Introduction of SOC estimation method

Gaojian Ren¹

¹CCTEG Chongqing Research Institute, Chongqing 400039, China
*Corresponding author’s e-mail: fjcdnf@qq.com

Abstract: This paper introduces the definition of SOC estimation and analyzes the common estimation methods, including discharge experiment method, open circuit voltage method, internal resistance method, ampere hour method, linear model method, neural network algorithm and Kalman filter method. Through the comparison and analysis of various methods, it provides a scientific choice for the SOC estimation method of nickel hydrogen battery.

1. Instruction
The state of charge (SOC) of mining Ni MH battery is the key content of battery management, but also the key and difficult content. The actual capacity itself cannot be accurately known, it changes with the voltage, current, temperature and other factors. The definition of battery SOC can be divided into two types, one is the nominal capacity, the other is the actual capacity of Ni MH battery, that is, the voltage drops to 5mv below the highest point. According to GB / t22084.2-2008, after the battery is fully charged with constant current of 0.1C under the environment temperature of 25 °C, under the same ambient temperature, the discharged electricity from 0.2C to 1V is defined as Ca, the current residual capacity is defined as Cr, and the SOC of the battery can be defined as:

\[
\text{SOC} = \frac{C_r}{C_a} \times 100\%
\]

If the initial state of Ni MH battery is defined as soc0, then after a period of charging and discharging, the SOC becomes:

\[
\text{SOC} = \text{SOC}_0 - \frac{1}{C_a} \int_0^\tau \eta \, I \, dt
\]

In the formula, the current I is positive in the case of discharge and negative in the case of charging. The upper limit of integral \( \tau \) is the duration, and \( \eta \) is the efficiency in the process of charging and discharging.

2. Classification of SOC algorithm
There are many methods to estimate the SOC of Ni MH battery, and their applicable scenarios and conditions are different, including discharge experiment method, open circuit voltage method, ampere hour method, internal resistance method, neural network method, linear model method and Kalman filter method. These algorithms are described below.

2.1 Discharge test method
Through the continuous discharge of Ni MH battery and the integration of current and time, the battery power is calculated. Discharge with standard rate current, because the discharge coefficient is 1,
it is a method for other algorithms to collect data, and this method is suitable for various capacity batteries and different types of batteries. The discharge experimental method needs a long time to discharge for SOC estimation, which can not be used as a real-time estimation method, but is often used as a data acquisition method.

2.2 Open circuit voltage method
The open circuit voltage of Ni MH battery is measured after a long standing time. There is a relatively stable corresponding relationship between the open circuit voltage and the SOC. The EMF of the battery can not be detected in the process of charging and discharging. Therefore, the open circuit voltage method alone can not detect the change of battery SOC in real time. The relationship among the real-time terminal voltage, charge discharge ratio and open circuit voltage should be obtained by combining with the battery model, and then the SOC values corresponding to the real-time terminal voltage and charge discharge ratio can be obtained.

At present, the battery models can be divided into three categories: electrochemical model, electrical model and mathematical model. The electrochemical model has high accuracy, but it is too complex, which is mainly used in power battery; the accuracy of mathematical model is low, which is mainly used in equipment with low requirements for battery state; relatively speaking, electrical model is more suitable for real-time SOC estimation, and the second-order electrical model proposed in reference is more suitable. The EMF and SOC of the battery can be well estimated, which is simpler and more accurate than the higher-order model.

2.3 Internal resistance method
The internal resistance of Ni MH battery can be divided into DC internal resistance and AC internal resistance, and the changes of them are closely related to the state of battery SOC. DC internal resistance is the ratio of voltage to current variation in a short time; AC resistance is a complex variable, which is the transfer function of battery voltage and current. The measurement equipment needs professional AC impedance meter, which is rarely used for SOC real-time estimation. For lead-acid battery, the resistance of DC resistance increases obviously in the later stage of discharge, so the internal resistance method can be used to estimate the SOC. However, Ni MH battery is different from lead-acid battery. Because it is difficult to detect the internal resistance of Ni MH battery in real time, the internal resistance method is rarely used to estimate the SOC of Ni MH battery in real time. Even if the internal resistance method is applied to lead-acid battery, it is only used as the calibration basis of ampere hour method in the later stage of discharge. Reference used ampere hour method and internal resistance method to estimate the SOC value of lead-acid battery.

2.4 Ampere hour method
The core idea of ampere hour method is: under the condition of knowing the initial soc0, the SOC1 is obtained by multiplying the integral of current and time by a certain attenuation coefficient (charge discharge coefficient). The sum of charging and discharging is the former minus the latter, and the value obtained is the current real-time SOC value. However, there are two problems in the simple ampere hour method, one is that the initial value is not easy to determine; the second is the improper
selection of charge discharge coefficient, which will bring serious cumulative error after a period of time. Therefore, the SOC estimation value obtained by the ampere hour method alone for a long time is not accurate. At the same time, if the wrong initial value is given, the SOC estimation value is meaningless.

