ENERGY STORAGE: A DISTRIBUTED RESOURCE

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ENERGY STORAGE RESEARCH, DOE

Stanford 11-2-07
Energy Storage provides Energy when it is needed

just as Transmission provides Energy where it is needed
Scales of Power

Current (A)

Voltage (V)

Hybrid Electric Vehicles

Military

Utility

Ships

Aerospace

Traction

Consumer Products
DRIVERS FOR THE MODERN GRID:

DIGITIZATION OF SOCIETY:
INCREASED POWER QUALITY

ECOLOGICAL CONCERN:
DISPATCHABLE RENEWABLES

GROWTH IN ENERGY CONSUMPTION:
INCREASED ASSET UTILIZATION

ENERGY STORAGE OFFERS A SOLUTION!
<table>
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<tr>
<th><strong>POWER</strong></th>
<th><strong>ENERGY</strong></th>
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<td>Seconds</td>
<td>diurnal</td>
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<td>PQ, Digital Reliability</td>
<td>Peak Shaving to Avoid Demand Charges</td>
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<td>Voltage Support, Transients</td>
<td>Mitigation of Transm. Congest. Spinning Reserve</td>
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<td>DER Support for Load Following</td>
<td>Dispatchability for Renewables, Micro Grids</td>
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**LOAD**

**GRID**

**ENERGY STORAGE APPLICATIONS**
Storage Technologies and Regimes of Application

A. Nourai
RELIABILITY AND POWER QUALITY

Has Become a Necessity for the Digital Society
Outage Costs for U.S. Industry estimated at $79 Billion Annually in a recent study by Joe Eto, LBL

Total U.S. Cost of Electricity $250 Billion Annually

Momentary Interruptions (<5min) are More Costly than Sustained Interruptions
Nine Nines of Reliability cannot be provided by Generation

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Only Energy Storage can provide seamless Continuity of Power Supply
L/A Battery for Power Quality and Reliability

10 MW - 30 sec System at Microchip Plant
Ni-Cd Battery for Outage Support

World’s most Powerful Battery
40 MW in Fairbanks, Alaska!
Flywheels for Grid Frequency Regulation

Current method to balance constantly shifting load fluctuation is to vary the frequency and periodically adjust generation in response to an ISO signal. Flywheel storage could respond instantaneously!
A Beacon Flywheel being assembled

Containerized 7 Flywheel System

CEC / DOE PROJECT:

Beacon Power 100 kW Flywheel System for Grid Frequency Regulation

Design for a 20MW Facility with 100 kW flywheels funded by DOE
Flywheels represent an 80% reduction in CO$_2$ emission over present methods.

In addition, Flywheels are twice as effective as Fossil Generation.

100 MW of storage could eliminate 90% of Frequency Variation in California.
DG LOAD FOLLOWING MICROGRIDS RENEWABLE DISPATCH
Aggressive Renewable Standards:

CA – 20% by 2017
NV – 20% by 2015
NY - 25% by 2013

Kyoto Protocol!!!
Such Mandates can only be reached if Renewables are smoothed and made dispatchable by Energy Storage
Fossil Fuel generation produces Greenhouse Gases

In addition, Coal-fired Generation has adverse Health impacts

Ontario Medical Association estimated such Health effects at $10 Billion annually for Ontario’s 3,000 MW of Coal
ULTRACAPS FOR A 1.25 MW MICRO-GRID:

450 kW Maxwell EC-Capacitors to provide Wind Smoothing and Backup Power for the Palmdale, CA Water Treatment Plant

CEC / DOE PROJECT

GENERATION:
- 950 kW Wind Turbine (Average!)
- 2 x 225 kW Energy Bridge Ultracaps
- 800 kW + 350 kW Backup Diesel
- 250 kW Natural Gas Backup Generator
- 244 kW Hydroelectric Generator

LOAD:
- 320 kW Critical Load
- 930 kW Non-critical Load

The Palmdale, CA Treatment Plant
Diesel / Wind / Battery Hybrid at King Island, Tasmania

