Research on SOC Estimation Algorithms for Aluminum Air Batteries

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Abstract. Present, the existing open-circuit voltage method and ampere-time integration method have large errors in estimating the SOC of aluminum air batteries, which are not accurate enough. To overcome this shortcoming, a new SOC estimation algorithm of aluminum air batteries based on open-circuit voltage method and time-integration method is proposed. A simulation model is established by using the method of phased SOC estimation. The simulation results show that this method can effectively reduce the errors caused by the first two methods, and ultimately control the SOC estimation within a high precision range.

Introduction

Aluminum air battery is a metal air battery with aluminum alloy as negative active material, oxygen in air as positive active material and strong alkaline or salt solution as electrolyte. It is a new type of fuel cell. Aluminum air battery has the advantages of high specific power, high specific energy, pollution-free and long-term stability. At present, it has been widely used in portable power supply, standby power supply, electric vehicle power supply and underwater propulsion device \cite{1}. The United States Advanced Battery Consortium (USABC) defines battery SOC as the ratio of battery residual capacity to rated capacity when the battery discharges under the same conditions \cite{2}:

\begin{equation}
SOC = \frac{Q_1}{Q_c}
\end{equation}

In this formula, $Q_1$ represents the remaining capacity and $Q_c$ represents the total capacity that can be released under certain current discharge conditions.

The internal structure of the battery is complex and the chemical reaction is strong. It has the problems of easy aging and high self-discharge rate. It is impossible to measure the SOC of batteries directly. Only some specific algorithms can be used to estimate the SOC of batteries. The accurate estimation of SOC is also an important part of battery energy management system. It can be used as an important basis for battery discharge control to ensure the safety of discharge.

At present, the existing SOC estimation methods are mainly open-circuit voltage method, time-integration method, Kalman filter method and neural network method. There are two main methods of SOC estimation for aluminum air batteries, one is the time integration method and the other is the open-circuit integration method. At present, the most widely used methods are the ampere-time integration method and open-circuit voltage method. It has some drawbacks: 1) the error will increase with the increase of discharge time, that is to say, it will bring cumulative error; 2) the initial value of SOC cannot be accurately determined; 3) the inaccurate detection accuracy of current will bring larger estimation error. Open-circuit voltage is the voltage of batteries in the static state, so the open-circuit voltage method also has an obvious disadvantage that the batteries need a long period of static state to restore to a stable state, which brings obvious difficulties to the measurement of open-circuit voltage of batteries.
Based on Open-Circuit Voltage Method SOC Estimation and Simulation

Open-Circuit Voltage Method

Open-circuit voltage refers to the potential difference between positive and negative electrodes when the battery reaches equilibrium without current outage in the discharge circuit [3]. The principle of open-circuit voltage method is that after discharge, the battery is stationary for a period of time, transitioning from discharge operation state to discharge stable state. The SOC value of the battery is calculated by measuring the terminal voltage and describing its relationship with the remaining battery capacity. Literature [4] points out that there is a certain relationship between the open-circuit voltage and the residual capacity of the starter battery. The corresponding SOC value can be obtained by measuring the open-circuit voltage of the battery.

It can be seen from the above that there is a specific curve between the open-circuit voltage (OCV) and SOC of the battery. The curve of the relationship between the open-circuit voltage and SOC of the aluminum air battery can be obtained by fast calibration experiment [5]. Specific experimental process is to ensure the full capacity of the aluminum air battery, the aluminum air battery is discharged at a constant current of 5% per discharging, then the battery is stationary to the end voltage stability, recording the value of the end voltage and SOC at this time, continue discharging 5% until the end of discharging, and finally the data obtained can be fitted with MATLAB to get the relationship curve between OCV and SOC, see Fig 1.

SOC Estimation Simulation Based on Open-Circuit Voltage Method

Aluminum-air battery can be effectively simulated by the second-order RC equivalent circuit model. The time-varying curve of circuit parameters can be obtained by real-time parameter identification, including the open-circuit voltage curve. This is the specific value of open-circuit voltage can be obtained by measuring terminal voltage and current, so whether the battery is in a long-term static state or in a discharge state. The open-circuit voltage method can be used to estimate the SOC of batteries in real time. A simulation block diagram of SOC estimation method based on open-circuit voltage method is established on Matlab according to its principle, as shown in Fig 2.

