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Battery SOH estimation method based on incremental capacity analysis to initialize traditional SOH estimation model parameters

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Abstract: This paper focuses on the problem that the traditional battery mathematical model depends very much on the initial value of the state of health (SOH) related parameters during parameter identification. An improved SOH estimation method is proposed. This method first uses the Incremental Capacity Analysis (ICA) method to estimate the battery SOH. Then it uses the estimated value to initialize the SOH related parameters in the traditional model. It can ensure that the optimization range of Genetic Algorithm (GA) parameter identification is small, and can effectively prevent it from falling into local optimal values.

Keywords: State of health, Battery, Incremental Capacity Analysis, Genetic Algorithm, Battery Mathematical Model.

1. Introduction

Accurate estimation of the health status of electric vehicle power batteries is extremely important. Accurately estimate the state of health (SOH) of the battery to maximize the performance of the battery. [1-3] In addition, it is more conducive to the estimation of other states of electric vehicle (EV), and provides better control strategies for the battery management system (BMS). [4] There are many methods that have solved the problem of battery SOH estimation. For example, using the health factor representation method [5-6]. This method mainly extracts health factors, and then estimates the SOH of the battery based on the relationship between health factors and SOH. Although this method has high accuracy, the extraction of healthy silver is more complicated, and it is inconvenient to apply to the BMS. Besides, the internal resistance method [7-8] is used to estimate the SOH of the battery. Although this method starts from the internal characteristics of the battery, there are many internal resistance measurements and influencing factors, which are difficult to accurately estimate. Finally, the methods adopted in [8-9] ensure real-time performance, but the initial values of parameter identification are still not accurate enough. Based on this method, this paper proposes a method for Incremental Capacity Analysis (ICA) to optimize the initial value [10-12] to make the algorithm more independent.

The SOH of battery is extremely important for car maintenance. Here we decided to use the ICA method to first determine the initial estimate of the battery SOH. Mainly because the SOH estimated by the ICA method is not accurate, So it can be combined with other algorithms. Then perform online identification according to the traditional battery mathematical model to achieve the purpose of accurately correcting the battery's SOH.

2. ICA optimizes SOH predictive modeling method

2.1 Introduction to ICA method

This method mainly uses the charging data obtained from the lithium-ion battery of EV to derive its charging capacity and terminal voltage. Then, store the peak value obtained by derivation. Fit the battery peak values of different life cycles with the true value of the known battery life to obtain the estimated value of the next battery life. Finally, the initial value of SOH obtained by ICA is used to correct the estimated value of SOH obtained by the battery model.

In the first step, the SOC of the battery is obtained by the ampere-hour integration by the following formula:

$$SOC_t = SOC_0 + \int_0^t \frac{\eta I(\tau)}{C_n} d\tau \tag{1}$$

Among them, SOC_0 is the SOC value at the initial moment, η is the battery efficiency coefficient, C_n is the rated nominal capacity of the battery, and $I(\tau)$ is the current of the battery.

The second step is to use the data of SOC and terminal voltage U to fit the relationship curve:

$$U = f(SOC) \tag{2}$$

In the third step, use equation (2) to set the value obtained by derivation with respect to the terminal voltage as IC. The expression of IC regarding voltage is as follows：

$$IC = g(U) \tag{3}$$

Set the value of the highest point among them as IC Peak, and obtain the linear prediction relationship between IC Peak and battery life of batteries with different lifespans. a0 and a1 are parameters.

$$SOH = a_0 * IC_{peak} + a_1 \tag{4}$$

2.2 SOH Traditional Thevenin Model

As shown in Fig. 1, Thevenin is composed of battery resistance and capacitance. where $U_{OCV}(SOC)$ is the Open Circuit Voltage (OCV) ; C_p is the polarization capacitance; R_p is the polarization internal resistance; R_o is the Ohmic resistance; U is the terminal voltage and I is the constant charging current;

