Research on SOC Calibration of Large Capacity Lead Acid Battery

W Q Ye and Y X Guo
1 School of computer science, Hunan University of Technology, Zhuzhou,China

Abstract: Large capacity lead-acid battery is used in track electric locomotive, and State of Charge(SOC) is an important quantitative parameter of locomotive power output and operating mileage of power emergency recovery vehicle. But State of Charge estimation has been a difficult part in the battery management system. In order to reduce the SOC estimation error better, this paper uses the linear relationship of Open Circuit Voltage(OCV) and State of Charge to fit the SOC-OCV curve equation by MATLAB. The method proposed in this paper is small, easy to implement and can be used in the battery non-working state SOC estimation correction, improve the estimation accuracy of SOC.

1. Introduction
This paper is based on the power battery management system of CRRC power repair locomotive. The sample used is 2V/160Ah's NM-160 valve controlled sealed lead-acid battery. The purpose of this thesis is to provide a more efficient SOC correction method for battery management system to improve the accuracy of SOC estimation in battery management system[1]. BMS (Battery Management System) can prolong the service life of batteries and prevent overcharge and over discharge in the process of using batteries. In this paper, the correction of SOC estimation is studied by exploring the corresponding relationship between the open circuit voltage and the SOC in stationary state. In order to better fit the linear relationship between OCV and SOC, a large number of charging and discharging experiments are carried out to collect data.

2. SOC Principle and Measurement
The SOC represents the battery's current state of charge, that is, the remaining battery power. The United States Advanced Battery Consortium (USABC) defines SOC as the ratio of the remaining capacity of the battery [3] to the nominal capacity under the same conditions at a certain discharge rate. According to this definition is derived from the definition of the ampere hour method:

$$SoC = \frac{CQ}{SOC_0} \int_0^t Ki dt / Q_c$$

Among them, $Q_c$ is rated capacity, $SOC_0$ is the initial battery capacity, $i$ is the discharge current at a certain time, and $K$ is the influence factor. Ampere hour method principle is simple and easy to implement. In addition, the computational complexity of the algorithm, but this algorithm has accumulated error and the accuracy depends on the current sampling frequency. The open circuit voltage method uses the linear relationship between the open circuit voltage [3][5] and the SOC to estimate SOC through the voltage when the battery is not working. This method is simple, but it needs to be done in the non-working state of the battery.
In addition, the estimation error of the algorithm is large when the battery runs. In this paper, the corresponding relation between the stationary voltage and the SOC of the battery is tested, and the estimation of SOC is corrected by the corresponding relation when the battery is not working.

3. Open circuit voltage
Open circuit voltage is an important parameter in the fitting of OCV-SOC relation\(^6\). In order to obtain the true correspondence of OCV-SOC, a lot of experiments have been carried out. The picture is a voltage change curve during the discharge of a lead acid battery. The region marked by the letter A represents the discharge process. The voltage rises at the end of the discharge. The voltage change is caused by the internal resistance of the battery. In addition, the voltage tends to be stable in a short time. The voltage at the stationary stage represents the voltage at which the battery is not working\(^7\). The steady change of the open circuit voltage is beneficial to fit the corresponding relation between OCV and SOC.

![Fig. 1 voltage change during the discharge of lead-acid battery](image)

4. Experimental analysis and simulation
The automatic test equipment of BTS-M battery parameters is used to control the experiment process in order to obtain more accurate data. The device supports programmable charging current, programmable charging time, programmable discharge current, and discharge time. The data collected by the device is sent to the computer terminal through the serial port. The experiment process has realized automation and digitization. The temperature is controlled by a constant temperature device to obtain experimental data at different temperatures. The experimental equipment and batteries are shown in Figure 2.

![Figure 2 experimental battery and charge and discharge test chamber](image)

4.1 Experimental design
In the experiment, the NM-160 valve controlled sealed lead-acid battery was used as the experimental object. Each individual cell voltage is 2V. The 3 individual batteries are connected in series to form a battery pack, which the voltage of battery pack voltage is 6V. Experiments were carried out at different temperatures and data were collected. The experimental steps are:

- The battery is charged by 0.2C constant current until the voltage reaches the cut-off voltage. When the cut-off voltage is reached, the constant voltage charge is applied until
the battery cutoff current is reached. The battery is stationary for 3 hours after charging.

- When the battery does not work, collect the voltage data for 10 minutes through the BTS-M device before discharging. Then, the battery is discharged in 0.1C constant current. The battery discharges to different depths each time. For example, 0.9SOC, 0.8SOC ... 0.1SOC.

- When the battery discharge is over, the device collects the battery voltage at standstill every minute. The acquisition process lasted three hours.

- The battery continues to discharge until the battery voltage reaches the cut-off voltage. Then, the battery is stationary for 5 hours. Experiment cycle execution step 1. But the discharge of the battery will be discharged at different currents. For instance, 0.2C, 0.3C ... 0.9C and 1C. The experimental data will be recorded that discharge currents is different.

4.2 Data analysis

The static voltage data at the same temperature, the same discharge depth and the discharge current are selected to analyze. Static voltage data at the same temperature, at the same discharge depth and at different discharge currents are used to analyze voltage variation trends. The voltage change curve is shown in Figure 3. In the figure, when the battery discharges at different currents to the same SOC, the static voltage tends to stabilize with the increase of the settling time. Therefore, the conclusion is that the final static voltage is related to the final charge of the battery.

