Research on Low-temperature Discharge Performance and Discharge Capacity Prediction of Lithium-iron Phosphate Battery

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ABSTRACT

In order to research on the low-temperature discharge performance of lithium-iron phosphate battery, the type 14500 and type 32650 batteries are selected as the research object, to test their low temperature discharge capacity and ohm internal resistance. The results indicate that the discharge capacity decreases as the temperature decreases, while the ohm internal resistance increases with the decrease of temperature, and the consistency between the battery monomer becomes worse. It is concluded tentatively that the influence of low-temperature on the discharge capacity of different types of batteries is different, the smaller the rated capacity, the smaller the discharge capacity ratio of the battery. The BP neural network model is established to take the normal temperature charging capacity, test temperature and ohm internal resistance as the input, discharge capacity as the output, and the error of the model is less than 8%, for the next step to achieve the battery at low-temperature discharge capacity of the online forecast to provide data support and theoretical basis.

INTRODUCTION

Lithium-iron phosphate batteries gradually replace lead-acid batteries, NiCd and NiMH batteries to become the main power battery in electric vehicles for its high power density, high energy density and long life, low self discharge rate, long storage time, no pollution and other excellent characteristics of fast charging.\(^1\)\(^2\) The actual operating conditions of electric vehicles are complex, and the temperature range is wide. The charge and discharge performance of lithium-ion batteries is directly related to the ambient temperature,\(^3\)\(^5\) especially the low temperature, which has a greater impact on the battery charging and discharging performance. Some studies have shown that the capacity and operating voltage of the lithium-iron battery for electric vehicles at \(-10^\circ\text{C}\) will be obviously reduced, and the performance will be deteriorated at \(-20^\circ\text{C}\).\(^6\)\(^7\) Li Zhe and other studies\(^8\) studied the temperature characteristics of the capacity, internal resistance of a lithium-iron phosphate battery, the results show that the ambient temperature have great influence on the battery capacity and internal resistance, at high temperature, the capacity change rate of the battery is less than that of the low temperature, and the ohm internal resistance is more sensitive to the temperature than the

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polarization internal resistance, and the change rate of ohm internal resistance at low temperature is higher than that of the high temperature.

At present, some scholars have studied the State of Charge (SOC), residual capacity and capacity attenuation of lithium-iron batteries by neural networks, but the experiments were carried out at normal temperature. On the basis of testing the discharge capacity and ohm internal resistance of lithium-iron phosphate battery at low temperature, analyzed the regularity of their temperature influence, and BP neural network is used to predict the discharge capacity at low temperature.

In view of the negative impact of low temperature on the performance of lithium-iron phosphate batteries, the discharge regularity in low temperature environment was mastered, and a certain model was adopted to predict its discharge capacity, this is of great significance to improve the practicality of electric vehicles in northern China.

EXPERIMENT

Experiment Subjects and Instruments

In order to measure the ohm internal resistance and discharge capacity of different types of lithium-iron phosphate battery under low temperature conditions, the selected experimental subjects are shown in Table 1.

| Group | Nominal voltage | Nominal capacity | Nominal internal resistance | Type specification | Sample size |
|-------|-----------------|------------------|----------------------------|--------------------|-------------|
| A     | 3.2V            | 600mAh           | 8Ω                         | 14500              | 50          |
| B     | 3.2V            | 4200mAh          | 5Ω                         | 32650              | 50          |

The experimental instruments are shown in Table 2.

| Instrument name               | Manufacturer          | Type specification |
|-------------------------------|-----------------------|--------------------|
| Battery performance tester    | Shanghai Zhuo Zhi     | EBC-X510, 8 channels |
| Battery internal resistance tester | Guangzhou Xinhui Long | VR200/400          |
| Cryogenic test chamber        | Cangzhou Xin Xing     | DW-40              |

Experiment Scheme

The new experimental subject should be circularly charge-discharged 3 times at the normal temperature(25°C) to activate the battery. Starting from 0°C, -4°C gradually lowered the test temperature to -40°C. The specific test scheme at each temperature test point is as follows: At normal temperature, the 1C constant current is charged to 3.65V and then changed to constant voltage charging to 0.1C; The test subject was placed in a cryogenic test chamber which had been cooled to the test temperature point, after 12 hours of sufficient freezing, test its ohmic internal resistance and then discharged at 1C rate to the discharge cutoff voltage 2.0V, and record discharge capacity; After testing, take out the battery from the cryogenic test chamber and place it adequately at the normal temperature, release the remaining capacity, and then start the test of the next temperature test point from step ।.
EXPERIMENT RESULT ANALYSIS

Influence of Low-temperature on Ohm Internal Resistance

The internal resistance of the battery is divided into ohm internal resistance and polarization internal resistance. Ohm internal resistance is the intrinsic internal resistance of lithium batteries, and is the main part of the total internal resistance of battery charging and discharging. Temperature is the key factor that affects the change of internal resistance of battery. Li Zhe and other studies\(^8\) have shown that within a wide SOC range, the internal resistance of the battery at the same temperature is essentially unchanged, whether it is ohm internal resistance, polarization internal resistance or total internal resistance. In this paper, the ohm internal resistance of the full electric state at each temperature point is measured to analyze the influence of low-temperature on it.

The ohm internal resistance of the full electric state at each temperature point was measured by the experimental scheme given before. The experimental data of any three samples in group A and group B were selected to draw the relationship between temperature and ohm internal resistance, as shown in figure 1.