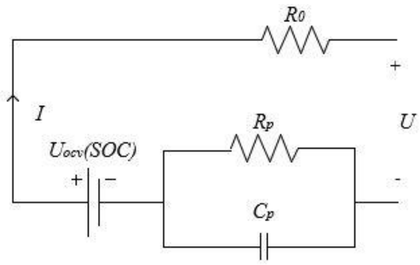

Fig. 1 Thevenin model

According to the literature [13-14] and Thevenin battery model, the following battery mathematical model can be obtained.

$$U^{'}(t^{'}) = U(k\cdot(t^{'}+\Delta t)) + a\cdot\exp(b\cdot k(t^{'}+\Delta t)) - c\cdot\exp(d\cdot t^{'}) + e \tag{5}$$

Where $U^{'}(t^{'})$ is the terminal voltage when battery is new; And $U(k\cdot(t^{'}+\Delta t))$ is terminal voltage When the battery is used. There are seven parameters $k,\Delta t,a,b,c,d,e$ in equation (5). $SOH = 1/k$.

The parameter identification initial value of the traditional battery SOH estimation method has a great influence on the estimated result，Therefore, this article proposes to use the SOH value estimated by ICA to initialize the parameter values in the traditional mathematical model. Therefore, the algorithm in this paper is more accurate。That is, the SOH obtained by equation (4) is used as the initial value of parameter identification when the traditional battery model is used to optimize the SOH obtained by the traditional model, so as to achieve the purpose of real-time estimation.

2.3 Improved SOH estimation method based on ICA

First, collect battery charging data through the BMS. When the amount of collected data reaches the threshold, perform SOH estimation. SOH estimation mainly includes the following steps:

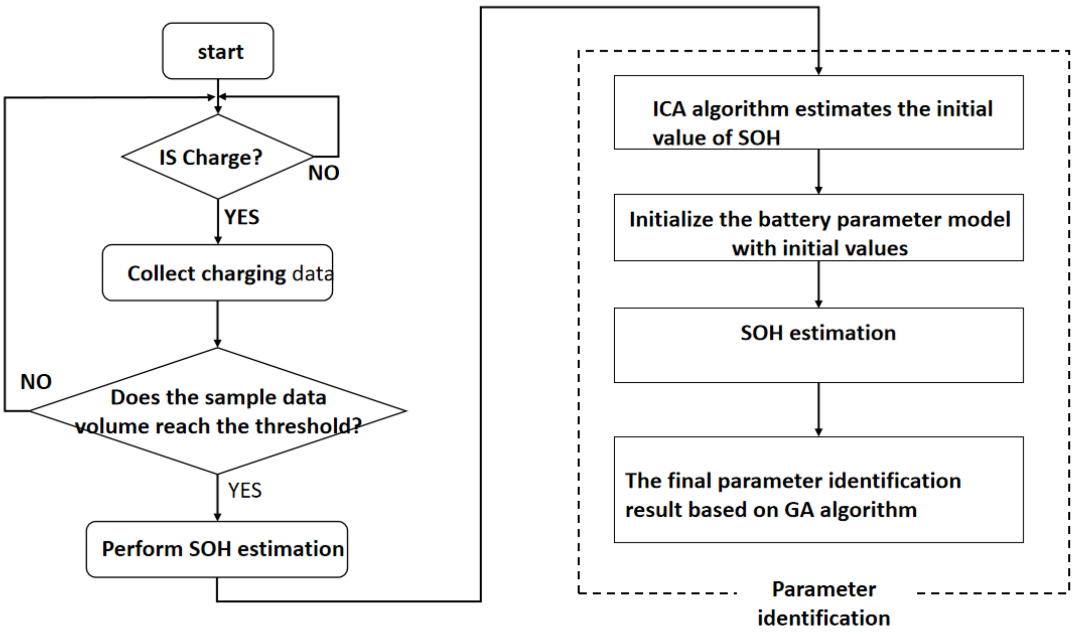

Fig. 2 Improved SOH method flow chart

ICA algorithm for SOH estimation

Calculate the SOC of the battery using the ampere-hour integral; Then derive the curve between the SOC quantity and the terminal voltage. We can get the curve of IC and voltage, and establish the equation by collecting the peak values of different SOH batteries.

