Electric energy is the only commodity that has not been successfully stored. The electric utility industry will experience a dramatic change when the industry learns to safely, reliably and affordably store energy.

Energy storage in the form of pumped hydro has been used in the United States since the early 1930s. However, until recently, many other types of energy storage applications have not been seen as commercially viable because of a lack of technological advancement and cost. However, the energy storage market potential has changed significantly since the introduction of California’s Assembly Bill (AB) 2514. The bill signified for the first time that a state saw the necessity to incorporate energy storage to meet the needs of a high reliability grid.

In October 2013, the California Public Utilities Commission (CPUC) finalized its proceedings on AB 2514. The legislation directed the CPUC to develop energy storage targets for California’s investor-owned utilities (IOUs) to integrate grid-scale energy storage into the state’s electrical power system. As a result of AB 2514, the CPUC set a target for the IOUs to procure 1.325 gigawatts (GW) of new energy storage applications by 2020 in California. The ruling did not include the capacity of the existing large-scale pumped hydro facilities in the state. The CPUC considered the needs for renewable firming, demand-side management, distributed energy support and transmission-like ancillary services when deciding the amount of energy storage to procure. All of these factors were considered for the purpose of increasing grid reliability, lowering the costs for consumers and decreasing carbon pollution.

The effects of AB 2514 are already being seen in the industry. One example of this is that in September 2014, San Diego Gas & Electric announced that it was seeking to procure between 500 and 800 megawatts (MW) of new resources by 2022 to offset the loss of the San Onofre Nuclear Generating Station. As part of this, a minimum of 25 MW of energy storage is to be included in the mix.

In addition to AB 2514, in July 2013 the Federal Energy Regulatory Commission (FERC) approved Order 784, which expanded previous Order 755. Order 755 directed regional transmission organizations (RTOs) and independent system operators (ISOs) to adopt a two-part, market-based compensation method for frequency regulation services. The RTOs and ISOs are required to compensate for storage capacity and a market-based performance payment. In addition to Order 755, Order 784 directs RTOs and ISOs to consider speed and accuracy as part of their regulatory energy production resources. In turn, this potentially makes the installation of energy storage devices more appealing than generators. Because energy storage devices inherently respond faster than generators when used for frequency regulation. Order 784 also revised accounting and reporting requirements for transactions at public utilities in the use of energy storage devices. This change creates opportunities for ancillary services from energy storage devices.
These policy changes are coupled with growing competition within the distributed generation (DG) market. Companies like SolarCity are actively pursuing electric utility customers to serve some or all of their electric needs while keeping the customer connected to the grid. This will be troublesome for utilities if energy storage becomes more cost-effective for residential applications as suggested in Rocky Mountain Institute’s paper titled “The Economics of Grid Defection.” Tesla, in partnership with Panasonic, is developing a “Gigafactory” in Nevada that will produce lower cost lithium-ion batteries in quantities previously unrealized. These batteries could be used in automobiles and residential applications. 

It is not difficult to imagine how the electric grid could change when these energy storage applications from developers and third parties become widespread in the residential and commercial markets. Each electric utility should recognize these coming technical changes and be prepared to offer their own storage solutions or other technical solutions to their customers.

This report provides an overview of the current state of technology on the known methods of energy storage. As technology advances, we will periodically update the status of these technologies.

**Pumped Hydro**

Pumped hydroelectric storage (commonly known as pumped hydro) is the largest energy storage application in the United States, providing more than 20 GW of energy storage at 40 locations nationwide. Pumped hydro can provide energy balancing, stability, storage capacity and network frequency and reserves on the ancillary services market.

Pumped hydro stores energy in the form of water in a reservoir at a higher elevation. Upon release from the reservoir, the water will pass through turbines on the way to a lower reservoir. In most cases, the water is stored in the lower reservoir until a period of low demand (and cost) and then will be pumped back to the higher-elevation reservoir. These pump stations are considered net consumers of energy because of the electrical losses generated from pumping the water back to the higher reservoir. However, it is still considered a highly efficient storage model, with efficiencies reaching greater than 80%.

However, there is a natural increase to the nitrogen levels in the water as it travels through the turbines to generate electricity. This causes local fish and plant habitats to die off; making it increasingly difficult to approve and permit a pumped hydro facility. In fact, there have been no new facilities constructed in the last 30 years. However, in spite of the environmental challenges, a permit for construction was awarded to the Sacramento Municipal Utilities District (SMUD) for a 400-MW pumped hydro facility in California in 2014. This award to did not come without its challenges, as SMUD began the permitting process over 10 years ago.
Compressed Air Energy Storage

Compressed air energy storage (CAES) stores high-pressure air, for use in a combustion turbine at a future date. The air is pressurized by a compressor unit that is powered by excess exhaust, wind turbines or natural gas. Essentially, CAES decouples the compressor unit and combustion turbine, adding storage between the two processes.

CAES has not been a widely adopted form of energy storage. Only two CAES units have been deployed in the world, but there are several projects in development. One of the main challenges with CAES is finding the right storage facility for the high-pressure air. Very large storage facilities are required because of the low storage density. Abandoned salt caverns provide ideal CAES facilities because there is no pressure loss and no reaction to the oxygen in the air and the salt-laced rock. Other cavernous locations can be used but engineers must verify that there are no other micro-organisms in the cavern and determine whether the oxygen reacts with the rock — these measures are essential before pursuing such locations.

