Business & Technology Strategies

# TechSurveillance

## Variability and Uncertainty in Renewables' Generation Pose Challenges for G&T Cooperatives

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The following *TechSurveillance* article is Part I of a two-part series. Part I discusses the challenges of utility-scale variable renewable generation. Part II will discuss how electric cooperatives are rising to the challenge of mitigating the risk by providing insights and recommendations on approaches to address ramping.


### EXECUTIVE SUMMARY

***What has changed in the industry?***

The installed capacity of renewable energy resources — primarily wind and solar photovoltaics (PV) — has been rising steadily over the past 10 years. As wind and solar PV account for a larger share of the generation mix, their intermittency and non-dispatchable nature (referred to as *variable renewable generation*) pose an issue for utilities, including cooperatives. Output from these renewable resources can drop suddenly — if a cloud or thunderstorm passes over a solar PV facility — or can rise suddenly — when the wind speed increases significantly at a wind farm due to a cold front or thunderstorm. These output changes, or *ramps*, can sometimes occur with little warning, affecting electric power operations by making the balancing of load and generation more difficult to manage. This can cause such issues as voltage and frequency transients, as well as phase imbalance, especially for distribution electric cooperatives.

The biggest factor in this growth is the advancement of wind technology, which will bring utility-scale wind to co-op territories once thought uneconomical. Many generation and transmission (G&T) cooperatives, especially those with fossil generating assets, should take this into consideration.




NRECA America's Electric Cooperatives

### *What is the impact on cooperatives?*

The intermittent nature of renewables has presented operational, reliability, and economic challenges for G&T cooperatives.

Among the operational issues is the need to cycle fossil-fuel-fired generating plants. Such cycling could entail *two-shifting* (shut down at night and hot restart in the day) or even *double two-shifting* (shut down at night, hot restart in the morning, shut down in midday due to increasing solar penetration, hot restart in late afternoon, and shut down in the evening hours).

Reliability issues for G&Ts and distribution electric cooperatives include voltage and, at very high penetration of renewables, frequency fluctuations that could cause inadvertent tripping of relays and circuit breakers, possibly resulting in unintended islanding and other consequences.

Key economic issues include:

- Potential increased operation and maintenance cost due to cyclic operation of fossil plants, and more frequent operation of voltage regulators/tap changers.
- Increased costs for replacement power due to increased outages and force outage rates, fuel due to increased plant heat rates, and start-up fuel due to a significant increase in plant starts.
- Volatile and negative market prices resulting from wind generation that bids into the market at a very low or zero cost due to production tax credits, reducing market prices for G&Ts to a level that can prematurely cause the shutdown of baseload power plants.
- Increase in wholesale power costs to cover the costs of building new, flexible, and fast start generation to fill the gaps, and transmission lines to reduce or eliminate congestion caused by variable renewable generation that typically is located in remote areas with insufficient transmission capacity to bring to load centers.

G&Ts with significant penetration of wind energy have experienced severe fluctuations of renewable output. Those G&Ts most affected are located in the Midwestern 'Wind Belt,' which runs from the Canadian border in North Dakota to Texas, and either own wind farms and/or buy wind energy through a power purchase agreement (PPA), or have significant wind capacity connected to their transmission lines. Significant penetration of wind will likely begin to spread into regions outside the 'Wind Belt' due to advanced technologies, which will bring utility-scale wind to co-op territories once thought uneconomical.

In electricity markets, such as those run by the Midcontinent Independent System Operator (MISO), the Electric Reliability Council of Texas (ERCOT), or the Southwest Power Pool, G&Ts may face negative locational marginal pricing (LMP) — which reflects the value of electricity at different locations on the grid. The LMP, which can be as low as negative $40 per megawatt-hour during off-peak periods due to high levels of wind generation on the system, will affect the revenues of fossil-fired or nuclear baseload plants that must pay the power system to stay online at minimum loads or shut down due to negative market prices. Another impact of high wind generation during off-peak periods is the potential for higher than usual power prices during peak periods, since not enough low-cost fossil units may be able to start back up during peak periods, necessitating the dispatch of more high cost combustion turbines.

### *What do cooperatives need to know and/or what can they do?*

There are several recommendations for G&T cooperatives, including:

- G&Ts facing current or potential growth in variable renewable generation, either from utility-scale or significant growth in distributed solar generation within their service territory, will need to know what share this energy may account for in their generation portfolio, and analyze and prepare for the impacts on the planning and operations of their systems.

- G&Ts experiencing high renewable penetration should include any projected increase in this energy supply in their analyses, taking into account any distributed solar photovoltaic (PV) generation in their service territory.
- Assess and improve their ability to forecast distributed generation, in order to be prepared for the potential impacts on their system.
- Consider performing a transient stability analysis to determine at what level wind and/or solar PV penetration could cause challenges.

**NOTE**: *Distribution electric cooperatives with significant penetration of distributed solar PV may have to conduct voltage stability analyses because of the potential variability in voltage, and forecast its impact on their distribution grid equipment operations. Such variability could cause inadvertent relay operation that opens circuit breakers and also causes unbalanced power flow on three-phase distribution lines.*

- If not done so already, consider assessing the cost of maintenance associated with fossil-fueled plant cycling, as well as the potential for a significant increase in forced outage rates.
- Evaluate their generation reserve margins in the event of a significant increase in the forced outage rates of existing fossil fueled generation due to cyclic operation. In addition, re-evaluate their fuel purchase and procurement strategy due to reduced plant capacity factors and increased purchases for start-up fuel.
- If not already doing so, conduct reliability studies to address any voltage and frequency fluctuations and any potential for increased power losses on their system.
- If operating in organized markets, monitor pricing trends in those markets, both daily and seasonally, because of the potential for negative prices due to high wind generation during off-peak hours, which can erode revenue.
- Consider monitoring potential increases in prices during peak hours, which can increase the cost of power purchases.

**Favorable economics for solar PV, especially utility-scale projects, are driving increased market share.**

## INTRODUCTION

The installed capacity of renewable energy resources — primarily wind and solar PV — has been rising steadily over the past 10 years. Among the drivers of this growth have been federal investment tax credits for solar PV and wind, production tax credits for wind, state renewable portfolio standards, reductions in the cost of large-scale wind, and significant reductions in the cost of residential, commercial, and utility-scale solar PV.

Annual installed solar PV capacity grew from 1,577 MW in 2011 to 6,137 MW in 2015, according to the 2015 *Utility Solar Market Snapshot* issued by the Smart Electric Power Alliance (SEPA). Cumulative growth jumped from 4,095 MW in 2011 to 22,454 MW in 2015.

Favorable economics for solar PV, especially utility-scale projects, are driving increased market share. The installed cost of an average utility-scale system in 2009 was $5.00 per Watt, according to the National Renewable Energy Laboratory. By 2015, the cost of an average 100-MW PV system had fallen to $1.77 per Watt. GTM Research estimates that by 2020, large-scale solar PV systems will fall below $1.00 per Watt. Furthermore, the cost of an average solar PV power purchase agreement (PPA) has fallen by 70 percent since 2009 to an average 5 cents per kilowatt-hour, according to a report by Lawrence Berkeley National Laboratory. GTM Research predicts that the price will fall below 4 cents per kilowatt-hour in the next 2 years. **Figure 1** shows fall solar PV prices over time.

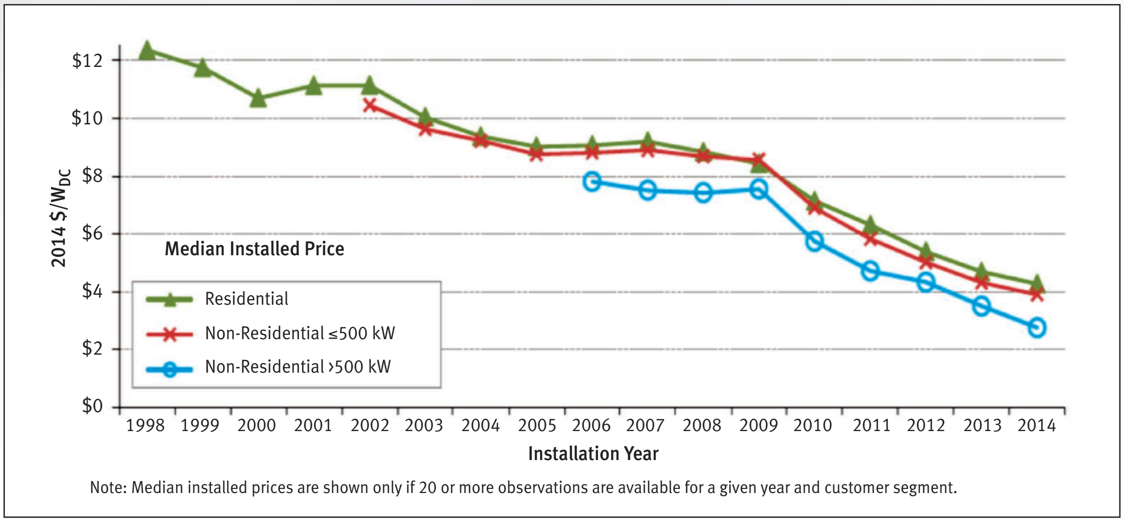



**FIGURE 1: U.S. Solar PV Prices 1998–2014** *(Source: LBNL Report)*

**Since 2006, the supply of wind energy grew by nearly 70 percent and solar by 93 percent.**

**Output changes occurring with little warning from renewables can make balancing load and generation more difficult.**

Since 2006, the supply of wind energy grew by nearly 70 percent and solar by 93 percent, reaching 74.5 GW of installed wind capacity and 27.4 GW of installed solar PV by the end of 2015. Utility-scale solar PV accounted for more than half of total solar installed capacity. By 2020, installed wind capacity could reach 113 GW, according to DOE's Central Study Scenario, and by 2030, it could reach 224 GW. An additional 16 GW of solar is expected to come on line in 2016. Solar PV installed capacity is expected to reach 37 GW by 2030, according to EIA's *Wind and Solar Data Projections*. However, if the EPA's Clean Power Plan takes effect, EIA expects solar PV installed capacity will reach 74 GW in 2030.

