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A study on parameter variation effects on battery packs for electric vehicles

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HIGHLIGHTS

- A battery pack model with 96 cells in series is proposed for the consistency of battery pack.
- The capacity loss composition of the battery pack is obtained by simulation and experiment.
- Use the battery pack available capacity as the inconsistency physical quantity.
- The battery pack screening and management scheme is proposed.

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ABSTRACT

As one single cell cannot meet power and driving range requirement in an electric vehicle, the battery packs with hundreds of single cells connected in parallel and series should be constructed. The most significant difference between a single cell and a battery pack is cell variation. Not only does cell variation affect pack energy density and power density, but also it causes early degradation of battery and potential safety issues. The cell variation effects on battery packs are studied, which are of great significant to battery pack screening and management scheme. In this study, the description for the consistency characteristics of battery packs was first proposed and a pack model with 96 cells connected in series was established. A set of parameters are introduced to study the cell variation and their impacts on battery packs are analyzed through the battery pack capacity loss simulation and experiments. Meanwhile, the capacity loss composition of the battery pack is obtained and verified by the temperature variation experiment. The results from this research can demonstrate that the temperature, self-discharge rate and coulombic efficiency are the major affecting parameters of cell variation and indicate the dissipative cell equalization is sufficient for the battery pack.

1. Introduction

Due to the commercialization of pure electric vehicle, the mileage range and the lifespan of electric vehicle have gained increasing interests to the researchers. Hence, a lot of studies have primarily focused on the single cell and new materials [1–4], power density and cycle life of the single cell. However, single cell is unable to meet the power and energy requirements for electric vehicles. Hundreds of the single cells need to be connected in series and parallel to each other to construct battery packs [5–8] so as to provide enough power and energy for electric vehicles to meet the requirements of its accelerated climbing and mileage. Unfortunately, due to the inconsistency of the manufacturing process and use of the process environment, the cell variations always exist [9–11] and are unable to eliminate. The energy density, durability and safety performances of the battery pack are affected by every single cell in group because of cell variation [5]. Therefore, the battery pack is usually equalized to reduce the inconsistency. There are two general equalization methods: one is the dissipative cell equalization, and the other is the non-dissipative cell equalization (energy transfer). The dissipative cell equalization method usually adopts resistance discharge equalization, and the non-dissipative cell equalization adopts topology diversity. The topology of non-dissipative cell equalization method is summarized in previous studies [12–13].

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In practical application, the poor uniformity of the battery cells will influence the performance of the whole battery pack. First, because of the inconsistent initial capacity and initial state of charge (SOC), the actual available energy of the battery pack is lower than any single cell; it will directly cause the loss of the energy density in group. Second, due to the non-uniformity of internal resistance, the maximum current of the series battery pack is limited by the worst power density of the single cell. So the power density of the battery decreases in the battery pack. Third, compared to the single cell, the actual available power of the battery pack is not only limited by the capacity fade, but also affected by the self-discharge and coulombic efficiency. So its life is shorter than any single cell. As the consistency of the battery cells is an important factor influencing the above three aspects which are adopted to evaluate the performance of the battery pack, the studies on the battery consistency have attracted greater attention recently.

Some studies indicate that the cycle life of the battery pack is much less than the single cell. Even the single cells have a cycle life more than 1000 cycles in group, without a balancing technology, the battery pack actual cycle life could be less than 200 cycles. The causes of this phenomenon is not that one cell cycle life is shortened to 200 cycles [14], but the capacity of the battery pack is limited by the minimum residual and rechargeable capacity of the single cells. The lifespan of the battery pack could be decreased when the cell inconsistency is increased. Significant efforts have been made from single cell models to pack-level models, taking into account cell variability [15–18]. However, the current studies [19–21] on the evolution mechanism of battery pack inconsistency are still in the stage of qualitative description. For example, Mathew et al. [19] investigated the simulation framework of cell replacement in a battery pack. Baronti et al. [22] compared five topologies for balancing series connected lithium-ion batteries by the statistical simulations. They showed that the cell to cell topology was the quickest and most efficient one. Dubarry et al. [23] investigated cells balancing behavior in parallel, and an equivalent circuit model was developed to simulate the spontaneous transient balancing currents in a battery system.

