Energy Storage: The Enabler of the Use of Solar and Wind Energy

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Overview

- Statement of the problem
  - Wind Energy
  - Solar Energy

- Useful Storage Technologies
  - Batteries
  - Compressed Air Energy Storage

- Opportunities in Arizona
  - Geology
Hourly Wind Production is not Reproducible

West Denmark
Wind & Net Trade
January 2006

MWh per h

Hours

Net Trade  Wind Production
Solar has short-term intermittency due to weather

Rated Power
2,640 Watts peak

Data from TEP Test Yard – Alexander Cronin
Sudden Drop in Wind Energy

February 2008 ‘Texas Event’: 1,200 MW drop in 3 hours

Source – MISO
Day-to-day Production Variation
(Data from TEP Test Yard – Alexander Cronin)
CAISO Wind Generation
July 2006 Heat Wave

Total Wind Generation Installed Capacity = 2,648 MW

Wind Generation at Peak

Source – California Energy Commission Report
Renewable Resource Capacity Profile
Typical Summer Load Profile versus Renewable Availability

Energy Generation does not match load

Provided by Mike Sheehan - TEP
Seasonal Mismatch Between Demand and Production

- PV Production 5.2 GW
- TEP Consumption

Months of the Year

MegaWatt-hours

Seasonal mismatch is evident, with peak production occurring in the summer months and peak demand in winter.
Energy Storage – A Critical Component in the Development of a Solar America

Energy storage is critical:
- Supply side: Intermittent renewable energy sources – Solar and Wind
- Demand side: Large variations in demand (peak-load shaving)
- Short term weather intermittency
- Day-to-day variations and sudden drop in power
- Load mismatch
- Seasonal Mismatch

Energy storage must be:
- Inexpensive, Efficient, Rapid reaction to loss of power
- Available in sufficient capacity
  - Seasonal arbitrage, load shifting, regulation
  - National Energy Reserve
Energy Storage

- Batteries
- Supercapacitors
- Flywheels
- Hydrogen
- Fuel cells

- Compressed air in vessels
- Underground compressed air
- Pumped hydroelectric
- Thermal storage
- Superconducting magnetic energy
Storage Technologies and Regimes of Application

- Full power duration of storage technologies
  - Duration
    - Biomass: 4 mos
    - Hydro: 3 weeks
    - CAES: 3 days
    - Thermal: 6 hours
    - Hydroelectric: 2 hours
    - Flow cell batteries: 40 min
    - Supercap: 10 min
    - Cathodic arc energy storage (CAES): 20 sec

- System power ratings
  - 1 kW to 1 GW
  - Power quality & UPS
  - Bridging power
  - Energy management

- Technologies
  - Metal-Air Batteries
  - Flow Batteries
  - ZnBr
  - VRB
  - PSB
  - NaS – Energy Mode
  - CAES
  - Lead-Acid Batteries
  - Ni-Cd
  - Li-ion
  - Other Adv. Batteries
  - High Energy Super Caps
  - Long Duration Fly Wheels
  - High Power Fly Wheels
  - High Power Super Caps
  - SMES

A. Nourai
### Summary of Energy Storage approaches:

#### Storage Technologies Primarily for Energy (kWh) Applications

<table>
<thead>
<tr>
<th>Technology</th>
<th>$/kWh</th>
<th>Rater Power (MW)</th>
<th>Efficiency</th>
<th>Lifetime</th>
<th>Discharge Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumped Hydro</td>
<td>250 – 260</td>
<td>20 – 2,400</td>
<td>78 – 83%</td>
<td>11,000+</td>
<td>10</td>
</tr>
<tr>
<td>CAES</td>
<td>550 – 650</td>
<td>110 – 290</td>
<td>50 – 75%</td>
<td>11,000+</td>
<td>10</td>
</tr>
<tr>
<td>Flow batteries</td>
<td>500 – 1,000</td>
<td>0.05 – 8</td>
<td>65 – 80%</td>
<td>500+</td>
<td>8</td>
</tr>
<tr>
<td>NaS batteries</td>
<td>2,500 – 3,750</td>
<td>0.05 – 50</td>
<td>70 – 80%</td>
<td>3,000+</td>
<td>7</td>
</tr>
<tr>
<td>NiCad batteries</td>
<td>610 – 1,700</td>
<td>0.01 – 27</td>
<td>60 – 65%</td>
<td>1,000+</td>
<td>4</td>
</tr>
</tbody>
</table>

