Energy Storage Technology

An Online Continuing Education Course for Engineers

Course Number: E-4016

Credit: 4 Hours / 4 PDH / 4 CPD

© 2023 Decatur Professional Development, LLC. All rights reserved.

Energy Storage Technology

Lee Layton, P.E.

Introduction: "Bottling Electricity"

Electricity is one of the major commodities in our economy and it is one of the few commodities that never had an economical or practical method to store the product. Electric power is produced and delivered at virtually the instant it is demanded. Generation and transmission systems must be designed to meet the peak instantaneous demand that may occur on the system. Considering a little extra capacity for reliability, this has resulted in a model where the capacity factor of the entire system is less than 50%. Although it is difficult to store electricity directly, electric energy can be stored in other forms, such as potential, chemical, or kinetic energy. Advanced energy storage technologies based on these principles are emerging as a potential resource in supporting an efficient electricity market. The term *energy storage* refers specifically to the capability of storing energy that has already been generated as electricity and controllably releasing it for use at another time.

Only about 2.5% of the total electric power delivered in the United States passes through energy storage, almost all of which is pumped hydroelectric storage. The restructuring of the electricity industry, along with increased requirements for power reliability and quality, has made utility-scale energy storage a subject of current interest.

Although the present-day electric grid operates effectively without storage, cost-effective ways of storing electrical energy can help make the grid more efficient and reliable. *Electric energy storage* (EES) can be used to accumulate excess electricity generated at off-peak hours and discharge it at peak hours. This application could yield significant benefits, including a reduced need for peak generation and reduced strain on transmission and distribution networks. Energy storage can also provide critically important ancillary services such as grid frequency regulation, voltage support, and operating reserves, thereby enhancing grid stability and reliability.

Technical applications of energy storage include grid stabilization, grid operational support, power quality and reliability, load shifting, and compensating for the variability of renewable energy sources. Restructured electricity markets provide opportunities for energy storage to participate in energy arbitrage and ancillary services.

©2020 Lee Layton, Portions ©2020 Decatur Professional Development, LLC All rights reserved. (r20l17)

The first application of large-scale energy storage in the United States occurred in 1929 when the first pumped hydroelectric power plant was placed into service. Pumping water from a lower elevation to a higher elevation was the most practical way to store large amounts of energy that could then be released during periods of high or peak demand. These power plants are still used to help manage grid frequency and provide clean reserve generation, known as ancillary services. During a 30-year period from the late 1950s to the late 1980s, approximately 19,500 MW of pumped hydroelectric storage facilities were brought into service in the United States. By 2000, about 3% of the total power delivered by the nation's grid was supplied through these energy storage facilities. Because of the need for significant elevation changes in pumped hydroelectric plant designs, the number of environmentally acceptable sites for future pumped hydroelectric facilities is limited. The siting of new plants will face the same objections that the siting of new transmission lines faces today.

Another energy storage technology is *compressed air energy storage* (CAES). A CAES demonstration power plant was placed in service in the early 1990s and has proven to be effective. Underground formations, such as salt domes and depleted gas fields, can be adapted for use with CAES technology. These systems appear to be practical in a power range from above 100 MW up to several thousand MW.

The most common form of energy storage in use today is based on batteries. The is a large installed base of lead-acid batteries in the UPS system. The rapid growth of the information age has spawned the construction of data centers to support the Internet and communications centers. These facilities are sensitive to power supply disruptions, so large, battery-powered protection systems have been and will continue to be deployed to achieve a high level of protection. Powering these types of loads currently accounts for over 1.5% of the total utility power consumption in the United States.

There are several other electrochemical technologies in use for electric backup power applications. These battery technologies are also being investigated or deployed for utility-scale applications. Battery technologies include lithium-ion, sodium-sulfur, zinc-bromine, vanadium redox, and polysulfide-bromide redox flow batteries, among others.

The two main classes of batteries in this distributed energy storage category are flow batteries and high-temperature batteries such as sodium-sulfur and sodium-nickel chloride batteries. Industry experts have found that, unlike lead-acid batteries, these devices can cycle daily and have useful operating lives in the range of 10 to 20 years. These systems can be designed for charge/discharge durations up to eight hours per day. All these devices are scaled chemistries with no emissions and quiet operation.

©2020 Lee Layton, Portions ©2020 Decatur Professional Development, LLC All rights reserved. (r20l17)

Flow battery technology utilizes an active element in a liquid electrolyte that is pumped through a membrane-like fuel cell to produce an electrical current. The system's power rating is determined by the size and number of membranes, and the runtime (hours) is based on the gallons of electrolyte pumped through the membranes. Pumping in one direction produces power from the battery, and reversing the flow charges the system.