As wind and solar PV begin to account for an even larger share of the generation mix, their intermittency and non-dispatchable nature can pose an issue for generation and transmission (G&T) cooperatives, especially those whose service territory lies within the Midwestern "Wind Belt," which runs from the Canadian border in North Dakota to Texas.

Output from renewable resources can drop suddenly — if a cloud or thunderstorm passes over a solar PV facility — or can rise suddenly — when the wind speed increases significantly at a wind farm. These output changes, or *ramps*, can occur with little warning, affecting electric power operations by making the balancing of load and generation more difficult to manage. See the sidebar ***Plotting the Unpredictable*** for a discussion and examples of wind and solar variability.

## MAJOR AREAS OF WIND AND SOLAR PV GENERATION

### Wind generation

Wind is expected to be the dominant renewable, according to the NRECA report ***Impacts of Increased Wind Penetration on Baseloaded Coal Generation***. Much of this penetration is occurring in the "Wind Belt."

Figure 2 shows typical wind speed and power output variability over a 10-hour period for a large wind farm in Minnesota.

While wind systems account for less than 1 percent of total U.S. generating capacity, in some regions of the country, they make up a much greater share. The Southwest Power Pool — which manages transmission in 14 states — recently set a record among organized electricity markets by meeting 50 percent of its load with wind, and is projecting that wind load share could reach 64 percent by the end of 2018.

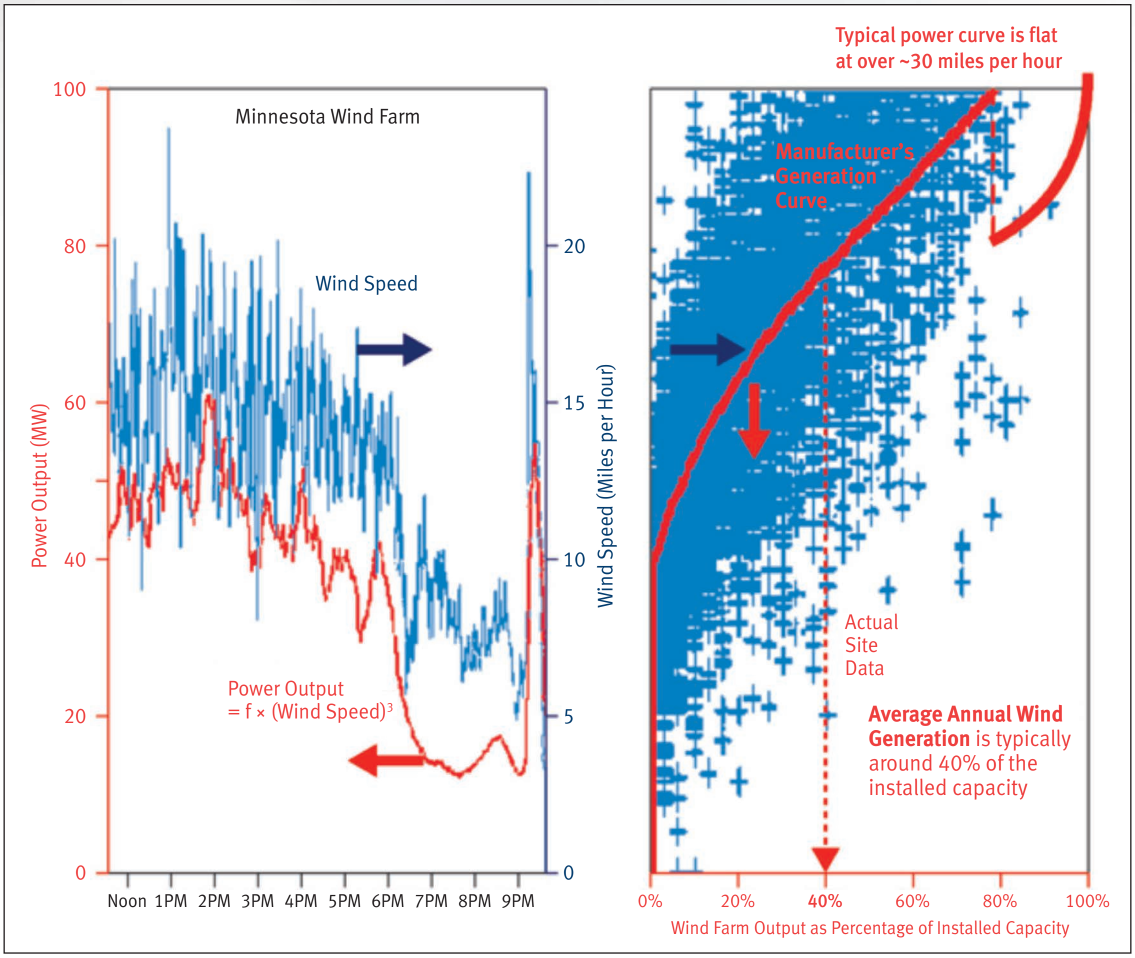



**FIGURE 2: Typical wind aped and power outage variability**

NRECA talked with representatives of G&Ts that own wind facilities and/or buy wind through a PPA, or have a significant capacity of wind in their region: Sunflower Electric Power Corp. in Kansas, Golden Spread Electric Cooperative, Inc. in Texas, and Tri-State Generation and Transmission Association, Inc. in Colorado.

***Sunflower Electric Power Corp.***

Sunflower Electric Power is owned by six distribution cooperatives. Those six distribution co-ops also own Mid-Kansas Electric Co., which is operated by Sunflower under an operations and maintenance agreement. Together, the two utilities have PPAs for 229 megawatts (MW) of wind. Figure 3 shows the Smoky Hills Wind Project.


**FIGURE 3: Sunflower Electric Power Corp. buys 50 MW of energy from the Smoky Hills Wind Project in Lincoln County, Kansas, and Mid-Kansas Electric Co. which is operated by Sunflower under an O&M agreement, buys 24 MW.** *Courtesy of Sunflower Electric Power Corp.*

"A problem with wind energy is that it's difficult to balance energy supply and demand," said Corey Linville, vice president, power supply and delivery for Sunflower and Mid-Kansas. Well over 1,500 MW of wind are currently connected to the co-op's transmission system. "There is substantially more wind generation connected to our system than the load we serve at our peak," he said. "Because wind typically blows the most during off-peak periods, it's not uncommon to have wind generation injected into our system almost triple the amount of load we are serving from the system. Nevertheless, more wind projects are planned for the co-op's territory."

**FIGURE 4: The Golden Spread Panhandle Wind Ranch, located near Wildorado, Texas, has a maximum output of 78.2 MW. The facility began operating in September 2011.** *Courtesy of Golden Spread Electric Cooperative*

**FIGURE 5: Today, solar PV tends to be concentrated in the U.S. Southwest.** *Courtesy of Tri-State Generation & Transmission Association, Inc.*

***Golden Spread Electric Cooperative***

Golden Spread currently has about 280 MW of wind in the form of owned generation or contracts, all of it built or procured within the past 5 years, said Matthew Moore, the co-op's director of marketing operations. However, this figure needs to be viewed in the context of total installed wind capacity in Texas: 17,711 MW, some of it in the Panhandle, where Golden Spread is located. According to ERCOT, by 2017, the Panhandle will account for one-quarter of the state's installed wind capacity. Another 5,486 MW of wind capacity is under construction in Texas.

***Tri-State Generation & Transmission***

Tri-State G&T has long-term PPAs for 292 MW of wind, with an additional 76 MW slated for 2017. It also supports 8 MW of member distributed wind projects. Tri-State currently pays its balancing authorities for regulation service and energy imbalance services for integrating variable energy resources.

While Tri-State is based in Colorado, which has 2,965 MW of installed wind capacity, its service territory embraces parts of three other states: Wyoming, Nebraska, and New Mexico — all of which produce wind energy. Wyoming has 1,410 MW of installed wind capacity, with an additional 80 MW under construction; Nebraska has 890 MW of installed wind capacity, with an additional 436 MW under construction; and New Mexico has 1,112 MW of installed wind capacity, with an additional 298 MW under construction.

**Solar PV generation**

Today, solar PV — both utility-scale and distributed generation — tends to be concentrated in the U.S. Southwest (see Figure 5). In California, solar PV is expected to account for an ever larger share of generation, as the state moves toward its 33-percent renewable portfolio standard

**As solar PV expands eastward, it could begin to cause the kind of ramping impacts experienced now in the Southwest.**

goal by 2020. As a result, the ramping impacts of solar PV are expected to increase, according to the California Independent System Operator (CAISO). See sidebar ***The Load Curve: If It Looks Like a Duck…*** for details.

Tri-State has a long-term PPA for 30 MW of utility-scale solar PV, with an additional 55 MW planned to be on line by the end of this year. By the end of 2017, Tri-State will be supporting 66 MW of member distributed solar projects, at which point the co-op will have approximately 151 MW of solar PV owned or under contract.

Arizona Public Service, the largest utility in the state of Arizona, also has experienced PV ramping impacts (see sidebar ***The Ups and Downs of Solar Generation in the Southwest***).

Even where solar PV is not expected to represent a major generating resource, it can pose ramping impacts for G&T member systems. In Minnesota, Great River Energy is building a 2.25 MW solar PV system that will provide energy to one of its members, Wright-Hennepin Cooperative Electric Association.

**Solar and wind energy together generally don't exacerbate the structural problems you might have with just one of those resources.**

*– Michael Wise, Golden Spread*

"So far, there is low penetration of PV onto member systems," said Andrew Bergrud, GRE's senior engineering project manager. "However, I think we will potentially see some ramping impacts on the 2.25 MW installation, because two other PV resources are already on that line and we'll be close to matching the minimum load on the substation in the summertime."

