How Battery Energy Storage Displaces and Replaces Conventional Generation – Trajectory of Storage Providing Supplemental Services, to Essential Services, to Full Replacement of Generation

Michael Jacobs
Union of Concerned Scientists
Two Brattle Sq. Cambridge, MA 02138-3780, United States of America

***Abstract*—The trajectory of energy storage substituting for conventional generation can be traced from actual practices, and projected further from demonstrated capabilities. Demonstration projects from 1987 proved benefits from utility-connected operations. Niche markets developed after 2005, further raising confidence and capabilities. With demonstrated efficiencies and supportive policies, U.S. battery storage installations began to serve as generation. This paper traces this trajectory, and suggests that retiring old generation and making replacements with storage-backed variable renewable generation is a viable technical option.**

***Keywords*— grid applications, policy, markets**

I. Introduction

The trajectory of energy storage substituting for conventional generation can be traced from actual practices, and projected further from demonstrated capabilities. The deployment of energy storage instead of fossil-fired generation is an important shift in the electric power industry, even if begun incrementally and first in niche applications. The implications of this on system planning, expansion, operations, and on energy markets have not been defined. The private and public stakeholders making new power capacity investment decisions should recognize this technological change could be a revolution.

From 1987 to 2005, a very small number of grid-scale battery systems were installed on power grids. Rare demonstration projects, provided proof that battery energy storage could be used in a utility system. Today, procurements, planning and announcements for utility-scale battery storage systems are widespread.

In US and Japan, a series of successful battery installations demonstrated a variety of storage technologies. Often these were connected at end-user locations, provided valuable learning and field experience. Important milestone projects date back to the 1987 installation of a 500 KW lead acid battery at the Crescent Electric Membership Cooperative in North Carolina, a distribution-only utility. A 10 MW, 40 MWH lead acid battery at Southern California Edison substation at Chino, CA demonstrated beginning in 1988 the fast response of storage could reinforce a transmission system. The 20 MW, 14 MWH lead acid battery installed in 1994 on the island grid of Puerto Rico provided utility PREPA with reserves and frequency control. This demonstrated how a battery can operate on a power system as an alternative to generation, and that was done with battery technology comparable to the Chino installation [1].

Development and demonstration projects in Japan soon followed, though with different emphasis. Utility KEPCO and manufacturer Sumitomo demonstrated vanadium flow batteries for peak shaving on in commercial customer settings from 1999. At the same time, utility TEPCo and manufacturer NGK began operating sodium-sulfur projects. Japanese installations alongside wind generation equipment proved the capability of energy storage in flywheels and flow batteries to provide generation services.

II. Overview of Storage Progress

A. How did this happen and What Does This Mean?

As the power industry demonstrates confidence in the increased functions of inverters and long-duration energy storage, decision-makers face the reality of storage replacing conventional power plant capacity with storage.

The record of the past decade shows energy storage making incremental replacement of the features, functions and roles of conventional generation. Initial commercial storage deployments provided operational flexibility to manage forecast errors and output variability. In Hawaii, limits set out in 2006-2007 on windfarm variability led to storage systems designed for high-power, low-energy application of smoothing short-term output. At the same time, a generation owner in Chile began to add storage to provide spinning reserves for contingency response previously provided by unloaded generator capacity.

The successes started to come through the identification of specialized functions provided by conventional generators that could be done economically by available or emerging storage technology. Confidence from initial projects led to more installations, followed by changes in assumptions and practices regarding the functions of megawatt (MW)-scale storage systems and fast-responding inverters with power-factor control supporting voltage. While most of the early grid installations and defined niches were not related to renewable energy, the potential for clean energy from intermittent sources combined with reliability attributes from energy storage soon grew from concept to reality.

By examining how energy storage has quickly matured from filling just a few functions in the past to understanding how in the present battery storage is a full participant in resource adequacy planning, utility industry observers and participants can prepare for a future where fuel-burning powerplants are replaced by storage systems, and the energy can be provided by variable renewable energy sources.

