Study on the Performance of Lithium-Ion Batteries at Different Temperatures

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Abstract. This paper studies on the performance of lithium-ion batteries at different temperatures. The charging and discharging and EIS experiments were carried out to explain the poor performance of the batteries at low temperatures. Experimental results show that as the decrease of the temperatures, the voltage of the battery reached the cut-off voltage rapidly and internal resistance of battery increases apparently, especially polarization resistance. Moreover, voltage platform of discharge drops, performance of high discharge rate is seriously deteriorated. The capacity and impedance of lithium ion batteries are not recoverable by low temperature charging. Thus, electric cars should not be used at low temperatures and preheated before starting at cold winter.

Introduction

The increasingly serious environmental pollution makes more people emphasize on environmental protection. New energy vehicles（NEVs）, as environmentally and friendly models are chosen to alternate traditional fuel vehicles. Lithium-ion battery with high power, energy and output voltage is chosen as power battery that is one of the three core technologies of NEVs. However, it also has many disadvantages such as high cost, thermal runaway and low temperature performance coupled to thermal effects. For examples, its electrochemical performance is extremely susceptible to ambient temperature. In the low temperature environment, the viscosity of the electrolyte increases, the electric charge moves slowly and the velocity of electrochemical reaction slows. In extreme cases, the electrolyte which is evenly frozen makes the battery discharge hardly so that the electric car cannot start successfully. In addition, the charging time becomes shorter and the charging capacity apparently decreased when the ambient temperature below zero degrees Celsius. If the battery in the low ambient temperature works for a long time, the battery life will be greatly reduced. Currently, the working range lithium ion battery is -20 degrees Celsius and 50 Celsius. But in actually use, most of the lithium-ion battery can only ensure the work performance above zero Celsius. Tippmann, S., et al [1]had done many experiments in which cells are charged under different operating conditions. Capacity fade is measured after a significant number of cycles and compared to the simulated anode potential. Charge capacity was identified as important parameter influencing degradation. S.S.Zhang[2] used electrochemical impedance spectroscopy (EIS) study cycling performance of battery cells in -60 Celsius and 0 Celsius. Results showed that In the fully charged and discharged states as well as at the low temperatures (≤20℃), the cell of the Li-ion cells is predominated, they explained two low temperature phenomena of the Li-ion battery: (1) Charging of a fully discharged cell is much more difficult than discharging of a fully charged cell, and (2) both the power (operating voltage) and energy (delivered capacity) are substantially reduced. Lei[3] had done the charge and discharge experiment at 20 °C to-40℃ environment, analyzed the relationship between temperature and the characteristics of charge-discharge, capacity, voltage, internal resistance and discharge power that were obtained by carrying static and dynamic testing on the lithium-ion batteries. The experimental results showed that: As temperature dropping, Lithium-ion battery discharge capacity and discharge voltage were reduced rapidly, constant current charging time was shortened greatly , constant current charge capacity was reduced. While the constant voltage charging time was extended, the total charge capacity was reduced. Yang[4] tested the charging

performance of battery at -15 and -25℃, the results showed that with the temperature descended, the battery charge power dropped significantly. At -25℃ the charging power has been reduced to 50% of room temperature charging power. Only after three low temperatures charging, the battery capacity attenuation has far exceeded the normal attenuation rate of the battery, and the lower the temperature, the more serious capacity attenuation. It seriously affected the normal operation of electric vehicles. In addition, the discharging performance was also tested, at the same ambient temperature.

Therefore, in order to maintain the battery's normal operating temperature, ensure the normal output power of the battery and extend the battery cycle life, it is essential to further master the performance of lithium-ion batteries at different temperatures. In this paper, a test for simulating cryogenic environment is carried out the characteristics of batteries at low temperatures which can provide the basis for the application of batteries at various conditions.

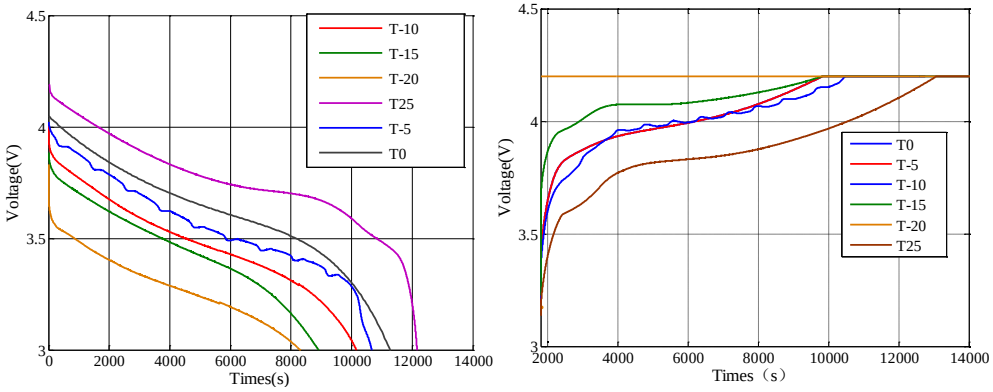
Charge/discharge characteristics of lithium-ion batteries at various temperatures