As solar PV expands eastward, it could begin to cause the kind of ramping impacts experienced now in the Southwest. Texas has 566 MW of installed solar PV capacity, and over the next 5 years, the state is expected to install more than 4,600 MW of solar capacity, according to a study, *U.S. Solar Market Insight, Q2 2016*, by GTM Research and the Solar Energy Industries Association. Also, the Tennessee Valley Authority has signed a long-term PPA for a 53-MW solar project.

**FIGURE 6: Tri-State G&T purchases power from the 30-MW Cimarron Solar Project, which began operating in December 2010.** *Photo credit: Tri-State Generation & Transmission Association, Inc.*

North Carolina ranks third in the country for installed solar PV capacity, with 2,087 MW. In Georgia, Green Power EMC — which sources, evaluates, and sells PPAs for renewable energy on behalf of 38 Georgia electric cooperatives — has approximately 240 MW of installed solar PV capacity. The Georgia Power Co. operates 444 MW of solar PV, which accounts for roughly 2 percent of its generation portfolio. "Together, that's about 1.5 percent of the state's generation portfolio," said Robert Casey, manager of member system planning for the Georgia Transmission Corp., a state-wide power generation and electricity transmission co-op. In addition, Georgia Power has plans to add another approximately 2,000 MW of solar PV.

Another factor may spur the development of PV. "Solar and wind are complementary energy resources (in that the wind tends to blow at night and the solar PV provides generation in the middle of the day)," said Michael Wise, Golden Spread's senior vice president for commercial operations and transmission. However, he added, the variability of each resource means that you take the energy when it is available. "But, as solar energy is generated during daylight hours and wind predominantly during

**Some G&Ts are investigating converting existing generators to synchronous motor/condensers to manage the voltage variability of wind farms.**

evenings and at night, together they generally don't exacerbate the structural problems you might have with just one of those resources."

In fact, Sunflower is exploring the option of a solar project on its system, said the co-op's Linville. "There's a lot of solar availability in southwestern Kansas, and a solar generation project could be placed online to provide renewable energy that matches our load shape more closely, while also potentially offsetting needed transmission upgrades." The amount of energy flowing through transmission lines would drop significantly, with solar cutting peak capacity by 10 to 30 percent. While capacity would be reduced on transmission lines, unit transmission charges would increase.

In some cases, G&Ts are investigating the possibility of converting existing natural gas-fired or coal-fired generators to synchronous motor/condensers to provide dynamic and instantaneous voltage support to dynamically manage the variability in the voltage of wind farms, in lieu of making investments in the transmission system.

**Areas where electricity is bought and sold on a bilateral basis tend to have a smaller pool of dispatchable resources for managing integration of renewables.**

*– Brendan Kirby, energy consultant*

## ROLE OF ORGANIZED MARKETS

Much of the "Wind Belt" — and the area of major solar PV penetration — lies within the footprint of an organized wholesale electricity market run by an Independent System Operator (ISO) or a Regional Transmission Organization (RTO). Participants (including utilities) buy and sell electricity and other services within these markets.

The major markets within the "Wind Belt" are the Midcontinent Independent System Operator (MISO), the Southwest Power Pool (SPP), and the Electric Reliability Council of Texas (ERCOT). SPP and CAISO serve as a marketplace for much of the solar PV in the Southwest.

SPP, which embraces 14 states, transitioned from its Energy Imbalance Service to a new Integrated Marketplace (IM) in 2014. The IM provides day-ahead and hourly energy markets, as well as 5-minute markets. With the increased penetration of wind in the western SPP regions — western Kansas and the Texas Panhandle — ramping requirements have increased. The 5-minute market can better manage the increased variations in loads caused by wind. SPP, not the participating G&T, is responsible for balancing load and, thus, addressing ramping in the relevant control area.

In many areas of the country, such as the Southeast and parts of the West, electricity is bought and sold on a bilateral basis. Utilities in these stand-alone balancing areas tend to have a smaller pool of dispatchable resources available to manage the integration of renewables, according to Brendan Kirby, an energy consultant.

Tri-State G&T, which has PPAs for wind and solar, does not participate in an organized market in its Western Interconnection system, but is a member of SPP in its Eastern Interconnection system. In the Western Interconnection, where nearly all of its renewable resources are presently located, the G&T works with several balancing authorities. Tri-State currently uses its dispatchable resources in combination with receiving ancillary services for regulation and energy imbalance from its balancing authorities to integrate its variable energy resources. Most of the solar PV resources are in one balancing authority and most of the wind resources are in another balancing authority, said Dan Walter, the co-op's senior manager of energy markets. "But there's a fair possibility that the Western Interconnection system will participate in an organized market in the next several years."

**Every time a fossil-fuel-fired plant is turned off and on, its components go through unavoidable large thermal and pressure stresses that cause damage…**

*– The National Renewable Energy Laboratory*

**Increased O&M and replacement energy costs can range from $10 to $29 million annually for a 400-MW coal-fired plant and wholesale power.**

*– Dale Bradshaw, consultant to NRECA*

An organized market, particularly as part of an RTO, offers the prospect of efficient regional generation dispatch, he said. And, under an RTO tariff, there is the prospect of a reduction or elimination of "pancaked" transmission costs — accumulation of transmission charges when moving power across multiple transmission owner systems. Tri-State is currently engaged with other neighboring utilities in studying the potential benefits of a regional transmission tariff, an organized market, and forming or joining an RTO in the Rocky Mountain region.

## MAJOR IMPACTS OF VARIABILITY

The co-ops that NRECA talked with cited several major impacts of wind and solar PV ramping:

- Fossil-fuel-fired plant cycling,
- Grid reliability,
- Volatile market prices, and
- Transmission congestion and costs.

### Cycling of fossil-fueled plants

G&Ts with significant wind penetration in their service territories or the markets in which they operate will need to cycle their fossil-fuel-fired plants in response to wind variability. That cycling can occur on a *two-shift basis* — shutting down at night and restarting in the morning — or even a *double two-shift basis* — shutting down in mid-day, restarting in late afternoon, shutting down in the early evening, and restarting in the morning. Other operating modes include load following and minimum load operation.

Every time a fossil-fuel-fired plant is turned off and on, the boiler, steam lines, turbine, generator and auxiliary components go through unavoidably large thermal and pressure stresses, which cause damage through thermal cycle fatigue, noted a report by the National Renewable Energy Laboratory.

"Increasing the number of hot starts by a coal-fired plant from a normal 10 to 20 per year to more than 60 per year can increase boiler tube failures from one to two per year to more than eight a year," said Dale Bradshaw, CEO of Electrivation LLC and a consultant to NRECA. "The end result is a dramatic increase in forced outage rates — from 5 to 10 percent when baseloaded to possibly 26 to 35 percent when two-shift operation is required more than 50 times a year. Such cycling will significantly reduce reserve margins, may require the building of additional peaking capacity, and may increase the cost for replacement energy."

The increased operation and maintenance (O&M) and replacement energy costs can range from $3 to $10 a megawatt-hour (MWh), said Bradshaw. "That's $10 million to $29 million annually added to the cost of a 400-megawatt coal-fired plant and wholesale power."

The Centre for Energy Advancement through Technological Innovation (CEATI) conducted four studies for NRECA on the impacts of fossil-fueled plant cycling, which are available on **cooperative.com** in the Generation, Environment, and Carbon Dioxide (GECO$_2$) area:

- **Damage to Power Plant Due to Cyclic Operation and Guidelines for Best Practices**
- **Impact of Cycling/Two Shift Damage on the O&M Cost and Reliability of Natural Gas-fired Combined Cycle (NGCC) Power Plants**
- **Impacts of Cyclic Operation on Maintenance Programs**
- **Damage to CCGT Plant Due to Cyclic Operation** (operational, technical, and cost issues)

In addition, NRECA issued a report on cycling damage, ***Impacts of Increased Intermittent Generation on Baseloaded Coal Operations***.

**"Most of the cost impacts associated with cyclic operation occur over several years, which makes the overall impact difficult to quantify."**

*– Corey Linville, vice president, power supply and delivery, Sunflower and Mid-Kansas*

**If gas-fired combined cycle plants are used for voltage control and the operation mode is not indicated by the Integrated Marketplace, there is risk of operating out of economic dispatch and increasing the market wholesale cost.**

These studies indicate that thermal stress and fatigue of large plant items, such as steel pipes and boiler tubes, can occur when plants operate at high operating temperatures and then cool during shutdowns, said Bradshaw. He noted that the one mechanism at present for cost recovery of potential damage to a plant stemming from forced outages and reduced reliability is by increasing the start-up cost bid into the market.

Sunflower's 360-MW coal-fired unit now cycles from minimum to maximum load, creating a lot of maintenance issues, said the co-op's Linville. "Our gas-fired facilities also get cycled when they run," he said. "Our internal combustion engines and combustion turbines are started more frequently, typically with short run times, partly to follow wind and provide ramping support to the Southwest Power Pool."

Asked about the impact of cycling, Linville said: "It's difficult to quantify the maintenance impact associated with increased cycling of a generation facility that was designed to operate as a baseload resource. We know that cyclic operation increases the number of starts and stops on large equipment, such as boiler fans and feedwater pumps. This increases the time between required major maintenance. Cyclic operation also results in thermal cycling of boiler components, which can increase the occurrence of creep in the specialized steel used to make boiler tubes. This damage results in reduced operating lifespans for these components. Most of the cost impacts associated with cyclic operation occur over several years, which makes the overall impact difficult to quantify."

Wind and/or solar PV variability "can contribute to the ramping and/or start/stop cycle of a thermal resource," said Tri-State's Walter. "But it's seldom the sole driver." He added that maintenance is an issue with fossil-fueled plant cycling. "We need to look at the true variable costs to assess the impacts on maintenance and reliability."

