PSE Healthy Energy

SCIENCE SUMMARY

AUG 2016

Energy Storage Technologies and Grid Applications

Energy storage can provide many benefits to the power sector. Batteries and other technologies can store solar energy during the day for use after sundown, or take on more complicated roles improving grid reliability and efficiency. Applications for storage can be found across the electric grid, from electricity generation through transmission and down to the household level. However, various barriers limit widespread storage deployment. Here we describe common energy storage technologies and applications, as well as challenges limiting widespread grid integration.

Technologies

Common storage technologies are described below.

Pumped hydro

The most common form of grid energy storage is pumped hydro, which refers to pumping water up a hill and running it down through a turbine when needed. Pumped hydro can be used for large capacity storage on long timescales, but its deployment is dependent on local geography and water resource availability.

Ultracapacitors

Ultracapacitors are structured like batteries, with two porous electrodes saturated with electrolyte, but in place of a chemical reaction, energy is stored in the electrochemical double layer that forms when ions in the electrolyte cover the surface of the electrodes. Ultracapacitors have high power density but low energy density.

Compressed air energy storage (CAES)

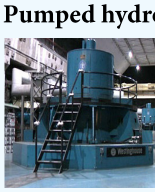
CAES systems store energy by compressing air in underground porous rock formations and later releasing that air to run a turbine. CAES is large-scale but dependent on local geology.

Grid storage examples

Lithium-ion battery: 5MW

A 5MW lithium-ion battery system is part of a microgrid in South Salem, Oregon, where it improves renewable energy integration and provides backup power and other support services [Harvey, 2013].

Pumped hydro: 1.2 GW



The 1.2 GW Helms pumped storage plant in California's Sierra Nevada mountain range has been running for nearly thirty years and is used for bulk energy management, like reducing peak demand [PG&E, 2011].

Energy vs. power

Energy storage technologies are often described by their **energy** or **power** capabilities. Energy capacity refers to the total amount of electricity that can be stored, usually given in megawatt-hours (MWh). Power is the *rate* at which that energy is used and often given in megawatts (MW). Some applications, like load shifting, require storage with large *energy* capacities like pumped hydro. Applications like frequency regulation, which requires quick bursts of power, employ technologies with high *power* density, like flywheels.

Flywheels

Flywheels store energy in the form of a rapidly spinning disk or cylinder. They can be charged and discharged very quickly but are less suited for long-term storage.

Thermal storage

Thermal storage can take many forms, ranging from heat stored in molten salts to later run steam turbines, to ice made during off-peak hours to reduce daytime cooling loads.

Batteries

Batteries depend on chemical reactions which, when reversed, release energy. The specific materials used in the battery electrodes and the electrolyte, which mediates the reaction, affect the energy density, power density, and number of times the battery can be cycled. Lithium-ion batteries are common in portable electronics, but grid storage projects also employ lead-acid, sodium-sulfur, and other battery chemistries.

Flow batteries

Flow batteries are similar to traditional batteries, but large and stationary and use liquid reactants. These reactants are stored in tanks, and flow across a membrane where the storage reaction occurs. Common chemistries include vanadium-redox and zinc-bromide.

Grid-scale applications

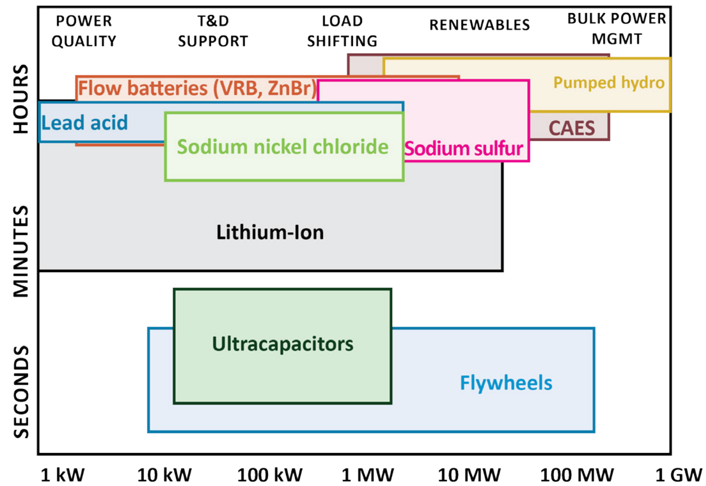
Factors like the timescale of the application (given below) determine which technology is best suited for a given grid application.

