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Energy Storage and Its Applications In the Development of a 21st Century Electrical Grid

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SUMMARY

The proliferation of renewable energy sources into the electrical grid, coupled with outage-creating storms that seem to strike with more ferocity than ever before, and—above all—our insatiable requirement for more and more electricity, present electricity providers and end users with a set of challenges that demand a truly flexible and innovative solution.

The traditional grid model in which power flows one way, from source to load, is undergoing a rapid transformation. Power simply doesn't flow just one way. In 2013 alone, twenty states in the US installed more than 20 MW of solar energy capacity. And, according to the Solar Energy Industry Association's *2014 US Solar Market Insight* report, in just the first quarter of 2014, 232 megawatts of residential photovoltaic capacity were installed.

Managing reverse power flow and the variable power output from renewable generation sources are key challenges facing the electrical grid, and need to be addressed to avoid situations that can result in system-wide disturbances. It should therefore come as no surprise that many experts in the industry have termed energy storage as the "holy grail" . . . the key to enabling the grid of the future. Energy storage is required to integrate renewable energy, so that this variable generation isn't synched with load demand and can be dispatched when it's needed. Energy storage also helps fulfil the reliability demands of today's loads and optimize the operation of a smarter distribution system. This paper explores these and other applications for energy storage that can be utilized to help develop and sustain the 21st-century electrical grid. The paper concentrates on battery storage, although many of the arguments are equally valid for other forms of energy storage.

KEYWORDS

Energy Storage, Peak Shaving, Frequency Regulation, Reliability, Peak Pricing Avoidance, Demand Charge Management, Energy Storage Applications, Renewable Energy, Wind Energy, Solar Energy

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Introduction

In the traditional grid model, power is supplied one way, from source to load. That model is no longer valid in many parts of the United States. For example, in 2013 alone, twenty states installed more than 20 MW in solar energy capacity [1]. According to the Solar Energy Industry Association's (SEIA) *2014 US Solar Market Insight* report, in just the first quarter of 2014, 232 megawatts of residential photovoltaic capacity were installed [2].

Managing reverse power flow and variable power output from renewable solar and wind generation sources are major concerns faced by the existing electrical grid, and need to be addressed to avoid situations that can result in system-wide disturbances.

Many experts in the industry believe that energy storage is the key to enabling the grid of the future. Energy storage is required to integrate renewable energy, so that this variable generation is not synched with load demand and can be dispatched when it is needed. Energy storage also helps fulfil the reliability demands of today's loads and optimize the operation of a smarter distribution system.

It's important to note that the beneficiaries of energy storage can vary, depending on utility structure and regulatory rules. This paper considers energy storage as a unique type of regulatory asset. Its benefits are considered on a holistic level. In other words, society as a whole will be better off if policies are implemented furthering the application of energy storage.

Background on Energy Storage

A variety of energy storage solutions are available today, including flywheels, pumped hydro, and batteries. In this paper we will focus on battery-based energy storage solutions. Within this category, a range of battery chemistries are available. The most common ones utilized today include lead acid, lithium ion, and sodium sulfur. Capacity (in kW) and energy (in kWh) varies between the different battery chemistries.

Energy storage can be segmented by size too. Large energy storage solutions are available, providing hundreds of MW, and are typically placed on the transmission network. Substation-level energy storage solutions are available as well, ranging in capacity from 2 to10 MW. The latest innovation in energy storage places storage on the grid's edge. In this application, a storage asset is located between a residential pad-mounted transformer and the residential electricity service connection. This type of storage ranges in size from 10 to 25 kW, and is commonly referred to as community energy storage.

