Utility Scale Energy Storage Systems

*Presented by:*
Douglas J. Gotham, Director
State Utility Forecasting Group
Purdue University

*Presented to:*
University at Buffalo Department of Electrical Engineering
and IEEE Buffalo Section

November 8, 2013
Acknowledgment

• This presentation is based on a report prepared for the Indiana Utility Regulatory Commission

• My fellow authors on the report were
  – Rachel Carnegie
  – Paul Preckel
  – David Nderitu
Thomas Edison, 1883

- "The storage battery is, in my opinion, a catchpenny, a sensation, a mechanism for swindling the public by stock companies. The storage battery is one of those peculiar things which appeals to the imagination, and no more perfect thing could be desired by stock swindlers than that very selfsame thing. ... Just as soon as a man gets working on the secondary battery it brings out his latent capacity for lying. ... Scientifically, storage is all right, but, commercially, as absolute a failure as one can imagine."
Thomas Edison, 1901

- Develops the nickel-iron battery
- Forms the Edison Storage Battery Company
• “If you get long-term energy storage, it obviates the need for significant energy infrastructure” – David Owens, Executive Vice President for the Edison Electric Institute, October 28, 2013
Also Last Month…

- California adopted an energy storage mandate
- Three IOUs (PG&E, SCE, SDG&E) are required to have 200 MW next year and 1,325 MW by 2020.
- Non-utility suppliers must have an amount equal to 1 percent of their peak load.
Why Energy Storage?

• Electricity cannot be stored directly
• Supply of electricity must always equal demand
• This has significant cost implications
• Storage systems can act as either a source of supply or a load depending on which is more valuable
Drivers

- The potential to reduce system peak demand and the costs associated with designing a system to meet extreme events
- The need to integrate distributed and intermittent renewable energy resources
- The increasing level of congestion in transmission and distribution systems
Drivers

• The provision of ancillary services that are critical to the efficient and reliable operation of the grid
• The need for high quality, reliable power with the increased use of devices and systems that are sensitive to fluctuations
The Real Driver ($$$)

• These are all things that we can (and do) deal with today

• But we end up using the power grid in a manner that is less efficient and more costly

• Energy storage technologies have the potential to allow us to operate the system better
Key storage technology examples in use on every part of the electric grid:

- Pumped hydro storage
- Wind + battery storage
- Fossil-fired powerplant
- Neighborhood-scale battery storage
- Flywheels providing regulation service
- Commercial campus with thermal storage
Benefits

- Time shift of energy delivery
- Capacity credit
- Grid operational support
- Transmission and distribution support
- Power quality and reliability
- Integration of intermittent resources
Peak Shaving

Source: NGK Insulators
Hypothetical Dispatch Curve
Installed Wind Capacity (2012)

Source: American Wind Energy Association
Average Indiana Load vs. Wind Output (2004-2006)
Storage Characteristics

- Discharge duration
- Response time
- Discharge depth
- Cycling frequency
- Cycle lifetime
- Energy
- Power
- Efficiency
- Cost
Applications by Discharge Duration and Cycling Frequency

Frequent

- 3 hour load shift
- 10 hour load shift
- Renewables time shift
- Renewables forecast hedging
- Avoid transmission curtailment

Short

- Fluctuation suppression
- Regulation control
- Voltage stability

Infrequent

- Power quality
- Frequency excursion suppression
- Angular stability

Long

- Renewables time shift
- Renewables forecast hedging
- Spinning reserve
- Power quality
- Avoid transmission curtailment
Energy Storage Systems

- Mechanical
  - pumped hydro
  - compressed air
  - flywheel
- Chemical
  - hydrogen
- Electric field
  - capacitor
- Magnetic field
  - SMES
- Electrochemical (batteries)
  - conventional (lead acid, NiCad, lithium)
  - high temperature (NaS, ZEBRA)
  - flow (vanadium redox, ZnBr)
- Thermal
  - molten salt
Pumped Hydro

• 22 GW of U.S. capacity (>99% of all bulk storage)
• Potential sites depend on topography
• Round trip efficiency 75-78%
• High power, high energy, long discharge
U.S. Pumped Hydro Sites