![Figure 1. Ohm internal resistance curves of A and B batteries at different temperatures.](image)

According to the figure 1, the ohm internal resistance is negatively related to the temperature at low temperature. From the figure 1, it can also be initially obtained that with the temperature drop, the gap between the internal resistance is getting bigger and bigger, the battery consistency is decreased, for further analysis, figure the mean variance of ohm internal resistance at each test temperature point. The relationship between the mean variance of ohm internal resistance and the temperature is shown in figure 2.
According to figure 2, with the decrease of temperature, the mean variance of ohm internal resistance of sample increases gradually, which means that the consistency of the battery monomer gradually deteriorates with the decrease of temperature.

Select any battery in group A and B, the comparison of ohm internal resistance before and after discharge at low temperature is shown in figure 3. As shown in the figure, the ohm internal resistance is basically the same, this is basically consistent with the research conclusion of Li Zhe et al. Therefore, the influence of SOC on ohm internal resistance can be neglected in a wide SOC range, and temperature is the key factor to influence ohm internal resistance.

**Influence of Low-temperature on Discharge Capacity**

In order to analyze the influence of the low temperature on the discharge capacity of the battery, experiments were carried out using the experimental scheme given before. The temperature-discharge capacity relationship fitting curve is shown in figure 4. As shown in the figure, as the temperature drops, the discharge capacity decreases gradually, when the temperature drops to -36°C, the discharge capacity drops sharply; when the temperature drops to -40°C, the discharge capacity is basically zero.
Figure 4. Fitting curves of temperature and capacity of batteries in A and B groups.

The discharge capacity at 25°C is used as a reference value, the discharge capacity at different temperatures is compared with the reference value, and the ratio is the Discharge Capacity Ratio (DCR). The average DCR of the two groups of A and B batteries is given as shown in Table 3.

| Test temperature(°C) | The average DCR in group A | The average DCR in group B |
|----------------------|-----------------------------|---------------------------|
| 0                    | 93.34                       | 99.48                     |
| -4                   | 91.02                       | 98.68                     |
| -8                   | 87.10                       | 95.68                     |
| -12                  | 79.68                       | 91.50                     |
| -16                  | 72.90                       | 86.46                     |
| -20                  | 65.12                       | 82.42                     |
| -24                  | 58.17                       | 77.80                     |
| -28                  | 49.73                       | 70.96                     |
| -32                  | 41.24                       | 62.87                     |
| -36                  | 29.83                       | 48.20                     |

According to Table 3, when the temperature drops to -20°C, the average DCR decreased to 65.12% and 82.42% respectively; when the temperature drops to -36°C, the average DCR decreased to 29.83% and 48.2% respectively. It can be concluded tentatively that the effect of low temperature on different battery monomer DCR is different, the smaller the rated capacity, the smaller the discharge capacity ratio.

DISCHARGE CAPACITY PREDICTION

Through the foregoing content, at low temperature, the discharge capacity of lithium-iron phosphate battery is affected by ohm internal resistance and temperature. The battery is a complex nonlinear system, the neural network as an effective prediction method has been widely applied in many fields for the prediction, so in this paper, BP neural network is used to predict the battery discharge capacity at low temperature.

The full capacity at normal temperature, the test temperature and the ohm internal resistance are chosen as the input layer nodes of the model, and the discharge capacity is used as the output layer node, selected Levenberg-Marquardt (LM) algorithm as the training function. The LM algorithm is a fast algorithm using the numerical optimization technique, which combines the gradient descent method and the Gauss-Newton method. It has the local
convergence of Gauss-Newton method, and the global velocity of gradient descent method, to a certain extent, it overcomes the shortcomings of BP algorithm, such as slow convergence speed and easy generation of local extremum, so it can effectively improve the convergence speed of the network.

Select each half of the two groups of A and B experimental data as training samples, build and train the BP network using the MATLAB neural network toolbox. After many experiments, found in the hidden layer with 4 nodes can more accurately predict the release capacity, the prediction error is within 8%, and the training data network prediction results are basically consistent with the actual measurement results. The training results are shown in figure 5 (a) and (b).

![Figure 5. Training result.](image)

In order to verify the accuracy of the forecast, the remaining data of two groups are imported into the network, the results of BP network prediction are compared with the measured data, and the result are shown in figure 6(a) and (b). According to the figure: the prediction results agree well with experimental results, the prediction error is less than 8%, the results show that the BP neural network based on the LM algorithm can predict the low temperature discharge capacity with high accuracy.

![Figure 6. Verification result.](image)
CONCLUSION

This paper is based on the low temperature experiment of lithium-iron phosphate battery, analyzes the relationship between the lithium-iron phosphate discharge capacity and low temperature, ohm internal resistance and low temperature, and using BP neural network to predict the low-temperature discharge capacity, specific conclusions are as follows:

(1) At low temperature, with the decrease of temperature, the ohmic internal resistance of the lithium-iron phosphate battery rises obviously, and the consistency of the battery monomer becomes worse;

(2) At low temperature, the ohm internal resistance of the lithium-iron battery is basically the same which before and after discharge, the influence of SOC on ohm internal resistance can be neglected in a wide SOC range, and temperature is the key factor to influence ohm internal resistance;

(3) At low temperature, the discharge capacity of the lithium-iron phosphate battery decreases with the decrease of temperature, it is tentatively concluded that the smaller the rated capacity, the smaller the discharge capacity of the battery;

BP neural network prediction model based on LM algorithm is established, which is used to predict the discharge capacity of low temperature and is validated, the prediction error is less than 8%. The verification results show that the BP neural network based on LM algorithm can predict the low temperature discharge capacity of lithium-iron phosphate battery with high accuracy.

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