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SOC prediction system based on ampere-hour integration and open circuit voltage method

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Abstract

Lithium battery state of Charge (SOC) is a key parameter in lithium battery management system. Real-time prediction of lithium battery SOC changes can not only control battery charging and discharging, but also directly affect the service life of lithium batteries while optimizing EV management. The real-time prediction of SOC of lithium battery is mainly affected by internal temperature of battery, self-discharge, discharge current and aging of battery, which makes the actual capacity of lithium battery difficult to be determined. Based on this situation, a new research idea combining amp-hour integration method and open-circuit voltage method is proposed in this paper, so that the actual capacity of lithium battery can be estimated more accurately.

Keywords

Ampere-hour integral method; Open circuit voltage method; SOC; Prediction system.

1. Introduction

With the continuous development of the electric vehicle industry, the number of electric vehicles increases daily. As a result, our attention to the safety issue of the electric car battery also grows. The lithium battery, renowned for its large capacity, high operating voltage, strong charge holding ability, wide working temperature range, long cycle life, low pollution, high safety, fast charging and discharging, small size, light weight, and high energy, is widely used as a power source for electric vehicles. SOC (State of Charge)[1], referring to the remaining electricity of the battery, also known as the charge state, is an important parameter during the battery usage process and a critical basis for diagnosing battery health. Therefore, an accurate estimation of the lithium battery SOC value is crucial to improving battery safety.

Currently, the commonly used methods for SOC estimation include the discharge test method, ampere-hour integration method[2], open-circuit voltage method[3], alternating current impedance method, as well as deep learning, neural network method, and Kalman filtering method. These methods are widely used both domestically and abroad. Among these estimation methods, the ampere-hour integration method is the most widely used because it does not consider the complex electrochemical reactions inside the battery. It can directly estimate the battery SOC by integrating the load current, making it easy to implement. The short-term estimation results of this method are relatively reliable. However, long-term current integration will introduce certain deviations due to measurement errors of current sensors and gradual capacity decay of the battery. On the other hand, the open-circuit voltage (OCV) method measures the data of SOC corresponding to the voltage at the end of the battery that does not correspond to the battery's working state when the battery is in an open-circuit state. The relationship between the end voltage and the battery SOC is fitted in advance, so the SOC of the battery can be estimated based on the measured open-circuit voltage of the battery during the charge and discharge process. This method has the advantage of high accuracy estimation, but

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it also has the disadvantage of requiring measurement of the open-circuit voltage when the battery is not working and ensuring estimation accuracy after the battery has been idle for a period of time.

The focus of the present text pertains to the predicaments associated with the extended period of rest required for the open-circuit voltage method and the incapability of the ampere-hour integration method to determine the initial value of the state of charge (SOC) of the battery. Consequently, the employment of these two techniques combined can facilitate an efficient and practical approach to accurately assess the SOC value of lithium-ion batteries.

2. Application of individual methods in SOC

2.1. Amtime integral method

One method for measuring real-time current of the main circuit of the battery pack, and integrating it over time, is referred to as Coulomb counting. This approach exhibits different polarities during charging and discharging. In the discharge phase, the electric charge decreases via integration, with the current charge being equivalent to the initial charge reduced by the integral value. Conversely, during charging, the electric charge increases via integration, with the current charge being equivalent to the initial charge plus the integral value. The expression can be formulated as follows:

$$\mathrm{SOC} = \mathrm{SOC}_0 - \frac{\int \mathrm{i}\,\mathrm{dt}}{\mathrm{C_r}} \tag{1}$$

In the formula: SOC_0:initial state of charge; $\mathrm{C_r}$:battery rated capacity (Ah); i :load current (A); t: time (s);

Reason for error: This method simply records the power in and out of the battery from the outside, without recording the change in the internal state of the battery. At the same time, there is also the problem of inaccurate current measurement, which will continuously accumulate SOC calculation error.The error mainly comes from the following three parts, as shown in Figure 1:

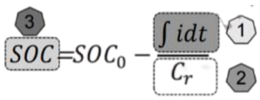

Figure 1 Source of error

The main errors are: 1. Error caused by current sampling: sampling accuracy and sampling interval; 2. Error caused by battery capacity change: temperature change, battery aging and discharge rate; 3. Difficulties in initial SOC estimation and error accumulation; the above three factors influence each other, which further reduces the reliability of this method. In order to improve the calculation accuracy and avoid its being affected by these factors, regular tedious and complicated calibration is necessary. Therefore, this method often constitutes fusion methods with other methods. For example, use an open-circuit voltage to determine the power battery initial SOC.