With the introduction of the Integrated Marketplace (IM), SPP's reliance on simple-cycle gas turbine generation has grown anywhere from 101 percent to 274 percent. But, the average energy output of gas turbines has plunged by 33 to 43 percent because of the start-stop cycle of operation. Golden Spread's 168-MW Antelope Station comprising 18 Wärtsilä reciprocating engines, for instance, was started 3,349 times in 2013 and through November of 2014 had started 11,961 times.

Asked if the start-stop operation of the Wärtsilä units — in response to the variability of wind output — had an impact on the units' efficiency, Steve Cross, the co-op's vice president of engineering, said: "Not at this time. The jury is still out on whether parts on the engines are wearing out."

SPP's rules and processes facilitate substantial renewable energy generation, said Golden Spread's Wise. "Many times, the large amount of renewable energy dispatching into SPP's IM causes fossil-fueled power plants to ramp down to minimize output levels or de-commit and come offline." Golden Spread has a gas-fired combined cycle plant in a constrained part of SPP's footprint, and it needs that unit to run at times for voltage control, he said. "One major concern is that currently SPP's IM does not tell us what mode the market wants [this plant] to run in." (See text box on next page for **Modes of Plant Operation**.) By operating a gas-fired combined cycle power plant out of economic dispatch for voltage control, the wholesale cost for the SPP will increase, which in turn will increase costs for utilities purchasing power within the SPP market.

## MODES OF PLANT OPERATION

- **Simple Cycle**
- **One-on-one Mode**
  One gas turbine with one heat recovery steam generator supplying a steam turbine
- **Two-on-one Mode**
  Two gas turbines with one heat recovery steam generator supplying a steam turbine

**The capacity qualification or credit is the peak demand less the peak residual demand, expressed as a percentage of the variable renewables installed.**

In addition to what is called a *one-on-one mode*, the plant can run in a *two-on-one mode*. "And by next spring, due to a major upgrade in SPP's market design, the co-op will be allowed to offer the combined cycle in three modes: simple cycle, one-on-one, and two-on-one, said Wise. "SPP's IM will decide which configuration it wants, which helps ensure greater market efficiency." Thus, the combined cycle unit will be able to bid into the SPP IM the lowest possible operating costs per megawatt bid and the SPP IM wholesale prices will be kept to a minimum in response to a highly variable load impacted by variable renewable resources.

Although the three modes of operation can be used to minimize damage due to two-shift cycling or double two-shift operation, thermal efficiency will decline as a combined cycle plant goes from two-on-one to one-on-one and then to simple cycle mode, said Bradshaw, though the net impact on the SPP IM wholesale prices will be a net reduction. High penetration of wind — such as SPP has experienced — offsets baseload resources that are critical to reliability, said Sunflower's Linville. "The more baseload assets are offset by wind, the greater the chance of reliability issues popping up." When baseload assets are forced to cycle, forced outage rates increase over time, which reduces reliability.

Great River Energy's 189-MW Stanton Station in North Dakota is a must-run, two-boiler unit, said John Weeda, the co-op's director of North Dakota generation. "When the market said we wouldn't make money, we switched to one boiler, and considered coming off line." The challenge then is start-up costs, which can be $15,000 to $20,000, he said. "We're very much competing with wind."

In July 2016, GRE announced that it plans to retire the Stanton Station by May of 2017. The reason: the plant is no longer economic to operate due to low energy prices in the regional market. The low prices are caused not only by high penetration of wind during the off-peak hours — sometimes causing negative system prices — but also by low-cost natural gas-fired generation during the on-peak hours.

### GRID STABILITY

Golden Spread has approximately 280 MW of wind in the form of owned generation and PPAs — all of it built or acquired in the past 5 years. The co-op's wind resources account for 10 to 15 percent of its capacity portfolio, said Moore, "although the capacity qualification is much smaller as a percentage." The capacity qualification or credit is the peak demand less the peak residual demand, expressed as a percentage of the variable renewables installed. For example, if 10 GW of wind power plants are installed in a region, and their capacity credit is 10 percent, then there will be a reduction of 1 GW in the amount of other plants required, compared to a situation with no wind capacity.

SPP has adopted a methodology to calculate the capacity contribution of wind. The approach is a monthly method, and results in 12 capacity measures for a wind plant. The process first examines the highest 10 percent of load hours in the month. Wind generation from those hours is then ranked from high to low. The wind capacity value is selected from this ranking, and it is the value that is exceeded 85 percent of the time. Up to 10 years of data are used, if available. For the wind plants studied in the

**If capacitance decreases enough and cannot restore voltage, the system voltage can spiral down, potentially leading to a system voltage collapse and blackout.**

**Daily reliability studies can help determine what voltage control devices must be in service to provide voltage support.**

SPP region, the capacity values ranged from 3 to 8 percent of rated capacity coincident with the system peaks. The methodology is described in an NREL **conference paper.** Basically, wind provides significantly more energy than capacity.

Voltage swings and system stability are now common concerns, said Golden Spread's Wise "Transmission systems are designed to take output from large dispatchable generating units, but they're not used to large swings in output from significant numbers of variable energy resources." He noted that it is the responsibility of the RTO or ISO to maintain voltage and frequency. "But that's becoming more difficult. New market products may be needed, so operators have more tools to choose from to maintain system reliability at the lowest cost. The two markets we engage in — SPP and ERCOT — are struggling with what enhancements are needed to encourage the types of generation that support reliable and low-cost operations in the new world of renewable generation that we're moving into."

Renewables can cause large fluctuations of voltage on the system, said Mary Ann Zehr, senior manager of transmission contracts, rates and policy at Tri-State. "But that's not due to the voltage control of the plants themselves. Rather, it's due to the megawatt loading fluctuation on the transmission system. This is very evident in high wind penetration, low load areas like Wyoming."

A rapid increase in wind or solar generation can cause a rapid increase in voltage on a system. Conversely, a rapid decrease in wind or solar can cause a rapid decrease in voltage before capacitors or load tap changers on transformers can respond; and worse, the capacitance of a capacitor decreases as the square of the voltage. Thus, a 2 percent decrease in the voltage can result in a 4 percent decrease in the reactive power provided by a capacitor. Moreover, if the capacitance decreases enough and cannot restore the voltage, the system voltage will spiral down further, decreasing the capacitance in a capacitor, potentially leading to a system voltage collapse and blackout.

The voltage from a wind or solar generator remains the same, but the variability of the generation can cause system voltages to vary. If there is a mismatch in the power system, a momentary spike in power can occur at a remote location. If capacitors or reactors are changed or a tap is moved, eventually the taps will wear out. The result may be arcing, which may cause overheating that could lead to a blown vent in the container where the tap is located. In the event of a spark, the tap changer could explode, which in turn could cause an explosion in the capacitor bank. The higher the percentage of wind generation, the greater the detrimental impact on grid voltage during periods of low loads.

So, what can a co-op do to mitigate impacts? One example is the daily reliability studies that Sunflower conducts to help it determine what voltage control devices must be in service to provide voltage support. The studies examine transmission system topology, including such issues as planned outages, forecasted load, forecasted output from wind generators, and forecasted dispatch of other generators that are planned to be on line. "We look at the combination of transmission lines, generators, and load to see if there are any potential thermal overloads or voltage issues. If we identify a potential reliability violation, we develop a mitigation plan, which may involve operating reactors (inductors) or capacitors or starting additional generation," Linville said.

Mitigation measures, such as starting additional generation and increasing operation of load tap changers for transformers will shorten their life, ultimately raising the cost to the overall system and the price of electricity.

**When the amount of wind generation sold into the market is high during off-peak hours, the locational marginal price can go negative.**

**If LMP remains lower than dispatch prices for coal-fired plants throughout the year, there may not be enough operating time for the coal-fired plants to cover O&M costs.**

### Volatile and negative market prices

Wind generation typically peaks at night, when market demand – and thus prices – are lower. Power pool purchases of wind are based on the locational marginal price (LMP), which reflects the value of wholesale energy at a specific location on the electric system. When the amount of wind generation sold into the market is high — especially during off-peak hours — the LMP can go negative.

Asked about the impact of negative LMPs on Golden Spread, the co-op's Moore said it can be significant. However, he added, the G&T can benefit from low LMPs, because they allow Golden Spread to shut down more expensive generation and buy negatively priced electricity, which will reduce costs to its distributors.

The lowest LMP he's seen? A negative $45 per megawatt-hour (MWh). "But as a general rule of thumb, wind farms associated with purchase power contracts should curtail output when the LMP falls below $23/MWh [the amount of the production tax credit]." Most markets have some mechanisms that provide the potential to hedge congestion between various locations. The allocation and feasibility of these hedging instruments is not always available, he said. "All of Golden Spread's wind contracts or owned wind generation serve the market and are dispatchable to the market," said Moore. This means that the wind farms can respond to price signals sent by the market, which makes for greater market efficiency.

Sunflower's market price is very inversely proportional to wind, said Linville. "If the wind is not blowing, prices will be higher and our coal unit will be at the top [of the dispatch list]. When the wind blows, prices are depressed and the coal unit is at the bottom." He said that the negative impacts are more detrimental than having lower prices.

If the LMP is significantly lower than the dispatch prices for coal-fired power plants for much of the time, it is possible that over the course of a year there will not be enough time for a coal-fired plant to generate enough margin or profit to pay for the costs of operation, maintenance, and staff, said Bradshaw. "As a result, a G&T may have to evaluate mothballing the plant during the spring and fall seasons when profitability is low or potentially even negative, or may have to consider a complete shutdown of the plant, replacing it with natural gas-fired combined cycle generation."

