Journal of Energy Storage 16 (2018) 160–166

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

Evaluation of battery inconsistency based on information entropy

Bin Duan, Zeyuan Li, Pingwei Gu, Zhongkai Zhou, Chenghui Zhang*

Shandong University, School of Control Science and Engineering, Shandong Province, China

ARTICLE INFO

Article history:
Received 30 October 2017
Received in revised form 27 December 2017
Accepted 15 January 2018
Available online xxx

Keywords:
Battery inconsistency
Information entropy
Evaluation factors

ABSTRACT

The power battery system is the core for electric vehicles, which is composed by hundreds or thousands of cells in series and parallel generally. Cells have inherent inconsistency because of slight deviations and uncertain factors in their production process. And they work in the complicated charge and discharge environment for a long time, so their inconsistency will be further aggravated to greatly reduce the available capacity and shorten the service life. There is an urgent need to establish an evaluation mechanism for the inconsistency of batteries to provide the gist for the high-efficiency and reliable management. The test platform and scheme are built to obtain accurate data. And a comprehensive evaluation method for battery inconsistency is proposed based on the information entropy. Taking the capacity, internal resistance and the ratio of constant current charge capacity to constant voltage charge capacity as evaluation factors, the inconsistency of the battery pack composed of twelve cells is analyzed comprehensively. Experimental results show that the method can scientifically evaluate the inconsistency of the battery pack in different life and has wide adaptability.

1. Introduction

The development of electric vehicles is one of the key ways to solve environmental and energy problems. The comprehensive performance of power batteries determines the performance of the whole vehicle [1,2]. Before batteries leave the factory, they must be firstly filtered out according to their performance, and then connected in series and in parallel to battery groups. The manufacturing process of lithium-ion batteries is complex, including the electrode manufacture, assembly, formation and detection process [3–5], where the nonuniformity of the production and material exist inevitably. Specifically, electrode thickness, electrolyte concentration and the formation of SEI film may vary from cell to cell. These could lead to the inconsistency of capacity, internal resistance, self-discharge rate and other parameters even if in the same production line and batch. This can be called the inconsistency of 'congenital birth'. On the other hand, because of the complex charge and discharge environment, there are temperature and ventilation differences among cells, which make the inconsistency of 'congenital birth' worsen and form the inconsistency of 'acquired environment'. The inconsistency will cause a 'short board effect' of cells and shorten the battery life [9,10]. So there is an urgent need to establish an evaluation mechanism for the inconsistency of cells to provide the gist for the high-efficiency and reliable management.

Scholars at home and abroad have researched on the causes, formations and laws of the inconsistency of cells. Zheng Yuejiu [4] demonstrated the evolution mechanism of the battery capacity by the scatter plot of the two-dimensional scale attenuation, and thought that the major influencing factors are the coulombic efficiency and temperature. Dubarry [5] et al. discharged the same batch of lithium-ion cells at C/2 current and obtained the normal distribution of cell capacity. Wang Zhenpo [6] et al. took the electric bus as the experimental object, and studied the dynamic and static performance of the voltage inconsistency of the lithium-ion battery pack. Dai Haifeng [7] et al. conducted a second pulse discharge experiment on the same production batch batteries with capacity of 8 Ah at 1 C discharging current. The distribution of DC internal resistance was measured as shown in Fig. 1, indicating that the distribution of DC internal resistance is consistent with the normal distribution.

Scholars also studied the evaluation method of battery inconsistency based on the statistical distribution rule. Shan Yi [1] et al. selected characteristic points on different charge and discharge curves, and took the cell voltage as the evaluation factor and regarded the European distance between different feature points as the evaluation index. Then the dispersion among cells could be obtained by the hierarchical clustering method. Zhang Bin [8] et al. established a dispersion model composed of integral dispersion and limit dispersion through the relationship between

* Corresponding author.
E-mail addresses: duanbin@sdu.edu.cn (B. Duan), zchui@sdu.edu.cn (C. Zhang).

https://doi.org/10.1016/j.est.2018.01.010
2352-152X/

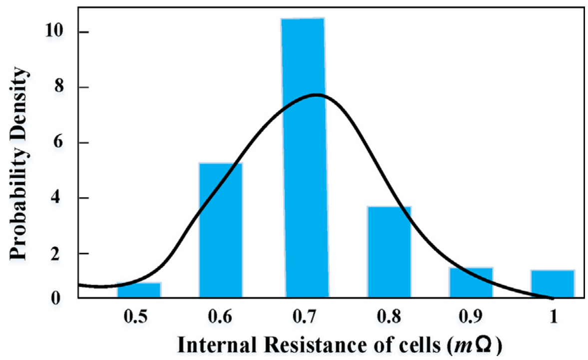

Fig. 1. Battery internal resistance distribution.

open circuit voltage (OCV) and state of charge (SOC), and proposed an evaluation method of battery inconsistency based on OCV-SOC to reflect the limit dispersion of individual cells.