1500 kW Diesel
2450 kW Wind
200 kW / 4 hrs VRB Batteries

Batteries:
Smooth short term Wind
Firm Capacity
Load Shift to optimize Diesel

Operation Schematic
COMPRESSED AIR ENERGY STORAGE:  
A DOE/ Iowa Muni Project

Inexpensive Off-Peak Power is used to Compress Air for Storage in Aquifers. On-Peak, Compressed Air is used as Input for Gas Turbine Compressor, increasing Efficiency

200 MW Aquifer Compressed Air Energy Storage (CAES) with 75 MW of Wind and off-peak Power planned by Iowa Associated Municipal Utilities
PEAK SHAVING
ENERGY MANAGEMENT
UPGRADE DEFERRAL
SODIUM-SULFUR (NAS) BATTERY

6 MW / 8hrs  NGK Sodium-Sulfur Batteries for Load Management and Backup at a Japanese Resort Town

Schematic Diagram of NaS Cell
1MW NaS Battery to Store Off Peak Power

NYSERDA / DOE PROJECT:
For 1,800HP Natural Gas Compressor in a Long Island NG Refueling Station for 220 Busses

Relieves LIPA Peak Load, Eliminates Night Shift at Plant

Partnership with NYPA
Costshares from NY ISO, TVA, EPRI, Southern, First Energy, ComEd, PSE&G, APPA, LIPA, Hydro Quebec, San Diego G&E

Three 600-HP compressors + 1 MW NaS battery
FLOW BATTERIES:

Power and Energy are separated. Power Depends on the Conversion Cell Energy Depends on the Stored Electrolyte

- Vanadium Redox
- Zinc-Bromine
Vanadium Redox Battery at Rattlesnake #22

- Castle Rock, Utah, at the End of a 209 Mile 125kV Feeder
- Feeder too small for Peak Loads
- Complaints about Outages, PQ
- Upgrade costly and 3 year delay
- DG not acceptable for Pollution Reasons
CASTLE ROCK, UTAH

VRB TANK INSTALLATION

500kW / 2MWh
Vanadium Redox Battery
By VRB Power Systems
Expandable to 1MW
Provides Peak Power
Without Distrib. Upgrade
Charleston, WV Appalachian Power Substation

**1.2 MW / 6hr NaS Battery for Substation Support:**

- First Commercial Application in US.
- Provides Backup during Peak Load
- Defers Upgrade by 5 to 6 Years
- Reduces Transformer Heat up
- Potential Arbitrage Benefits 10K/month

**AEP / DOE PROJECT**

Generic Design funded by DOE

S&C Power Conditioning System developed with DOE Funding (R&D 100)

Commissioned June 26, 2006
Energy Storage can:

Provide Power Quality and Digital Reliability,

Bridge Outages Seamlessly,

Allow Load Following for DG, and make Renewables Dispatchable

Provide Peak Shaving and Transmission Upgrade Deferral
Distributed Storage, Distributed Generation, and Distributed Intelligence will be essential for the Grid of the Future.
Requirements for Storage Technologies in Utility Applications

- Cost, Cost, Cost!
- Reliability
- Lifetime
- Efficiency
- Environmental Acceptability
- Safety
- Compactness
Research Directions:

Improve Battery Energy Density \((C V^2 / 2)\)

- Increase Surface Area of Electrodes
  - Carbon Foam, Nanostructured Powders, Carbon Nanotubes
- Increase Voltage
  - Aqueous electrolytes <2V
  - Non-aqueous can be <6V
  - tailor asymmetrical cations

Quantum Modeling of Dynamics

Improve Membrane characteristics

Decrease Manufacturing Costs

Develop Markets (Linkage with PHEV?)

See also [http://www.sc.doe.gov/bes/reports/list.html](http://www.sc.doe.gov/bes/reports/list.html)
DOE-Off. of Science: Basic Research Needs for Energy Storage
CONCLUSIONS:

• Energy Storage can be an effective Tool for Utilities as well as Customers

• Storage Technology is developing more Options for more potential Applications

• The Importance of Storage is becoming increasingly Accepted
Energy Storage is a Disruptive Technology whose Adoption will induce a Paradigm Shift in the Entire Utility Industry !!!
RESOURCES

http://www.sandia.gov/ess/

EPRI/DOE Energy Storage Handbook

ESA Annual Meeting (Anaheim, May, ’08)

DOE Prog. Rev. (DC, Oct. ‘07)