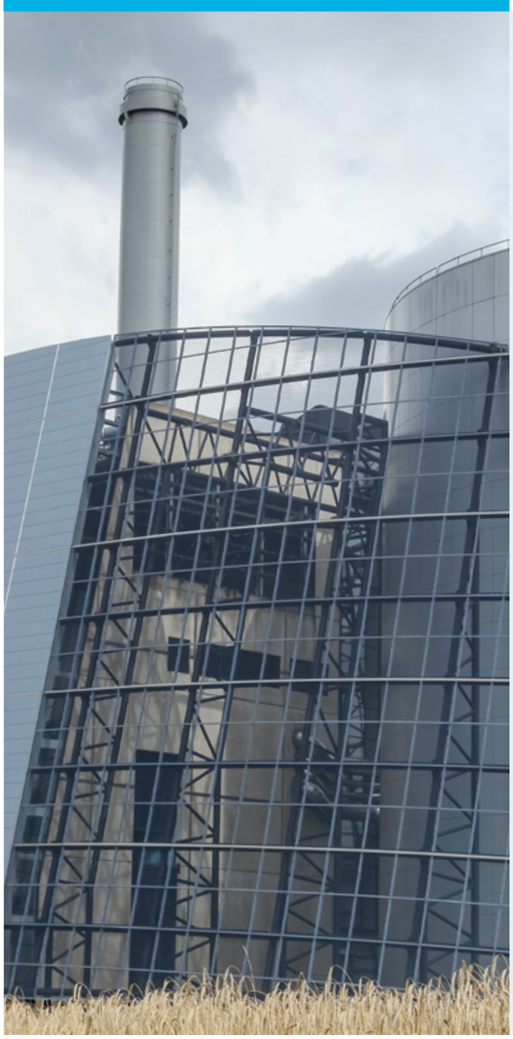
White Paper

How Energy Storage Will Feed the Duck and Keep the Grid Stable

By Harjeet Johal and Kenneth Collison



Shareables

1. Markets with high solar photovoltaic (PV) penetration can create negative prices that lead to loss of ancillary services and threaten grid stability.
2. Energy storage solutions could help to restore lost ancillary services via economic arbitrage.
3. Incorporating energy storage systems with stacked applications is essential to position storage as a cost-effective flexible resource.

Executive Summary

Solar PV is poised for a steady and continued growth with a projected annual solar market of 20 GW by 2020.[1] As solar PV grows, the need accelerates to improve the flexibility of the grid via changes in the operational structures and incentives for new technologies such as storage systems. Some markets with high solar PV levels are seeing negative prices, resulting in a loss of both critical down reserves and stability margins. (Continued)

[1] Mike Munsell, Greentech Media Research, "Investment Tax Credit Extension Will Increase Solar Installations 54% Through 2020," December 16, 2015; available at http://www.greentechmedia.com/articles/read/investment-tax-credit-extension-will-increase-solar-installations-54-throug

Executive Summary (Continued)

Most markets lack the mechanisms to provide adequate incentives to storage systems for providing flexibility services to the grid. For example, the markets compensate units that operate at their minimum block through uplift payments, masking the actual market price signals that would have provided incentives to other technologies.[2]

Recent policies such as the Federal Energy Regulatory Commission's (FERC's) order 755 (or pay for performance regulation) and its recent notice of inquiry on adequacy of primary frequency response[3] are steps that can incentivize storage deployment. Developing a suite of stacked applications to extract value from all possible grid services (in the capacity, ancillary, and energy markets) is needed if storage is intended to play a meaningful role.

Capacity payments could be a significant incentive for storage systems.

Most of the markets do not have mechanisms to allow for this compensation. California Independent System Operator (CAISO), for example, allows for capacity market payments for a storage system with a four-hour capacity. In a recent study of the value of storage in a market in the east, the authors found that payments from provision of capacity service were the largest source of revenues for the storage system. Developing an industry consensus on quantifying the capacity value of energy storage is a critical path forward for supporting deployment of energy storage devices.

What's Going On?

The past few years have seen strong growth in utility-scale and non-utility scale (or distributed) solar PV systems. Incentives such as net energy metering (NEM)[4] and the federal investment tax credits (ITCs)[5] are helping to lower the overall cost of ownership. Third-party financing models allow customers to spend far less upfront than they did even a year ago. The cost of solar PV systems continues to decline ahead of expectations.[6]

Solar generation is still only 1 percent of U.S. output, with two-thirds of the output from central solar power plants and the remainder from distributed solar installations.[7] California accounts for 40 percent of distributed solar installations in the United States. Five states—New Jersey, Arizona, Massachusetts, New York, and Hawaii—have 34 percent of the installations. Thus, the operational experience with distributed solar PV on the bulk power grid has been fairly limited.

[2] FERC, Price Formation in Energy and Ancillary Services, FERC Docket AD14-14-000, January 16, 2015; available from http://www.ferc.gov/CalendarFiles/20150116165903-AD14-14-000TC.pdf.