Energy Storage and Renewables Integration

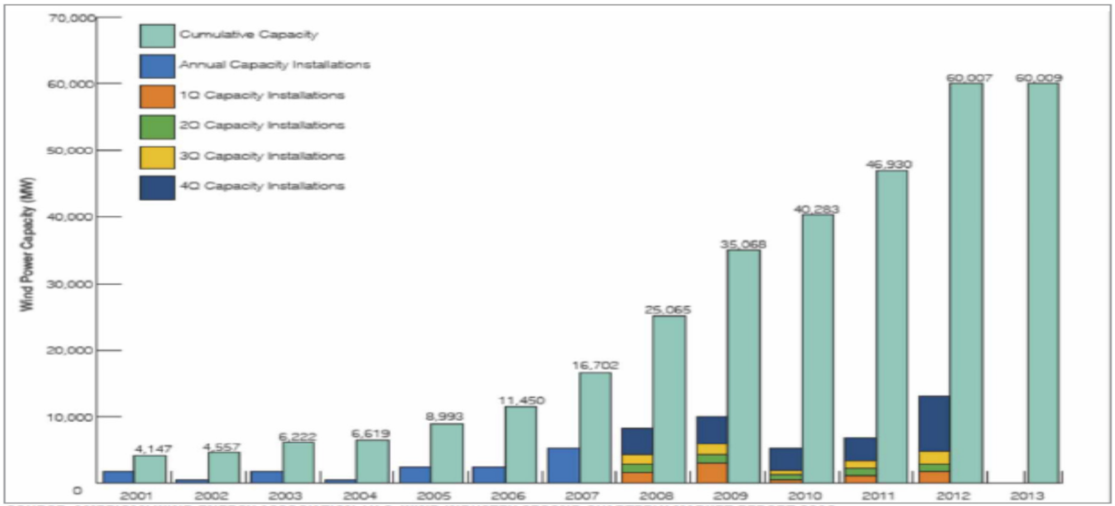
Renewable energy penetration on distribution-level feeders is increasing at a very rapid rate in the US. In fact, photovoltaic panel generation on some circuits in the US now exceeds 20% of power consumption during periods of low loading [3]. On the other hand wind energy has grown exponentially at an average rate of 29.7% per year over the last decade [4]. Utilities are thus dealing with a network that not only has power flowing in both directions, but includes output from renewable sources that can be very intermittent. Distributed energy storage systems—particularly those located in close proximity to renewable energy sources—are uniquely suited to address such challenges.

Research carried out by Greentech Media Inc. showed that the traditional means for regulating distribution voltage—switched capacitor banks— typically require five minutes to reenergize after they are turned off, thus reducing their ability to dynamically manage and optimize the feeder during voltage sags and provide effective reactive power control [5].

The Greentech Media report also showed that line capacitor banks, though capable of providing reactive power in 200-kVAR increments, cannot provide solid reactive power support due to their low-level granularity on feeders that have a high penetration of intermittent renewable energy sources [6]. On feeders having a high penetration of renewable energy sources, voltage swings can require a voltage regulator that can move through all of its tap positions and back in less than 10 minutes . . . a duty for which most voltage regulators are not intended [7].

Energy storage can be used to better manage the misalignment in time between renewable generation output and distribution grid and system peaks, and better manage the intermittency and volatile ramp rates of renewable energy sources that cause voltage fluctuations.

Energy storage can further help mitigate the tremendously varying voltages associated with photovoltaic generation, as needed to maintain system voltage within standard. Energy storage, in this case, will either supply or absorb VARs from the distribution grid on a very fast basis to maintain the desired grid voltage. This type of voltage smoothing cannot be accomplished with capacitor banks or other traditional power system solutions.



