The LiFePO₄ battery sorting method based on temperature analysis

Zhenyu He¹, Xijin Wu^{1,a}, Xin Li¹, Qingshan Wang², Yan Li².

¹NARI Group Corporation (State Grid Electric Power Research Institute), Nanjing 211100, China

²Economic and Technical Research Institute of State Grid Jiangsu Electric Power CO., LTD., Nanjing 210008, China

Abstract. Using temperature as the main state basis for sorting the LiFePO₄ battery can solve the problem of insufficient response to the internal working state of the cell. By tracking and monitoring the status of each cell inside the module, which can reflect the consistency of the complex system after large-capacity grouping. Here, the dynamic temperature change of the LiFePO₄ battery is detected, the temperature rise and the temperature rise rate are compared. The corresponding temperature rise rate of the old cell were significantly higher than the new cell. The temperature difference can be used to judge the consistency of the single cells in the battery module.

1 Introduction

When electric energy or heat energy of the battery pack input and output, the same degree of the parameters, like voltage, state of charge, temperature, capacity, its decay rate, self-discharge rate and its changes over time etc., between single cells were called the consistency of the battery [1-4]. After combined into a battery pack, because of the differences in battery manufacturing raw materials, production parts, production processes, and use environment, there will inevitably be differences in the performance of the monomers [5]. As the number of single cells increase, the differences between the monomers obvious significantly. At present, more than a dozen single batteries were generally selected for series battery in electric bicycles, but hundreds or even thousands of battery cells were applied in electric vehicle, so the inconsistency caused by the differences between the individual cells will be more obvious [6]. The cycle life of the same batch of single cells can reach thousands of times, but after the battery pack was connected in series and parallel, its life span was only a few hundred times, which was the typical inconsistency. The inconsistency of the single cells in the battery pack not only affected the correct judgment of the state of charge and health of the battery pack, but also caused the capacity degradation and life expectancy of the battery pack, and may even cause safety problems [7].

In view of the inconsistency of the LiFePO₄ battery, two methods are proposed by researchers, the first was to monitor and manage the state of the cells in the battery pack through the battery management system (BMS) [8], where the equalization system was commonly used in battery management, like adjust the battery's power and voltage and other state parameters, so that the cells in the same battery pack can be maintained in a consistent state

of output. The second was to sort the cells into groups through the measurement and comparison of similar parameters, such as voltage, internal resistance, and capacity before the batteries are grouped to improve the consistency of the cells in the battery pack [9].

The disadvantages of the methods in the application process are as follows. Firstly, the state of the cell can only be adjusted based on the certain criterion such as voltage and apparent SOC, and such external parameters, cannot completely reflect the internal working state of the battery (such as SOH, etc.). Secondly, the cells were tested in the static state, the dynamic working conditions during the actual operation of the cells cannot be reflected. Thirdly, the use environment of the battery in practical applications such as energy storage systems or electric vehicles were relatively complicated, and the existing static sorting methods cannot cope with the battery consistency requirements of complex systems after large-capacity grouping of batteries [10].

During the working process, the aging of the cell and the change of internal resistance will be reflected by the heat generation in the working state [11]. Due to the internal aging of the old cell (such as the amount of active lithium, electrolyte impurities, SEI film thickness, etc.) was larger than the new cell, when the new cell and the old cell of the same model was charged and discharged in parallel, resulting in the large energy loss of the old cell [12]. The lost energy will be reflected in the form of heat, and the corresponding temperature rise rate of the old cell were significantly higher than the new cell. Using temperature as the main state basis for sorting the LiFePO₄ battery can solve the problem of insufficient response to the internal working state of the cell. By tracking and monitoring the status of each cell inside the module, which can reflect the consistency of the complex system after large-capacity grouping. By the

^a Corresponding author: wuxijin@sgepri.sgcc.com.cn

charging and discharging test of the LiFePO_4 battery, to detect the dynamic temperature change of the cell, compare the temperature rise and the temperature rise rate, to reflect the internal performance of the cell during the dynamic working process. The LiFePO_4 battery showed good performance at 20~30°C, considering the LiFePO_4 battery may operate under extreme conditions, the effects of temperature (-5°C, 25°C, 35°C) were investigated. The method can be used to identify battery inconsistencies and screen unqualified batteries.