Experiment scheme of low temperature charge and discharge

The positive and negative wiring of battery clamp are connected to the end of charge and discharge test instrument. The lithium-ion battery placed in high and low temperature constant warm box. During the test, the battery is completely exposed to the test of the thermostat. In the thermostat box, the circulation of the dry constant temperature cold air in the warehouse makes the battery in the cold air.

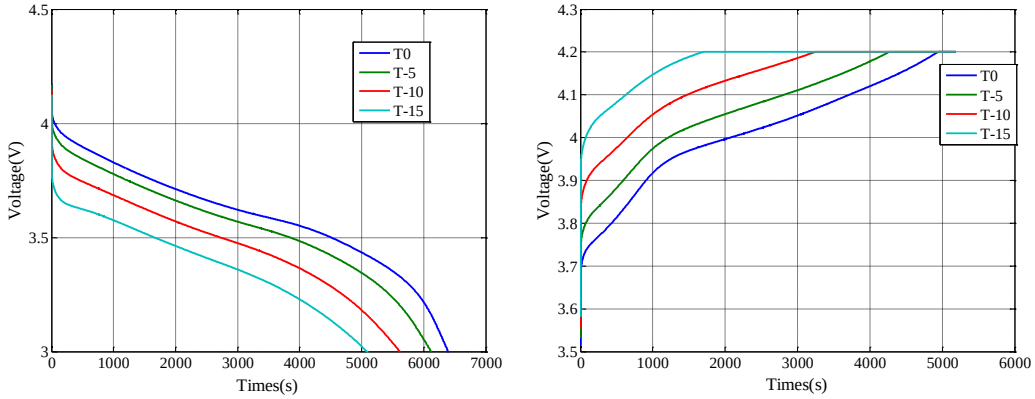
The test temperatures of the batteries when charge/discharge are-15℃,-10℃,-5℃0℃,25℃.Before starting the charging/discharging test, the test battery rest at the target temperature for more than four hours to make sure the inside and outside temperature of the battery are same and reach the required temperature. Then the different charge/discharge rate is 0.3C 0.5C and 1C respectively to test the characteristics of the batteries at corresponding temperatures.

Results and discussion



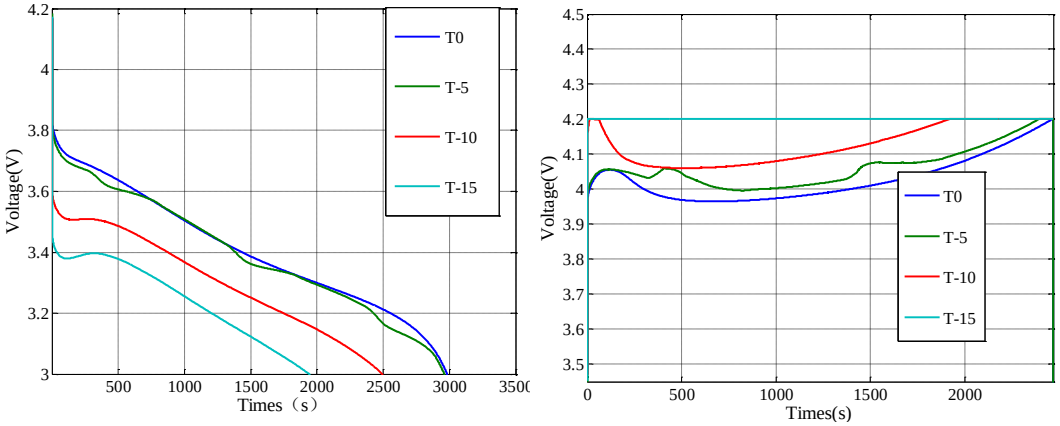
a) Discharging curves` b) Charging curves`

Figure 1. Discharge and charge curves of 0.3C at different temperatures



a) Discharging curves` b)Charging curves`

Figure 2. Discharge and charge curves of 0.5C at different temperatures



a) Discharging curves` b)Charging curves`

Figure 3. Discharge and charge curves of 1C at different temperatures

As shown in the curves of the above Figures, the following conclusions can be drawn: (1) Discharged with the same discharge ratio, the voltage of the battery increases with the increase of temperature. Take the 0.3C constant current discharge for example, at - 20℃and 25 ℃, the average discharge voltage of the battery decreased by 1V. (2)At low temperatures, especially, large current discharge, the discharge curve has a distinct wave trough peak shape, and the discharge voltage fluctuates greatly. For example, when discharged at 1C, the discharge curve is normal, and there is no wave valley peak. When the temperature is reduced to -15℃, the discharge curve appears obviously. (3) The charging curves show that the lower the temperature the battery, the higher the starting voltage of the charge is, the shorter the constant current charging time is.

