ENERGY STORAGE *SMOOTHS* THE DUCK CURVE

As solar energy becomes a bigger piece of the electric generation pie, utilities are grappling with the challenge of putting gigawatts of power online every afternoon.

By John Kosowatz

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THE STABILITY OF THE ELECTRIC GRID AFFECTS millions of residential and business customers. One blip—amounting to just seconds—can interrupt critical systems across a city or an entire region.

Maintaining grid stability is a challenge as utilities rush to add renewable power to their generating portfolio. The business case for renewables is undeniable: as prices for wind turbines and solar panels keep dropping and the costs of installation go down, renewable electricity becomes some of the cheapest power available. But the inherently inconsistent nature of solar and wind energy has grid operators looking for new ways to seamlessly integrate their output into the system.

This challenge is being faced around the world, and in the U.S. it is playing out initially in California.

A law passed by the California legislature in 2015 mandated utilities to reduce greenhouse gas emissions and increase the capacity of renewable projects. In response, the California Independent System Operator, CAISO, began seeing solar power provide an increasing share of electricity in the middle of sunny days. By 3:00 PM each day, however, the sun begins to sink toward the horizon and the power provided by the state's solar projects also starts to fall off—and this loss in power happens just as daily electricity demand starts to rise.

To meet that demand, California utilities figured they would turn to natural gas-fired peaking plants that could ramp up quickly. Southern California Edison, one of the state's three major electric utilities, owns five such peaking plants.

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In 2015, however, a massive leak of natural gas from underground storage wells at Aliso Canyon threw that strategy into question. The leak—the worst in U.S. history—threatened the reliability of fuel for those gas-fired peaking plants, and the California Public Utilities Commission ordered SCE to quickly build an energy storage project to mitigate the supply loss.

The utility turned to battery storage. In January 2017, utility officials opened two 10-MW battery systems supplied by Tesla at its Mira Loma substation that can store 80 MWh of renewable energy, one of the largest battery storage projects in the country. Today utilities and systems operators are recognizing battery storage as one of a number of effective tools for managing an increasingly interactive electric grid powered by more and more renewable energy projects. These tools will have to respond quickly to the sharply rising demand and must scale so as to add gigawatts of power in as little as an hour.

For an industry that had relied on large and lumbering baseload power plants, these sorts of fast and flexible systems may feel like a shaky foundation to support critical energy infrastructure. But the new energy paradigm promises to be cheaper and cleaner than anything that has come before.

THE DUCK CURVE

Over the course of a typical weekday, the electrical load follows a regular pattern. After a lull in the middle of the night, demand for electricity ramps up between 5:00 am and 9:00 am. From then, demand often stays fairly constant until the late afternoon or early evening, when residential lighting and air conditioning overlaps with the last few hours of the business day. The load only begins to decline around 9:00 PM as stores close and early risers head to bed. (The load curve changes on the weekend and over the course of the year, with August seeing the highest peak demand and April the lowest.)

Traditionally, the rise and fall of the load was met via a combination of baseload power generation from coal-fired or nuclear power plants and nimble peaking plants or dispatchable power from hydroelectric dams. But the addition of wind and solar power to the energy mix has altered the calculus. Wind, for instance, often blows most steadily in the middle of the night when demand is at its lowest. In regions where there are a large number of wind farms, deliverable wind power can at times be greater than the total demand.

Solar power can be more predictable than wind—on sunny days, the sun shines most strongly in the middle of the day—but it creates its own challenges to the load curve. Solar power generation ramps up in the morning and stays constant until mid-afternoon before fading for the last few hours before sunset. Unfortunately, that diminishing power supply corresponds with the rising load in the late afternoon, meaning the net load—the difference between electricity demand and the portion met by solar power—rises even faster than the actual load. That means peaking power has to be added, and fast.

Back in 2008, researchers at the National Renewable Energy Laboratory traced out the net load curve as it responded to more and more solar power being added to the grid. One wag noted that in time the curve looked like the back of a duck: high like the tail in the morning, sagging down in midday, then sharply up along the neck in the late afternoon and only rounding over the top of the head and bill in the evening. From that point on, that net load profile was referred to as the "duck curve."

In California, the middle is sagging ever deeper and the neck is growing even steeper as the state leads the way in mandating more renewables. By 2030 renewables must account for 50 percent of each of the state's large investor-owned utilities' generation portfolio.

