. Discussing the three major factors effecting lithium-ion battery interface resistance, ambient temperature is the most influential one; the influence of current and DOD are relatively weak. Through the ohmic interface resistance's real-time examination, and according to operating condition, some useful reference for battery lifetime evaluation can be got.

IV. Transfer Function And Algorithm Identification For Battery Internal Resistance Model

Figure 2 shows the third-order linearized equivalent circuit model of lithium-ion battery, the transfer function can be inferred as follows:

When system is in normal operation, battery's input signal is the current i , taking discharging current as positive value, charging current as negative one, output signal is battery's voltage u. According to the model's voltage relationship:

$$u = u_{R_0} + u_{oc} + u_p$$

after this system is conducted by dispersing processing, suppose the zero-order holder transfer function is $G_0(s) = (1 - e^{-T_s}) / S$

may infer the following frequency-domain analysis formula:

$$G(s)=G_0(s)*G_p(s)=G_1(s)*\frac{1}{s}G_p(s)$$
$$=(1-e^{-T_s})*(-\frac{R_0}{s}-\frac{R_p}{s}+\frac{R_p}{s+\frac{1}{R_pC_p}})$$

T is the system dispersing processing sampling length of stride.

By the way of Z Transformation, the difference equation on this system can be obtained as follow:

$$U_k=aU_{k-1}-R_0I_k+[a(R_0+R_p)-R_p]I_{k-1}$$

and $a=e^{-\frac{T}{R_pC_p}}$

The parameters should be identified are R_0, a, R_p and C_p, C_p can get from $a=e^{-\frac{T}{R_pC_p}}$.

After determination of model structure, model's parameter can be identified by using the data which obtains from experiment. In the domain of parameter identification, the least square method is an important basic one; on the other hand, considering that realization of adaptive control and tracking the variable parameter, recursive algorithm must be used to obtain online identification, therefore, the recursive least square method is used in this paper to identify the parameter [3].

The basic philosophy of recursive least square method can summarize as below:

This time (new) estimated value =
previous time (old) estimated value + correction term

By this kind of recursive least square method, computer does not need to store and repeatedly calculate the complete former input and output data, therefore, this may reduce computer's data reserves and the computation work greatly, so this method is especially suitable for real-time calculation and identification [4].

V. CONFIRMATION OF INTERNAL RESISTANCE EQUIVALENT MODEL

Taking a certain type 8Ah lithium-ion power battery as the test sample, the lithium-ion battery internal resistance model established in this paper and the power battery electric circuit model established by PNGV are all simulated by MATLAB/Simulink, the real-time identification can be carried out through the recursive least square method, after comparison of ohmic resistances obtain from the different models (value of R_0), the serviceability of this simplified model to identify ohmic internal resistance can be confirmed.

Through the platform experiment in “start” series fuel cell vehicle, taking the actual values of current excitation and the voltage as the input of model, identification algorithm can be carried out, partial result can be seen in Figure 8.

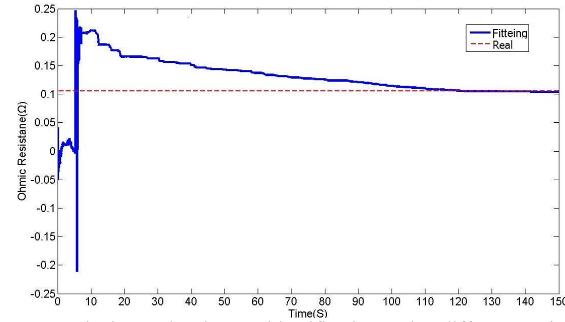

Figure.8. The internal resistance identification under different equivalent model

As shown in Figure 8 above, freely picking the initial value of resistance(using 1mΩ as initial value of resistance in Figure 8), the ohmic internal resistance will converge rapidly in 15 seconds, the convergence curves is close; its precision satisfies the actual request basically.

Moreover, through establishing stochastic operating condition, using the electronic load MACCOR to carry on load for battery, putting the value of the current excitation and the gathering voltage as input, the identification algorithm for internal resistance can be carried out, its flow is shown in Figure 9:

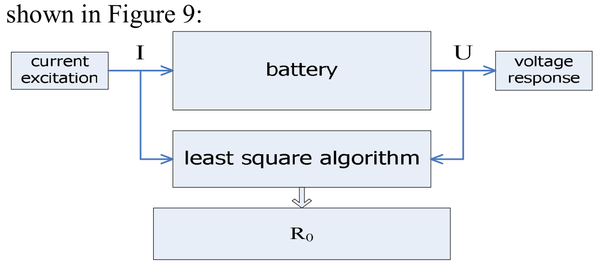

Figure.9. Lithium-ion battery internal resistance identification flow chart

Comparing the ohmic internal resistance obtained by parameter identification of this equivalent model with the actual value of resistance obtained by impulsive discharge method, the error can be controlled in 2%, the accuracy of this internal resistance model can be confirmed.

VI. PROCESS FOR LIFETIME EVALUATION

In summary, the process to carry on the lifetime evaluation for lithium-ion power battery can be concluded in Figure 10 :

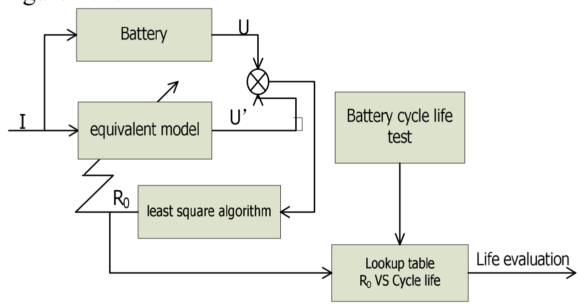

Fig.10. Battery lifetime evaluation flow

Through taking actual values of current excitation and voltage response as the input of equivalent model, with the aid of parameter identification which based on recursive least square method, the ohmic internal resistance of the battery R0 can be obtained. By the datum gotten from battery accelerate lifetime experiment, the changing trend of battery's ohmic internal resistance under the different operating condition can be induced, and battery life condition can be obtained according to the above, so the battery lifetime will be evaluated at last.

VII. SUMMARY

Based on present general battery model, the characteristic of lithium-ion power battery internal resistance is analyzed in this paper, and based on it accelerate lifetime experiment is developed to obtain the evaluating indicator for lithium-ion power battery lifetime under the different operating conditions, and the simplified equivalent circuit model is established at last. Through the simulation experiment and the comparison with the experiment results, the serviceability of this model for internal resistance identification can be confirmed, this method reduce operand of identification algorithm greatly, so the rapid assessment for interface resistance of lithium-ion battery can be realized, it also provide the condition for the transplant of algorithm and on-line identification for internal resistance. In view of the fact that characteristic of fuel cell and lithium-ion battery as well as the equivalent circuit model's similarity, this analysis method and simplified equivalent model established in this paper have the possibility to be used in fuel cell system, so further analytical study will be worth doing in future work.

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