Initialize the SOH related parameters of the traditional battery model

We can use the SOH obtained by ICA to initialize the SOH related parameters of the traditional battery model. The parameters are initialized mainly through the following equations.

$$k=\frac{1}{a_0 * IC_{peak}+a_1} \tag{6}$$

Perform SOH estimation

Here, GA can be used for parameter identification. The specific implementation process of GA algorithm is shown in Fig. 3. The fitness function is mainly based on the fitness value to survive the fittest. Crossover and mutation belong to individual evolutionary methods. Crossover mainly refers to the set crossover operation probability. Then the individuals of a certain generation and individuals of other generations are subjected to corresponding mathematical operations. The final individual is the new individual after the crossover. Mutation refers to the method of setting mutation probability and corresponding mutation strategy to obtain new individuals. The GA algorithm flow chart is as follows:

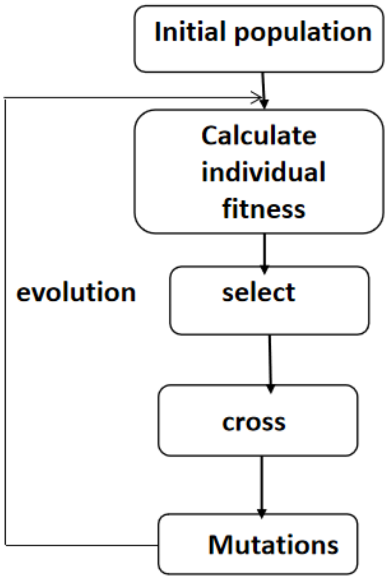

Fig. 3 GA algorithm flow chart

Based on the above steps, the final result of parameter identification is obtained. we can Achieve accurate estimation of SOH.

3. Experimental analysis

3.1 Data Sources

This article uses the B0005 battery data in the NASA database for verification. The main reason is that this data is more comprehensive and can fully simulate the actual state of the battery data. Among them, the battery data in the NASA database is mainly collected from experimental tests on 18650 lithium-ion batteries.

Before the start of the test, first set the indoor temperature to 24°C, and secondly, carry out the battery experiment in three different modes. Including: constant current-constant voltage (constant current-constant voltage, CC-CV) charging phase, constant current discharge phase, impedance measurement phase [15-16]. The charging process includes two modes: CC mode, CV mode. The specific experimental steps for the charging process are: At the beginning, charge the battery in CC mode with a current of 1.5A until the battery voltage reaches the cut-off voltage of 4.2V. Then continue to charge in CV mode until the current drops to 20mA. The specific conditions of the experiment are as follows:

Table 1 Expriment condition of battery B0005

Battery	cut-off voltage(V)	Lowest voltage(V)	Discharge current(A)
B0005	4.2	2.7	2

According to the introduction of the above battery data and the research and application of the battery data in the NASA database by related researchers [17-18]. The battery data is relatively complete, and can more comprehensively reflect the external electrical characteristics of the battery during its full life cycle. In addition, from the perspective of later recurrence verification, the use of public data sets for algorithm verification is also convenient for researchers to verify the effectiveness of the algorithm.

3.2 Improved SOH estimation method based on ICA

Here we use 50, 100, 200, 400,600 cycle data to verify the simulation results. Mainly because these data are distributed throughout the battery life cycle. Take the battery data of cycle100 as an example to perform the first steps of ICA.

Fig. 4 is the ampere-hour integral diagram of the B0005 battery cycle100 using formula 1. The abscissa represents the charging time of the battery, and the ordinate represents the SOC of the battery.