In order to deeply analyze the inconsistencies evolution mechanism of battery packs, the basic features and description method of the consistency performance in battery packs for pure electric vehicles are investigated in this paper. The battery pack model with 96 cells in series is established. The influence factors of the consistency on battery pack are studied by simulation and experiment. The capacity loss composition of the battery pack is obtained and verified by the temperature variation experiment. Finally, the battery pack screening and management scheme regarding the consistency of the battery pack is proposed.

2. Description for the consistency characteristics of a battery pack

2.1. Consistency characteristics and the influence factors of battery packs

Practice shows that the consistency of the battery pack will experience a gradual deterioration process. In general, the inconsistencies damage to the battery pack life is more serious than that of the durability of the single cell. Most of the literature suggests that the inconsistencies between cells reflect in the voltage, SOC, capacity, internal resistance and temperature. In fact, the inconsistency of these parameters is only reflected in the current state, so it is not complete. Considering the variation of the time, the inconsistency between the cells also includes the inconsistency of the self-discharge rate, the inconsistency of the coulomb efficiency, the inconsistency of the capacity degradation and the aging of the internal resistance etc. The inconsistencies of these parameters in the process will be directly reflected in the inconsistency of state.

Fig. 1 demonstrates the mutual relations among various parameters of cells. We divide them into three classes, the initial states, the current states, and the time accumulations. Their mutual influence cell parameters are shown in Fig. 1. Generally, we use the current states to express inconsistency of the battery pack. The current states include the capacity, voltage, SOC, internal resistance and temperature. Specifically, direct impacts on the practical battery energy output are the capacity and SOC, while the internal resistance decisively affects the practical power output. Moreover, the voltage and temperature are relatively easy to measure. Therefore, these current states are popularly adopted in the battery pack consistency analysis for practice applications. But in fact the influence factors of battery consistency are the initial states and the time accumulations. The initial states are the states when the cells are just constructed, and the parameters of the initial states have great influence on the short term consistency of the battery pack. And since their measurement and control difficulty is relatively low, the initial state becomes the main factors in the screening process for battery cells. The time accumulations affect the long-term consistency of the battery pack, and the influences are greater than the initial states. So screening process for the time accumulative factors is more important. However, due to the difficulty of screening the time accumulations, these parameters are less likely to be screened in practice.

The above analysis and practice show that the consistency of the battery pack has the following basic characteristics:

2.1.1. Coupling property

Parameter inconsistencies of the cells are coupled together, forming a complex association network. In particular, temperature inconsistency affects almost all other cell parameters. Some parameters are coupled to form a positive feedback to accelerate the inconsistency of the battery pack, such as coupling temperature and internal resistance results in greater inconsistency of the temperature and internal resistance. Due to the presence of coupling, the battery pack inconsistency behave complex. The evolution mechanism of cell inconsistencies is difficult to reveal.

2.1.2. Statistical property

The consistency of the battery pack is reflected by the statistic characteristics of the single battery cell. The battery pack is usually made in parallel and series by thousands of cells, and all parameters of the battery cells meet certain statistical behavior.

2.1.3. Weight property

The worse performance of the cell will have worse effects on the

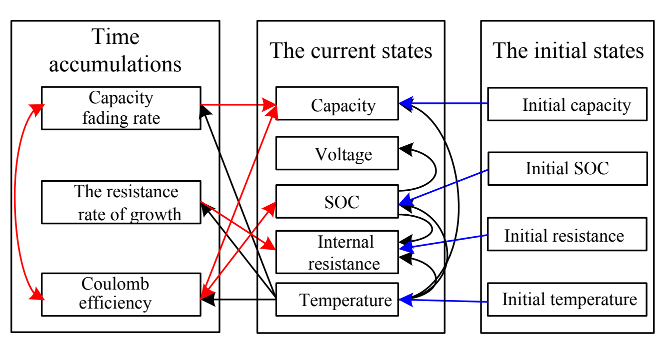

Fig. 1. Influence relationship of cell parameters.