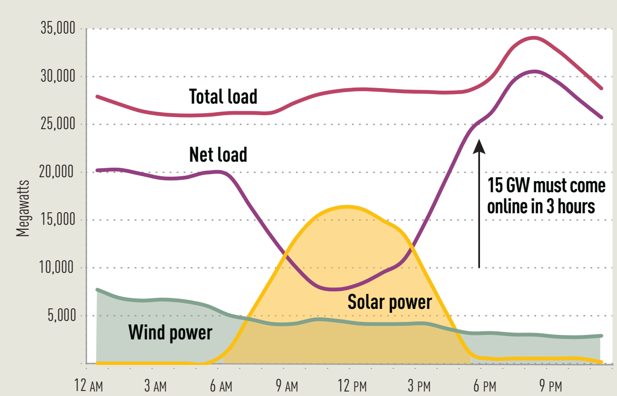
"Those are aggressive renewable goals," said Vibhu Kaushik, SCE director of grid technology and modernization. "Renewables have a lot of intermittency in them. Batteries can change momentarily to balance and maintain reliability. It is not the only thing, but storage for integration will be a big chunk of flattening the curve."

While the utilities are required to increase their mix of renewables, CAISO manages the grid and is responsible for integrating that power into the state's grid. At present, the system now comprises just under 30 percent of renewable sources. Of that, 48 percent is generated by solar power.

"Our job is to maintain reliability and renewables are just one part," said Peter Klauer, CAISO senior advisor for smart grid technology. "We don't favor one technology over another.

Shape of the Duck Curve

More renewables on the grid lead to stress on the system.



Load, solar, and wind profiles for California on a typical day in late March

In this scenario, wind and solar both make up 11 percent of annual generation.

Source: NREL

This 100 MW, 129 MWh battery array in South Australia was built by Tesla in just 63 days. The stored electricity helps Australia overcome inconsistency in power delivery that has led to blackouts. *Photo: Tesla*

But there is a lot of solar generation hitting the grid and that presents an operating challenge to balance with other resources."

CAISO looks at many ways to find the highest value of its assets at the lowest cost. Klauer notes battery storage is just one way to do that. Shipping excess energy outside of the grid to neighboring states and connections is more effective.

Curtailing demand from renewables also is an option, and has been CAISO's most effective tool for managing oversupply. But that results in the state not using all of the renewable energy it could be generating.

According to CAISO data, in 2016 the system operator was forced to curtail more than 308,000 MWh of renewables, up from 187,000 MWh the year before. Most of that came in the form of economic curtailments: During times of oversupply, the bulk energy market competitively selects the lowest-cost power sources. Renewables can bid into the system in a way to reduce production when prices start to fall and CAISO's market optimization software automatically adjusts supply with demand.

Curtailing renewables runs counter to the state's economic and environmental goals, notes Klauer. As costs for lithium-ion batteries come down, battery storage "is helpful, and can alleviate the rush of solar during the day," he said.

"The whole energy world is shifting," noted Mark Frigo, vice president of energy storage North America at E.ON Climate and Renewables North America, part of global energy developer E.ON. The company has 2,700 MW of renewable projects in the U.S. "One factor is cost-effective renewables. But the increasing electrification requires a high quality of electricity and a decentralized demand-response system to deliver. Things are much more complex than ever before. That's where battery storage can come into play."

Battery storage can solve several simultaneous problems, from maintaining grid stability to deferred transmission and distribution. It provides both supply and load, although batteries are limited in how long they can produce power.

Operating batteries is not as simple as flipping the switch. It requires utilities to buy electricity in advance to charge the batteries, and at a low price so that the value of discharge is greater than the value of charging.

SCE's emergency 10-MW project has supplied power every day since being commissioned, the utility reports. It now has 400 MW of storage in its portfolio mix, including long-running pumped-storage hydroelectric plants. But in an innovative twist, it also is using batteries to supplement gas-fired peaking plants and respond to the state's frequency regulation market.

Peakers are linked to the frequency regulation market, but because they are nonspinning, they can take as long as 10 minutes to go online.

Adding batteries that can react immediately while the gas turbines are starting makes the entire unit eligible for spinning reserve status—that is, capacity immediately available to the grid and thus more valuable.

Last year, SCE partnered with GE and Wellhead Power Solutions to install an 11-MW, 4.3-MWh battery at two substations, pairing them with a 50-MW gas-fired peaking plant. The utility calls the Hybrid Enhanced Gas Turbine the world's first low-emission hybrid battery storage system to be fitted with a gas-fired peaker.

"These relatively small batteries unlock a lot of value with existing plants," Kaushik said. "The batteries are always synched to the grid and provide power at a moment's notice until the peaker comes on line."

Over the 40-year life of the plant the batteries are also projected to reduce operating costs for the turbines by 60 percent.

There is a lot to like about battery storage, Kaushik said. "For a small capital investment, you can add value to the grid and so much more," he said. "They are modular, easily stacked. It is a game-changing technology."

And batteries are getting cheaper. A recent analysis by Lazard pegs the cost of lithium ion batteries used for peaker replacement between $282 to $347 per MWh, with costs projected to drop by 36 percent over the next five years. Those declining costs will entice more utilities and systems operators to add installed battery capacity, though Kaushik sees more value in hybrid applications, except in locations where congestion pricing on the grid is high.