Tri-State, too, has seen some negative pricing, said Walter. "It's generally due to a combination of transmission congestion, low load, and high regional winds." He noted that the wind production tax credit (PTC) — a federal incentive paying 2.3 cents/kWh to wind projects — means that for a near zero production cost resource like wind to be backed down for economic reasons, prices must reach a negative value of approximately the PTC or a negative $23/MWh. From an economic standpoint, wind resources are the last to be backed down, and a negative price is typically required to incentivize them to do so.

Sunflower's Linville noted that the LMP consists of three components: marginal cost of energy, congestion, and losses. "You have a stack of resources, from the cheapest to the most expensive. Whatever is the cheapest will drive the marginal cost of energy. And, the more you load the [transmission] line, the more losses you have."

But ultimately, maximizing use of a near zero production cost resource like wind will decrease the LMP and, thus, decrease the wholesale costs for the G&T and its distributors, even though there will be other increases in operation and maintenance, fuel, and replacement energy costs, for their existing fossil generation.

**"When you have more wind than load, you have transmission congestion."**

*– Corey Linville, vice president, power supply and delivery, Sunflower and Mid-Kansas*

**Transmission congestion, costs**

The transmission system was built to serve a rural load, not to export excess generation, said Linville. "When you have more wind than load, you have transmission congestion."

One way to solve congestion is to build more transmission, he said. "A large project went on line in December 2014, and it significantly reduced transmission congestion." But since then, the benefits are fading as the line's capacity is reached. "Because of the way SPP allocates costs for transmission upgrade projects, our members have to pay for transmission upgrades caused by the addition to our system of wind that is intended to serve other loads external to our area."

There is talk of a high-capacity DC transmission project, the Grain Belt Express Clean Line, that would allow wind to be exported from Kansas and Texas to points in MISO, said Linville. "It would be isolated from the existing AC transmission system, so you might be able to avoid the current congestion impacts – but it is expensive and faces many hurdles." If such a project is not built, he said, there will likely be more transmission upgrade costs associated with wind, which will increase the overall cost of electricity to member systems.

Texas, too, has seen wind overtake the capacity of transmission lines to carry it. In a bid to address congestion, ERCOT has developed Competitive Renewable Energy Zones (CREZ) — transmission projects for wind generation. The projects, costing almost $7 billion, stretch nearly 3,600 miles, and carry 18,500 MW of wind energy across the state.

"The CREZ lines were built for thousands of megawatts," said Golden Spread's Wise. "But even more (wind generation) showed up." With the system nearing capacity, the Texas Public Utility Commission authorized additional investment in the Panhandle's CREZ transmission system to allow more renewable energy resources to connect and ensure that ERCOT operators can maintain system reliability.

Sharyland Utilities recently added a new transmission line, which connects Golden Spread's Antelope Elk Energy Center with the ERCOT CREZ transmission system. The CREZ line enables Golden Spread and other interconnecting generators to provide power, including wind power, to the ERCOT market.

DC transmission lines are seen as a way of facilitating the delivery of large amounts of wind energy. However, the United States has only 11 DC transmission lines or back-to-back AC to DC terminals in service at present, according the North American Electric Reliability Corp. (NERC). These lines or back-to-back AC to DC terminals are limited in capacity, ranging from 150 MW to 600 MW. An additional 28 DC projects have been proposed, some with capacities as great as 4,000 MW.

Five of these projects have been proposed by Clean Line Energy. One of those projects, the 4,000-MW Plains & Eastern line, has received approval from DOE. The $2.5 billion line will run from the Oklahoma Panhandle through Arkansas to Tennessee. Construction is expected to begin in 2017, with the line coming into service in 2020. If completed by that date, the project will have taken 11 years from proposal to reality. Clean Line asked Iowa regulators to suspend their review of a second project — the 3,500-MW Rock Island line — because of opposition from landowners. A third project — the 3,500-MW Grain Belt Express line — was blocked by the Missouri Public Service Commission because the developer had not proven the need for the $2 billion project. No information was available on the status of the 3,500-MW Centennial West line or the 1,500-MW Western Spirit line. Siting high-voltage AC lines and even lower visual impact high-voltage DC lines involves long lead times — sometimes a decade or more — with significant regulatory hurdles before construction can begin.

## PREPARING FOR RENEWABLE VARIABILITY

Planning for ramping involves evaluations of a couple of factors: projecting growth in renewables generation and load; and identifying the flexible assets available to address ramping.

### Projecting growth in renewable generation and load

Asked if they plan to add wind generation to their portfolio over the next five years, both Golden Spread and Sunflower said no. But, that does not mean wind will have no impact on their operations. "Plans for a 400-MW wind farm in western Kansas were recently announced," said Sunflower's Linville. "This wind farm would simply add to the operational challenges already presented by the roughly 1,500 MW of wind in our area." As the amount of installed wind increases — and with it, transmission congestion — the impacts on the wholesale power market and on the cycling of existing fossil-fuel resources are exacerbated, he added.

Greater wind generation can lead to more cycling and two-shift operation of the co-op's coal-fired plant and result in a significant increase in the number of starts of the co-op's combustion turbine and reciprocating internal combustion engine units, said Bradshaw.

Tri-State G&T, on the other hand, could continue to add wind and solar PV to its generation portfolio, said Walter. "If more renewables are mandated by the state or the federal government, or justified for economic reasons, the co-op "will keep building them," he said.

## CONCLUSION

The growing penetration of wind and solar PV — especially in the Midwestern "Wind Belt" and the Southwestern part of the country — has led to increased variable power and energy output from intermittent and non-dispatchable renewable generation that can make it more difficult to balance load and generation. This variability, or *ramping*, is affecting G&T cooperatives that rely on wind and/or solar PV for a share of their generation. These co-ops are experiencing operational issues associated with fossil-fuel-fired plant cycling, as well as reliability issues in their system. Furthermore, through their participation in organized electricity markets, they are subject to volatile pricing and transmission congestion.

As the penetration of wind and solar PV resources, including distributed solar PV resources, increases across larger swaths of co-op territory, G&T and electric distribution co-ops will be confronted with additional issues associated with the ramping caused by these resources. This ramping will cause cyclic operation of fossil-fueled generation — both coal- and natural gas-fired power plants — resulting in:

- Increased forced outage rates,
- The need for additional peaking capacity, increased O&M costs, and increased replacement energy costs,
- Voltage and frequency spikes that can trip either under/over voltage or under/over frequency relays,
- Phase imbalance in three-phase lines,
- Reduced system reliability,
- Increased transmission congestion, and
- Volatile market prices.

Advanced wind technologies, lower costs for solar PV, and the extension of the PTC and ITC will likely increase the penetration of variable generation renewables. G&Ts that have not experienced high penetrations can learn from those that have, and begin mitigation measures discussed in this article as well as in Part II of this article series.

The second *TechSurveillance* article in this series on renewable variability will explore how some co-ops are using such options as flexible generating assets, and precise forecasting and ancillary services to address renewables ramping. ■

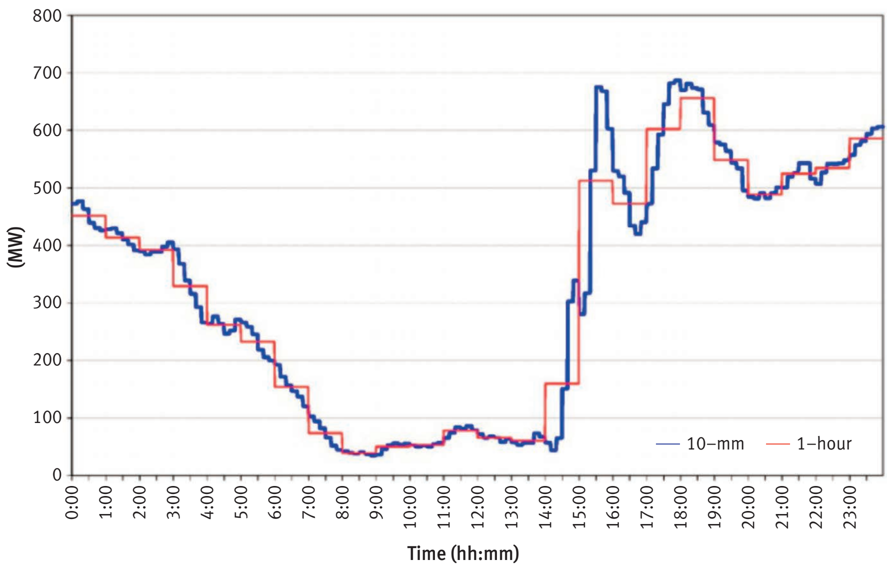
## PLOTTING THE UNPREDICTABLE

The characteristics of utility-scale wind and solar variability differ significantly from one another.

*Wind variability.* Wind variability can occur in minute and hourly intervals, as well as on a daily and seasonal basis. Such ramps can result in wind power level changes in the thousands of megawatts in locations with a significant concentration of large-scale utility wind generation, according to the National Renewable Energy Laboratory (NREL), which analyzed ramping behavior in ERCOT.

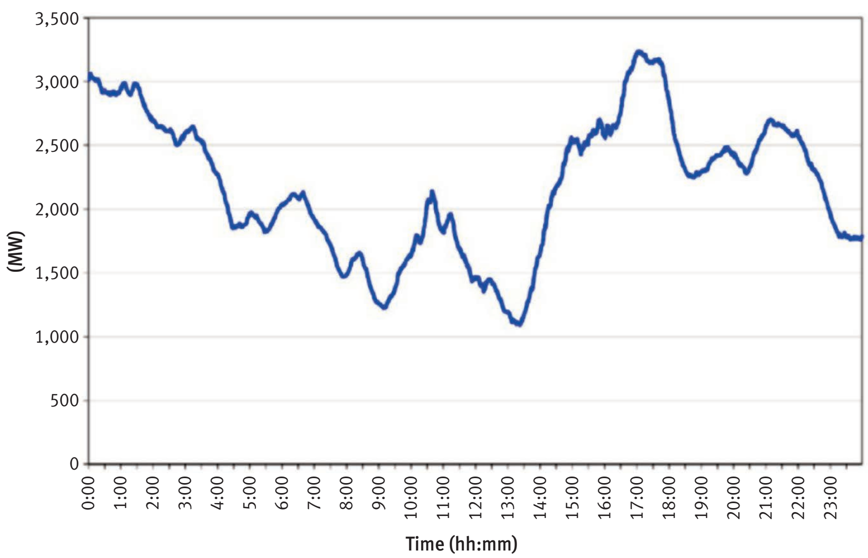
Over a 10-minute period, for example, NREL found that the ramp rate can be equivalent to 4.5 percent of total wind capacity. Over an hour, it can be equivalent to 26.6 percent. Figure 1 is an example of a Texas daily wind power profile plotted with 10-minute and hourly average values.