B. What Is the Storage Asked to Do?

Throughout the discussion in support of energy storage deployment, the role and use cases for storage have sought to clarify the functions for energy storage on the grid [2]. This range of options available from energy storage, and the breadth of discussions is important, but should not become an overwhelming distraction. Rather than starting with storage as a many-talented tool and asking how to value many functions, the successful paths to deployment have been found where necessity or value is in the simulation or replacement of a traditional power system asset that is particularly scarce, expensive or difficult to provide. Where planners or stakeholders can determine the performance specifications for the needed power system component, this becomes the benchmark for comparisons with energy storage designs suited to fill that need. Identification of high value needs has proven to be a quicker means to identifying real-world applications for storage than an inventory of features and benefits abstractly available from storage technology.

III. Trajectory of Experience

A few trail-blazing efforts have opened markets to successful energy storage deployments. Each of these innovations sought to optimize existing grid assets by taking on a specific cost-effective role for storage. In doing so, these each established a commercial demonstration of battery storage providing a function previously provided by conventional generators. Cumulatively, this creates a trajectory suggesting that storage additions are reducing the operation of existing power plants, reducing additions of conventional power plants, and ultimately that storage can be combined with renewable energy supplies to replace existing conventional plants.

One of these explored and established a hold on an ancillary service in U.S. markets managed and operated by independent system operators (ISOs). That service, frequency regulation, proved to be attractive in PJM, the ISO serving the region from northern Illinois to North Carolina and New Jersey. Another set of niches developed in isolated areas of northern Chile and in Hawaii, where generator reserves and related services are not easily obtained. The final proving ground in very recent years is California, where public policies directing utility procurements of energy storage capacity have demonstrated competition between storage types, and between storage and any other asset class capable of providing resource adequacy.

A. Path to US Ancillary Services Market

The separation of generation from transmission in the U.S. by Order 888 of the Federal Energy Regulatory Commission (FERC) created a small number of ancillary services required to operate the power supply. The wholesale energy markets that formed after this decision defined and priced these services with varying levels of precision and differentiation. As storage technology companies made practical advances, their initial market development efforts focused on commercial opportunities that value the speed of response and short-lasting power output, rather than substantial amounts of stored energy. The supply of frequency regulation service, a short-term balancing of supply and demand needed for the grid operators to maintain the desired frequency (e.g. 60 hz in North America), proved to be a good match between emerging energy storage capabilities and higher value in the range provided by energy markets.

Combined efforts in 2006-2007 by Beacon Power, start-up manufacturer of flywheel energy storage units, Pacific Northwest National Laboratories (PNNL), Bonneville Power Administration, California Energy Commission and California Independent System Operator successfully demonstrated the benefits of flywheel storage technology and argued for a higher value for rapid, accurate response to grid operator direction for frequency regulation. These efforts were reported in two reports published in 2008 characterized California ISO regulating units' characteristics; determined the value of fast responsive resources, and compared efficiency of fast regulation units with the hydro units. One critical finding established a fast responding resource is more efficient than the average hydro power units used for regulation, allowing a smaller amount of fast acting capacity to substitute for a larger amount of hydro capacity, or even less-responsive thermal capacity [3], [4].

Beacon Power and global utility conglomerate AES Corporation led a campaign to present an economic case for compensation for faster, more accurate performance of frequency regulation with advocacy at FERC, ISO-New England and PJM.

Beacon installed a small storage facility (initially 1 MW) on a distribution line in New England in 2008. At the same time, lithium-titanate battery manufacturer Altairnano began work under a 2007 agreement with AES to validate and then deploy a MW-scale battery for frequency regulation at the headquarters of PJM [5], [6]. Each of these installations were designed specifically for frequency regulation needs. Frequency regulation is unusual in the realm of ancillary energy services because of the need to move small amounts of energy in both directions.

FERC took notice and at the same time (2011) PJM took steps through its stakeholder process to reward more accurate and faster regulation resources. In 2010 FERC began a technical review of frequency market designs, value and benefits. The resulting rule in Order 755 directed the organized markets to change the measurement and compensation of frequency regulation service [7]. FERC, as regulator of rates and markets where they exist, designed this policy change in 2011 to foster explicit competition by energy storage with grid generation capacity held for this function. How the markets implemented FERC's order varied, but ultimately the economics of these frequency regulation markets were affected by the small size and limited demand for frequency regulation capacity.

