DISTRIBUTED BATTERY ENERGY STORAGE SYSTEMS:
METHODS TO MEASURE AND IMPROVE THEIR PERFORMANCE
BATTERIES

Reference and applicability

• Large-scale battery banks in utility system
• Complexities of distributed energy system
• Improving Performance
• Battery management, controls and safety
• Battery with DC link capacitor
BATTERIES

Large scale banks in utility system

• **Lithium Ion**

• Electrodes: Lithium cobalt oxide and carbon

• Electrolyte: Mostly lithium salt LiPF6

• Volts/Cell: 3.7 v

↑ Compact, fast response, high cycle efficiency

↓ Expensive, thermal runaway
BATTERIES

Large scale banks in utility system

- **Vanadium Flow**
- **Electrodes**: Vanadium oxide
- **Ionic solutions** $V^{+2}$, $V^{+3}$ in the -ve end, $V^{+4}$, $V^{+5}$ in the +ve end

↑ High power and energy, low self-discharge

↓ High initial/maintenance cost, low efficiency

Sketch courtesy: Trends magazine, September 2014
BATTERIES

Large scale banks in utility system

• **Advanced Lead Acid**

• Electrodes: Lead oxide, lead and carbon

• Electrolyte: Sulfuric acid

↑ Relatively high energy

- Higher rate partial state-of-charge operation

↓ Short lifespan, need temperature control

BATTERIES

Large scale banks in utility system

- **Sodium sulfide**
- Electrodes: Molten sulfur anode, molten sodium cathode
- Electrolyte: Solid beta alumina ceramic

▲ Deep, fast discharge, high energy density

▼ Safety issues with temperature, sodium

## DIFFERENT TYPES OF STORAGE BATTERIES

**Li-ION vs Flow vs Lead Acid: How do they compete against each other?**

<table>
<thead>
<tr>
<th>Type</th>
<th>Li - ION</th>
<th>Flow</th>
<th>Lead Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power (kW/unit weight)</td>
<td>Very high</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Energy (kWhr/unit weight)</td>
<td>High</td>
<td>Very high</td>
<td>High</td>
</tr>
<tr>
<td>Cost, $/kWhr</td>
<td>Very high</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Most suited for….</td>
<td>Electric car, Cell phones</td>
<td>Utility grid, C &amp; I</td>
<td>Residential</td>
</tr>
</tbody>
</table>
DIFFERENT TYPES OF STORAGE BATTERIES

(a) ESTIMATED INSTALLED BATTERY CAPACITY. 2012 - 2014

(b) COMMISSIONS (MW) IN THE WORLDWIDE POWER SECTOR

Battery banks stabilize intermittent power sources

Stationary storage to adjust load profile

Provides voltage support and frequency regulation

Supports small microgrid power systems

Behind meter residential energy storage

CHALLENGES

Complexities of distributed energy system
ENERGY STORAGE HAS POTENTIAL APPLICATIONS ACROSS THE ENTIRE ELECTRICITY ENTERPRISE VALUE CHAIN

Source: EPRI
Flow batteries are ideal for the stationary energy storage market.

Flow batteries are energy batteries. Best suited for large scale, long duration (4-6 hour) deep discharge applications.

Li ion batteries are power batteries. Best suited for small scale, short duration (<1 hour) shallow applications.

Source: The Great Battery Race: Goldman Sachs, October 18, 2015
ENERGY STORAGE CASE STUDY (1)

- McAlpine Creek Retail Substation, Charlotte, NC
  - 200 kW/500kWh system capacity
  - Containerized battery and inverter system
  - Lithium-iron-phosphate battery
  - Located on a 24 kV distribution circuit
ENERGY STORAGE CASE STUDY (2)

- Bainbridge island, Seattle, WA
  - 11,000 customers, 75 MW max load, 3 Substations
  - Power outage on a winter morning takes hours to reinstate
  - Adding a 4th Substation vs Adding a 4 MW Battery storage system

OPPORTUNITIES

Improving performance – Advanced lead acid batteries

- Many cells in series/parallel combination
- Long usage causes stratification of electrolyte
- Deposit of lead sulfate: Cell degradation
OPPORTUNITIES

Improving performance – Advanced lead acid batteries

• Charging 2 series connected banks
• Each bank – 12 cells/2 v each
• Bank position switched: Cell voltage improved
OPPORTUNITIES

Improving performance – Advanced lead acid batteries

• Cell switching scheme
• Measure and find lowest voltage cell
• Set corresponding switch and reset others

IF $V_{B1} = \text{MIN}\{V_{B1}, V_{B2}, V_{B3}, V_{B4}\}$ THEN SET $S_{W1} = 1$, RESET $S_{W2}, S_{W3}, S_{W4} = 0$;
ELSE_IF $V_{B2} = \text{MIN}\{V_{B1}, V_{B2}, V_{B3}, V_{B4}\}$ THEN SET $S_{W2} = 1$, RESET $S_{W1}, S_{W3}, S_{W4} = 0$;
ELSE_IF $V_{B3} = \text{MIN}\{V_{B1}, V_{B2}, V_{B3}, V_{B4}\}$ THEN SET $S_{W3} = 1$, RESET $S_{W1}, S_{W2}, S_{W4} = 0$;
ELSE_IF $V_{B4} = \text{MIN}\{V_{B1}, V_{B2}, V_{B3}, V_{B4}\}$ THEN SET $S_{W4} = 1$, RESET $S_{W1}, S_{W2}, S_{W3} = 0$;
END_IF ;
IMPROVEMENT

Switching schemes
IMPROVEMENT

Battery management, controls and safety

If Cell B1 is at lowest voltage, S1 is connected.

Current flow  ——  ———
IMPROVEMENT

Battery management, controls and safety

If Cell B3 is at lowest voltage, S3 is connected.

Current flow
IMPROVEMENT

Adding a battery bank to a DC link capacitor
IMPROVEMENT
STATCOM fault response without battery
IMPROVEMENT

Battery bank added to DC link capacitor of STATCOM
IMPROVEMENT

STATCOM fault response with battery
BETTING ON OUR FUTURE…

Key stationary energy storage growth drivers

**Increasing renewable penetration and changing electricity mix**
- Solar PV added 46 GW in 2016 to 302 GW (+18%)
- Wind added 55 GW in 2016 to 487 GW (+13%)
- US coal plant retirements in 2015: 15 GW to 313 GW (-5%)

**Climate and energy storage regulations**
- Paris COP21 signed by 195 countries
- Renewable energy goals set by numerous nations
- Renewable Portfolio Standards in most US states
- California’s AB2514: 1,325 MW of energy storage by 2020

**Needed investments in grid infrastructure**
- Grid investment not keeping up with electricity growth rates
- Distributed generation is challenging the historically unidirectional grid system
- Microgrids for energy security
- Smart grid initiatives

**Vehicle electrification**
- Vehicle and industrial electrification to reduce carbon and other emissions

**Battery improvements**
- Capital cost reductions
- Power and energy performance increases
- Improvements in battery cycle life

Source: Primus Power
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