Another example of a daily ramp is shown in Figure 2, which profiles wind output in the ERCOT system. In the example, the difference between daily maximum and minimum power is more than 2,100 MW, according to NREL It noted that many smaller up and down movements with durations ranging from minutes to hours interspersed in between created the peaks and valleys. The example, said NREL, "points to the difficulty of objectively identifying wind power ramping events."




Daily wind power profile example. Reprinted from the National Renewable Energy Laboratory report "*Analysis of Wind Power Ramping Behavior in ERCOT*" (March 2011), by Y. H. Wan, http://www.nrel.gov/docs/fy11osti/49218.pdf, accessed August 5, 2016.

**FIGURE 1: Total Texas Wind Power Profile July 23, 2005** *(NREL, Analysis of Wind Power Ramping Behavior in ERCOT)*




Example of daily wind power profile plotted with 10-minute and hourly average values. Reprinted from the National Renewable Energy Laboratory report "*Analysis of Wind Power Ramping Behavior in ERCOT*" (March 2011), by Y. H. Wan, http://www.nrel.gov/docs/fy11osti/49218.pdf, accessed August 5, 2016.

**FIGURE 2: ERCOT Wind Power Daily Profile Example** *(NREL, Analysis of Wind Power Ramping Behavior in ERCOT)*

*Continued*

## PLOTTING THE UNPREDICTABLE (CONT.)

In ERCOT, a relatively large ramp with a magnitude of at least 25 percent of total wind capacity will occur about once every other day, said NREL. The majority of up ramp events start in the afternoon hours and the majority of down ramp events start in the morning hours.

In addition to daily ramps, wind facilities are subject to seasonal variations. Wind generation performance varies throughout the year as a result of highly seasonal wind patterns, according to the U.S. Energy Information Administration (EIA). Nationally, wind plant performance tends to be highest during the spring and lowest during the mid- to late summer, while performance during the winter (November through February) is around the annual median. However, added EIA, this pattern can vary considerably across regions, mostly based on local atmospheric and geographic conditions. Figure 3 shows monthly median wind capacity factors in various regions of the country.

The effect of seasonal wind patterns can be easier to predict than minute and hourly patterns, according to NREL. Very large wind ramp events tend to occur in winter, it said, noting that 10 of the 12 largest ramp events in ERCOT occurred in winter.

*Solar ramping*. Solar PV generation tends to begin about 9 a.m., peak at noon and drop off rapidly about 3 p.m., producing a bell curve. Like wind, solar PV output can vary from minute-to-minute and on an hourly basis. But while multi-hour wind ramps can vary significantly (as shown in **Figure 2**), solar PV produces the kind of bell curve shown in **Figure 4** and **Figure 5**.

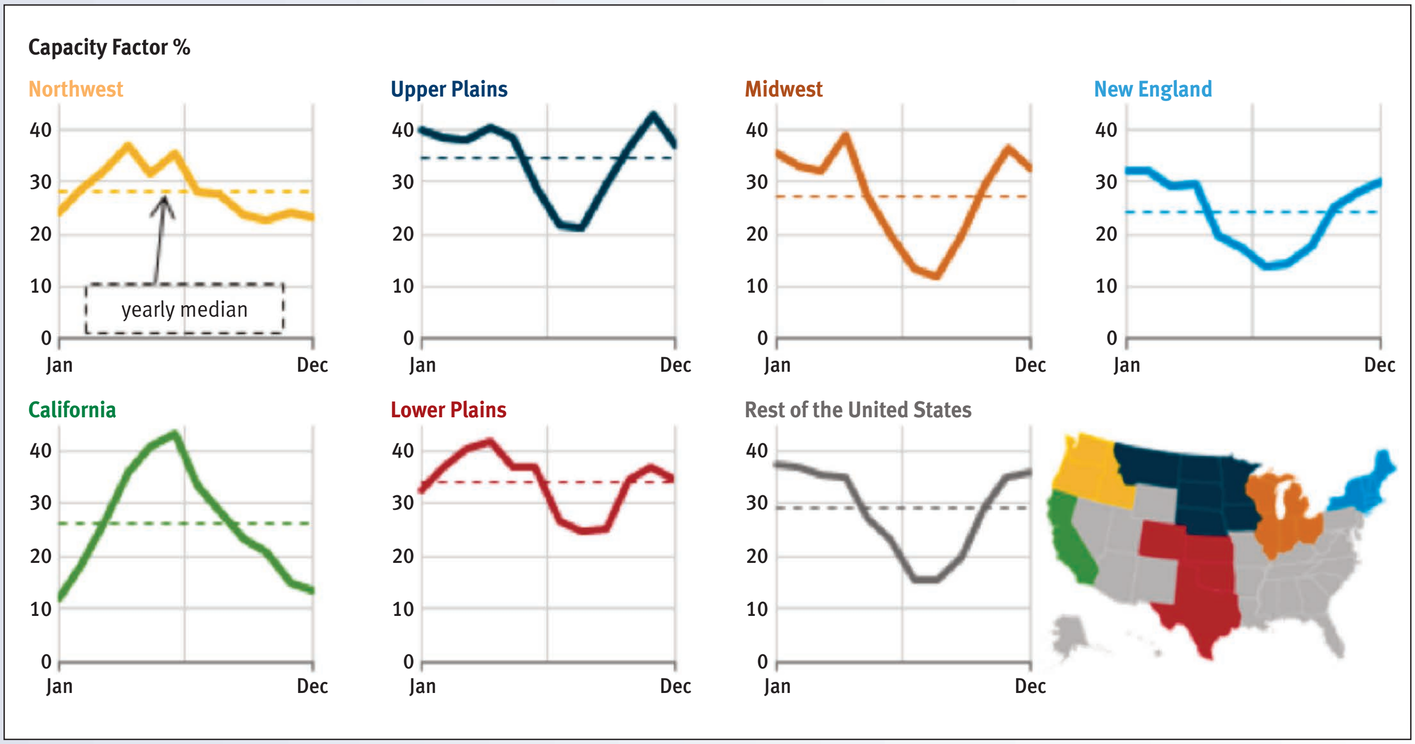


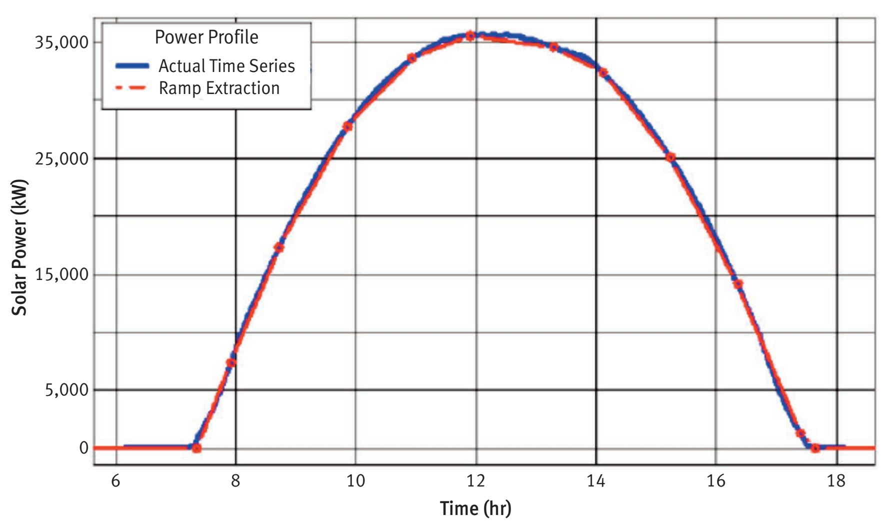

**FIGURE 3: Monthly Median Wind Plant Capacity Factors (2001–13)** *(Energy Information Adminstration)*

*Continued*

## PLOTTING THE UNPREDICTABLE (CONT.)

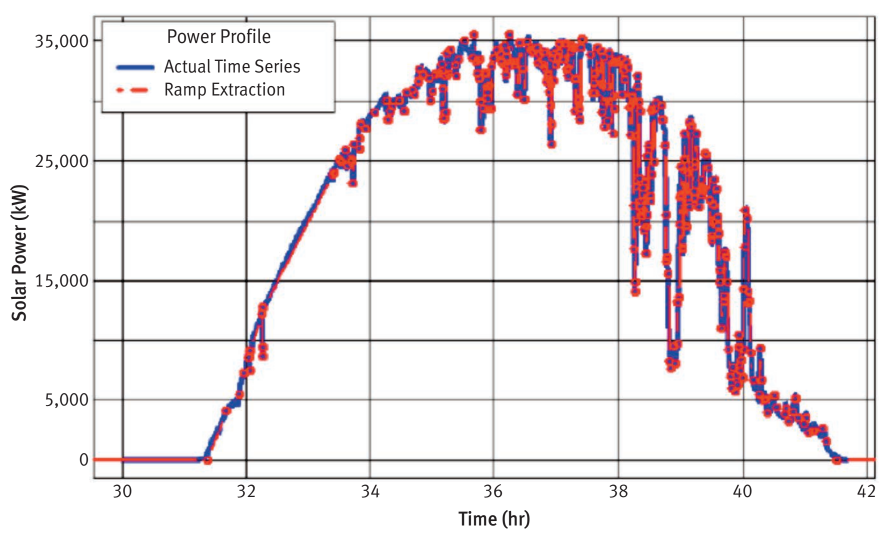
Regional weather patterns can increase or decrease solar output during specific times of year. In the Southwest, for instance, during the North American Monsoon — a regional-scale circulation pattern associated with a dramatic increase in cloud cover and rainfall — solar PV output declines in the months of July to September. Among the states affected by the monsoon are Arizona, New Mexico, Southern California, Utah, and Colorado.