Absent new technologies, frequency regulation and other ancillary services are provided by conventional generation holding some fraction of generating capacity in reserve for dispatch in response to instruction from the grid system operator. On the mainland U.S., all the ancillary services total 5- 10% of the costs of wholesale energy. PJM is the largest market for frequency regulation from storage, but in 2013, the first year of implementing the frequency market design changes of Order 755, PJM had installed generating capacity of 183,095 MW and PJM's daily average quantity of frequency regulation service needed was 784 MW, a decline from 943 MW in 2012 [8]. PJM indicated at the outset that the need for capacity reserved and used for this service would be lower: "fast following resources decrease the total regulation requirements necessary to maintain reliability requirements" [9]. As the PNNL studies has indicated, the PJM experienced efficiency gains from the fast and accurate provision of frequency regulation. This benefit, which PJM reported as an average of 2.6 MW of slower capacity replaced by 1 MW of fast regulation resource, allowed PJM to lower daily procurements [10].

In terms of the money in PJM's wholesale electricity market, the cost of providing the specific function of frequency regulation is roughly 0.5% of total price of a megawatt-hour (MWh) [11]. In New England, where the existing practices for tracking performance were adopted by FERC in Order 755, the frequency regulation requirement range for ISO-NE was 50 – 170 MW on a power system of roughly 25,000 MW. The risks of over-supply in such small markets were better anticipated in New England, and soon realized in PJM.

B. Storage in generation role on small grids

Providing reserves is an appropriate application for battery energy storage, given the good match between battery storage system capabilities and grid requirements for this service. Reserves are used relatively infrequently, for a defined period. Generally, reserves are deployed from generating capacity that is synchronized but unloaded. Rapid response is important, if not critical, to grid support. Where the grid is small and capacity constrained, these attributes are scarce and more valuable than on a large system with numerous generators partially loaded at any time.

Early examples of commercial energy storage deployment to displace conventional generation were in isolated grids where very small generator fleets are limited in capability and capacity limits constrain grid operations. These early deployments, installed between 2009 and 2011, take the place of conventional generation providing reserves.

Important cases in northern Chile and in Hawaii, illustrate where energy storage provides ancillary services otherwise required from generators, allowing conventional generation to either 1) increase output to serve load (Chile) or 2) not operate as the combination of renewable generator provides energy and the battery energy storage system (BESS) provides reserved capacity (Hawaii).

C. Battery systems in Chile provide spinning reserve

The power systems of the northern mining region of Chile and the Hawaiian Islands are smaller grids in isolated areas. High prices or unmet demand for energy in these locations helped support the selection of battery (BESS) to provide modest amounts of reserves.

In Chile's Atacama Desert, AES is one of many generation providers in the Northern Interconnected System, which has 3,700 MW total generation. Power system constraints limited the energy and capacity available to meet growing demand from the energy-intense mining industry in the region [12]. Each generator on this system has an obligation to maintain capacity unloaded as reserves. All else equal, an economically competitive generator would make more energy sales if the obligation to provide reserves is shifted to a storage system. Two BESS installations by AES Gener in Chile provide this alternative source of reserves. A 12 MW/4MWh BESS integrated with AES Gener's Norgener power plant in 2009 and the larger Angamos BESS (20MW/5MWh) installed in 2011 provide immediate response to frequency deviations and continue to discharge while supply balance is restored [13]. AES increased the available capacity of its Norgener plant by 20 MW with operational performance improvements provided by the 20 MW BESS. Reports by the grid operator indicate this BESS is among the most reliable and provides for quicker restoration and stability of the system compared to reserve capacity provided by thermal plants [14]. These BESS provide a substitute for conventional generation, and have demonstrated the function known in the U.S. as primary frequency response, which is sometimes mentioned as an "essential reliability service."

D. Battery systems in Hawaii smooth renewables

The power system in the Hawaiian Islands offers opportunities for energy storage and renewable energy not found elsewhere in the U.S. Each island's grid is separated from any other; oil is the dominant fuel used in generation; and state policies drive increasing use of renewable energy. The resulting prices are high compared to the mainland, and the push for renewable energy is very pronounced in the market and in policy. The results in less than 10 years have been the inclusion of storage in renewable energy projects to modify wind and solar generation from the original description of "as available" energy into a closer approximation of conventional generation.