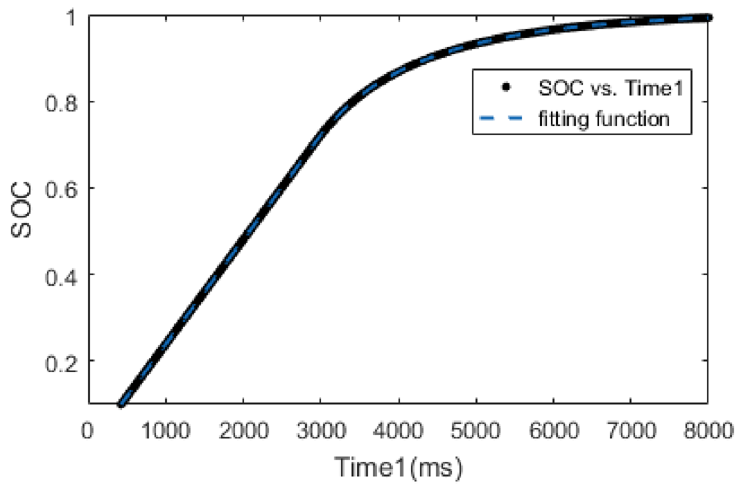

Fig. 4 SOC and t relationship diagram

Fig. 5 shows the relationship between SOC and terminal voltage of B0005 battery cycle100, where The abscissa represents the SOC of the battery, and the ordinate represents terminal voltage U.

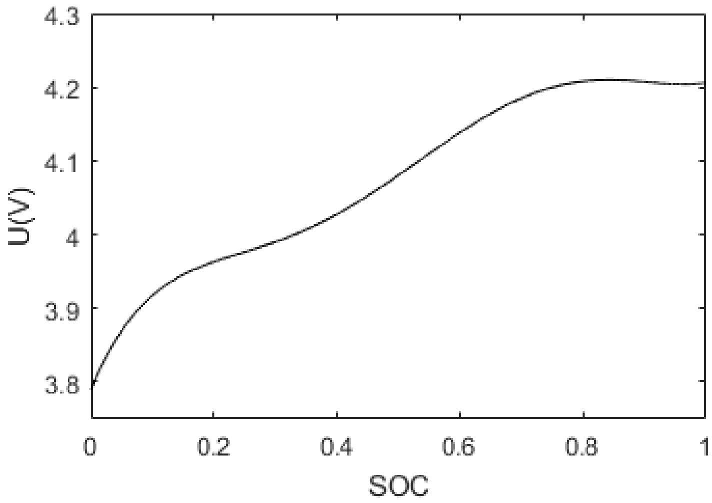

Fig. 5 SOC and *U* relationship diagram

Fig. 6 is the derivation diagram of SOC and U, the abscissa represents the terminal voltage, and the ordinate represents the IC value derived from SOC to U. The ordinate of the highest point is IC_{peak}.

Then perform the above steps in sequence with the charging data of battery cycle 50, cycle 100, cycle 200, cycle 400, cycle 600. So, we can get the relationship between the IC_{peak} value and the terminal voltage at different cycles of the battery. Where the highest points of the black, green, and yellow curves represent the IC_{peak} values of cycle 50, cycle 100, cycle 600 respectively. After, The established model can be used to predict the SOH of cycle 200, cycle 400.

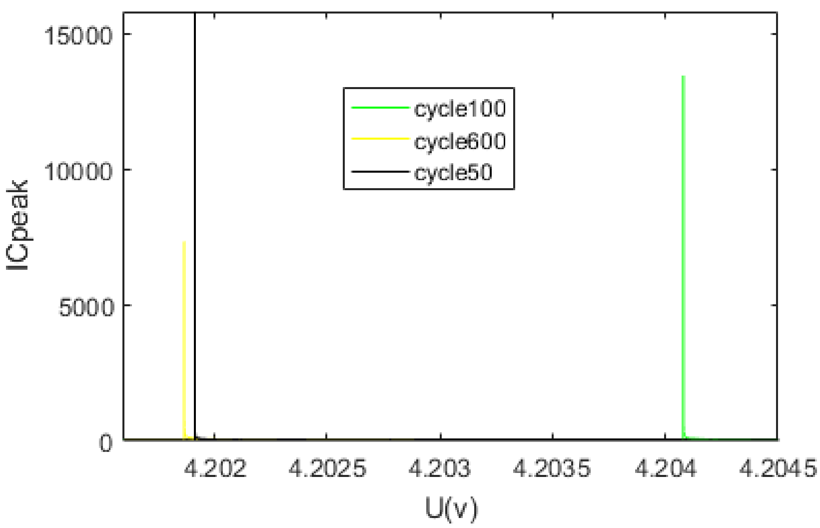

Fig. 6 IC_{peak} and *U* relationship diagram

Establish the relationship between SOH and IC_{peak} offline on the premise that the previous battery life is known in advance. The relationship between SOH and ICpeak of Cycle50, 100, and 600 batteries is known in the following table.It should be noted that the ICpeak value at this time has also been reduced by 104.

