Cycle Life Analysis of Lithium-Ion Batteries Connected in Series with Temperature Difference

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In real life application of Hybrid Electric Vehicles (HEVs), battery packs require thermal management systems to control the temperature within. A practical method is to apply conditioned air directly into the battery packs, cooling the cells by convection. But due to the layout of the cells and a nonuniform cooling flow, it is difficult to keep uniform temperature inside the battery packs. Although it is well known that temperature difference will affect the performance (discharge voltage and capacity) of the battery pack, the degree of this influence, however, requires further qualitative and quantitative analysis. This analysis can be performed by the aid of battery pack modeling.

The temperature at which a lithium-ion cell is exposed has a significant influence on the cell's electrochemical behavior. The cell's discharge voltage and capacity depends on the temperature of the discharge process. As a consequence, the presence of temperature difference between cells inside a battery pack can cause an imbalance of performance of the cells. That is, the change of temperature of one cell in a series connection will affect the performance of the whole pack.

Due to the manner of the series connection inside the battery pack, cells connected in the same series are coupled together; when a single cell's operating status is altered, it will affect the performance of the whole series connection chain. By constructing an isothermal one-dimensional electrochemical model of ten lithium iron phosphate (LFP) cells connected in series and further assigning individual temperature parameters, the effect of temperature difference on series connected lithium-ion batteries can be analyzed. In order to verify the validity of the model, the simulated discharge curve of a single 26650 LFP cell after a single cycle is compared with experimental data[1]. A capacity fade model[2] has also been adopted to characterize the cycle life property of the 26650 LFP cell. By combining the capacity fade and the isothermal one-dimensional electrochemical model, the temperature effect on cycle life of a single 26650 LFP cell can be quantified.

After quantifying the performance of a single 26650 LFP cell, we simulate the battery pack cycle life property of ten 26650 LFP cells connected in series. For all the cells within, their assigned temperature values differ from each other, generating a temperature difference inside the pack by design. The assigned distinct temperature values artificially provide a scenario of performance imbalance for the 10 series connected cells. Due to the imbalance situation, a preliminary simulation result has shown a correlation between capacity degradation and temperature change. As shown in figure 2, the higher the temperature difference is, the greater the capacity degradation is. This increase of capacity degradation will be intensified as the battery pack is cycled further, and temperature difference gradually becomes a non-negligible effect.

The result obtained from the modeling of temperature difference on cells connected in series can assist car manufacturers in predicting the cycle life property of a specific battery pack design. A more detailed and integrated analysis of battery packs formed by imbalance performance cells will be presented and discussed in this work.

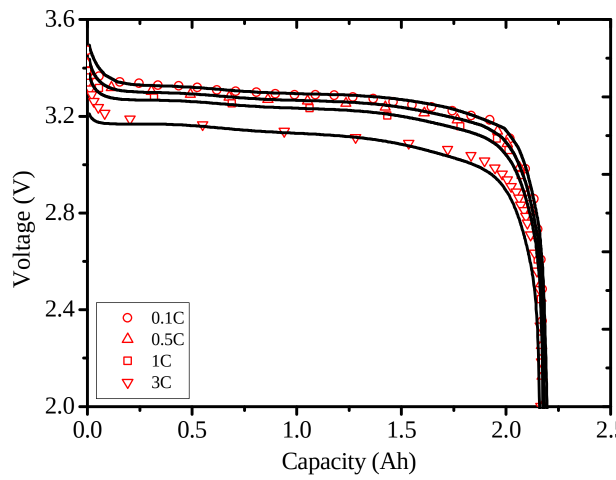

Figure 1 Model validation of a 26650 2.3 Ah lithium iron phosphate cell. The cell is discharged with different C-rates at 25°C. The points represent the experimental data[1] and the curves are simulation results obtained from the isothermal one-dimensional electrochemical model[3].

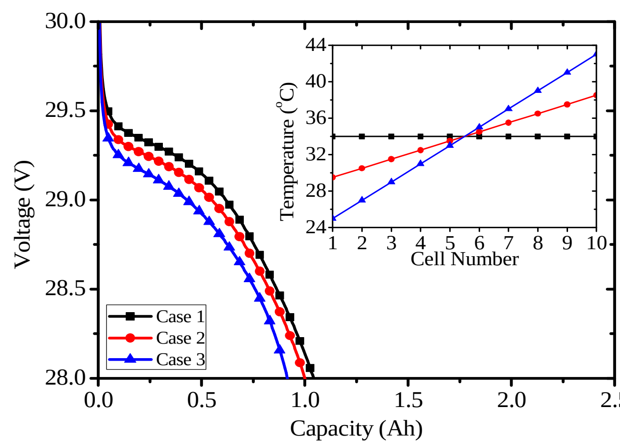

Figure 2 Simulated cycle property of ten 26650 LFP cells connected in series under different given temperature distribution conditions. Case 1 indicates the cells are cycled at 34°C with no temperature difference among the cells. Case 2 indicates a 9°C temperature difference between cells 1 and 10, and case 3 represents an 18°C temperature difference. All cases have the same average temperature of 34°C and are cycled at the same number of times. Case 3, which has the greatest temperature difference, results in the greatest capacity degradation.

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