The physical constraints of Hawaii make the integration of variable renewable energy on the electric grid more challenging. The largest of the island grids, on Oahu, is 1,000 MW. The grids on the islands of Maui and Hawaii are 250 – 300 MW and the Kauai grid is 125 MW. Starting Oahu combustion turbine units requires 15 minutes. On the island of Hawaii, steam units predominate, so reserves are slow-moving [15]. These conditions result in very limited sources of flexibility or ancillary services and a utility policy of requiring ramp-rate controls on renewable generators.

The increased use of windpower in Hawaii led the utility to impose a limit on the rate of change in energy production in power purchase agreements for new renewable generators. These ramp-rate limits effectively created a requirement for new generators to provide frequency response and spinning reserves in proportion to their intra-hour variability. As a practical matter, planning to mitigate variability for windfarms planned on slopes was inexact. Rather than estimating and mitigating the aggregated, and partially offsetting, movement of all sources of variability this required a solution dedicated to each individual windfarm.

Hawaii received considerable attention regarding renewable energy as energy storage and renewable energy integration technologies emerged. In April 2008, the National Renewable Energy Laboratory signed a memorandum of understanding with First Wind to establish a Remote Research Affiliate Partner Site at First Wind's Kaheawa Wind Power on Maui. First Wind, the developer most active in Hawaii at the time, soon invested in a 1.5 MW/1 MWh BESS for a pilot demonstration of windfarm smoothing at that site.

This pilot led to planning and eventual deployment of full-scale 15MW/10 MWh BESS for 30 MW windfarm on Oahu. Prior to installation in 2011, developer made decisions regarding control algorithms and recognition in interconnection planning for control including using the planned BESS to meet a need for fast response to manage grid conditions after a transmission fault on the line connecting the loads and new windfarm on the North Shore of Oahu. This latter set of functions involved voltage and frequency stabilization functions not available from a generator.

Also in 2011, the Kauai utility purchased a 1.5 MW/1 MWh unit from the same BESS vendor to address variability from a growing number of solar installations, an on-going need for frequency response, as well as spinning reserves. Kauai subsequently made additional procurements of energy storage, and solar projects combined with storage as it progressed from 5% of its energy coming from renewable energy to present level of 36% [16]. Two such projects, from SolarCity/Tesla (17 MW solar, 13 MW/52MWh storage) and AES (28 MW solar, 20 MW/ 100 MWh storage), are designed to meet utility system evening peak for several hours [17].

IV. California Events Accelerate Storage As Peaker Unit

One indicator of the contemporary acceptance and confidence in utility-scale storage is the continued procurement of peaking generation built entirely from energy storage. This stage has been established in California through a mixture of state policies and events in the energy market.

California leadership in energy policy dates from at least the late 1970's and hosted the first boom in renewable energy in the U.S. in the 1980's. Attention turned to storage in the last several years, with policy action in the form of a commitment in law: SB2514, enacted in 2010. Implementation of this law, directed by the California Public Utility Commission (CPUC) in 2013, laid out a 7-year schedule for procurements in three broad categories, for the three investor-owned utilities totaling 1,325 MW under contract by 2020. This proved to be a minimum as events and additional legislation came to pass.

Industry expectations regarding the role of storage as an alternative to peaking generation changed when Southern California Edison (SCE) announced the results of its 2013 Local Capacity Resource procurements in late 2014. SCE selected 260 MW of energy storage, 100.5 MW in front of the meter, at a time when the regulatory obligation was to acquire 50 MW of storage resources in that process. This five-fold greater commitment to storage for reliability needs, instead of generation, was a distinct signal that was noticed.

A. 2016: Year of Further Gains

State policy actions taken in 2016, combined with utility procurement activity, provide a foundation for energy storage as peaking power plant. In February, SDG&E (he utility serving San Diego area) released an energy storage procurement for local capacity requirements totaling 140 MW [18]. In May, in response to an emergency created by the failure of the natural gas storage facility at Aliso Canyon, the CPUC ordered expedited energy storage procurement suitable for meeting resource adequacy. This led to SDG&E contracting for another 37.5 MW/150 MWh of battery energy storage [19]. Another 57 MW of BESS with 4-hour duration was purchased by SCE under the direction of the Aliso Canyon resolution.