Source: www.hydroworld.com
Compressed Air Energy Storage

• Charge by pressurizing air, discharge by using compressed air in a combustion turbine
• Large systems can be in the 100s of MW with 10-30 hours of storage, usually in underground formations
• Small systems often 10-20 MW with less than 5 hours of storage, usually in manmade vessels
• Efficiency varies by type, 73-89%
Flywheels

• Energy is stored in the kinetic energy of a spinning mass
• Motor draws energy to spin the rotor, acts as a generator to discharge
• Immediate response applications (UPS)
• Power and energy are a function of the mass and speed
• Roundtrip efficiency 70-80%, standby losses 1-2%
Electrochemical Storage

• Conventional batteries
  – cathode and anode with electrolyte in a sealed container

• High temperature batteries
  – molten electrodes

• Flow batteries
  – electrolyte stored in an external tank
Lead Acid Batteries

- Mature (used in the 1870s for load leveling)
- Low energy and power density, short cycle life, high maintenance, toxicity
- Low cost
- About 35 MW in use for power applications worldwide
Nickel Electrode

- Nickel cathode and various materials for the anode (Cd, Fe, Zn, H, metal halides)
- NiCd and NiFe mature, NiCd most common for power applications
- Long cycle life, high energy and power density, reliability, but low efficiency
- Cost is higher than lead acid, but lower than many others (especially NiCd and NiFe)
- About 27 MW worldwide
Lithium Ion

• Metal-oxide cathode, carbon anode, organic electrolyte w/ lithium ions, and a polymer separator
• High energy density, low losses
• Less mature, does not tolerate full discharge, thermal instability, high cost
• Considerable work ongoing due to potential for automotive uses
Lithium Ion Demonstrations

Source: D. Rastler, *Smart Grid: A 360 View of Battery Storage*
Sodium Sulfur (NaS) Batteries

- Molten sulfur cathode, molten sodium anode, solid ceramic electrolyte
- Quick response, good energy and power, efficiency 70-90%
- High cost, high temperature

Source: Sandia National Lab
Sodium Nickel Chloride Batteries

- ZEBRA (Zero Emission Battery Research)
- NiCl cathode, molten sodium anode
- Research has been focused on automotive applications
- High efficiency (85-90%), tolerant to overcharge/discharge, quick response
- High cost
Flow Batteries

• Separate storage of electrolyte allows flexibility in energy storage (need more energy, add more electrolyte)
• Decent efficiency (70-80%)
• High cost and complexity (adding pipes, pumps and tanks adds cost and leakage issues)
• Vanadium redox and ZnBr are most common (ZnBr patented in 1885)
Capacitors

- Known as double layer, ultra or super capacitors
- Energy stored in electric field
- Immediate response, high cycle life
- Energy and power characteristics depend on design, but usually one or the other
- Safety issues (fire and chemical hazards), high cost (in part due to disposal costs)
Superconducting Magnetic Energy Storage (SMES)

- Energy stored in magnetic field
- Immediate response, high efficiency (95%), high cycle life, high reliability
- Very high costs (refrigeration), low energy density
Thermal Energy Storage

- Can be cold (make ice at night for cooling during the day) or hot (heat bricks or water)
- Molten salt has been used with solar installations (concentrated sunlight melts salt, which is used to make steam when the energy is needed)
- High energy but slow response
Countless Others

• There are many more ways to convert electricity to some other form of energy for storage
• For example, electrolysis of water and a fuel cell
• Aluminum plus water makes hydrogen and aluminum oxide, which can be converted back to aluminum using energy
Power vs. Energy vs. Discharge Duration

Source: International Electrotechnical Commission
Power vs. Discharge Duration

Source: V. Koritarov, Argonne National Lab
Efficiency vs. Cycle Life

Source: Electricity Storage Association
Applications to Technologies Map
Maturity vs. R&D Expenditure

Power Cost vs. Energy Cost vs. Discharge Duration

Source: L. Shaw, Illinois Institute of Technology
Further Information

State Utility Forecasting Group
www.purdue.edu/discoverypark/energy/SUFG/

Douglas Gotham
765-494-0851
gotham@purdue.edu