Modeling of Nonuniform Degradation in Large-Format Li-ion Batteries

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Abstract

An empirical degradation model capturing the effects of both storage and cycling was developed for the Li-ion Nickel Cobalt-Aluminum chemistry. The degradation model is coupled with NREL’s multi-dimensional multi-scale (MSMD) cell model to explore the impacts of nonuniform degradation on Li-ion cells. The model is applied to a high-capacity cylindrical cell in a PHEV-type application (20 Ah). Degradation in the cell is characterized by nonuniform cycling and temperature coupled with NREL’s multi-dimensional multi-scale (MSMD) cell model to explore the impacts of nonuniform degradation on Li-ion cells. The model is applied to a high-capacity cylindrical cell in a PHEV-type application (20 Ah). Degradation in the cell is characterized by nonuniform cycling and temperature.

Degradation Model

Empirical model used to fit data for the Li-ion NCA chemistry.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>$V = V_0 - \frac{Q}{C_{max}}$</td>
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<tr>
<td>Capacity Fade Model</td>
<td>$C(t) = C_0 \left(1 - \frac{t}{t_{50}}\right)^{\alpha}$</td>
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where $V_0$ is the initial voltage, $C(t)$ is the capacity at time $t$, $C_{max}$ is the maximum capacity, and $\alpha$ is a parameter that depends on the cycling rate.

Background and Approach

• Context: Trend towards larger cells

• Objectives
  - Understand impact of large-format cell design
  - Encourage multi-scale/multi-dimensional modeling
  - Develop models for large-format cells

• Limitations
  - No accelerating trend observed for low-rate cycles
  - No accelerating trend observed for high-rate cycles

• Summary
  - Large-format Li-ion cells are being developed for PHEV applications
  - Multi-dimensional/multi-scale modeling is needed to understand degradation

Multiscale approach for computational efficiency

- Length scales:
  - Time (1-100 µs to 10000 s)
  - Spatial (100 nm to 100 mm)

- Time scales:
  - Repeated cycling profile (minutes)
  - Degradation effects (months)

Empirical degradation model considers both storage and cycling effects

- Storage (Calendar)
  - Typical 2nd order dependency
  - Often constant in LiFePO4

- Cycling (1st order)
  - Capacity fade model

- Capacity Fade Model
  - Temperature
    - Voltage
  - Dependence from impedance growth model

- Cycling (2nd order)
  - Cycling life (number of cycles)

- Calendar Storage (1st order)
  - Battery life

- Relative Capacity
  - Regions near terminals suffer most significant capacity loss

- Battery life
  - Better cell design and management

- Capacity fade model
  - Illustrates strong coupling between nonuniform degradation and cell performance

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