High-temperature batteries operate above 250C and utilize molten materials to serve as the positive and negative elements of the battery. These chemistries produce battery systems with very high-power densities that serve well for storing large amounts of energy. The sodium-sulfur battery, such as the unit shown on the right, is currently being deployed in the United States by several large utilities in demonstration projects.

Photo Credit: US Department of Energy

Other energy storage devices such as flywheels and supercapacitors are being applied for power quality applications and frequency regulation for utilities and other load-balancing uses to reduce emissions from diesel generator-powered devices such as port cranes. For these systems, energy storage is measured in minutes.

One energy storage technology that may be the future of utility energy storage is Plug-in Hybrid Electric Vehicles (PHEVs). The acceptance of these vehicles and the ensuing rate of adoption by the public will determine the timing of their impact on the overall power demand of the utility grid. Assuming most charging of PHEVs occurs at night, the relative impact on the grid over time should be positive in conjunction with the anticipated significant growth of wind energy. Uncontrolled daytime or early evening charging by PHEVs, by contrast, could pose challenges to system economics and capacity, as the extra demand could increase congestion or peak use.

There are many benefits to deploying energy storage technologies into the nation's grid. Energy storage can provide:

- A means to improve grid optimization for bulk power production.
- A way to facilitate power system balancing in systems that have variable or diurnal renewable energy sources.

©2020 Lee Layton, Portions ©2020 Decatur Professional Development, LLC All rights reserved. (r20l17)

- Facilitation of integration of plug-in hybrid electric vehicle (PHEV) power demands with the grid.
- A way to defer investments in transmission and distribution (T&D) infrastructure to meet peak loads for a time.
- A resource providing ancillary services directly to grid/market operators.

Depending on the principal application of the energy storage technology, energy storage may be viewed as a generation, transmission, distribution, or end-user resource.

Pumped hydroelectric and CAES technologies are considered bulk power energy storage systems. In contrast, new classes of batteries have been developed that are considered suitable for smaller applications and are referred to as “distributed” utility storage systems. (In this context, the term “distributed” is used as a differentiation from “large centralized” energy storage technologies, analogous to large-centralized power plants.) The term *distributed energy* storage means deployment of these devices close to load centers, transmission system points of reinforcement, or renewable generation sources, typically in or near utility substations. In other contexts, the term “distributed” denotes location on distribution feeder circuits or at consumer premises behind the meter.

Full integration of new sources of energy demand coupled with the overall increase in electricity use is a major challenge facing the designers of the electric grid of the future. Energy storage technologies need to be examined closely to understand where storage can add value to the overall electricity infrastructure. Examples of the value of energy storage technologies could include capital deferral, energy maintenance during *islanding*, and better utilization of generation in coordination with the variable output nature of renewable energy generation.

Islanding: Continuing to power a portion of a grid independently from the utilitv source.

The ratio of storage energy capacity to charge/discharge power rating, or the duration of the energy storage that is required, varies depending upon the application and favors different technologies accordingly. Energy density, cost, efficiencies, and environmental concerns are additional factors that affect the applicability of different technologies to different purposes. The electric vehicle application drives most R&D for advanced materials today, but it should be noted that it is also the most demanding application and thus the one that justifies higher costs. In the long term, the best energy storage technologies for utility-scale applications may be different from those used for electric-drive vehicles.

©2020 Lee Layton, Portions ©2020 Decatur Professional Development, LLC All rights reserved. (r20l17)

Determining the amount and overall value of energy storage that should be added to the grid begins with an examination of the marginal cost of generating electricity. The electric power industry runs at low capacity factors. This level of capacity has been acceptable to the industry because generation resources have traditionally been more cost-effective sources of capacity than energy storage resources. The growth of renewable energy will likely lead to even lower capacity factors for traditional generation sources.

Many of the drivers for a smart grid are based on a desire to improve capacity factors by shifting the demand curve through either incentives or controls. Beyond some point that remains to be determined, there is likely to be some public resistance to the degree of load shifting entailed in the deployment of demand response programs. Energy storage technology offers another path to help balance the system to adapt production to demand while improving capacity factors.

Another positive aspect of the implementation of energy storage technologies is the potential to capture and store electricity from wind energy when there is a lack of transmission infrastructure. For example, wind curtailment has already become common in Texas because of a lack of transmission capacity to move that power from western Texas to load centers in other parts of the state. In many regions, including Texas, transmission projects are moving forward to better connect wind power plants with load centers, although energy storage technologies may have potential value in the interim. In addition, as wind power deployment increases, wind output may begin to exceed electricity demand during certain times of the year, which would necessitate curtailment. This problem may also be aggravated by inflexible nuclear and coal power plants that have limited ability to decrease their output, given the difficulty of powering up or powering down these large baseload facilities.

