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Performance Tests and Analyses on $LiFePO_4$ Battery

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Abstract

$LiFePO_4$ is considered to be widely used in electric vehicles in the future, for its advantages in safety performance and the cycle life. The performance of a certain LiFePO4 battery produced by one Chinese company is analyzed in this paper, which includes the characteristics of capacity, efficiency, resistance, temperature and inconsistency. The battery is designed for electric vehicles, UPS and so on. The energy density of the battery is 77.84Wh/kg. The battery keeps 73% capacity at -20℃. The relationship between OCV and SOC tested in this paper will be useful for SOC estimation. 10 cells are used to research the heat generating characteristics and inconsistence of the battery. In natural convection environment, the average temperature rising rate is 0.2957℃/min in 1C discharge, and 0.228℃/min in 1C charge. This research will be useful for $LiFePO_4$ battery thermal management. The charge energy inconsistence of cells is most obvious, while that of discharge energy is most unobvious. The available capacity inconsistence of cells should be strictly controlled in parallel connections.

Keywords: lithium battery, thermal management, efficiency, electric vehicle

1 Introduction

LiFePO4 is considered to be widely used in electric vehicles in the future, for its advantages in safety performance, the cycle life and so on. This paper researches on a certain $LiFePO_4$ battery produced by one Chinese company, which is designed for electric vehicles, UPS and so on. The performances of capacity, efficiency, resistance, temperature and inconsistency are tested and analyzed. The specifications of the battery are shown in table 1.

Table 1: Specifications of the LiFePO4 Battery

Voltage	Weight	Dimensions (T×W×L)	Nominal Capacity
3.2V	2.1kg	48mm × 122mm ×195 mm	50Ah

2 Test Methods

The battery tests include voltage characteristics test, capacity characteristics test, efficiency characteristics test, resistance characteristics test, temperature characteristics test and inconsistence characteristics test.

Voltage characteristics include open circuit voltage characteristic tested by HPPC test (Hybrid Pulse Power Characterization Test), and working voltage characteristic which is tested by different constant current charge and discharge.

Capacity characteristics and efficiency characteristics are calculated by data from standard constant current charge and discharge tests. The standard currents will be C/3 (33.3A), C/2 (50A), 1C (100A). The discharge end voltage is 2.3V. The charging test includes two steps. First, charge the battery to 3.6V in a constant current, then charge the battery in a constant voltage at 3.6V until the current reduces to 2A.

Resistance characteristics are tested by HPPC (Hybrid Pulse Power Characteristics). HPPC test is set according to FreedomCAR Battery Test Manual. The discharge and regen resistance is calculated by formula 1 and 2. Figure 1 shows where the resistance calculation time points are.

Temperature characteristics include the heat generating characteristics and thermal characteristics. Heat generating characteristics are tested by measuring the surface temperature in different working condition. Thermal characteristics are tested in a constant temperature cabinet. The voltage characteristics, capacity characteristics and efficiency characteristics are tested in different constant temperature, which will be compared to research the temperature influence to the battery.

Inconsistency characteristics are tested by comparing the characteristics of each cell and the inconsistency influence to the module’s heat generating characteristics are researched in this paper.

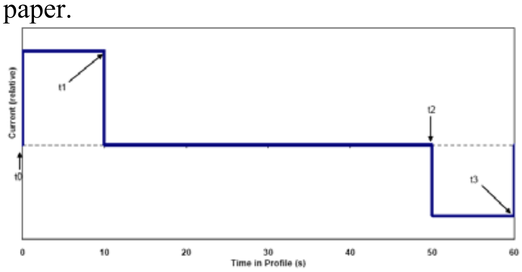

Figure 1: Resistance Calculation Time Points

$$\text{Discharge Resistance} = \frac{\Delta V_{discharge}}{\Delta I_{discharge}} = \frac{V_{t1}-V_{t0}}{-(I_{t1}-I_{t0})} = \frac{V_{t1}-V_{t0}}{I_{t0}-I_{t1}} \qquad (1)$$

$$\text{Regen Resistance} = \frac{\Delta V_{regen}}{\Delta V_{regen}} = \frac{V_{t3}-V_{t2}}{-(I_{t3}-I_{t2})} = \frac{V_{t3}-V_{t2}}{I_{t2}-I_{t3}} \qquad (2)$$

3 Performance Characteristics

3.1 Voltage Characteristics

Figure 2 shows the discharge voltage characteristics in different currents. Figure 3 shows the charge voltage characteristics in different currents. The discharge voltage is around 3.1V and the charge voltage is around 3.4V. In figure 2, the battery discharging in different currents reaches the end voltage at the similar SOC; but in figure 3, the battery charging in 1C reaches the end voltage much earlier than the others.