![Figure 3](image)

Figure 3 different current discharge to the same SOC voltage curve.

During the experiment, the battery discharges to different SOC at different discharge rates (0.1C, 0.2C, 0.3C ... 1C). Figure 4 shows the trend of the open-circuit voltage when the battery is discharged to a different SOC. When the remaining battery power is not the same, the open circuit voltage of the battery is obviously different. However, the open circuit voltage of the battery with the same remaining power remains stable after about 20 sampling periods. When the discharge is completed, the battery has more residual energy, the higher the voltage of the battery.

![Figure 4](image)

Figure 4 Battery packs are different from the SOC corresponding to the static voltage

The constant current discharge experiment was carried out on a NM-160 valve-regulated sealed
lead-acid battery (160 Ah, 2 V) at a discharge rate of 0.1 °C at 30 °C. According to the experimental data, the corresponding curves of OCV and SOC are obtained by processing and analyzing in MATLAB software[8]. Figure 5 shows that there is a good linear relationship between SOC and OCV. This good linear relationship facilitates the estimation of the current SOC in the stationary state by measuring the OCV. In order to better correct the SOC and exclude the influence of temperature on the SOC estimation, this paper adopts different methods to deal with the data at different temperatures.

In MATLAB, the cftool tool is used to fit the linear formula. Where Uocv represents open circuit voltage. The formula for fitting at 30 degrees Celsius is:

\[
SOC = -0.1022 \times U_{ocv}^2 + 3.729 U_{ocv} - 10.1
\]  

Similarly, the formula at 25 degrees Celsius is:

\[
SOC = -2.949 U_{ocv}^2 - 21.55 U_{ocv} - 38.07
\]  

The charge and discharge data of the NM-160 VRLA battery are collected as simulation and simulation data. The charge discharge data of NM-160 valve controlled sealed lead-acid batteries are used as the simulation data to analyze errors. Through the data comparison of Table 1, it is found that the error range is not more than 5%. Therefore, the fitting formula is very helpful to the correction of SOC estimation. And the accuracy is relatively high.

| expected value | Measuring voltage | Estimated SOC | Deviation |
|----------------|-------------------|---------------|-----------|
| 0.1            | 1.988             | 0.1048        | 0.048     |
| 0.2            | 1.989             | 0.2078        | 0.039     |
| 0.3            | 2.042             | 0.3081        | 0.027     |
| 0.4            | 2.057             | 0.4144        | 0.036     |
| 0.5            | 2.074             | 0.5215        | 0.043     |
| 0.6            | 2.094             | 0.6192        | 0.032     |
| 0.7            | 2.109             | 0.7287        | 0.041     |
| 0.8            | 2.128             | 0.8248        | 0.031     |
| 0.9            | 2.141             | 0.9252        | 0.028     |
| 1              | 2.193             | 1.05          | 0.05      |

5. Conclusion
The discharge experiments of lead-acid batteries are carried out at different depths to obtain the
open circuit voltage at standstill. In order to eliminate the influence of temperature on SOC, experiments were carried out at different temperatures. Then, with the aid of MATLAB software, a large amount of data is used to fit the corresponding relationship about \( \text{soc} = f(U_{ocv}) \). This relationship will be used to correct BMS's estimate of SOC at rest\(^9\). What's more, this method is high precision and reliability and easy to implement. But the fitting formula also has some limitations. For complex battery environments, there may be unknown errors.

References

[1] SHAO Chun-sheng, LI Bei, CAI Ji-he. SOC estimation of manganese acid lithium battery using rebound voltage\([J]\). *Power technology*, 2017, (02): 211-213+269.
[2] Zhang Ting, Du Shejiao. SOC estimation method of lithium battery based on improved Thevenin model\([J]\). *Power technology*, 2015, (11): 2400-2402+2496.
[3] Li Zheng, ZHI Ruodun, SUN Honwan. SOC estimation method based on the prediction of open-circuit voltage\([J]\). *Hebei Journal of Industrial Science & Technology*, 2017, (01): 36-40.
[4] HAN Xue-bing, OUYANG Ming-gao. Characteristics analysis of open circuit voltage of aged LiFePO 4 battery for electric vehicle\([J]\). *Power technology*, 2015, (09): 1876-1878.
[5] DENG Ye, HU Yue-li, TENG Hua-qiang. Open-circuit Voltage Prediction and SOC Estimation of Li-ion Battery \([J]\). *Instrumentation Technology*, 2015, (02): 21-24.
[6] Deng Kun, Wang Fuzhong, Wang Zhaosheng. Open experiment research for the measuring precision of the voltage - ampere hour method effect \([J]\). *Energy Conservation*, 2013, (08): 25-28+2.
[7] XU Xin-ge, YANG Song, LI Yan-fang. A method of SOC-estimate based on forecast of open-circuit voltage\([J]\). *International Electronic Elements*, 2011, (14): 127-129.
[8] Wu Jiajia, Zhao Youqun. Parameter Identification of Ni / MH Battery Used in Hybrid Electric Vehicles Based on Thevenin Mode \([J]\). *Agricultural equipment and vehicle engineering*, 2014, (01): 1-5.
[9] Hu Xiuzhi, Jin Peng, CHANG Rui-feng. Ni-mh battery simulation based on Thevenin model \([J]\). *Power technology*, 2014, (11): 2063-2065.