Pairing batteries with a gas-fired peaker plant like this one creates a hybrid that is more efficient and less expensive.
Image: General Electric

In Gaildorf, Germany, about 65 km northeast of Stuttgart, a private developer is using another hybrid concept, pairing a wind-power station with pumped-storage hydroelectricity. Max Bögl Wind AG has built four 12 MW wind turbines atop 40 m tall concrete tanks on top of 200 m high hills. The tanks will eventually serve as the upper reservoir for the pumped-hydro power plant, holding enough water to produce 70 MWh of electricity with a peak output of 16 MW. When completed later this year, the storage component will have a response time within 30 seconds.

"Pumped storage is a proven technology and this has a design life of about 50 years," said Susanne Kleineheismann of Max Bögl Wind. Batteries, she points out, must be replaced after about eight to 10 years.

The company will not release project costs, reportedly at $81 million, but Kleineheismann says capital costs for what the firm calls a "water battery" will be 300 to 400 Euros per kWh.

Even the Battery Hurdles Are Bigger in Texas

The electric grid in Texas is isolated from the rest of the country. Battery storage of electricity could find a great deal of use there, as the state is faced with integrating a slug of renewables into the system. Since 2000, 20 GW of wind power projects have come online, most on the sprawling plains of west Texas. Another 21 GW of solar power are expected to come online by 2021, according to the Electric Reliability Council of Texas, the state's grid management agency.

Unfortunately, the state's peculiar rules don't define how batteries can or should be used. State regulators differentiate between deregulated power generators and regulated power distribution companies. Most utilities cannot deliver and generate power, and private merchant generators worry that batteries, in smoothing price hikes when demand is high, will cut into profits.

The state's Public Utility Commission earlier this year announced it would begin to write rules for utilities that want to use batteries, but turned away a proposal from AEP Texas, a large utility, to use batteries to back up over-loaded transmission systems in two remote and sparsely populated towns. The utility argued that batteries for backup power would be cheaper than doing expensive upgrades to an aging, hard-to-access transmission line.

E.ON has found some battery success in Texas. The company is building two 9.9-MW short-duration lithium-ion battery systems at wind farms in west Texas.

Compared to the market opportunity, though, it's a drop in the bucket.

Pumped hydro is not an option at sea level, so for offshore wind projects, electrochemical batteries still make sense. In March, Bay State Wind announced a partnership with NEC Energy Solutions to add 55 MW and 110 MWh of battery storage to a planned 800-MW offshore wind farm 15 miles off of Martha's Vineyard, Mass. Bay State claims the combination will help reduce Massachusetts winter electricity prices by some $158 million per year. In the U.K., Danish power company Ørsted said it will install a 2-MW battery to provide frequency regulation at its offshore 90-MW Burbo Bank wind farm. And the world's first floating wind farm, Norwegian energy giant Statoil's 30-MW Hywind complex, will be fitted with a 1.3 MWh battery system.

In a show of the flexibility and potential of battery storage, the electric car company Tesla installed a 100-MW station in South Australia last year in the wake of widespread outages, after a bet by Tesla's Elon Musk that the firm could have the station built and operational within 100 days. The station can respond to power outages within 140 ms and competes with natural-gas plants for peaking power and frequency regulation services. Grid operator Australian Energy Market Operator reports lower prices being bid into the system since the battery plant's startup.

By combining a wind turbine with pumped hydro, Max Bögl Wind AG created renewable energy storage that's more durable than batteries.
Image: Max Bögl Wind AG

RULES AND REGULATORS

Another way to smooth out the duck curve is to increase demand during the day, instead of tossing out the excess renewable energy. SCE, as part of its plan to meet California's energy and environmental mandates, thinks much of that wasted energy can be deflected to charging stations as electric vehicles gain market share.

In Columbia, Mo., Columbia Power & Light Co. last year started to pay higher rebates for solar arrays facing west rather than south. The move is an effort to bring solar production more in line with peak demand, as west-facing solar panels produce more power later in the day when demand picks up.

Batteries and storage now are getting a boost from the Federal Energy Regulatory Commission. In January it approved an order directing operators of wholesale markets to devise market rules for energy storage in wholesale, capacity and ancillary services. The rules, scheduled to be developed and implemented in two years, should codify how energy storage can be applied across the country, establishing market-driven parameters. That will change how the market has developed until now, driven by state regulatory demands. California, New York, and Massachusetts are already ahead of the ruling, and Texas is following suit.

Texas does not yet have California's duck curve, but E.ON's Frigo says most parts of the country will soon face the challenge of integrating renewable power.

"The renewable train has left the station," Frigo said. "We'll see much greater numbers of renewables on the grid. Fossils will be retired. But that brings challenges of intemittency so you will see the duck curve elsewhere. Here's where energy storage plays as a good solution." **ME**

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