Power quality (seconds to minutes)
Frequency and voltage control require rapid response times and are critical for ensuring grid power quality and consistency. Storage used for these services must supply rapid burst of power, but the total capacity of energy stored can be low.
Technologies: flywheels, ultracapacitors, batteries

Spinning reserve/peak shaving (minutes to hours)
Mid-size storage can replace natural gas plants used for peak demand by reducing peak load, reducing ramp rates, and providing start-up capabilities. Storage used as spinning reserve provide rapidly ramping backup services.
Technologies: batteries, flow batteries

Renewables integration (minutes to hours)
Storage can be used for renewables integration, including smoothing short variations in output, lowering ramp rates when renewable resources come on and off line, and storing off-peak renewable generation for periods of high demand. Storage can also allow solar and wind generators to improve power dispatchability.
Technologies: batteries, flow batteries, CAES, pumped hydro

Transmission support (hours)
Energy storage distributed throughout the transmission and distribution (T&D) system can reduce system costs by deferring the need for grid upgrades, reducing congestion and improving efficiency.
Technologies: batteries, flow batteries



Common storage technologies and broad application categories plotted by typical system capacity and discharge time, as reported in the DOE Global Energy Storage Database [DOE, 2016].

Load shifting (hours to days)
Energy storage can perform load shifting by charging when demand and prices are low, such as at night, and providing electricity when demand and prices rise during the day.
Technologies: pumped hydro, CAES, batteries, flow batteries

Emergency backup (days to months)
Energy storage is used as distributed emergency backup when the grid fails. For these applications, batteries with shorter cycle lives but low capital costs, like lead-acid cells, provide emergency bridging power to key systems during outages.
Technologies: batteries

Overcoming barriers to deployment

Technical, regulatory and economic factors limit widespread integration of grid-level energy storage.

Technology
Each storage technology faces unique technical challenges, but many share a few barriers. Longer cycle life will bring down the levelized cost of battery storage. Better thermal management of batteries will reduce rates of battery failure and hazardous incidents like fires, improving safety. Because current large-scale energy storage technologies like pumped hydro are geography dependent, other technologies must demonstrate the ability to scale to large capacity installations. Increased storage efficiency will also reduce the total cost of storing energy. Additional material challenges include finding greener chemistries, improving recycling, and advancing manufacturing technologies.

Regulations
Most current electricity markets and regulations were structured without considering storage. As a result, storage either cannot participate in some markets or is undervalued. Recent FERC rulings have improved access to frequency markets, allowing storage to compete in power quality applications, and redefined the metrics used to evaluate performance so that storage value is more accurately captured. However, storage competitiveness is still limited by regulations preventing storage from being used for multiple grid applications at the same time, which would allow these technologies to be more cost-competitive.

Cost
Grid integration of storage is feasible, but often limited by cost. Regulatory improvements will improve cost competitiveness, but storage is still expensive for many markets. Many technologies are still in pilot phase, so they have not taken advantage of economies of scale. As the number of projects increases, costs should fall, much as has been seen in the solar industry.

References
1. Harvey, G. and White, F. "Power grid getting smarter with big battery in Salem." PNNL: News. May 31, 2013. www.pnnl.gov/news/release.aspx?id=990
2. Leadbetter, J. and Swan, L.G. "Selection of battery technology to support grid-integrated renewable electricity." J. Power Sources, 216 (2012): 376-386.
3. PG&E. "By the numbers: Helms pumped storage facility." PG&E: Currents. October 17, 2011. www.pgecurrents.com/ 2011/10/17/by-the-numbers-helms-pumped-storage-facility
4. DOE "Department of Energy Global Energy Storage Online Database." Accessed 8/2/16. Available at: www.energystorageexchange.org