2 Materials and Methods

The LiFePO_4 battery produced by CALB (Luoyang) Co., Ltd., has a single cell voltage of 3.2 V and a nominal capacity of 72 Ah, was used in the experiment. Electric charging and discharging tests of the LiFePO_4 battery are conducted by the BTS-5V 600 A battery testing instrument (Shenzhen Xinwei Electronics Co., LTD). Each cell was discharged to 2.5V at a constant current of 1C. After standing for 10~12 hours to ensure the stable state of the battery voltage, followed by putting the battery under different temperature conditions at -5°C, 25°C, 35°C for 5~8 hours, which was achieved through Tomino high and low temperature test chamber (Jiangsu Tomino Environmental Testing Equipment Co. LTD), to create different charging and discharging test environments of cells. The K-type thermocouple was directly arranged at the centre of the outer surface of each cell, and the temperature data collection and storage were realized through YOKOGAWA MV2000 series paperless recorder. The cell was charged with 1C constant current until the cell was fully charged, discharged each cell to 2.5V at a constant current of 1C, and record the temperature change during the charging and discharging process.

3 Results & Discussion

To understand the internal performance of the cell during the dynamic working process, charging and discharging tests were performed and analysed at -5°C, 25°C, 35°C. Detecting and recording the dynamic temperature changes of the batteries, and comparing the temperature rise and the temperature rise rate.

Figure 1-3 showed that the temperature change trend of the cell during charging and discharging at -5°C, 25°C, 35°C. The used cell was used in the energy storage power station for one year, and the new one was purchased from the same manufacturer. Due to the internal aging of the old cell (such as the amount of active lithium, electrolyte impurities, SEI film thickness, etc.) was larger than the new cell, the aging of the cell and the change of internal resistance will be reflected by the heat generation in the working state. When the ambient temperature kept at -5°C, 25°C or 35°C, the temperature rise of the old cell with a higher degree of aging was obviously higher than the new cell during charging and discharging. The corresponding data changes were shown in Table 1-3. At -5°C, the maximum temperature difference, the average

temperature rises rate of the used cell were 18.74 and 2.602×10^{-3} , respectively. The maximum temperature difference, the average temperature rises rate of the new cell were 13.90 and 1.930×10^{-3} , respectively. At 25°C, the maximum temperature difference, the average temperature rises rate of the used cell were 8.22 and 1.142×10^{-3} , respectively. The maximum temperature difference, the average temperature rises rate of the new cell were 5.73 and 7.96×10^{-4} , respectively. At 35°C, the maximum temperature difference, the average temperature rises rate of the used cell were 12.73 and 1.176×10^{-3} , respectively. The maximum temperature difference, the average temperature rises rate of the new cell were 10.16 and 1.411×10^{-3} , respectively. The results showed that the temperature difference can be used to judge the consistency of the single cells in the battery module.

3.1 The temperature change of the LiFePO_4 during charge and discharge process at -5°C

Figure 1. Temperature change trend during charging and discharging process at -5°C.

Table 1. Analysis of the cell's temperature changes.

Name	Maximum temperature (°C)	Maximum temperature difference(°C)	Average temperature rise rate(°C/s)
The used cell	13.74	18.74	2.602×10^{-3}
The new cell	8.895	13.90	1.930×10^{-3}
The used cell	13.74	18.74	2.602×10^{-3}

3.2 The temperature change of the LiFePO_4 during charge and discharge process at 25°C

Figure 2. Temperature change trend during charging and discharging process at 25°C.

Table 2. Analysis of the cell's temperature changes.

Name	Maximum temperature (°C)	Maximum temperature difference(°C)	Average temperature rise rate(°C/s)
The used cell	33.22	8.22	1.142×10^{-3}
The new cell	30.73	5.73	7.96×10^{-4}
The used cell	33.22	8.22	1.142×10^{-3}

3.3 The temperature change of the LiFePO₄ during charge and discharge process at 35°C

Figure 3. Temperature change trend during charging and discharging process at 35°C.

Table 3. Analysis of the cell's temperature changes.

Name	Maximum temperature (°C)	Maximum temperature difference(°C)	Average temperature rise rate(°C/s)
The used cell	47.73	12.73	1.176×10^{-3}
The new cell	45.16	10.16	1.411×10^{-3}
The used cell	47.73	12.73	1.176×10^{-3}

3.4Consistency identification of 10 single cells

Ten pieces of cells from the same manufacturer were tested, and the temperature change data in charging and discharging process of the cells were recorded. The temperature change during charging and discharging was shown in Figure 5. The temperature rises of two of them was significantly higher than that of the other eight. The eight pieces of cells had a similar temperature rise. When

batteries were grouped in series or parallel, the batteries numbered 4 and 6 can be discard and more suitable batteries can be continued to screen in the same way.