2.2. Open-circuit voltage method

The open circuit voltage method is one of the most widely used methods based on characterization parameters. When the open circuit voltage (Open Circult Voltage, OCV) of the battery changes, the lithium ion concentration inside the battery will also change linearly, so as to indirectly fit the linear relationship between it and the battery SOC. When the battery is charged and discharged, the current battery SOC can be obtained by looking up the OCV-SOC relationship table according to the measured voltage value of the two ends of the battery.The OCV-SOC relationship is shown in Figure 2:

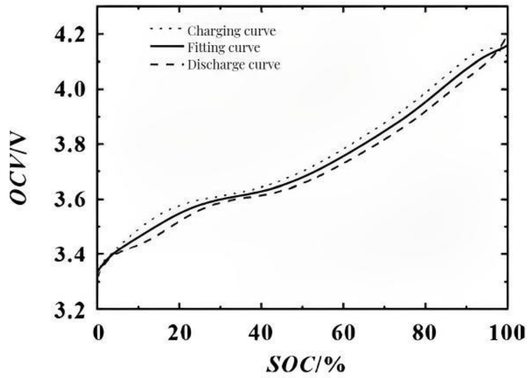

Figure 2. The OCV-SOC relationship diagram

The advantages of the open circuit voltage method are: it can accurately estimate the initial value of SOC, but there are also some disadvantages, its disadvantages: it is easy to measure the open circuit voltage is not easy to charge, and need to let the battery stand for a considerable period of time to stabilize the voltage, both after charging and discharge.

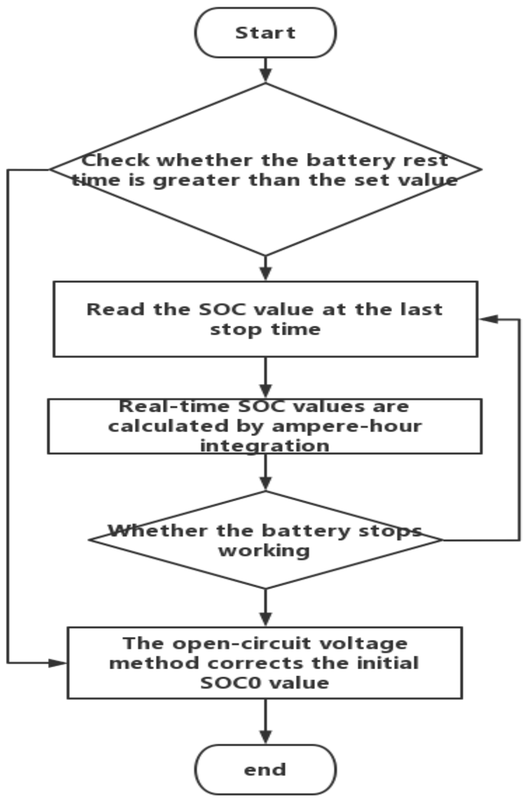

Figure 3 Flow chart of the SOC algorithm

3. The integral method is combined with open circuit voltage method

The hour-hour integral method can measure the current of the main loop of the battery pack in real time and integrate the time to reflect the charge and discharge situation. Charge direction is negative, and discharge direction is positive. During the discharge process, the current power is obtained by subtracting the initial quantity, using the initial quantity and the integral result. Open circuit voltage method, the battery standing time is long enough (2h or more) for the system to obtain the initial SOC.

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In this paper, the combination of ampere integral and open-circuit voltage method is used to estimate the battery SOC to improve the accuracy. When the battery is not working, the SOC value is corrected by open circuit voltage method to eliminate the cumulative error of the ampere method; when the battery is working, the ampere method is used to update the SOC value in real time.

The key to optimizing the SOC algorithm is to set a standing time standard to determine the state of the battery. If the battery is in a stop state, we can use the open circuit voltage method to establish a data table of the relationship between SOC value and open end voltage, so as to get the initial remaining power of the battery, and calibrate to eliminate the error accumulated by the hour-time integration method. During the period of the battery operation, we will obtain the initial value saved by the battery before the last stop operation and correct it, and then use the ampere integral method to estimate the SOC of the battery.SOC_0The algorithm flow chart for the calculation is as follows:

3.1. Establishment of dichotomization table checking method

Dichotomous search is a search algorithm in computer science. It is also known as a broken half search or a log search. The algorithm is suitable for finding specific elements in ordered arrays. The search process starts with the middle elements of the array, and if the middle element is the element to find, the search is over. If the element to be found is larger or smaller than the middle element, then continue the comparison in the corresponding half array and search with the middle half as a new starting point. If the array is empty, the element was not found. The advantage of this algorithm is that it can half half the search range for each comparison, which is simple and highly efficient.

SOC_0 is mainly related to open circuit voltage; C_r is mainly related to battery pack temperature θ, cycle times n and charge / discharge current i. In order to simplify the calculation, the nonlinear curve of the SOC is made into SOC_0- OCV, C_r- θ, Cr-n and Cr-i. The SOC_0 and Cr are constantly updated through the dichotomy table method to improve the operation efficiency of the program and accelerate the system response.