[3] FERC, Essential Reliability Services and the Evolving Bulk-Power System—Primary Frequency Response, Docket No. RM16-6-000, February 18, 2016; available from http://ferc.gov/whats-new/comm-meet/2016/021816/E-2.pdf.

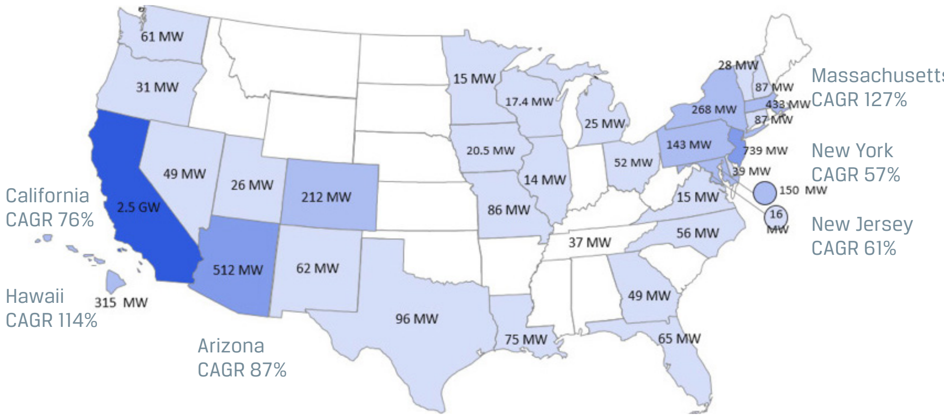
[4] Net energy metering allows the residential or commercial solar PV systems to offset their consumption through self-generation. Excess generation from the consumer is essentially settled at the retail utility rate. NEM is determined state by state and is a powerful mechanism for incentivizing distributed solar. Policies have varied greatly in part because the tariffs generally allow for large shifting of the payment of embedded costs across customer classes and subgroups. Hence the scope of solar development across states is likely to be variable.

[5] ITC is a federal tax credit for residential and commercial solar PV systems. The credit is set at 30 percent for 2016–2019 and then declines from 2020–2022 before falling to 10 percent.

[6] Munsell, op. cit.

[7] U.S. Energy Information Administration, Today in Energy, "EIA electricity data now include estimated small-scale solar PV capacity and generation,"December 2, 2015; available from http://www.eia.gov/todayinenergy/detail.cfm?id=23972.

EXHIBIT 1. NON-UTILITY-SCALE SOLAR PV GROWTH RATES IN TOP SIX STATES (2010–2014)



Note: States shaded white have less than 10 MW of installed distributed PV capacity.

Source: EIA 2014 Electric Power Annual (Table 4.7.B) for current installation estimates. CAGR estimates based on data from GTM Research

Even at these relatively low levels of solar generation, increasing zero marginal cost solar penetration is contributing to negative prices in some regions. Negative prices indicate excess generation relative to demand. Hence the output must be curtailed, or else the generator must pay to keep producing.[8] Under such conditions, utility-scale generators that incur marginal costs to operate may find continuing uneconomical and therefore shut down. Some thermal generators could continue operating due to minimum runtime, minimum downtime, or other inflexibility constraints; but they would likely operate close to their minimum power levels. Such operating conditions can be challenging from system stability perspectives, especially when a significant portion of generation comprises the "uncurtailable" type–the prime example being distributed solar PV.

Unlike the utility-scale plants, the output from distributed generation cannot be controlled by the grid operator, although discussions as to how this control might occur and its surrounding architecture are starting to occur. Today the grid must accommodate all the energy produced from such resources. During certain extreme contingency situations, high penetration of these resources creates difficulty in maintaining balance between load and generation and in stabilizing the grid frequency.

Here is one example of what could happen: Imagine a fault occurs on a load-serving substation leading to operation of local protective controls and a planned disconnection of the load from the grid.

As a result, an instantaneous generation-load imbalance manifests, and the frequency of the grid begins to rise. The controls on the online thermal generators (primary frequency responsive governor controls) respond to such frequency deviations by reducing the power output of the generator to restore thegeneration-load balance.

[8] The same phenomenon will occur in regions that do not publish locational marginal prices under similar excess generation conditions.

These controls are effective only if adequate "legroom" or down reserves[9] are available on the thermal generators. When all the thermal units are operating close to their minimum power levels and the remainder of the generation is the "uncurtailable" type, down reserves or other levers (such as curtailment of renewable plants) may not be sufficient to effectively maintain generation-load balance under contingency conditions. The result is erosion of the grid stability margin. Today power grids like Hawaii are at the forefront of customers with solar PV generation and are actively assessing the viability of different strategies in counteracting such stability issues.[10]

California is addressing this problem primarily via export of excess solar power by using existing lines. In fact, California legislated that CAISO must integrate with other western states. CAISO has made significant progress in integrating the real-time energy imbalance markets (EIM).[11] This development also is reminiscent of the 2005 ruling by the Public Utilities Commission of Texas to develop necessary transmission infrastructure (referred to as competitive renewable energy zones) to allow for the integration of wind energy.

