Title: PG&E Report of CAISO Battery Storage Trial: Coming of Age or Cautionary Tale

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Synopsis: An energy analyst's executive summary of PG&E's recently released report on its EPIC Project 1.01 utility-scale battery storage trial in CAISO.

Tags: electricity, storage, batteries, grid

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The Hope

In the wake of the massive natural gas leak from Sempra Energy's Aliso Canyon storage facility in 2015, the California State Assembly and California Public Utility Commission directed the state's electric utilities to build and deploy electricity storage at an unprecedented scale and pace. The current requirement is [1,325 MW of battery storage](#) by 2020, with emergency authority to fast-track projects that can be online by 31 December 2016. This electricity storage capacity is intended to replace nimble, fast-ramping natural gas plants that are currently required to buffer and back up the intermittent power produced by California's fleet of wind and solar farms. These natural gas plants are short of fuel reserves for the winter due to the leak, and California legislators also want to move away from fossil fuel plants long-term to reduce CO_2 emissions.

The Trial

This week, Pacific Gas and Electric [released a report](#) of an 18-month trial of installed utility-scale battery storage on the grid. The trial encompassed 6 MW of storage split between two sites, both integrated to function as dispatched by the California Independent System Operator (CAISO) that manages operations of the state's grid and wholesale power market. The specific storage hardware examined was sodium-sulfur batteries, which are at the high-end of the technology maturity scale and the low end of the cost spread for storage options of similar performance, having been used at utility scale in several nations for 25 years.

The Report

The report contains very valuable details of the various grid services that batteries can provide, and the market prices of those services. It also illuminates the unique complexities of managing non-generating resources that don't have a pre-purchased fuel supply and thus a reasonably stable volumetric O&M cost. In a nutshell, operating electricity storage is to simultaneously play multiple markets: the day-ahead and real-time markets for various grid services that batteries happen to be postured to perform, and the real-time market for the cost of wholesale electricity from the grid from which the batteries must repeatedly pull and push power as they perform their services. It is not unlike playing poker and blackjack at the same time and only getting a net payoff when both hands are winners.

The Spin

Various web sites and advocacy groups are trying to spin this PG&E report as purely positive and a sign of battery storage coming of age. However, a careful reading and some simple mathematical analysis reveal this report is actually a cautionary tale.

My Executive Summary:

1. Batteries are still far from cost-effective. Certain grid services can generate enough revenue to cover operating costs, but none can come close to recouping the capital investment, even within the trial's very optimistic assumption of 20-year battery life. Therefore deploying battery storage today has to be for reasons other than intrinsic economics. A 2MW/14MWh sodium-sulfur battery storage array (PG&E's Vaca site) cost approximately $11 million ($5,500/kW, $783/kWh) to build. The report included two external studies that found that cost of battery storage must come down to about $800/kW to achieve economic break-even. However that number has two false assumptions baked in: a 20-year service life and only 15-minutes of storage capacity. To aggressively dispatch the batteries as was done in the trial to maximize revenue requires at least 30 minutes of storage capacity and would consume the 4,500-cycle service life within 10 years. With these adjustments, the real break-even cost is approximately $200/kW. Indeed, $197/kW is the estimate PG&E itself empirically found to be the break-even cost for a typical month in 2015. This is a factor of 27 cheaper than the Vaca

system cost of $5,500/kw.

2. Charging and discharging batteries for *energy arbitrage* (charging when electricity is cheap and discharging when it is expensive) is what first comes to mind as an obvious use of electricity storage. This time-shifting of generation to match consumption peaks involves techniques such as peak shaving and load leveling; these are easy to envision and model and optimize when looking at yesterday's load and price curves, but very difficult to do in real-time when the load and price are varying stochastically and neither the height nor timing of the actual load peak can be known or recognized till well after the fact. In practice, energy arbitrage only generated enough revenue to barely cover operating expenses. The margin achieved in cost of power arbitrage was consumed by the 25% power lost between cycles due to charging and discharging inefficiencies and the stream of energy necessary to keep the batteries at operating temperature. When marketed to CAISO for all possible services including energy arbitrage, the $11 million 2MW array netted less than $9,000 per month.

3. The most lucrative use of batteries on the grid, as evidenced by this trial and the almost universal employment of utility-scale battery storage around the world, is what is called *frequency regulation*. In this mode, the batteries are maintained close to 50% charge levels and stand ready to charge or discharge rapidly to damp out momentary dips and spikes in grid frequency that mark mismatches between generation and load. CAISO monitors grid frequency continuously and sends out automatic generation control (AGC) signals every 4 seconds that tell generators to ramp up or ramp down to chase increasing or decreasing load. Those resources that can ramp the fastest and most precisely can earn the most money for this service. Batteries are ideal for this role as they can follow the AGC signal almost instantaneously with their full capacity. However, the frequent charging and discharging is hard on the cells and causes them to age more quickly. This high stress is also unforgiving of any mechanical failures or design flaws, and batteries used in this role have the most frequent incidence of fires. The relatively low capacity of batteries also limits how much regulation they can do in a particular direction, as they must stay within their charge and discharge limits. In this case, the guessing game is to predict whether more up-regulation or down-regulation is expected in the next operating period, and to enter that window with the appropriate state of charge (SOC) to allow maximum headroom. Since SOC must be managed by real-time power purchases and sales, energy arbitrage can work for or against revenue when operating in frequency regulation mode. When marketed exclusively for frequency regulation, the 2MW storage array netted less than $35,000 per month; much better than other strategies, but still far short of achieving payback for the expensive capital asset.