#### Storage Technologies Primarily for Power (kW) Applications

<table>
<thead>
<tr>
<th>Technology</th>
<th>$/kW</th>
<th>Rater Power (MW)</th>
<th>Efficiency</th>
<th>Lifetime</th>
<th>Max Discharge Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaS batteries</td>
<td>3,000 – 4,000</td>
<td>0.05 – 50</td>
<td>70 – 80%</td>
<td>3,000+</td>
<td>300</td>
</tr>
<tr>
<td>Li-Ion batteries</td>
<td>1,000 – 4,500</td>
<td>0.005 – 1</td>
<td>90 – 95%</td>
<td>20,000+</td>
<td>15</td>
</tr>
<tr>
<td>NiCad batteries</td>
<td>1,560 – 3,780</td>
<td>0.01 – 27</td>
<td>60 – 65%</td>
<td>1,000+</td>
<td>15</td>
</tr>
<tr>
<td>Lead acid</td>
<td>1,050 – 1,890</td>
<td>0.01 – 10</td>
<td>70 – 75%</td>
<td>250+</td>
<td>15</td>
</tr>
<tr>
<td>Flywheels</td>
<td>2,500 – 4,000</td>
<td>0.5 – 1</td>
<td>90 – 95%</td>
<td>500,000+</td>
<td>15</td>
</tr>
<tr>
<td>Super capacitors</td>
<td>N/A</td>
<td>0.003 – 0.01</td>
<td>90 – 98%</td>
<td>500,000+</td>
<td>seconds</td>
</tr>
</tbody>
</table>
Ideal Combination of Storage Technologies

- Fast Response (expensive):
  - Supercapacitors (milliseconds)
  - Batteries (hundreds of milliseconds)

- Longer time response with higher capacity (lower cost):
  - Compressed air energy storage
  - Pumped hydroelectric
  - Thermal storage technologies

- Very long time response (lowest cost):
  - Demand response or load control
Solar Application: Wakkanai Project

1.5MW NAS Battery for 5 MW Solar

Financed by NEDO (New Energy and Industrial Technology Development Organization)

Project Size:
Solar Panel: 5MW
NAS Battery: 1.5MW

Absorb PV output fluctuation

Peak Shift

Peak time discharge (Evening etc.) by Storing Day-time Energy
Case study: frequency regulation
A123Systems Li-Ion: AES Corporation

- 2-MW, 500-kWh unit assembled in trailer
- Operational and performing frequency regulation for AES-owned Huntington Beach, CA natural gas plant
- Air cooled, but plans for liquid-cooled version
- Plans to install several other units at AES facilities worldwide
- Lithium phosphate-based technology also being aimed at EV market

Caption: A123’s Hybrid Ancillary Power Unit (H-APU) being placed in service
Source: A123Systems
Case study: frequency regulation
Altairnano Li-Ion: PJM Interconnection

- 1-MW, 250-kWh system housed in 40-ft trailer
- Utilizes fast charge/discharge capability of lithium titanate oxide technology to dispatch frequency regulation services on PJM
- One unit currently in operation at PJM headquarters; Trial previously completed at IP&L
- Batteries feature extended lifetime of 25,000+ cycles, but come at a higher cost than other Li-Ion chemistries
- Courting new opportunities in frequency regulation and renewables integration

Caption: Interior view of the Altairnano battery management system
Source: Altair Nanotechnologies
Compressed Air Energy Storage

- Generation/storage systems integration
- Efficiency w/o heat recovery: 65%, with: 85%
- Isothermal vs adiabatic pumping
- Turbine vs vessel size
- Costs and economics

Air Storage:
- Subsurface imaging to greater than 2,000 feet
- Solution mined salt, drilled alluvium
- Depleted natural gas wells, abandoned mines
- Above-ground tanks, underwater tanks
Energy Storage – A Critical Component in the Development of a Solar America

- **Compressed Air Energy Storage (CAES)**
  - Above ground (vessels)
    - Storage for a few hours
  - Automotive applications

- **Underground Compressed Air Storage** (1,100 psi, 75 atmo.)
  - Needs salt deposits (primary)
  - High efficiency and low price (65-90%)
  - Needs additional fuel for operating the turbine (natural gas or biofuels)

- **UA research –**
  - Adiabatic pump with heat recovery using molten salt storage
  - Hydrogen heating for additional fuel
  - Salt deposits and alluvium for underground storage
  - Mining sites and mine tailing banks
  - Demonstration site (Riverpoint Solar Research Park)
Load Shifting Function

Energy Demand and Generation (Grid, PV, Storage)

- System Load Demand
- Grid Energy (1.27 MWh/h)
- 1.5 MW PV Array and Battery
- CAES Storage Energy

Energy in MWh

Time of Day (August 15, 2007)
Addition of CAES to Meet Seasonal Differences

PV Production 5.2 GW
CAES Produced Electricity
TEP Consumption
CAES Stored Energy

Months of the Year
MegaWatt-hours

-600,000
-400,000
-200,000
0
200,000
400,000
600,000
800,000
1,000,000
1,200,000
1,400,000
Holbrook salt basin covers 3,500 square miles and is 300 feet thick.

Holbrook basin has the capacity to store 30TW of electrical production – more that the US total energy demand (3.3 TW) or 30 times the electrical demand (1 TW).

Many salt basins are distributed throughout Arizona.

Luke, Picacho and Holbrook are currently used to store natural gas or propane.
Other Technologies

- Liquid Air
- Thermal systems
- Pumped hydroelectric
- Flywheels
- Supercapacitors
- Other batteries:
  - Deep discharge, graphite enhanced lead acid batteries
  - Vanadium redox flow batteries