Table 2 SOH and IC value table for 50，100，6001 cycles of battery B0005

Cycle number	SOH	IC_{peak}
50	0.9835	2.362
100	0.9351	1.346
600	0.6935	0.7345

Establish the fitting relationship between SOH and IC_{peak} as equation (4)：

$$SOH = 0.1649 * IC_{peak} + 0.6265 \tag{7}$$

Fig. 7 shows the fitting relationship between SOH and IC_{peak}. The abscissa represents the IC_{peak}, and the ordinate represents the SOH of the battery.

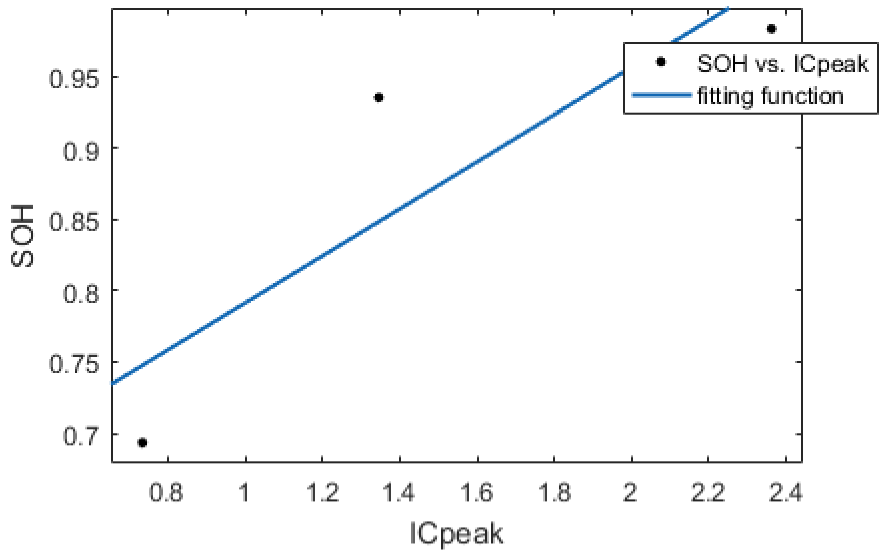

Fig. 7 IC_{peak} and SOH relationship diagram

After the model is established, the IC_{peak} value can be obtained according to the data of the battery cycyle200. Put it into Equation (7) to get the SOH at this time. The reciprocal of SOH is the initial value of the parameter identification parameter of the traditional model for prediction.

Among them, the IC_{peak} value at battery cycle200 is 1.11 after being reduced to the same degree. So if you bring Equation 7 into it, you can get SOH of 0.8095.Using formula 6, get the initial value *k* of the traditional mathematical model parameter identification.

Finally, the GA algorithm is used to search for the optimal initial population to obtain a more accurate SOH estimation process.

Using battery charging data and equation (3) of the traditional battery life model, and then according to the GA algorithm, the estimated SOH value of cycle200 can be obtained, which is 0.9016. The true SOH value is 0.9001, and the error is very small.

4. Conclusion

The traditional battery SOH estimation method has a high dependence on the initial parameter value during parameter identification. Besides real-time estimation of battery SOH is also very necessary in the field of EV. This paper proposes an improved SOH estimation method. This method mainly relies on the ICA method to initialize the parameter identification value of the traditional method. So, It can not only remove the error caused by the ICA method, but also ensure the real-time SOH estimation. Besides the accuracy of SOH estimation can be improved, and the algorithm complexity can be reduced. Parameter identification of battery mathematical model through GA algorithm, which can reduce the time complexity of the algorithm. Therefore, the method proposed in this article can better meet the real-time and rapid purpose of EV.

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