![Figure 1. OCV-SOC curve.](image1)

![Figure 2. SOC simulation model based on open-circuit voltage method.](image2)

From Fig 3, it can be seen that the initial SOC value obtained by simulation is inaccurate because of the error of OCV in initial parameter identification. However, with the increase of simulation data in the later stage, the open-circuit voltage value is constantly revised by the algorithm, and the SOC value obtained by simulation is close to the actual value. However, it can be clearly seen from Figure 3 that the SOC value estimated by open-circuit voltage method increases significantly in the stage of stable discharge operation, that is, when discharge voltage tends to be stable, as shown in Fig 4.
SOC Estimation and Simulation Based on Ampere-Time Integral Method

Ampere-Time Integral Method

The main principle of the ampere-time integral method is that it does not consider the external structure and chemical reactions of the battery. The net discharge of the battery can be seen only by continuously detecting and integrating the current flowing through the battery. The expression of the principle of the time integral method is as follows:

\[
SOC = SOC_0 - \frac{1}{C} \int_0^t I \, dt
\]  

(2)

In the formula: the initial battery power; C is the rated capacity of the battery; I is the discharge current of the battery.

It can be seen from the formula that the ampere-time integration method has nothing to do with the complex chemical reactions inside the battery, but only focuses on the amount of electricity emitted by the battery as a whole system. It can also be seen from the formula that the accuracy of the ampere-time integration method is closely related to the accuracy of battery initial capacity and current detection, and there are measurement errors when the discharge current detection is unstable or even varies in a large range. At the same time, with the increase of discharge time, the cumulative error will be generated and increased. At the later stage, the initial capacity will have a larger error, and the final SOC estimation will have a serious deviation from the actual value.

SOC Estimation and Simulation Based on Ampere-Time Integral Method

According to the principle of the time integration method, an estimation simulation model based on the time integration method for aluminum air batteries is established on Matlab, as shown in Fig. 5 below. Fig. 6 is the error comparison between simulation value and actual value of aluminum-air battery based on the ampere-time integration method. It is obvious that the cumulative error caused by the ampere-time integration method is more obvious. At the time of discharge, especially in the middle and later stages of discharge, the error increases gradually. In Fig. 7, it can be seen from the curve that the error changes with time. With the discharge operation, the error increases gradually and deviates from the actual value of SOC.
SOC Estimation Simulation Based on Open-circuit Voltage Method and Ampere-Time Integration Method

Piecewise Estimation Method

As shown in Fig. 8, according to the existing discharge characteristic curves of Al-air batteries, the discharge is divided into three stages: the initial stage, the running time and the end stage. According to the three different stages, different methods are proposed to estimate the SOC value according to different curves. Firstly, in the initial stage of discharge, the initial SOC value of Al-air battery is determined by open-circuit voltage method. Then, with the discharge voltage tending to be stable, the SOC value is estimated by the ampere-time integration method, and the change of discharge point power is expressed by the integration of current. When the discharge is running, especially in the middle and later stages, with the increase of the discharge time, the time integration method will bring cumulative errors. So in this stage, the open-circuit voltage method combined with the time integration method is used to estimate SOC, and the SOC is modified by the open-circuit voltage. It can be seen that at the end of the final discharge stage, the voltage begins to drop sharply. In this stage, the open-circuit voltage method is used to estimate SOC, which can avoid the large cumulative error caused by the ampere-time integration method, and eliminate the influence of the large self-discharge rate of aluminum-air battery on the estimation of SOC, and thus the estimation accuracy of SOC is greatly improved.

SOC Estimation Simulation Based on Open-Circuit Voltage Method and Ampere-Time Integration Method

According to the principle of piecewise estimation of SOC used in this paper, a simulation block diagram is established in Matlab, as shown in Fig 9.

Figure 7. Estimation error of soc based on safety-time integral method.

Figure 8. Discharge characteristic curve of aluminum air battery.

Figure 9. SOC simulation model based on open-circuit voltage method and ampere-time integration method.

The simulation results are shown in Fig10 below. It is obvious that the estimation of SOC is closer to the actual value than the first two methods. The error between the model error and the actual value is shown in Fig 11. This method reduces the SOC estimation error to less than 0.02, because the error is inevitable due to the influence of model error and actual environment [6-7].


Conclusion

In this paper, a SOC estimation method based on open-circuit voltage method and time-integration method for aluminum air batteries is proposed. Three models of SOC estimation methods are established in Matlab and simulated. By comparing the simulation results with the actual values, it is finally confirmed that the proposed open-circuit voltage method combined with time-integration method for the discharge characteristics of aluminum air batteries is more effective in SOC estimation. Precise. This method not only solves the problem of large error of open-circuit voltage method in discharge stabilization stage, but also corrects the cumulative error caused by the ampere-time integration method.

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References