This shows that electricity is at low temperature, the initial stage of discharge in a large current, the active substance of the battery cannot be fully utilized because of the low temperature. The polarization is serious, the internal resistance of the battery is large, and the discharge voltage of the battery decreases rapidly at the initial stage of discharge. In the process of discharge, Current flow through battery, the internal resistance of the battery produces Joule heat, which makes the cell temperature rise rapidly and the active substance part of the battery is activated. Therefore, the discharge voltage of the battery rises, and the discharge voltage of the battery decrease with the decrease of the capacity of the battery.

Impedance spectroscopy experiment (EIS) at low temperatures

The resistance is another important characteristic of the lithium-ion batteries which also changes dramatically with various temperatures. The impedance spectroscopy experiments of lithium-ion batteries

are tested to explore the performance of the resistance at different environment. The state of charge about the tested battery is calibrated at 50% for the EIS measurement. Using Wantong impedance analyzer measures the EIS at a sinusoidal excitation of 5 mV amplitude with the frequency range is 10^4 Hz~ 10 mHz. The thermostat box controls and monitors the temperature of the tested battery at every 5℃ from -20℃ to 5℃. The batteries are soaked at each set temperature before EIS tests for more than 4 hours to make sure temperature equilibration.

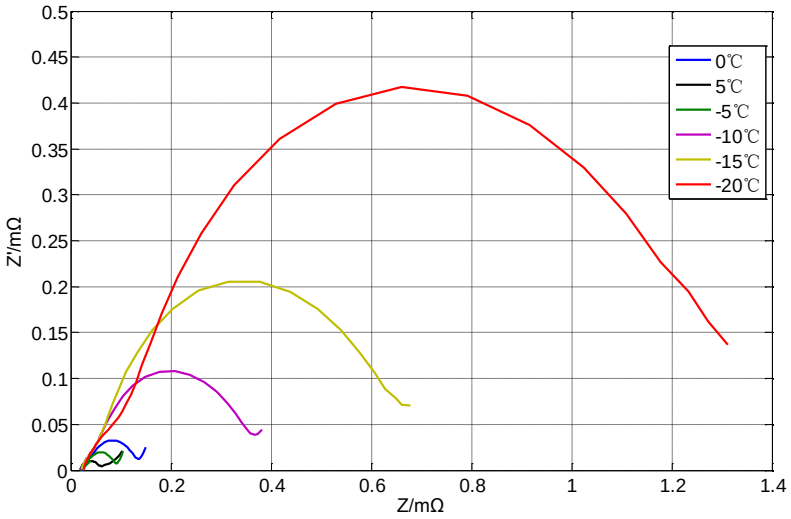


Figure 4. The EIS at different temperatures

As shown in the Figure4, the internal resistance of the batteries increases rapidly with the decrease of temperature,

Conclusion

When charging/discharging at low temperature, the lithium from the cathode is removed from the electrolyte by the cathode. A partial lithium-ion and negative charge are formed on the surface of the negative electrode, lithium cannot be embedded in the negative electrode to form irreparable lithium plating.

Experiments show that the low temperature charging/discharging performance of the battery is continuous with the decrease of temperature deterioration: the battery capacity drops, the discharge voltage of the battery decreases, and the resistance increases. The discharge performance deteriorates and the discharge cannot be realized when the temperature is too low. Low battery temperature discharge performance seriously affects the normal capacity of the batteries, therefore, electric cars should be avoid using and heated in too cold condition.

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References

[1] Tippmann S, Walper D, Balboa L, Spier B, Bessler WG. Low-temperature charging of lithium-ion cells part I: Electrochemical modeling and experimental investigation of degradation behavior. Journal of Power Sources. 2014;252:305-16.

[2] Zhang S, Xu K, Jow T. Electrochemical impedance study on the low temperature of Li-ion batteries. Electrochimica acta. 2004;49:1057-61.

[3] Lei zhiguo. Thermal characteristics and thermal model of lithium ion batteries for electric vehicles. Advanced Technology of Electrical Engineering and Energy. 2015;34:59-4.

[4] Yang Yingying, Wei Xuezhe, Liu Yaofeng. Study on low temperature performance of car lithium ion batteries. Mechatronics. 2016:30-5.