Life Cycle Testing and Evaluation of Energy Storage Devices

October 21, 2011

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Sandia National Laboratories
SNL Energy Storage System Analysis Laboratory

Providing reliable, independent, third party testing and verification of advanced energy technologies for cell to MW systems

**Testing Capabilities Include:**

**Cell Testing**
- Temperature chambers for thermal control
- 100+ cell and battery testing channels:
  - 72 V 1000 A Bitrode (2 Channels)
  - 60 V 200 A Arbin (2 Channels)
  - 36 V 100 A Bitrode (3 Channels)
  - 36 V 25 A Bitrode (5 Channels)
  - 10 V 10 A Arbin (48 Channels)
  - 5 V 3 A Arbin (48 Channels)

**System Testing**
- Temperature chambers for thermal control
- New Energy Storage Test Pad (ESTP) expands testing capabilities to include megawatt (MW) scale energy storage. This versatile facility is capable of testing in several configurations for many different applications.

72 V 1000 A Bitrode (2 Parallel Channels)

Energy Storage Test Pad (ESTP) (April 2010)
SNL Battery Abuse Testing Laboratory

Battery testing, cell measurements, and materials development to support the development of inherently safe lithium-ion chemistries

- Safety and abuse tolerance evaluation of energy storage devices from cells to kWh batteries:
  - Mechanical abuse
  - Thermal abuse
  - Electrical abuse

- Understanding degradation mechanisms that lead to cell failure

- Provide experimental data to support abuse and thermal modeling

- Cell prototyping facility for materials development
FY 2011 testing activities

**Cell Level Testing**
- East Penn Advanced Battery Cells (D. Enos 4:00 pm Thur.)
- Altairnano Lithium-titanate oxide cells 60 Ah and 11 Ah
- International Battery Li-FePO₄ Cells

**Module Level Testing**
- East Penn Ultrabattery® Modules
- Furukawa Ultrabattery® Modules
- RedFlow 10kWh Zn-Br flow battery module (D. Rose 10:00 am Friday)
FY11 Testing of Ultrabattery® modules

- Both Ultrabattery® designs incorporate a supercapacitor in parallel with the negative electrode in a VRLA 12 cell, 1,000 Ah, 24V battery module.
- Tested with both a ‘PV’ and ‘utility’ cycle.

East Penn

Furukawa
Cycling protocols employed in testing

VRLA Life cycle data S. Drouilhet, B.L. Johnson, 1997 NREL
East Penn Ultrabattery® performs much longer than VRLA

**PSOC utility cycling**

- Ultrabatteries® 1,000 AH, 0.4 C and 0.3 C 5% PSOC cycling
- VRLA 30 AH, 1C 10% PSOC cycling
- Temperature rise in Ultrabattery® modules required reducing current for further testing
East Penn Ultrabattery® performs much longer than VRLA

PSOC utility cycling

- East Penn Ultrabattery® shows no capacity loss after more than 13,000 cycles without recovering the battery.
- Furukawa Ultrabattery® operated at elevated temperatures, leading to thermally activated degradation.

- Ultrabatteries® 1,000 AH, 0.4 C and 0.3 C 5% PSOC cycling
- VRLA 30 AH, 1C 10% PSOC cycling
- Temperature rise in Ultrabattery® modules required reducing current for further testing
East Penn Ultrabattery® performs much longer than VRLA

**PSOC utility cycling**

- **East Penn Ultrabattery®**
  - 5% DOD cycle

- **Furukawa Ultrabattery®**
  - 5% DOD cycle

- **VRLA Battery**
  - 10% DOD cycle

**Equivalent complete discharges**

- Ultrabatteries® 1,000 AH, 0.4 C and 0.3 C 5% PSOC cycling
- VRLA 30 AH, 1C 10% PSOC cycling
- Temperature rise in Ultrabattery® modules required reducing current for further testing

Furukawa Ultrabattery® operated at elevated temperatures, leading to thermally activated degradation

East Penn Ultrabattery® shows no capacity loss after more than 13,000 cycles without recovering the battery
Elevated temperatures occurred in Furukawa Ultrabattery®

Furukawa Ultrabattery® operated at elevated temperatures, leading to thermally activated degradation.
Ultrabatteries® also perform much longer in PV cycling than VRLA.

Even at 40 day deficit charge, Ultrabatteries® have performance far surpassing traditional VRLA batteries even with as low as a 7 day deficit charge (without recovery by taper charge).
Cell level testing underway

FY11 testing on battery cells

- International battery Li-ion FePO$_4$ large format prismatic cells (160 Ah, 3.2 V)
- Altairnano lithium-titanate oxide cells (60 Ah and 11 Ah, 2.3 V)
International battery cell capacity remains high after 15K+ cycles

Two International Battery cells currently operating under utility cycle testing protocol: 10% SOC cycles at 100 A current

11% capacity loss after 15,000+ cycles
International battery cell performed well under aggressive abuse

Under overcharge abuse the cell vented and the case deformed but remained intact without catastrophic failure and thermal runaway did not occur.
Characterization of Altairnano cells

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Initial Capacity</td>
<td>12.58 ± 0.06 Ah</td>
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<tr>
<td>3 Month Self-Discharge</td>
<td>4.82 ± 0.03%</td>
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Capacity as a function of T

Simon P, Gogotsi Y Phil. Trans. R. Soc. A 2010;368:3457-3467
Summary/conclusions to date

• East Penn Ultrabattery® performs best in fast utility cycling, completing over 13,000 5% cycles with no loss in capacity.

• Furukawa Ultrabattery® performs best under deep DOD slow PV cycling, even at 40 day deficit charging.

• International Li-ion FePO₄ cells have lost 11% of the initial capacity after over 15,000 10% cycles.

• Altairnano Li-titanate oxide cells have had initial characterization and will be cycled in FY12.
FY-12 testing activities

- Complete cycling of UltraBattery® modules and International Li-FePO₄ Cells
  Continue Utility Cycle Test; end condition of 20% capacity loss or 365 days cycled
- Utility Cycle Altairnano Li-Titanate Oxide Cell
  Utility Cycle Test end condition of 20% capacity loss or 1 yr is complete
- Bring flow battery testing online with:
  - Red Flow Zn-Br modules
  - CUNY Ni-Zn modules
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Acknowledgments

– Thank you to Dr. Imre Gyuk for funding energy storage testing
– Thank you to collaborating battery manufacturers