In the Southeastern part of the country, on the other hand, there can be significant cloud cover in January and February, while the summer can be partly cloudy with periodic thunderstorms. Spring and fall are typically partly cloudy, with spring being the best season for solar PV. Figure 6 shows the output for a September day in the Southeast.




Typical example of ramp extraction from the first of two days of power at a PV solar plant, showing a clear day leading to a smooth profile. Reprinted from the National Renewable Energy Laboratory report "*Identifying Wind and Solar Ramping Events: Preprint*" (January 2013), by A. Florita, B.M. Hodge, and K. Orwig, http://www.nrel.gov/docs/fy13osti/57447.pdf, accessed August 5, 2016.

**FIGURE 4: Typical example of ramp extraction from the first of two days of power at PV solar plant, showing clear day.** *(Source: NREL, Identifying Wind and Solar Ramping Events)*




Typical example of ramp extraction from the second of two days of power at a PV solar plant, showing up and down ramps because of clouds. Reprinted from the National Renewable Energy Laboratory report "*Identifying Wind and Solar Ramping Events: Preprint*" (January 2013), by A. Florita, B.M. Hodge, and K. Orwig, http://www.nrel.gov/docs/fy13osti/57447.pdf, accessed August 5, 2016.

**FIGURE 5: Typical example of ramp extraction from the second of two days of power at a PV solar plant, showing up and down ramps because of clouds.** *(Source: NREL, Identifying Wind and Solar Ramping Events)*

*Continued*

## PLOTTING THE UNPREDICTABLE (CONT.)

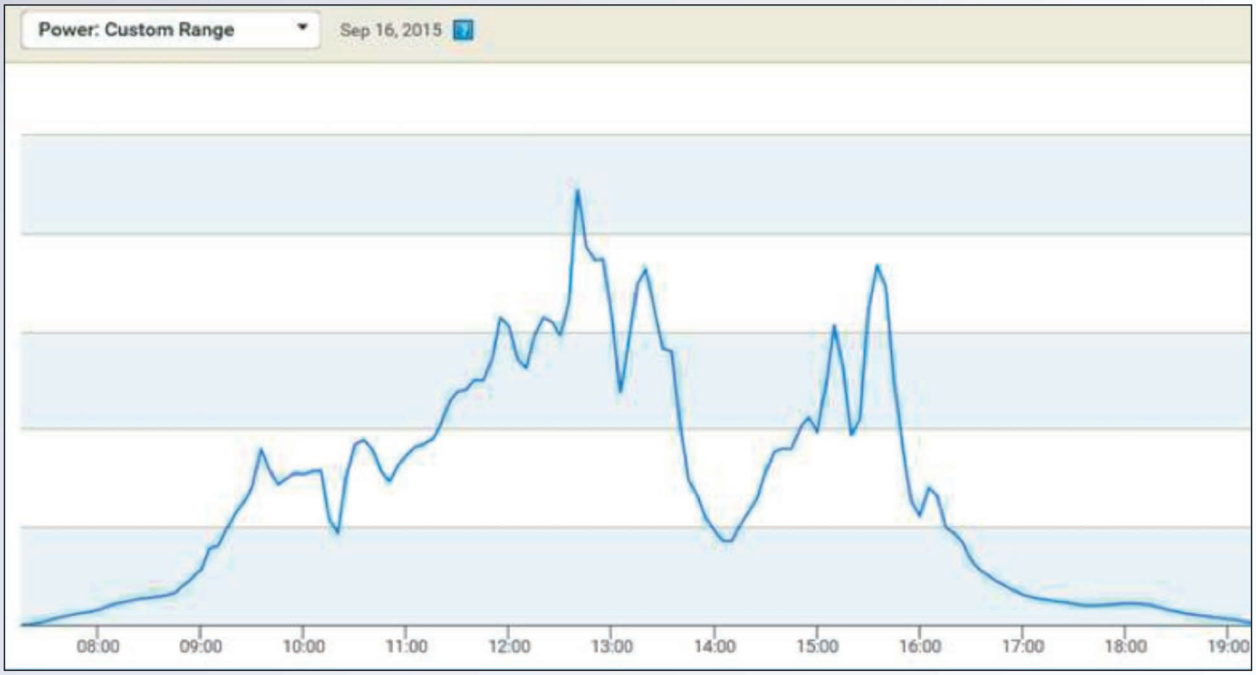



**FIGURE 6: Output from a solar PV system on a September day in the Southeastern United States.**
*(Source....)*

## THE LOAD CURVE: *IF IT LOOKS LIKE A DUCK...*

California leads the nation with more than 10,000 megawatts (MW) of installed solar capacity — both utility-scale and distributed generation. And, with a goal of providing 33 percent of its electricity from renewable resources by 2020 and 50 percent by 2030, the state will have even more solar.

Therein lies the challenge.

As solar penetration grows, it will increase the ramping down and up of resources designed as baseload resources (i.e., fossil-fueled resources) due to the variable nature of the resource. The California Independent System Operator (CAISO) has produced a graphic — the so-called duck curve — that shows the extent to which solar generation will displace baseload generation between about 8 a.m. and 6 p.m. over the next several years. With each succeeding year, the extent of thermal generation's down ramp in the morning and up ramp in the late afternoon increases.

Overgeneration of solar — the duck's "belly" — is greatest in the mid-afternoon. But, as solar output begins to drop sharply in the late afternoon, and significant baseload generation is needed to meet the load.

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## THE LOAD CURVE: *IF IT LOOKS LIKE A DUCK…*(CONT.)

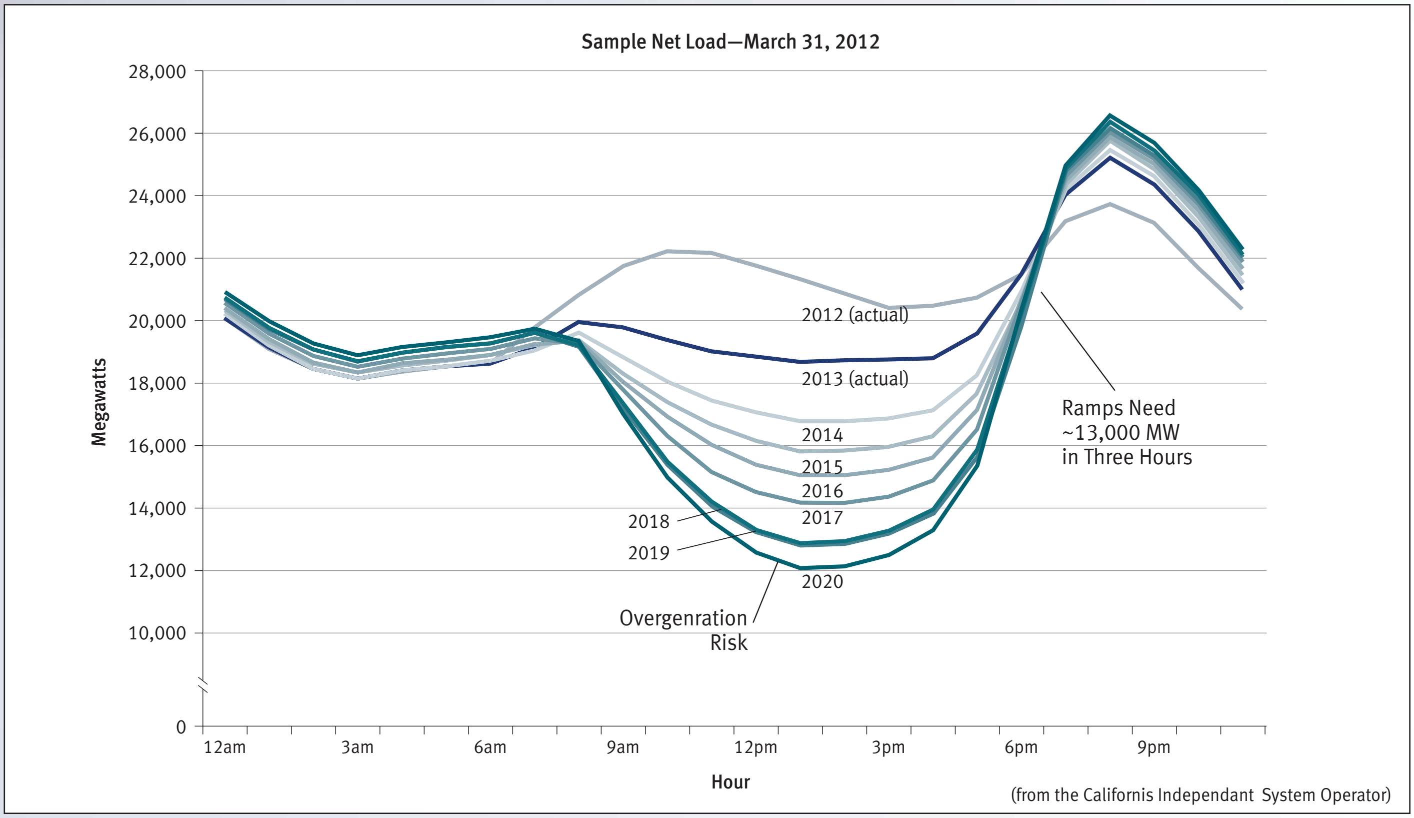


**FIGURE 1: The Duck curve shows steep ramping needs and overgeneration risks**

CAISO has identified several emerging conditions that will require specific resource operational capabilities. They include:

- **Short, steep ramps** — when the ISO must bring on or shut down dispatchable generation resources to meet an increasing or decreasing electricity demand quickly, over a short period of time.
- **Oversupply risk** — when more electricity is supplied than is needed to satisfy real-time electricity requirements. This will become a growing problem, initially in the spring and the fall when the loads are low, as more solar is installed. This will become a problem as the CAISO has generation that must operate like baseload nuclear plants, qualified combined heat and power facilities (as defined by the Public Utility Resource Policy Act or PURPA), and hydroelectric facilities with minimal flow requirements. There is also a concern that prior to 2020, CAISO may have insufficient spinning reserves for emergencies, insufficient generation to provide frequency regulation, or insufficient system inertia to respond to dynamic or transient system instability. To help mitigate these risks, California has a mandate to install 1,350 MW of energy storage by 2020. Energy storage can be used to provide system inertia, frequency regulation, and spinning reserve.
- **Decreased frequency response** — when fewer dispatchable generation resources are operating and available to automatically adjust electricity production to maintain grid reliability.