In fact, battery inconsistency is often comprehensive characteristics of the cell in the capacity, internal resistance, self-discharge rate and other aspects. The single parameter evaluation method can't fully reflect the real situation of battery inconsistency. Multi-parameter evaluation method is appropriate. However, the existing evaluation methods are often simple mathematical operations, the reliability of evaluation is poor. This paper starts with obtaining real and reliable comprehensive data of battery, and studies the method for evaluating the inconsistency of power batteries based on information entropy.

2. Acquisition of the test data of lithium-ion battery inconsistency

The inconsistency of the lithium-ion cells will be more and more serious with charge and discharge cycles. The comprehensive test scheme for the cell's life and characteristic is designed based on the twelve 1.55 Ah 18650 lithium-ion cells in series into a pack. The test platform diagram and the test process are shown in Figs. 2 and 3, respectively.

The test platform mainly includes the cell tester, internal resistance tester, temperature controller and computer. The cell tester can measure 16 channels in parallel, whose voltage test range is 0–5 V and measurement accuracy is up to ±0.1%. The controllable temperature range is −40–130 °C, and the temperature change rate is 2.5°/min, which can be switched freely through programming. The high-performance computer provides enough storage space and stable testing process.

In order to explore the battery inconsistency variation in different cycle conditions, the cycle plan is designed. Specifically, all cells are charged by the constant current-constant voltage (CC-CV) method and discharged at 2 C current to the lower cut-off voltage as a charge and discharge cycle, and one hundred cycles are a set of large cycles. After each group of large cycle, the maximum capacity test, HPPC test are carried out, respectively. The specific steps for the maximum available capacity [11] test are as follows:

(1) At temperature 25 °C the cells are discharged to the lower cut-off voltage at 1C current, and rested for one hour;
(2) The cells are also charged to the upper cut-off voltage at 1 C current and then charged using the constant voltage method. When the charge current drops to 0.05 C, stop charging and rest for one hour;
(3) The cells are discharged at 1 C current to the lower cut-off voltage. The capacity average of every cell could be calculated after the maximum available capacity test is conducted for three times. Accordingly, the capacity decay process of the twelve cells from the initial state to four hundred cycles is shown in Fig. 4.

As shown in Fig. 4, there is little difference in the capacity of the twelve cells in the initial state, where the maximum capacity difference is 36 mAh. But their capacity attenuation is serious, and inconsistent situation is significant with the continuous cycles. After four hundred cycles, the maximum capacity difference becomes 270 mAh and the diffusion of the inconsistency among the cell capacity is also more obvious.

A new hybrid pulse power characterization (HPPC) charge and discharge test scheme is designed with reference to the Freedom CAR battery test manual [12] of the United States, as shown in Fig. 5. Compared with the traditional voltage impulse response method, the HPPC has the richer incentive to fully reflect the ohmic resistance. The specific test steps are as follows:

(1) Cells are discharged at 1/3 C current to the lower cut-off voltage, and then rested for two hours to start testing;
(2) Cells are discharged at 0.2 C current for ten seconds, and then rested for forty seconds. Then cells are charged at 0.5 C current for ten seconds, and then rested for forty seconds. According to the above rule, cells are still charged and discharged at 1 C, 1.5 C, 2 C, respectively;
(3) Cells are charged by 5% SO C at 1/3 C current, and then rested for two hours.

The difference between the discharge and charge process of the HPPC test is that the cells are discharged to the lower cut-off

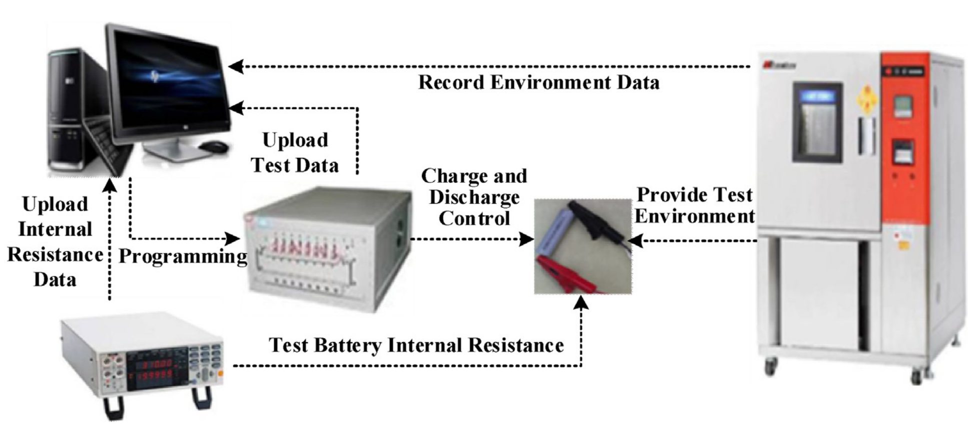

Fig. 2. Schematic diagram of battery test platform.