Figure 4. Temperature change trend during charging and discharging process at 25°C.

Table 4. Analysis of the cell's temperature changes.

Name	Maximum temperature (°C)	Maximum temperature difference(°C)	Average temperature rise rate(°C/s)
#1	30.73	5.73	7.958×10^{-4}
#2	30.99	5.99	8.320×10^{-4}
#3	31.07	6.07	8.431×10^{-4}
#4	33.22	8.22	1.142×10^{-3}
#5	31.32	6.32	8.778×10^{-4}
#6	32.83	7.83	1.088×10^{-3}
#7	30.73	5.73	7.958×10^{-4}
#8	30.49	5.49	7.625×10^{-4}
#9	30.97	5.97	8.292×10^{-4}
#10	30.91	5.91	8.208×10^{-4}

4 Conclusion

Through the detection and analysis of temperature changes, the problem of insufficient response to the internal working state of the cell can be solved. The dynamic temperature change of the cell can be detected by the charging and discharging test. Comparing the temperature rise and the temperature rise rate, to reflect the internal performance of the cell during the dynamic working process. Considering the cell may operate under extreme conditions, the effects of temperature (-5°C, 25°C, 35°C) were investigated. The temperature rise of the old cell with a higher degree of aging was obviously higher than the new cell during charging and discharging. The method can be used to identify battery inconsistencies and screen unqualified batteries. Tracking and monitoring the status of each cell inside

the module, which can reflect the consistency of the complex system after large-capacity grouping. It can improve the energy efficiency of the energy storage module and guarantee the safety of the energy storage module.

Acknowledgments

This work is supported by the Science and Technology Project of SGCC (5400-201940486A-0-0-00).

References

1. Wang B, Yang L I, Zhang N J C J O P S. Study on consistency of lithium-ion phosphate power battery pack after circulation[J], 2016.
2. Meng Z, Na L, Yuan J, et al. Evaluation Index of Consistency of Internal Resistance of Echelon-use Lithium Battery[J], 2018.
3. Fan F, Tai N L, Zheng X D, et al. Equalization Strategy for Multi-Battery Energy Storage Systems Using Maximum Consistency Tracking Algorithm of the Conditional Depreciation[J], 2018, PP: 1-1.
4. Feng W, Cheng L, Jiang J, et al. A New Evaluation Method to the Consistency of Lithium-Ion Batteries in Electric Vehicles[C]. Power and Energy Engineering Conference (APPEEC), 2012 Asia-Pacific, 2012.
5. Bhardwaj R C, Hwang T, Mank R M. BATTERY PACK WITH CELLS OF DIFFERENT CAPACITIES[J], 2012.
6. Tanboonjit B, Fuengwarodsakul N H. Implementation of charger and battery management system for fast charging technique of Li-FePO₄ battery in electric bicycles[C]. Ninth International Conference on Ecological Vehicles & Renewable Energies, 2014.
7. Zheng Y, Ouyang M, Lu L, et al. Cell state-of-charge inconsistency estimation for LiFePO₄ battery pack in hybrid electric vehicles using mean-difference model[J], 2013, 111: 571-580.
8. Baronti F, Fantechi G, Roncella R, et al. Design of the battery management system of LiFePO₄ batteries for electric off-road vehicles[C]. IEEE International Symposium on Industrial Electronics, 2013.
9. Kajimoto T. Stabilized voltage generating circuit and internal voltage down converter and a method of generating an internal operating power supply voltage for a dynamically operating circuit. US, 1996.
10. Madlener R, Kirmas A J E P. Economic Viability of Second Use Electric Vehicle Batteries for Energy Storage in Residential Applications[J], 2017, 105: 3806-3815.
11. Juarez-Robles D, Jeevarajan J A, Society P P M J J O T E. Degradation-Safety Analytics in Lithium-Ion Cells: Part I. Aging under Charge/Discharge Cycling[J], 2020, 167(16): 160510.
12. Horowitz Y, Ben - Barak I, Dan S, et al. Study of the Formation of a Solid Electrolyte Interphase (SEI) on a Silicon Nanowire Anode in Liquid Disiloxane Electrolyte with Nitrile End Groups for Lithium - Ion Batteries[J], 2019, 2(3).