Grid-Scale Energy Storage

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NPRE 498: Energy Storage Systems

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About Myself
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• Power and Energy Systems Group
  – Advisor: Thomas J. Overbye

• Research Area
  – Modeling of Equivalent Systems to Preserve Transient Characteristics of Large-Scale Power Systems
Outline

1. Goals
2. Renewable Energy Sources
3. Effects of Intermittent Renewables and Storage
4. Energy Storage Devices
5. Summary
Goals

• Survey renewable energy sources, recent progress, associated problem areas, and grid interfacing

• Understand system level effects of intermittent renewables and energy storage
  – Motivate the necessity of storage in integration of intermittent renewables with the grid

• Survey grid-scale storage technologies

• Evaluate possible solutions
Forms of Renewable Energy

- Wind
- Hydro
- Biofuel
- Solar
- Biomass
- Geothermal
Renewable Portfolio Standard (RPS)

- A regulation that requires an established level of production or purchase of energy from renewable energy sources, such as wind, solar, biomass & geothermal

- Renewables in Western Interconnect
  - 17% of generation by 2020
Western Interconnection: Predicted Generation (2010 – 2020)

• Dispatchable generation capacity: small increase

• Renewable generation capacity: increase of 33,000 MW
  – Mainly nondispatchable
  – Will require balancing by conventional sources.

• Grid-scale storage units can essentially be coupled with intermittent sources to create hybrid dispatchable generation
Effect of Intermittent Renewables on the Western Interconnect

WECC Large Generation Drop Simulation Using PowerWorld version 16 (1/3 real-time playback)
Grid Interfacing of Renewables

- **Good locations are distant from existing transmission networks**
  - Solar and wind corridors

- **Improper placement of solar/wind farms will most likely affect stability of electric grid**
  - Planning studies are essential
Benefits of having Storage Capacity on the Electric Grid

- Mitigate intermittency of renewables
- Possibly eliminate the need for new transmission and distribution lines
  - Better use of existing branches during non-peak conditions
- Provide regulation services
- Quickly deployable, typically in a few quarters
  - Fossil plants take years (almost impossible to site in urban areas)
Including Storage while Modeling Generation Intermittency

- Small-scale model of the Western Interconnect
- Model loss in generation at a fictitious wind farm in the southern part of the system
- Evaluate effect and location of storage placement
Case 1: No Storage

Frequency (Hz) versus Time (s)
Case 2: 750MWh Storage – 1 Unit At One Location

Frequency (Hz) versus Time (s)
Case 3: 75MWh Storage - 10 Units Around Middle-Region

Frequency (Hz) versus Time (s)
Case 4: 75MWh Storage - 10 Units Around Southern-Region

Frequency (Hz) versus Time (s)
# Energy Storage Devices

<table>
<thead>
<tr>
<th>Storage Technology</th>
<th>Main Advantage (Relative)</th>
<th>Disadvantage (Relative)</th>
<th>Power Application</th>
<th>Energy Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-speed Flywheels (FW)</td>
<td>High Power</td>
<td>Low Energy Density</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Electrochemical Capacitors (EC)</td>
<td>Long Cycle Life</td>
<td>Very Low Energy Density</td>
<td>✗</td>
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<tr>
<td>Traditional Lead Acid (TLA)</td>
<td>Low Capital Cost</td>
<td>Limited Cycle Life</td>
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</tr>
<tr>
<td>Advanced LA with Carbon Enhanced Electrodes (ALA-CEE)</td>
<td>Low Capital Cost</td>
<td>Low Energy Density</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Sodium Sulfur (Na/S)</td>
<td>High Power and Energy Density</td>
<td>Cost and Needs to Run at High Temperatures</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Lithium-ion (Li-ion)</td>
<td>High Power and Energy Density</td>
<td>Cost and Increased Control Circuit Needs</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Zinc Bromine (Zn/Br)</td>
<td>Independent Power and Energy</td>
<td>Medium Energy Density</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Vanadium Redox (VRB)</td>
<td>Independent Power and Energy</td>
<td>Medium Energy Density</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Compressed Air Energy Storage (CAES)</td>
<td>High Energy, Low Cost</td>
<td>Special Site Requirements</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Pumped Hydro (PH)</td>
<td>High Energy, Low Cost</td>
<td>Special Site Requirements</td>
<td>✗</td>
<td></td>
</tr>
</tbody>
</table>

- **Fully capable and reasonable**: ✗
- **Reasonable for this application**: ✗
- **Feasible but not quite practical or economical**: ✗
- **Not feasible or economical**: NONE
Leading-Edge Technologies

- Metal-air batteries
- Na/S cells
- Li-ion cells
- Lead-carbon batteries
- Na-ion / Na-halide batteries
- Flow battery
- Above-ground CAES
- Mini-CAES
- Valve regulated lead-acid batteries with electromechanical capacitor
Cost Considerations

Energy Density and Cost vs. Storage Technology

- **Long duration storage, frequent discharge**
- **Long duration storage, infrequent discharge**
- **Short duration storage, frequent discharge**
- **Short duration storage, infrequent discharge**

Storage Technology:
Mapping Technology to Usage

System Ratings
Installed systems as of November 2008

- CAES: Compressed air
- EDLC: Dbl-layer capacitors
- FW: Flywheels
- L/A: Lead-acid
- Li-ion: Lithium-ion
- Na-S: Sodium-sulfur
- Ni-Cd: Nickel-cadmium
- Ni-MH: Nickel-metal hydride
- PSH: Pumped hydro
- VR: Vanadium redox
- Zn-Br: Zinc-bromine
Storage Location on the Grid

Devaluators:
- Limited Value to Customer
- High Security Risk
- Technology not quite ready
- Grid Constraints
- High Discharge Losses (on peak)

Devaluators:
- Limited Value to Grid (ancillary)?
- Esthetics
- Higher PCS cost?
- Central Control issue?

Ancillary Services

Peak Shaving, upgrade deferral, Improved service reliability
More Data on Website
www.electricitystorage.org

- Weight energy density vs. Volume energy density
- Capital cost per unit energy vs. Capital cost per unit power
- Capital cost per cycle
- Efficiency vs. Lifetime
Recap of Technologies

Increasing power → Increasing energy

- **pumped storage**
- **flow battery**
- **CAES**
- **NaS battery**
- **EC capacitor**
- **flywheel**
- **lead-acid battery**
- **Li-ion battery**
- **Ni-Cd battery**
- **SMES**

Source: Electricity Storage Association
Summary

• Number of renewables directly connected to electric grid is on the rise
  – Environmental & political reasons

• Is the electric grid ready to handle the large penetration of intermittent renewables?
  – Energy storage and coordinated control are possible solutions

• Hybrid plants – couple generation capacity with storage
  – Concentrated solar plants with molten salt energy storage
  – Wind farms with compressed air energy storage

• Substation level storage for towns and cities
  – Flow batteries
Summary

- **Substation level storage for frequency regulation**
  - Flywheels, superconducting magnetic energy storage

- **Community energy storage Units**
  - Chemical batteries

- **Combination of technologies will be used**
  - Match time scale of intermittency being mitigated
  - Match energy storage and power needs
  - Charge and discharge capabilities
  - Cost considerations
  - Volume & weight
  - Efficiency
  - Lifetime
Selected References


Thank You for your attention!