An Accurate Electrical Battery Model Capable of Predicting Lifetime and I-V Performance

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Motivation

Design Goal of Portable Electronics
- Low power dissipation
- Maximum battery lifetime

Model Applications
- Design energy-aware circuits and systems
- Optimize circuit and system performance
- Predict battery lifetime
- Emulate batteries with electronic circuits
- Improve battery energy efficiency
Modeling Methods

Electrochemical models
- Using deductive method (fundamental mechanism)
- Providing macroscopic and microscopic information
- Involving a system of coupled, time-variant, spatial, partial differential equations (numerical technique)

Mathematical models
- Using inductive method (empirical equations or mathematical methods)
- Providing system-level behavior (lifetime, efficiency, or capacity)
- Involving relatively complex mathematical equations

Electrical models
- Using inductive method (empirical equation)
- Providing lifetime and I-V performance
- Involving curve fitting of a bundle of measurement
Electrical Models

(a) Thevenin-based battery models, (b) Impedance-based battery models, and (c) Lifetime-based battery models
Proposed Model

Battery Lifetime

Voltage-Current Characteristics

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Test System and Procedure

Voltage (V)

Current (A)

Time (Second)

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Model Extraction

![Graphs showing model extraction results](image)

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Model Validation I

TABLE II
MODEL EXTRACTION ACCURACY (POLYMER LI-ION BATTERY)

<table>
<thead>
<tr>
<th>Pulse Discharge Current (mA)</th>
<th>Max Error Voltage (mV)</th>
<th>Lifetime Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>15</td>
<td>0.039%</td>
</tr>
<tr>
<td>160</td>
<td>17</td>
<td>0.118%</td>
</tr>
<tr>
<td>320</td>
<td>18</td>
<td>0.020%</td>
</tr>
<tr>
<td>640</td>
<td>21</td>
<td>0.029%</td>
</tr>
</tbody>
</table>
Model Validation II

### Model Validation Results (Polymer Li-Ion Battery)

<table>
<thead>
<tr>
<th>Load Profiles</th>
<th>Max Error Voltage (mV)</th>
<th>Lifetime Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Discharge</td>
<td>15</td>
<td>0.395%</td>
</tr>
<tr>
<td>Pulse Charge</td>
<td>30</td>
<td>0.133%</td>
</tr>
<tr>
<td>4-Step Discharge</td>
<td>20</td>
<td>0.338%</td>
</tr>
</tbody>
</table>
Summary

- An accurate, intuitive, and comprehensive electrical model has been proposed to capture the entire dynamic characteristics of the battery.
- This model has been validated by comparing simulation results from Cadence with experimental data on polymer Li-Ion batteries.
- Less than 0.4% lifetime error and 30mV voltage error offers circuit designers the possibility to improve system efficiency and prolong battery lifetime for portable electronics.