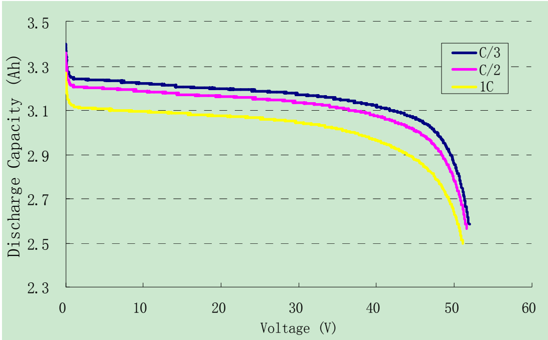

Figure 2: The Voltage Characteristics in different discharge currents

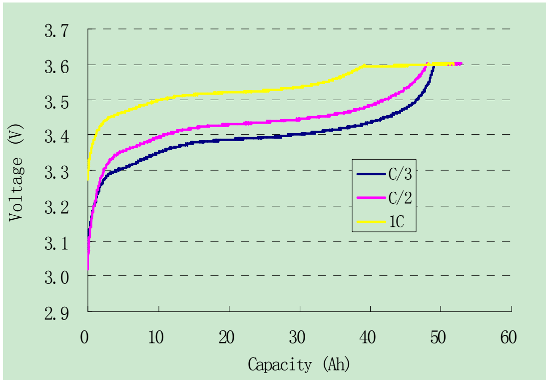

Figure 3: Voltage characteristics at different charge current

Figure 4 shows the open circuit voltages (OCV) at different SOC points. The OCV values monotone increase with the SOC values. But the OCV values from 0.3 SOC to 0.7 SOC is similar with each other, which are the main SOC range in the operating condition. These characteristics will be useful for SOC estimation. Considering measurement errors, the temperature effect to OCV from 20℃ to 55℃ is not obvious.

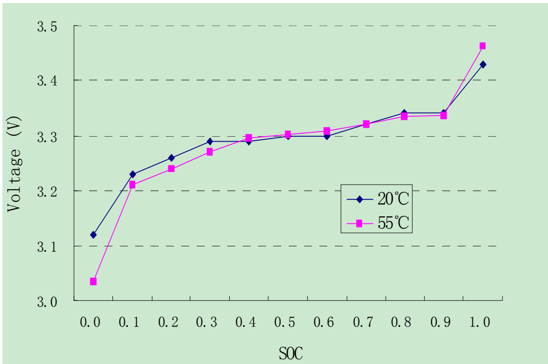

Figure 4: The OCV in different SOC at different temperature

3.2 Capacity Characteristics

Figure 5 shows available capacities and energies in different currents (C/3, C/2, 1C) and different temperatures (-20℃, 20℃, 55℃). The specific energy is the available capacity at 20℃, which is 163.5Wh. The energy density is 77.84Wh/kg.As the discharge current increases, the available capacity and energy decreases. The discharge capacity in 1C discharge current is more than 97% of the discharge capacity in C/3. The temperature influence to capacity and energy is obvious. The available capacity and energy at 55 ℃ are higher than those at 20℃. The available capacity at -20℃ is 85% of that at 20℃, while the available energy at -20℃ is 73% of that at 20 ℃. So it is important to avoid the battery working temperature to be too low.

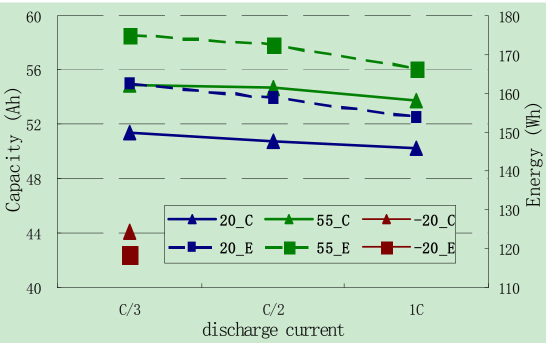

Figure 5: Available capacity and available energy

3.3 Efficiency Characteristics

Figure 6 shows the columbic efficiency and energy efficiency characteristics. As the temperature rises or the discharge current decreases, the efficiency is improved. The energy efficiency at -20℃ is 66%, which means the resistance at -20℃ is much higher than that at 20 ℃.

