Experimental Study on Thermal Runaway of LiFePO$_4$/C Battery under Heating Condition

Fei Gao$^1$, Yang Kai$^1$, Congjie Wang$^2$, Wei Liu$^3$, and Yanli Zhu$^2$

$^1$ State Key Laboratory of Operation and Control of Renewable Energy & Storage Systems, China Electric Power Research Institute. Beijing 100192, China
$^2$Beijing Institute of Technology, 100081, China
$^3$State Grid Anhui Electric Power CO. LTD, Hefei, 230000, China
$^*$Corresponding author’s e-mail: zhuyanli1999@bit.edu.cn

Abstract. The safety of lithium ion batteries is a hot topic in battery application and research at present. LiFePO$_4$/C batteries are generally believed to be safe and have been widely used. The LiFePO$_4$/C batteries are taken as the research object, the thermal runaway characteristics of the LiFePO$_4$/C batteries are analyzed from the changes of battery temperature and voltage during the test process. The results show that the battery voltage fluctuated greatly before the thermal runaway occurred for the battery under one side heating, however, the battery voltage did not fluctuate and dropped to 0 V for the battery under two sides heating. For the battery group under one side heating, the thermal runaway chain reaction did not occur, which meant that the LiFePO$_4$/C battery possessed good safety.

1. Introduction

In recent years, with the rapid development of Lithium-ion battery (LIB) technology in China, its safety accidents occur from time to time, which has aroused great attention [1-3]. The LIB thermal runaway will cause fire or explosion, and one of the main inducing factors of the thermal runaway is thermal abuse.

Scholars at home and abroad have conducted a lot of experimental research on the safety of LIBs under the condition of thermal abuse. Changwei Ji et al. [4] conducted a heating abuse test on the 32650-type LiFePO$_4$/C battery, which results showed that the higher the state of charge, the lower the safety of the battery. Guangchao Du et al. [5] studied the thermal runaway characteristics of the cylindrical ternary LIB under the condition of overheating by means of the adiabatic calorimeter, which results showed that the starting temperature of the battery self-heating was mainly related to the decomposition of SEI film, which was little affected by the state of charge. Fei Gao et al. [7] studied the thermal runaway of LiFePO$_4$/C battery, which showed that the time of thermal runaway is shorter with the increase of charging current and there is a power function relationship between the time of thermal runaway and overcharge current.

The above research work is of great significance for understanding the thermal runaway characteristics of LIBs and optimizing the thermal management of LIBs, but most research focus on small-scale LIBs. At present, most of LIBs used for electric energy storage in China are LiFePO$_4$/C batteries, and the capacity is relatively large, but there are few studies on the thermal runaway of this kind of LIBs. In this paper, the thermal abuse test of 60 Ah LiFePO$_4$/C battery was carried out by...
means of heating plate, and the characteristics of thermal runaway of this type of battery were summarized.

2. Experimental scheme

The 60 Ah LiFePO₄/C batteries were taken as research objects, which electrolyte consist of ethylene carbonate, dimethyl carbonate and diethyl carbonate. All batteries used in the test are fully charged, and the battery group is composed of four fully-charged batteries fixed side by side. For the single battery thermal abuse test, as shown in Figure 1 (a), the temperature of the contact surface between the heating plate and the battery was recorded as Tᵥ, the temperature of the opposite side of the battery was recorded as Tᵥ. For the battery group thermal abuse test, as shown in Figure 1 (b), the batteries were respectively marked as 1#, 2#, 3#, 4#. The heating plate was fixed on the left side of the battery (1#). The temperatures of the contact parts between batteries were recorded as T₁-₂, T₂-₃, T₃-₄ and T₄. All temperatures were measured by thermocouples.

![Figure 1 The experimental diagram, (a) battery, (b) battery group.](image)

Figure 2 shows the experiment devices, including the heating plate, thermocouples, data recorder, etc. The battery voltages and temperatures were recorded by data recorder. When the experiment began, the heating plate began to work. And as soon as the voltage of batteries dropped to 0 V, heating was stopped manually.

![Figure 2 The experimental device.](image)
3. Analysis
The temperatures and voltages of LiFePO4/C batteries under heating condition are shown in Figure 3. According to the changes, the thermal runaway process of the battery heated on one side was divided into three stages, which was shown in Figure 3(a).

Stage I: Th rose to 600°C quickly, while Tc changed very little and the battery voltage almost contained a constant value (3.42 V), which meant the thermal runaway had not occurred.

Stage II: The temperatures (Th and Tc) continued to rise, and the voltage dropped to 0 V gradually. At this stage, the voltage experienced an obvious voltage fluctuation, which dropped rapidly from 3.25 V to 2.34 V at the 13th min, then rising again. This phenomenon showed that there was a slight short circuit within the battery. At the end of stage II, the voltage dropped to 0 V, which indicated that the battery was short-circuited fully.

Stage III: The voltage maintained 0 V and Tc rose quickly. At this stage, the battery thermal runaway occurred.

For the battery heated on both sides, there was no obvious voltage fluctuation during the heating process, which was shown in Figure 3(b). Due to the increase of the received heat, the internal side reaction of the battery is accelerated, resulting in a significant shortening of the time to trigger an internal short circuit.
Figure 4 showed the temperatures and voltages of batteries in the battery group under one side heating condition. In the battery group, the voltage of the battery (1#) close to the heating plate was similar to that of the single battery test (Figure 3(a)), and there was also a large voltage fluctuation (decrease of 1.42V). When V1 dropped to 0 V, the battery (1#) was short-circuited. Then the thermal runaway occurred, and T1-2 value rose above 200 ℃. For other batteries (2#, 3# and 4#), their voltage always kept a constant value, and the T2-3, T3-4, T5 value rose slowly, which indicated that the thermal runaway of other batteries (2#, 3#, and 4#) had not occurred. In summary, for the LiFePO4/C battery group under one side heating condition, the thermal runaway chain reaction did not occur.

4. Conclusion
In this paper, the thermal runaway process of the 60Ah LiFePO4/C battery under heating condition was studied. The conclusions are as follows:

(1) Under the condition of one side heating, the battery voltage fluctuated greatly, then the voltage dropped to 0 V and the thermal runaway occurred.

(2) Under the condition of both sides heating, the battery voltage did not fluctuate greatly, and the thermal runaway occurred quickly.

(3) For the LiFePO4/C battery group under one side heating condition, the thermal runaway chain reaction did not occur, which meant that the battery possessed good safety performance.

Furthermore, the critical condition and threshold value of thermal runaway chain reaction of the LiFePO4/C battery under heating condition need further in-depth study.

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