SOURCE: AMERICAN WIND ENERGY ASSOCIATION | U.S. WIND INDUSTRY SECOND QUARTERLY MARKET REPORT 2013

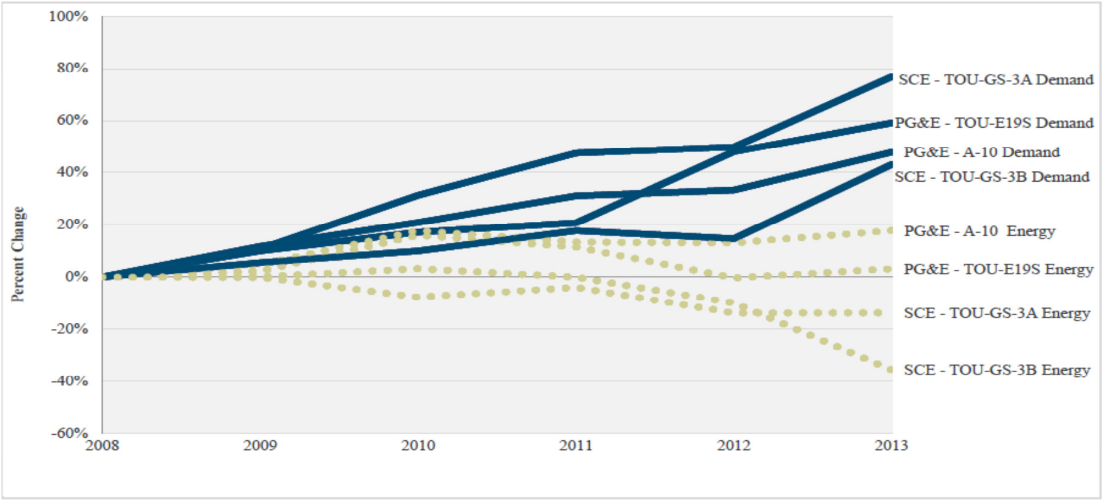
Figure 1. Electricity Generated by Wind [4]

Energy Storage and Peak Shaving

Storing energy at one time of the day and discharging it another time can effectively shift this energy for use when it's most beneficial. Typically, the energy is stored in the batteries when power costs are low and discharged when they are high. The stored energy can be used during on-peak price conditions, when the most-expensive generation is pressed into service and energy prices are higher, thus avoiding the need to pay high peak prices. This practice is known in the industry as "load shifting," even though the load isn't actually shifted in time; it's served when the user wants it to be served. The load is, however, served with lower-cost power during peak times. The stored energy can alternately be sold in the energy market at a time when energy prices are high, generating revenue for the seller. This practice is known in the industry as "energy arbitrage."

In service areas such as New York and California, demand charges can constitute up to 50% of an end user's monthly bill [8]. Recent trends at two major utilities in California reveal that while energy rates have risen only slightly, demand charges have gone up by 40% in absolute value between 2008 and 2013 [9]. Demand charge is a measurement of capacity, or the rate at which a customer uses energy. Within a given customer class, if two customers use the same amount of energy but one has higher demand charge, that customer will receive a higher bill.

Energy storage could be used by end users to reduce their demand charges, by reducing power draw during specified periods . . . normally the utility's peak-demand periods. To reduce or avoid demand charges, the batteries are charged when low or no demand charges apply. The batteries are subsequently discharged when demand charges apply. Energy storage can similarly reduce an end user's time-of-use energy cost when these charges apply. Again, the batteries are charged with low-priced energy, and discharged when energy prices are high.



Source: Stem, GTM Research

Figure 2. California demand charge increases, 2008-2013 [9]

Energy Storage and Frequency Regulation

At any given moment, the amount of electric supply capacity may be greater or be less than the load on the grid. To avoid the risk of a system blackout, this mismatch must be corrected as quickly as possible, normally by dampening the difference using a frequency regulation service that balances the sources with the load. But this means is difficult to apply if the system has limited reserves.

Energy storage can provide an extremely fast response to such events and prevent the system from moving towards a blackout situation. The regulation service is provided by energy storage units that can react to an automatic control signal from an Independent System Operator or Regional Transmission Organization within seconds. This signal is independent of an economic cost signal such as ex-ante location marginal price in a real-time energy market. As a point of information, such a regulation signal is sent every 2 seconds by the PJM Interconnection, every 6 seconds by New York Independent System Operator, and every 4 seconds by ISO New England.

Prior to 2011, there was no mechanism in place by FERC to compare the efficiency of energy storage versus conventional generation in providing frequency regulation. But there is a significant difference: energy storage is approximately a 100 times faster than conventional generation in responding to regulation signals [10]. The graphs below illustrate the response of a traditional regulation resource to PJM Interconnection's frequency regulation signal versus that of energy storage to the same signal [11]. Obviously, energy storage completely outperforms conventional generation-based frequency regulation.