4. Actual revenue during the trial was less than predicted by CAISO-approved models for storage. This was due to two main factors: falsely idealized load and price curves that proved less predictable in practice, and over-estimated market price for the various grid services.

5. The trial also revealed how different batteries are from actual generation resources. To optimally take advantage of day-ahead and real-time market pricing, dispatch

(operational control) has to be managed remotely by CAISO, as it does for generators. However, it proved essential that the dispatcher know the battery SOC at all times, as it affected what types of services the batteries could immediately perform. Batteries morph in their capabilities and value for specific grid services depending upon SOC, and the dispatcher must be kept abreast of that shifting menu of the moment. A critical question is who decides when and how much to charge the batteries – the owner/operator (PG&E) or the customer (CAISO)? A bad decision can prevent the asset from being optimally dispatched for the most lucrative service, or might prevent it from being utilized at all. Or the energy arbitrage costs of charging and discharging to manage SOC may consume the revenue from the actual services. Maintenance of SOC and precise dispatch is also complicated by parasitic load, a periodic maintenance task called "string balancing," and charging rates that differ depending upon SOC. Optimal use of storage is dependent upon developing finely-tuned algorithms tailored to a specific battery technology and the rules and prices of a particular wholesale market and independent system operator (ISO), and also upon developing the necessary supervisory control and data acquisition (SCADA) linkages to allow robust remote monitoring and dispatch. These factors exceed in complexity their counterparts for generation resources.

6. Round-trip efficiency for the two systems tested averaged 75%, matching a thumb rule that has been true for decades.

7. Parasitic load for sodium sulfur batteries averaged 60kW/MW. These particular batteries have to be heated to 300C to operate, and thus consume more electricity for maintenance when they are idle and less when they are generating heat from activity. Other battery types have to be cooled when they are active and thus have more parasitic load when in use. Since this parasitic load comes off the same grid the batteries are serving, it changes the batteries' raw input/output to a net input/output that makes their performance less precise and complicates dispatch.

8. A surprising finding was that wholesale electricity price varied so much by geographic location on the California grid that often it was not economical for these two battery arrays to store surplus power being generated by wind or solar farms. California now has enough "renewable" energy capacity that it can produce negative locational marginal price (LMP) in the vicinity of the wind and solar farms. However, these low prices do not necessarily propagate as far as the electricity storage sites. This is often blamed on "grid congestion" as if to say it is a shortcoming of the pre-existing grid, but in reality this bottlenecking is a predictable consequence of adding large capacities of remote, diffuse, and uncontrollably intermittent generators at the fringes of the grid far from the load centers that consume their power. If batteries are to be used for energy arbitrage, they would be optimally co-located at the fringes with the wind or solar farms. However, if they are to be used for frequency regulation, they are better located near the loads in cities and industrial centers. Since the revenue stream of the latter is much more attractive than the former, it is likely that the utilities would prefer downtown rather than desert locations for assets they own. That leaves solar and wind developers to install storage at their sites.

PG&E's Cautionary Summary Statement to the California Assembly:

> "The project gained significant real-world data on the financial performance of battery energy storage resources providing energy and ancillary services in CAISO markets that can better inform an assessment of market benefits in cost-effectiveness valuations of future battery storage procurements. Over the course of the 18 months of market participation during this project, the financial revenues from battery participation in CAISO markets were limited. If revenues from market participation are to be the key driver of evaluating the cost-effectiveness of battery storage, it is recommended to be conservative in the forecasting of those revenues. With California Assembly Bill 2514 and its requirements that utilities procure 1.3 gigawatts of energy storage, California ratepayers could expect to pay billions of dollars for the deployment and operations of these resources."

Other Battery Technologies

While not mentioned in the trial, it is good for comparison purposes to briefly consider alternative battery technologies. The most common lithium-ion battery storage chemistry in commercial use today as manufactured by Panasonic and utilized by Tesla is lithium nickel cobalt aluminum oxide (NCA). It is good for about 500 cycles, 1/9th the life of sodium-sulfur batteries. Alternative lithium battery chemistries with 1,000-8,000 cycles of service life are emerging and may be on the verge of become price competitive with sodium-sulfur. Many of the near-term proposals being heard by the California Public Utility Commission are for lithium batteries. It is telling to note that ancient lead-acid battery technology continues to be competitive enough in cost and performance to be the starter battery of virtually every automobile on the road, including every state-of-the-art Prius hybrid, and has only recently faded as a grid-storage player. Despite all the hype and giga-promises, there has yet been no breakthrough in electricity storage technology that delivers all the requisite features of high energy density, high power, long life, high roundtrip efficiency, safe handling, and competitive cost.

Conclusion

Batteries are still a long way from being a substitute for fossil fuel power plants or any other actual power generators because of physical and economic limits of current technology.

About the Author

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