B. Hybridization by generator manufacturers

Recent energy storage deployments by generator equipment manufacturers demonstrate another turning point in the substitution of BESS for conventional generation. Present (October 2016) state-of-art technology adoption includes manufacturer General Electric (GE) hybridization of storage with their LM aeroderivative generators to improve the performance of peaking plants [20].

With short duration storage now understood as providing ancillary and essential services, GE is delivering hybrid plants with storage and a gas turbine integrated in a system with a single set of controls. The GE hybrid system uses the storage to provide the reliability capabilities of the gas generator with instantaneous response, regardless of whether the unit is started and burning fuel when response is needed.

General Electric completed a hybrid battery-gas turbine system installation at a site in Norwalk, Calif., for SCE. The system combines two 50 MW LM6000 gas turbines with a 10 MW, 4.3 MWh battery storage system. Manufacturers of internal-combustion generators Caterpillar, Cummins and Wartsila have all recently announced offerings of hybrid generation systems combining storage and conventional generation [21].

V. End-Stage Long-Duration Storage and Renewable Generation

If the trajectory described here is the accumulation of incremental steps, this is appropriate as power system expansion planning is incremental. However, there is a difference in assumptions and modeling for a changing future where incremental capacity and services are predominantly attributed to a BESS while the energy is provided from one or more variable renewable sources. Lessons learned from the past decade of assessing the capabilities and roles for energy storage can be applied to current questions.

A. Prospects for Repowering Old Generation with BESS in Critical Locations?

As part of a recent analysis of options for replacing an old generating facility in the Chicago area, UCS and students at the University of Wisconsin-Madison considered the potential role of storage. While the question was posed as, "can storage and renewables replace a major water-front fossil generator?" the analysis required a series of smaller questions, including one familiar in this discussion, what is the storage asked to do? Further, should the replacement mimic the production pattern of the plant undergoing replacement? In effect, how much energy is needed and how much on-peak capacity is needed?

Multiple feasible combinations of storage with renewable generation can provide capacity, energy, and ancillary services, as well as unpaid “essential services” in satisfaction of power system performance expectations. The value of the replacement will likely be higher with a production pattern and capacity characteristics that are matched to the local system. To make a realistic assessment, the needs for voltage support in the area must be included.

The capabilities and characteristics of replacement resources in this sort of change in generation resources is the subject of the NERC Essential Reliability Services Task Force (ERSTF) created in 2014. proposed measures to guide change in the generation mix. The ERSTF summarized the needs for this kind of assessment as frequency response, ramping energy output, and voltage support [22]. As the narrative above describes the expanding role for energy storage as a replacement for conventional generation, all of these identified needs are obtainable from BESS.

Analysis of options for the Waukegan Generation Station in northern Illinois illustrates 4- hour duration storage paired with variable renewable generation for full satisfaction of reliability and capacity market requirements. More refined study is needed, but clearly energy storage is quickly meeting critical milestones to satisfying these expectations. In addition, NERC’s essential services have been confirmed in field testing of utility-scale commercial deployment of inverters at solar facilities [23].

Conclusion

In a very short time, energy storage facilities have demonstrated all the capabilities required of generation on the U.S. power grid in commercial deployments. Taken discreetly, the reliability contributions of conventional power plants are available from battery energy storage systems. When combined with renewable energy generation, this combination is equivalent to that the operating characteristics of the conventional generation sources that are being replaced.

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Mike Jacobs develops recommendations and strategy to shape electricity markets and policies to encourage demand-side and renewable energy. Prior to coming to UCS, Mr. Jacobs worked at two renewable energy and energy storage companies that together built four storage facilities in Hawaii. Two of these facilities demonstrated grid support and transmission capabilities. While on the staff of the American Wind Energy Association, he led settlement efforts at the Federal Energy Regulatory Commission to streamline generator interconnection rules for wind and distributed generation. He has served on the boards of renewable energy organizations and the Northern Maine Independent System Administrator.