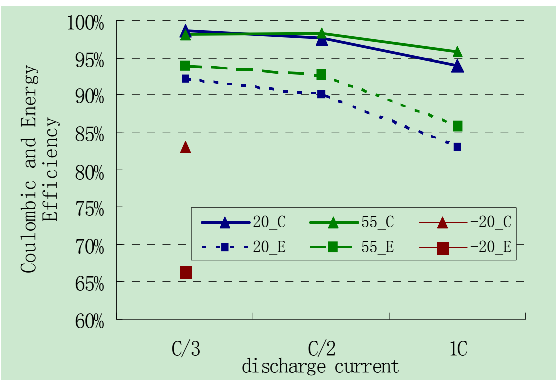

Figure 6: Columbic efficiency and Energy efficiency

3.4 Resistance Characteristics

Figure 7 shows the discharge resistances and regen resistances at different SOC points. The discharge resistances are similar with the regen resistances. These resistances are lower than 3 mΩ. As the SOC increases, the resistances decrease in the main trend.

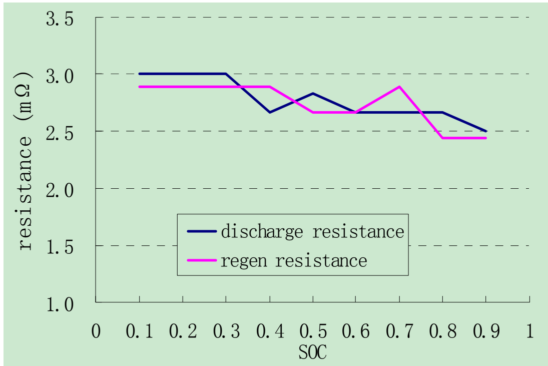

Figure 7: discharge resistance and regen resistance

3.5 Temperature Characteristics

Temperature influences to other battery characteristics have been shown in above figures. Figure 8 and figure 9 show the heat generating characteristics at 1C discharge and 1C charge in natural convection environment. There are 10 cells used in this test. Every two cells are connected in parallel to form a module, and these five models are connected in series. These cells are connected in full filled station. When tests start, the surface temperatures of cells are recorded every 3 minutes. The average temperature rising rate of 1C discharge is about 0.2957℃/min, and that of 1C charge is about 0.228 ℃/min. The temperature rising rates of each cell are similar with each other and highly linear. These characteristics are in coordination with the resistance characteristics. The temperature rising rate of cell 6 is different with others. This phenomenon will be explained in next chapter.