3.2. Initial value correction of the state of charge

Determine whether the initial SOC value needs to be updated based on the standing time. If the stand time exceeds 6 hours, update the SOC value: find the SOC-OCV table through the dichotomy method, determine the SOC value, and clear the cumulative capacity value; otherwise, keep the SOC value as the value of the last shutdown, and save the cumulative capacity value.

3.3. Capacity calibration (correction)

The joint correction calibration capacity value is based on the combined influence of battery pack temperature θ, cycle number n and charge and discharge current i. To regularly check the temperature of the battery pack, it can be done every 0.5 hours. In order to obtain the calibration capacity correction value ($C_{r\theta}$) corresponding to the temperature, the binary check table method can be used to query the array table; the response speed of C_r is relatively slow. After every 30 cycles, the calibration capacity correction value (C_{rn}) will be updated; detect the charge and discharge current regularly, and the calibration capacity correction value ($C_r - i$) corresponding to the current is obtained by finding the C_{ri} array table.

From the perspective of engineering application, the focus of the research is to simplify the data processing process as much as possible, while ensuring a certain calculation accuracy. Therefore, the direct linear processing of $C_{r\theta}$, C_{rn} and C_{ri} array tables, theC_{rtni} scalar value was obtained. C_{rtni} See the calculation formula in the equation (3):

$$C_{rtni} = C_{r0} - C_{r\theta} - C_{rn} - C_{ri} \quad (3)$$

Where C_{r0} is the calibration capacity value of the battery at the factory.

3.4. Optimized an-time integral method formula

Combined with the above content, the calculation principle of the optimized an-time integration method to predict SOC is shown in equation (4).

$$SOC = SOC_0 - \frac{\int i\,dt}{C_{rtni}} \tag{4}$$

4. Experimental results and analysis

4.1. Voltage rebound experiment

Two different batteries were used in the experiment, namely, the Chinese-made lithium-ion battery sample 1 and the imported lithium-ion battery sample 2.All the cathode materials are $LiNi_{0.5}Co_{0.3}Mn_{0.2}O_2$, while all the cathode active materials are graphite, their rated capacity is 2500 mAh.Use the Shenzhen-made BTS-5V3A single power battery test cabinet at 0℃ and 25℃.The test process is divided into two steps: first, the constant current of 1.3A charges to 4.2V, then the constant current of 0.52A is discharged, and the voltage value is recorded. The voltage rebound test results are shown in Table 1:

Table 1 voltage experiment of lithium battery at 25℃ and 0℃

Battery samples	Experimental temperature	Voltage/mV		
		Discharge termination	After resting for 1h	After resting for 10h
1	0	2750	3410	3439
2		2750	2920	3016
1	0	2230	4050	3655
2		2300	4090	3655

According to the data in Table 1, the terminal voltage rebound rate of sample 1 is 25℃ is 24% for 1 hour and 25% for 10 hours, while the data for sample 2 is 6.18% and 9.67%, respectively. The voltage rebound rate of samples 1 and 2 reached 81.61% and 77.82%, respectively, and remained stable after 1 hour of low temperature rest. This indicates that the resting time and temperature have a large influence on the voltage rebound of the battery. Notably, the voltage rebound of sample 2 is more pronounced.Therefore, when estimating SOC, the OCV method should not be used directly, but should be appropriately adjusted to use conditions to avoid large errors.

4.2. SOC value estimation results experiment of different algorithms

Considering the influence of the temperature of the voltage rebound experiment, in order to verify the reliability and accuracy of the improved real-time estimation method in the lithium battery (standard capacity 8A), we chose a 25℃ environment for the discharge experiment, and the collected data was uploaded to the control system through the sensor.

Table 2 Analysis of SOC values by different algorithms

Discharge time (h)	SOC estimation method			Error amount	
	Discharge experiment (%)	Ampere integration (%)	Improved ampere-hour integration (%)	Error before improvement (%)	The improved error (%)
1	71.30	72.21	71.29	1.28	0.014
1.5	56.96	58.32	56.95	2.39	0.018

2	46.62	44.43	46.61	4.25	0.021
2.5	28.27	30.54	28.26	8.03	0.035

In Table 2, the results compare the discharge experiment method, ampere integral method and consider the influence of many factors. According to the results of the discharge experiment method as a standard, we found that the error of the improved an-hour integral method was significantly lower than that before the improvement, reaching below 0.035%. This means that the improved ampere method can improve the accuracy of the SOC estimate.

In this way, by integrating the two methods, the actual value of SOC can be predicted more accurately, so that the actual capacity of lithium battery can be made more accurately estimated.

5. Conclusion

This paper mainly analyzes the characteristics and problems of the hour integral method and open circuit voltage method, the open circuit voltage method requires a long time standing to handle the battery and the time integral method, not only to determine the battery SOC size of the temperature, which considered the charge and discharge current, and in the process of charging and discharging, improve the estimation accuracy. It has certain reference value to estimate the charge state of lithium battery. In the next step, deep learning will be further added to increase the accurate determination of estimate the charge state of lithium battery.

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