Thermal Energy Storage

There are two types of thermal energy storage (TES). The first is based on sensible heat in various solid or liquid materials; that is predominantly used in residential and commercial HVAC systems. The second is based on the latent heat of phase change reactions, which can be used in larger-capacity systems and, possibly, in conjunction with utility scale solar.

Thermal energy storage within HVAC units uses off peak time to freeze various solid or liquid materials to assist with cooling during peak load times. This application is used as a cost saving strategy for the commercial and residential sector.

Concentrating solar power (CSP) has two common design methodologies: parabolic troughs and power towers. CSPs concentrate sunlight onto heat transfer fluids, which are then used to drive a steam turbine. The excess heat generated can then be stored in molten salts, which have proven high storage efficiencies. Molten salts are ideal for this application for several reasons: their capacity for reaching high temperatures without boiling; their low-cost and efficiency as a medium for storage; their operating temperatures being compatible with modern steam turbines; and their non-flammable and non-toxic nature. There already is a lot of experience with using molten salts as a heat-transport material in the chemical and metal industries. Several hundred megawatts of CSP facilities are using TES in the United States.

Batteries (Lithium-Ion)

Battery options for energy storage are increasing. Lithium-ion batteries have seen early success in the commercial sector with portable electronics and electric vehicles. Since the development
of lithium-ion storage technology in 1991, it has continued to gain favor and now has a production volume of 10 GWh to 12 GWh annually as estimated by the California Energy Commission (CEC). Lithium-ion batteries feature high energy density and are relatively lightweight, which make them ideal choices for electric vehicles and portable devices. In addition, the batteries have appealing life cycles and compactness in combination with their roundtrip energy efficiency that exceeds 85%, according to the CEC.

Although the technology is available, lithium-ion batteries haven’t been widely adopted because of their cost. Tesla has plans for mass production of the batteries with hopes of reducing their cost by at least 30% in the next 10 years through economies of scale. The industry is experiencing a lot of public exposure as companies increase research and development efforts, production and durability evaluation. This increased production capacity is intended to handle the demand caused by the emerging popularity of hybrid and all-electric vehicles. Analysts estimate that the increase in production will reach 35 GWh by 2015. The future is bright for lithium-ion batteries because of the auto industry’s positioning of it as the technology platform for plug-in hybrid electric vehicles (PHEV) and electric vehicles (EV). General Motors does extensive research on its batteries for its automobiles and to find second life uses for the batteries. This long term research is intended to help offset the high initial cost of the battery finding an environmentally conscious application of the battery once it has exceeded its useful life in the automobile.

Manufacturers are finding new ways to incorporate lithium-ion batteries in more applications. The Electric Power Research Institute (EPRI) indicated that manufacturers are looking at distributed energy storage systems at a community scale, transportable systems for grid support, commercial end-user energy management, home back-up energy management systems, frequency regulation, and wind and photovoltaic smoothing. With all the new applications for lithium-ion batteries, there will be no shortage of implementation opportunities.

Despite the current high costs of utility scale battery installations, there have been successful and economically advantageous applications on the grid. When PJM, an East Coast RTO, adopted FERC Order 755, it partnered with AES Corp. on a 32-MW lithium-ion battery storage facility in West Virginia paired with a 98-MW wind farm. Now AES has set its sights on a 400-MW battery storage facility for the Long Island Power Authority (LIPA).

**Flywheels**

Flywheel energy storage (FES) works by accelerating a rotor — or flywheel — using excess energy from the grid, transferring and storing electricity in the form of kinetic energy. The higher the operating rotor speed, the more energy it can store. Advanced FES systems have operating speeds of 20,000 to 50,000 revolutions per minute (RPMs) in a vacuum enclosure. The vacuum technology makes flywheels one of the most efficient storage options in the industry. Current models yield as much as 93% efficiency.
Today, the most common applications of flywheel technology store 2 kWh to 6 kWh for small telecommunication backup power applications. However, the University of Texas at Austin completed research and development of a flywheel that had 133 kWh of energy storage. This is said to be the record for carbon-composite flywheels. Beacon Power also successfully developed a flywheel network consisting of 40 25-kWh wheels capable of storing 1 MW of energy. Yet, flywheels typically experience far lower capacity than other storage applications.

The significant limitation of capacity is directly related to the tensile strength of the material of the rotor. Flywheels are made of advanced composite materials and steel. By using lighter weight material with the same strength components as steel, the flywheel can spin faster, raising capacity. However, these materials tend to cost more than steel counterparts. Finally, the common flywheel will last for approximately 15 seconds before an alternative energy source is needed. This allows the backup power source to fire up without losing power on the grid. This is why flywheels may be best suited as a complement for a battery or a generator.

Conclusion

Although pumped hydro dominates the energy storage market today, its future within the industry may be limited. Compressed air energy storage, thermal energy storage, batteries and flywheels are the most industry-ready energy storage applications available. These applications can provide electric utilities with the necessary diversity to assist with renewable firming, demand-side management, distributed energy support and transmission ancillary services.

Policy from state regulators is requiring that electric utilities use more storage applications on their system. As markets continue to be driven by these policies across the country and more states adopt these policies, the technology and efficiency of energy storage will continue to develop and improve. Ultimately, each electric utility will need to be aware of the variety of storage applications available and understand which application is best suited for its system and customers.

Biography

Peter Boos is a project development strategist at Burns & McDonnell. He spent several years designing substation facilities for major electric utilities. Peter is in engaged in the application of advanced technologies on the electric and gas transmission and distribution system throughout North America. He has a bachelor’s degree in architectural engineering and a master’s degree in structural engineering from Kansas State University.