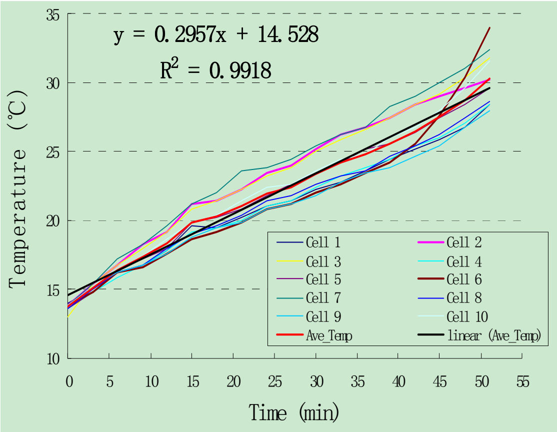

Figure 8: Heat generating characteristics in 1C discharge

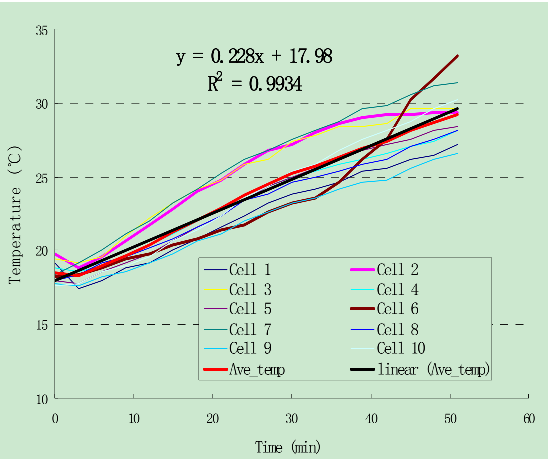

Figure 9: Heat generating characteristics in 1C charge

3.6 Inconsistence characteristics

Table 2 shows the inconsistence of 10 cells. In the table, Δ means relative average deviation. The deviation is the most obvious in the charge energy, and the least obvious in the discharge energy. And the energy efficiency deviation is larger than the columbic efficiency. So the energy loss in charge process is an importance factor to inconsistence characteristics.

Table 2: The inconsistence of characteristics of Cells

Cell Num	charge capacity (Ah)	discharge capacity (Ah)	charge energy (Wh)	discharge energy (Wh)
1	51.1	50.6	171.1	160.3
2	53.3	51.9	179.9	163.5
3	55.0	53.9	187.9	167.6
4	53.1	51.4	179.7	161.4
5	53.8	52.3	183.0	163.1
6	54.4	53.4	186.7	165.3
7	54.7	53.8	186.8	167.6
8	53.4	51.9	180.5	163.2
9	54.2	51.1	183.0	160.6
10	53.2	51.9	180.8	162.1
Δ	7.2%	6.4%	9.2%	4.4%

Cell Num	available capacity (Ah)	available energy (Wh)	columbic efficiency	energy efficiency
1	50.6	160.3	99.1%	93.7%
2	51.9	163.5	97.5%	90.9%
3	53.9	167.6	98.1%	89.2%
4	51.4	161.4	96.7%	89.8%
5	52.3	163.1	97.2%	89.1%
6	53.4	165.3	98.1%	88.6%
7	53.8	167.6	98.3%	89.7%
8	51.9	163.2	97.2%	90.4%
9	51.1	160.6	94.4%	87.7%
10	51.9	162.1	97.5%	89.7%
Δ	6.4%	4.4%	4.8%	6.6%

Table 3 shows the difference of cells in parallel. According to the data in table 1 and table 2, the most obvious characteristic of the module including cell 2 and cell 6, is the difference of the available capacity. And the available capacity of cell 6 is much higher than that of cell 2. In the operating condition, the difference of available capacity represents the difference of operating voltages. So when in the discharge test, the operating voltage of cell 6 is higher than that of cell 2, and there is current charge from cell 6 to cell 2. So in the second half of the discharge test, cell 6 is in the over discharge state and the temperature rising rate is higher than others. These also explain why the temperature rising rate of cell 2 is lower than others in the second half of the discharge test. The same reason can explain the high temperature rising rate in charge test.

So when the cells are selected to be connected in parallel, the inconsistency of the capacity should be controlled strictly.

Table 3: The difference of cells in parallel

Cell number in parallel	1,9	2,6	3,7	4,8	5,10
charge capacity (Ah)	2.92	1.08	0.20	0.25	0.54
Discharge capacity (Ah)	0.50	1.40	0.14	0.50	0.36
charge energy (Wh)	3.35	1.86	0.27	0.22	0.61
Discharge energy (Wh)	0.07	0.54	0.01	0.57	0.30
Available	0.50	1.40	0.14	0.50	0.36

Capacity(Ah)					
Available energy (Wh)	0.07	0.54	0.01	0.57	0.30
columbic Efficiency	2.42	0.32	0.06	0.25	0.19
energy efficiency	3.27	1.31	0.28	0.35	0.31

4 Conclusion

According to the characteristics of a LiFePO4 battery tested in this paper, there are some conclusions as follows:

The energy density of the battery is 77.84Wh/kg;

The available energy at -20℃ is 73% of that at 20℃;

The monotone relationship between OCV and SOC will be used for SOC estimation;

In natural environment, the average temperature rising rate is 0.2957℃/min in 1C discharge, and 0.228℃/min in 1C charge. These data will be useful for $LiFePO_4$ battery thermal management;

The inconsistence of charge energy is most obvious, while that of discharge energy is most unobvious;

The inconsistence of available capacity should be strictly controlled in parallel connections.

References

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