



PJM Interconnection supports energy storage projects of all types to enhance the capability of the electric grid. Energy storage on the grid adds flexibility to the supply mix, particularly important as the amount of intermittent resources expands.

One of the challenges facing grid operators like PJM is the inability to “store” electricity during times of oversupply or low prices for later use during times of high demand, high prices, or when other power sources are not available. Unlike other forms of energy, such as oil or natural gas, electricity cannot be stored in the traditional sense. Electricity is consumed at the time it is produced.

Until recently, the only large-scale energy storage option for electricity available was pumped-storage hydroelectricity. Pumped-storage resources employ two connected reservoirs at different elevations. During the night-time hours, when electricity costs are low, water is pumped from the lower reservoir to the upper reservoir to be stored. During the day, when power demand and/or electricity costs are high, the water is released from the upper reservoir and flows through a turbine to generate electricity.

In effect, pumped storage converts low-cost off-peak energy into higher-priced on-peak energy. The largest pumped storage facility in the U.S. is located in the PJM territory, and these resources have helped grid operators match generation supply to load demand for decades.

However, pumped storage resources are very difficult to build, and new technologies are being developed that offer the promise of more widespread storage options for grid operators and utilities. These technologies will become even more important as intermittent renewable energy sources play a greater role in the nation's electricity supply.

Today, additional options for storing electricity are emerging and are being tested. These technologies – such as batteries, flywheels, compressed air energy storage, thermal storage, and electric and plug-in hybrid electric vehicles – may give grid operators

additional flexibility in their efforts to ensure the reliability of the electric system.

There are a number of reasons why additional storage capacity is needed on the grid. The primary one is the dramatic increase in electricity from renewable sources that is expected. These sources typically are intermittent – their production isn't available all the time, as for example, with the lack of energy when the wind isn't blowing or the sun isn't shining – and their output may not be available at times of peak demand when it is needed most.

Taking full advantage of renewable sources, while managing the challenges of their fluctuating output, will require a significant increase in flexible resources on the grid, including energy storage.

The lack of sufficient storage already has caused issues for PJM. In some areas, abundant wind production in the off-peak (night-time) hours has driven electricity prices negative.

Given states' requirements for renewable energy and economic incentives for the development of renewable projects, the expected expansion of renewable power will magnify these issues, along with the challenges for grid operators in dealing with fluctuations in the output of these power sources.

The following are some examples of new storage technologies for the grid:

**Battery storage** – A one-megawatt array of lithium-ion batteries provided frequency regulation service in the PJM market for several years. The battery facility, housed in a shipping container on the PJM campus, was owned by AES Energy Storage, a subsidiary of The AES Corp. AES now has a two-megawatt battery facility on the PJM campus. A much larger battery facility, 32-MW AES Laurel Mountain in West Virginia,



went into operation in 2011 in conjunction with a 98-MW wind farm. The battery facility helps PJM quickly balance variations in load to regulate frequency as an alternative to adjusting the output of fossil-fuel generators; it is capable of changing its output in less than one second. In response to PJM requests to balance the grid, the battery unit can supply power into the grid by discharging its batteries or store excess electricity from the grid to charge its batteries. As of April 2017, the total nameplate amount of battery storage projects in PJM is more than 280 megawatts.

**Flywheel storage** – This technology involves the use of a rotating flywheel to store energy. A motor draws energy from the grid to accelerate the flywheel, storing the energy in the rotating device. When the grid needs regulation, the flywheel drives a generator to produce electricity for the grid as the flywheel slows. A Beacon Power flywheel system has been providing frequency regulation for the ISO New England grid since 2008, and a 20-MW facility was completed in New York in 2011. The first phase of a 20-MW Beacon flywheel facility in PJM went into service in 2013 in Pennsylvania.

**Compressed air energy storage** – Compressed air energy storage is another promising form of storage. Like pumped-storage hydro, it uses less-expensive off-peak power, in this case pumping and compressing air in underground containment areas. The air is held until power is needed and then is released through a combustion turbine with the natural gas fuel, increasing the efficiency of the generator to provide more economical electricity at times of high demand.

**Electric vehicles** – Vehicle battery storage using electric and plug-in hybrid electric vehicles connected to the grid is another storage technology that is being evaluated. Off-peak or low cost electricity from the grid could charge the vehicles, shifting load to the nighttime hours or otherwise helping to match supply and demand. Electric vehicles could also provide reliability services to the grid, such as frequency regulation or fast-start reserves. With the University of Delaware,

PJM is evaluating a group of electric vehicles providing frequency regulation service to PJM market in a demonstration of “vehicle-to-grid” (V2G) technology.

Also being evaluated at PJM is thermal storage, using large electric water heaters that respond to grid needs when they receive pricing and regulation signals from PJM dispatchers.

Storage technologies can help grid operators and utilities address the impact of a large-scale addition of renewable energy sources to the electricity system, including the intermittent nature of renewables, the off-peak timing of much wind energy output, and the potential impact on the operation of baseload power plants.

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