Wind is a growing contributor of energy, but only a small, insignificant contributor to electrical generating capacity. Wind power's intermittency—which results in generation that is not dispatchable—is well documented. The output of a wind farm can vary from zero to the full rated output of the facility. This is an issue even with large wind farms, which have some self-compensating ability because they are geographically dispersed. For modern wind turbine farms, the yearly average capacity factor—the portion of time they produce full output—is around 40%. As the percentage contribution of wind grows, so does its effect on the grid, creating problems of frequency stabilization and system reliability. Energy storage options could be employed to supplement or compensate for the variability of the wind power's output.

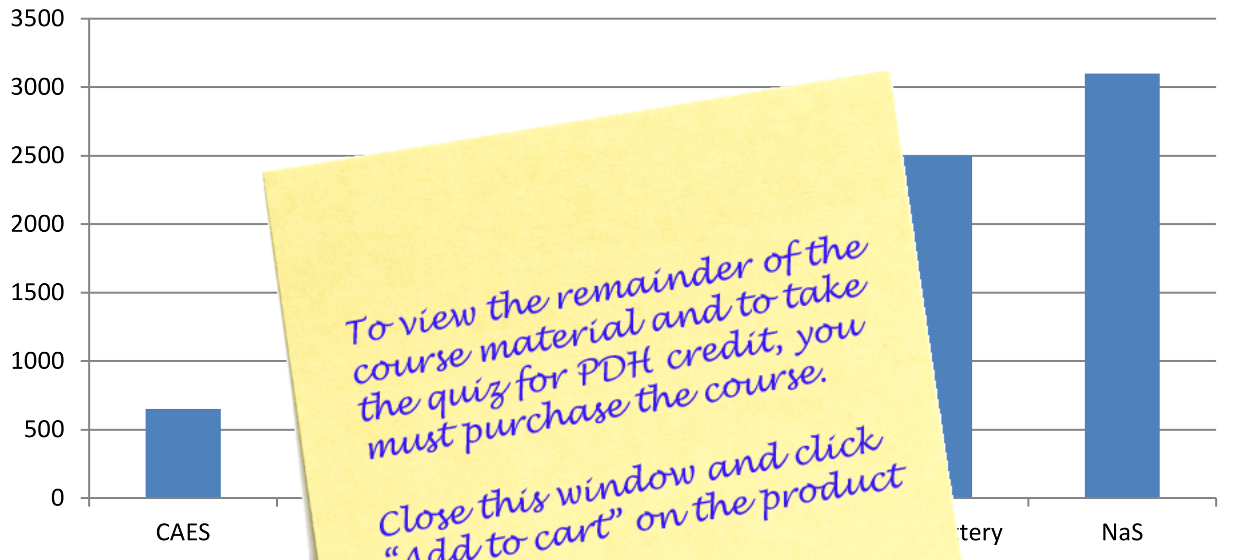
Much like wind energy, photovoltaic energy is also an intermittent source of electricity. The output from a solar array will vary with the location, weather conditions, and time of day. It also varies throughout the day, increasing from morning to midday and dropping off in the afternoon. In many cases, photovoltaic energy production does not coincide with the late

©2020 Lee Layton, Portions ©2020 Decatur Professional Development, LLC All rights reserved. (r20l17)

afternoon summer peak demands that most utilities experience. There is also the intermittency caused by passing cloud cover, which can momentarily reduce a photovoltaic array's output to virtually zero. Energy storage can smooth the output of photovoltaics by filling the shoulder period—the afternoon drop-off of power from the sun. It can also buffer the effect of momentary power loss due to passing cloud cover. Because the output from a solar array is DC, it does not require the AC to DC conversion that wind energy needs. This allows direct connection of the battery to the solar DC bus through electronics but without AC/DC conversion. The capital cost should therefore be less and the efficiency higher than those of wind power conversion equipment.

In analyzing energy storage alternatives, Figure 1 shows the current cost estimates for various types of energy storage technologies available today. Except for CAES, all other forms of energy storage have no emissions associated with the energy discharge cycle. CAES systems burn a mixture of compressed air and natural gas to generate power. CAES technology requires fuel costs for discharging, which are not captured in Figure 1. If the system operated on compressed air alone, the costs per kilowatt (kW) would be approximately three times greater.

Figure 1
Cost Estimates for select ESS Technologies



Energy storage technolog n their
economically practical du *minutes of runtime*.
Currently, flywheels and bearing in the grid
today for ancillary service rgy storage
technologies can provide dition to use in ancillary services such
as frequency regulation.

To view the remainder of the course material and to take the quiz for PDH credit, you must purchase the course.

Close this window and click "Add to cart" on the product page.

©2020 Lee Layton, Portions ©2020 Decatur Professional Development, LLC All rights reserved. (r20l17)