Simply increasing the down reserves requirement can alleviate this situation, but can lead to an increase in the system production cost. Another possible technology solution is to use energy storage as a fast-acting flexible resource that is capable of providing down reserves and other valuable grid services.

Marrying Solar PV with Energy Storage

The ability of storage to arbitrage high and low prices is quite intuitive. However, as storage draws power to charge during the low-price period, it also increases the down reserves on the system. As an illustrative example, the figure below shows an average daily net-load curve (on the left) under high penetrations of solar PV energy—also commonly referred to as the "duck curve" in the industry. During the middle of the day, the belly of the duck can pose a risk to system stability if the down reserves on the system are depleted and all the thermal generation is backed down to the minimum power level. During this time, the electricity prices are likely low or in extreme situations negative (as shown by the chart on the right-hand side). These phenomena are commonly observed today in California and parts of the southwest United States, but could appear in other areas as the penetration of solar PV increases.

Incorporating a storage system under these conditions, either as a hybrid solar PV and storage system or on a stand-alone grid-connected basis, will not only help to avail the economic arbitrage, but also indirectly replenish the stability

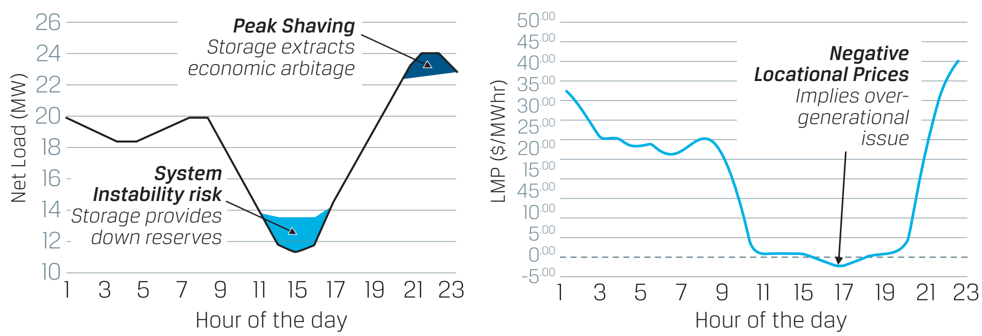
[9] Down reserves refer to the capability on the unit to curtail the output and mathematically equal the dispatched power point minus the minimum power point.

[10] Harjeet Johal, Derek Stenclik, Gene Hinkle, et al., Hawaii RPS Study, May 2015; available from http://www.hnei.hawaii.edu/sites/www.hnei.hawaii.edu/files/Hawaii%20RPS%20Study%20Executive%20Summary%20Final.pdf.

[11] EIM coordinates the dispatch decisions on a least-cost basis, every five minutes, across a few regions in the Western Electric Coordinating Council.

margin of the grid. Economic arbitrage works by storing energy during the time period of low or negative prices[12] and discharging during peak-load conditions when the prices are higher. The energy storage system charges during the day (time of low prices) by storing excess energy from the solar PV, and thus "filling" the belly of the duck. It allows the thermal units to be dispatched at higher power points and thus automatically restores capability of the thermal units to provide the down reserves. As the evening peak-load conditions arrive, the energy prices rise back up to "normal" positive values, and the stored energy in the battery system is well positioned to take advantage of the economic arbitrage. Although the energy arbitrage has been widely discussed, less noticed is the fact that a hybrid solar PV and storage system provides an important ancillary service to the grid and contributes to enhancing the overall system flexibility.

THE "DUCK CURVE" AND THE NEGATIVE LOCATIONAL PRICES



Source: ICF, unpublished data.

Recently, FERC issued a notice of inquiry to seek comments on the need to reform its regulations for the provision and compensation of primary frequency response. Such an ancillary service would maintain the grid frequency within a prescribed limit under contingency events of loss of generation or load.[13]

Conclusion

The application of an energy storage system for providing down reserves, as highlighted in this paper, essentially improves the primary frequency response capability on the grid. Capturing the benefits of energy storage from such services enables the development of a suite of stacked applications in the capacity, ancillary, and energy markets. In addition, energy storage represents a cost-effective flexible resource for the power grid under higher and higher penetration of renewable energy.

[12] Incidences of low or negative prices as solar PV penetration levels increase would add to the rising tension over incentive rates such as net metering. In particular, under these conditions, the economic benefits of solar are lowest at the time when its output is highest.

[13] FERC, "FERC Seeks Comment on Provision, Compensation of Primary Frequency Response," Docket No. RM16-6, February 18, 2016; https://www.ferc.gov/media/news-releases/2016/2016-1/02-18-16-E-2.asp#.

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