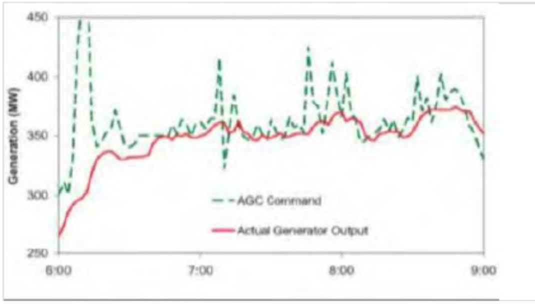


Figure 3. Fossil plant regulation response [11]

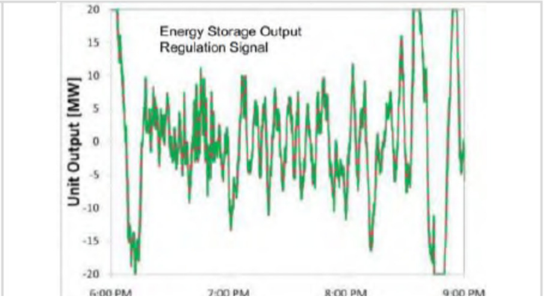


Figure 4. Energy storage regulation response [11]

As a result of the fast ramp rate of energy storage resources, FERC implemented order 755 and mandated that ISOs and RTOs compensate regulation providers on a “pay for performance” scheme. Faster assets are now allowed to be compensated more than slower-performing assets.

PJM Interconnection complied with this ruling by implementing a new rate structure for frequency regulation. Early indicators show that energy storage assets are being paid at least twice as much as slower regulation generators in the PJM market [12].

Energy Storage and Reliability

Power interruptions and outages don’t just inconvenience commercial and industrial customers, they affect the customers’ bottom lines as well. A 2005 study by the Lawrence Berkeley National Laboratory estimates that power outages cost the US $80 billion annually [13].

The latest statistics from the IEEE Distribution Reliability Committee indicate that the average U.S. utility customer experiences 1.29 outages annually, resulting in 143 minutes of power interruptions [14]. Consider a typical feeder serving 2000 customers, with a mix of 90% residential users and 10% commercial and industrial users. Using the “Ice Calculator” tool published by the US Department of Energy, the 143 minutes of interruptions per feeder annually results in approximately $500,000 in sustained interruption costs [15]. Investments that improve the grid’s reliability can help offset the costs of such interruptions and spur the economic growth of an area.

Energy storage systems, located at substations or close to loads, can reduce the frequency and duration of interruptions that would otherwise impact service at the extremities of the grid.

A recent energy storage project completed at BC Hydro provides an example. The town of Field, located approximately 50 km the east of Golden in British Columbia, Canada, is supplied by a single 25-kV feeder from Golden. The feeder frequently experiences sustained outages as a result of the heavily forested environment and often-severe weather. And the rugged terrain adds to the difficulty in locating and repairing faults to restore service. BC Hydro decided to apply a 1-MW battery-based energy storage system to mitigate the sustained outages on the feeder. The system has already reduced the impact of several lengthy outages to the town of Field. BC Hydro estimates that the system will ultimately reduce the number of extended outages to the town by 80% [16].

In addition to improving reliability, the BC Hydro energy storage project has demonstrated its ability to provide peak shaving by reducing peak load on the grid, potentially extending the life of existing assets.

Conclusion

The advantages of energy storage to the 21st century grid have been clearly demonstrated in this paper. But the applications for energy storage aren’t limited to those discussed in the paper. Energy storage systems can be installed to achieve or enhance transmission and distribution asset deferral, carbon reduction, phase balancing, electric supply reserve capacity, transmission congestion relief, reduced cold-load pick up after an outage, and reverse current flow mitigation.

At the moment, power-related applications for energy storage dominate over energy-intensive applications. This trend is expected to continue for the next few years, until technologies such as flow batteries make more headway in the marketplace.

While utilities are beginning to embrace energy storage, it is important to remember that the benefits derived from energy storage can flow to different parties, depending on utility structure, and regulatory rules. Energy storage should be treated as a unique type of regulatory asset. Its benefits should be considered on a holistic level, as society as a whole will be better off if policies are implemented furthering the application of energy storage.

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