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Diagnostics of Li-Ion Commercial Cells – Experimental Case Studies

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The reliability and safety of battery system's functions have an intimate tie to the battery's performance and degradation. To understand how battery degrades and the associated mechanisms in different battery chemistries is quite challenging, especially if the intention to gain the knowledge is to develop the understanding in a cause-consequence context in which such a cause-consequence relationship is clearly quantified. The difficulty to gain such knowledge is mainly due to the lack of effective diagnostic tools to characterize the degradation with a temporal resolution sufficiently to describe the cause-consequence relationship through aging. For Instance, postmortem analyses may reveal the cause of degradation and failure of a battery, but they are not useful to provide temporal resolution to allow practical battery monitoring, protection, and diagnosis during operation, nor can they provide useful information for prognosis. The empirical approach used by battery engineers to derive algorithms to describe the cause-consequence relationship continues to suffer accuracy issues. In our view, an effective battery diagnosis needs to have two major elements: a reliable method to determine the state of a battery and a high-fidelity toolbox to analyze the complex current-voltage relationship in a cell under polarization. To achieve such a goal, an analytical method that can determine the state of battery and reliable parameters for battery modeling and simulation has been recently developed by us capable of considering different "what if" scenarios to permit the associated voltage-current relationships simulated. This unique diagnostic tool is built upon a synthetic model that is developed recently by us [1].

The "what if" scenarios are achieved by the simulation of considering possible degradation modes, mainly loss of lithium inventory, loss of active material, and the change of impedance in the electrodes, in the model with a proper mix of contributions. Through comparison of simulation results with the experimental data, the accuracy of the model can be achieved and the fidelity assessed. This capability is used for diagnosis and prognosis to quantify the impacts of each degradation mode on the cell performance.

Here we present a few case studies in which this unique diagnostic approach is employed to illustrate how effective battery diagnosis can be achieved.

For example, a discussion on the degradation of high energy (HE) and high power (HP) cell designs using a graphite intercalation compound (GIC) negative electrode and a $LiFePO_4$ (LFP) positive electrode is reported here. The aging behavior of a commercial GIC || LFP HE cell is presented in Figure 1. The capacity fade follows a gradual decade at low rates such as C/25. At C/5, the capacity is steady over the first 100 cycles and then it fades following a similar trend as in the previous one. At rates higher than C/5, the capacity increases initially in the first 100 cycles before the fades follow the same trend as at the lower rates.

Another case study is the degradation in a commercial LTO || NMC pouch cell that experienced an overcharge to 3.6 V for a short duration, exceeding the recommended 2.8 V cutoff but lower than the built-in 3.7 V safety shutdown for the cell [2]. Such an event results in a 20% capacity loss and a significant change in the incremental capacity (IC) signature of the cell (Figure 2), including a decrease in the intensity of all IC peaks and an appearance of extended intensity above 2.55 V.

Additional case studies include the degradation of a commercial GIC || {NMC+LMO} cell cycle-aged at room temperature and the calendar aging of a GIC || LFP cell. These analyses were performed based on experimental data obtained in our lab or from the literature.

References:
[1] M. Dubarry, C. Truchot, B.Y. Liaw, *J. Power Sources*, **219**, 204-216 (2012).
[2] "Nano-Based Lithium-Ion Batteries for Electric Vehicles", V. Evan House, EPA Pollution Prevention Through Nanotechnology, September 25-26, 2007, Arlington, Virginia

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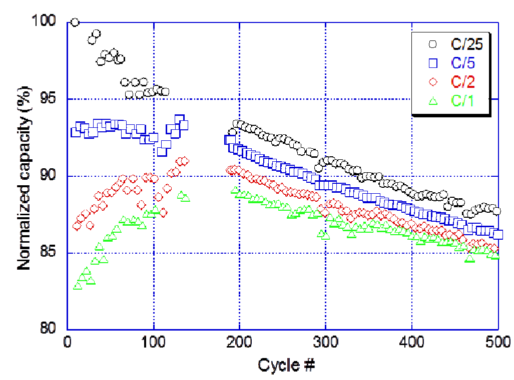

Figure 1: Degradation of a commercial high energy GIC || LFP cell under a cycle aging test.

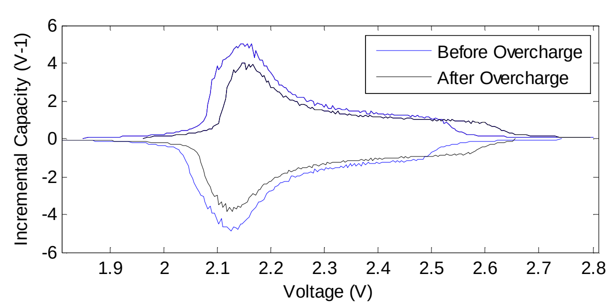

Figure 2: Incremental capacity curves of a LTO || NMC cell before and after a 3.6 V overcharge event.