Due to the problems of single ampere hour method, in practical use, ampere hour method is often combined with other algorithms. A method combining with electromotive force method is given in reference. The two algorithms estimate SOC independently, and then conduct weighted average to obtain more accurate SOC value. In reference, SOC value is estimated by combining ampere hour method, electromotive force method and Kalman filter method, and the initial value soc0 of SOC is obtained by EMF method, and then the Kalman filter method is used to quickly converge to the true value to get SOC1. Finally, SOC1 is taken as the initial value, and then the subsequent SOC value is estimated with ampere hour method.

2.5 Linear model method
The linear model method is based on the terminal voltage U (k), charge discharge current I (k), SOC change $\Delta$ SOC (k) and SOC (k-1) at the last moment

$$\Delta SOC(k) = \beta_1 U(k) + \beta_2 I(k) + \beta_3 SOC(k-1) + \beta_0$$

$$SOC(k) = \Delta SOC(k) + SOC(k-1)$$

The $\beta$ (l = 0,1,2,3) in the above formula has no special physical meaning. It is based on the least square method and uses the reference data to obtain the coefficient. This model is suitable for the case of small charge discharge rate and slow change of state of charge. When the data provided by initial conditions has errors or errors, the linear model method has good robustness. In theory, the linear model method can be applied to different types of batteries and different aging stages of batteries. At present, only lead-acid batteries can be used. Whether the linear model method is suitable for Ni MH batteries needs further research, and the accuracy under variable current conditions also needs to be further confirmed.

2.6 Neural network algorithm
SOC change of battery state of charge is highly nonlinear. It is difficult to get accurate SOC estimation value by establishing mathematical model. Neural network has good adaptability for nonlinear system and has the ability of learning, verifying and inferring. Therefore, neural network algorithm is used to estimate the SOC of Ni MH battery in real time. Neural network needs a large number of training samples and enough experimental data. The accuracy of SOC estimation is affected by many factors such as network parameters, training data and methods.

The input node variables include current, voltage and temperature. The output node variables can be selected from SOC, or one of other algorithms, such as battery model. Reference uses neural network algorithm to output parameters of second-order model circuit; Reference directly outputs battery SOC value; reference uses genetic neural network to estimate SOC value.

Neural network method is a new algorithm to simulate human brain and its neurons to deal with nonlinear system. It does not need to study the internal structure of the battery. It only needs to extract a large number of input and output samples from the target battery in advance and input them into the system established by this method, and then the SOC value in operation can be obtained. The post-processing of this method is relatively simple, which can effectively avoid the error caused by the linearization of the battery model in the Kalman filtering method, and can obtain the dynamic parameters of the battery in real time. However, the neural network method has a large amount of work in the early stage, and needs to extract a large number of comprehensive target sample data to train the system. The input training data and training methods will affect the estimation accuracy of SOC to a great extent. In addition, due to the complex effect of different battery temperature, self
discharge rate and aging degree, the accuracy of this method will be greatly reduced if it is used for a long time to estimate the SOC value of the same battery.

2.7 Kalman filter method
Kalman filtering is a new optimal autoregressive data filtering algorithm proposed by American mathematician r.e.kalman in the paper "new achievements of linear filtering and prediction theory" published in the early 1960s. The essence of the algorithm is that the state of complex dynamic system can be optimally estimated according to the principle of minimum mean square error. The nonlinear dynamic system will be linearized into the state space model of the system in the Kalman filter method. In practical application, the system updates the state variables to be obtained according to the estimated value of the previous time and the observed value of the current time, and follows the "prediction measurement correction" mode to eliminate the random deviation and interference of the system. When using Kalman filtering method to estimate SOC of power battery, the battery is transformed into a state space model in the form of power system, and SOC becomes a state variable in the model. The system is a linear discrete system.

Kalman filter takes the change of SOC as a state variable of battery. The minimum variance estimation of SOC of battery is calculated by recursive state equation formed by filter gain and filter calculation. Under the premise of known input quantity of battery voltage, current and temperature, the filter gain is obtained by recursive calculation of statistical characteristics of variables, and combined with pass through status The error of the estimated SOC is obtained by recursion of the estimated SOC.

The Kalman filter method is applicable to all kinds of batteries. On the premise of accurate battery model, it can provide accurate SOC estimation, and has a good correction and suppression effect on the selection error of initial value of charge and discharge and noise in the process. Generally, this method is widely used in the SOC estimation of electric vehicles. The equation of state can be obtained from a variety of battery models, including ampere hour deformation, electrical model, electrochemical model, etc. Reference uses the deformation of SOC calculation formula in ampere hour method as state equation; reference [33] uses electrochemical model to establish state equation.

3. Conclusion
This paper describes the definition of battery SOC, introduces different key technologies of power management SOC estimation algorithms, analyzes the advantages and disadvantages of different algorithms, and provides theoretical basis and basis for improved comprehensive SOC estimation algorithm.

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