Figure 2 shows the loads dipping below system minimum generation.

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## THE LOAD CURVE: *IF IT LOOKS LIKE A DUCK*...(CONT.)

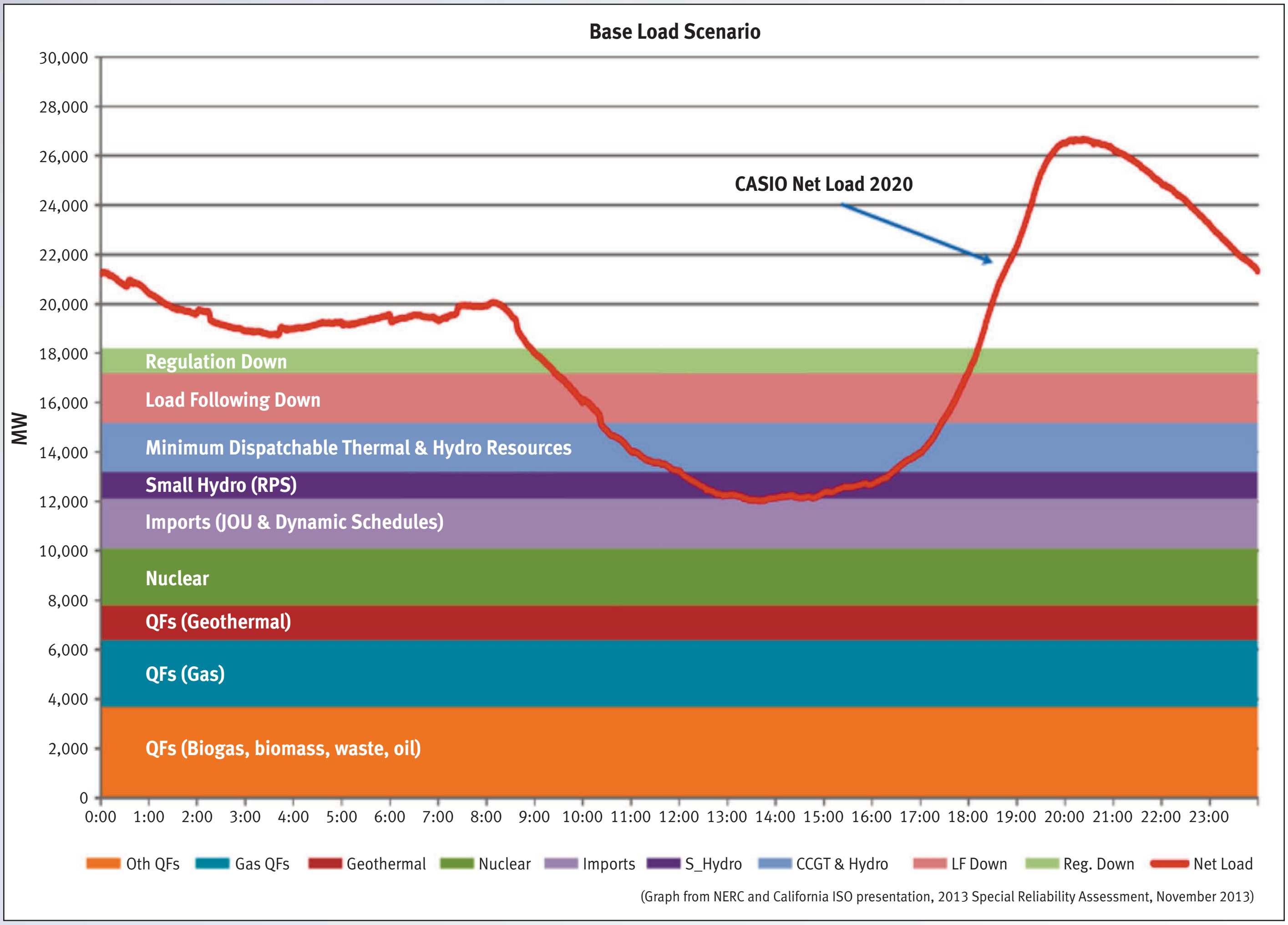


**FIGURE 2: Potential Overgeneration Conditions – March 2020**

To reliably operate in these conditions, the ISO said it needs flexible and fast responding generation resources defined by their operating capabilities, such as the ability to sustain upward or downward ramps, change ramp direction quickly and start with short notice from a zero or low-electricity operating level. Examples of this would be hydroelectric resources, fossil fired generation resources operating at above minimum load, energy storage, and fast-response natural gas-fired reciprocating internal combustion engines or aeroderivative gas turbines.

Overgeneration of solar — current and projected — appears to be an issue created in part by California's ambitious renewable portfolio standard (RPS). But, if other states boost their RPS goals or solar PV prices continued to drop to where a significant quantity of residential and commercial solar PV is installed, the duck could be landing elsewhere in the country.

California is working on strategies to mitigate the impact of variable generation. On April 24, 2016, simultaneous wind

*Continued*

## THE LOAD CURVE: *IF IT LOOKS LIKE A DUCK*…(CONT.)

and solar output exceeded 10,000 MW (approximately 7,000 MW of total solar capacity). Wind and solar together are helping to balance the system (i.e. taming the duck curve). In CAISO, there are an estimated 4,000 MW of roof top solar. In early 2016, CAISO renewables provided 50 percent of the generation needs. If hydro and nuclear are included, over 70 percent of generation was provided by carbon-neutral resources. In one instance, however, approximately 2,000 MW of renewable production had to be curtailed because of oversupply. Current CAISO projections indicate that renewable curtailment in 2024 — assuming a 40 percent RPS — is projected to be significant. CAISO is considering the following mitigation measures:

- Additional energy efficiency
- Increased storage and demand response
- Enable economic dispatch of renewables
- Decarbonize transportation fuels (use of electric vehicles)
- Retrofit existing power plants
- Align time-of-use rates with system conditions
- Diversify resource portfolio
- Deepen regional coordination

CAISO monitors and studies impacts on essential reliability services. For example, meeting ramping requirements during certain hours of the day, e.g., when the sun is going down. Another example is meeting the challenge of variability and forecasting (e.g., lost 2,000 MW due to cloud cover in one instance). CAISO is ahead of the curve, but still has a long way to go. In the future, it will likely be a model of what to do and not to do.

## THE UPS AND DOWNS OF SOLAR GENERATION IN THE SOUTHWEST

Arizona Public Service (APS) is a major player in solar PV, ranking 4th in the country for cumulative megawatts for an investor-owned utility. APS has 235 MW of grid-scale capacity, owned and under contract; 250 MW of solar thermal capacity, under contract; and 549 MW of distributed solar PV capacity — mainly customer-leased. The solar thermal plant has six hours of integrated storage, and during the summer, it operates until midnight or beyond.

Of the utility's total peak installed capacity of just over 9,000 MW, solar accounts for roughly 10 percent. But, solar's output already is great enough to necessitate the cycling of APS's fossil-fueled units, said Brad Albert, general manager of resource management. "We're cycling our [coal- and natural gas-fired] units on and off, to work through the solar production. It's a fact of life for us." But, the number of starts and stops of the utility's natural gas-fired units, especially its large combined cycle unit, has created maintenance issues. "Eventually, cycling will trigger the need for an advanced overhaul," he said.

At a certain point in the year, if the air conditioning load is high enough in the middle of the day, [cycling] mitigates operational challenges, said Albert. "From November to April, we're solidly in the duck curve — a phenomenon depicted by a graphic showing the extent to which solar generation will displace baseload generation between about 8 a.m. and 6 p.m. over the next few years. With each succeeding year, the extent of thermal generation's down ramp in the morning and up ramp in the late afternoon increases. "It's an everyday occurrence that we have to manage," said Albert.

*Continued*

## THE UPS AND DOWNS OF SOLAR GENERATION IN THE SOUTHWEST (CONT.)

**Impacts of variability**

The impact of lower natural gas prices and the duck curve has led to the economic curtailment of APS's coal plants, sometimes for months. "But, we have a number of high-efficiency gas-fired combined cycle units, and although they have relatively high minimum loading levels, they ramp so quickly up and down that they are workhorses."

In the last 10 years, APS has acquired roughly 500 MW of quick-start combustion turbines that represent very flexible assets, said Albert. "Although our gas-fired fleet provides some degree of flexibility, we have identified the need for more flexible assets." Under an RFP issued last year, the winning bidder will modernize the older gas-fired steam boilers and install quick-start — but also highly efficient — GE LMS 100 aeroderivative simple-cycle combustion turbines. "That's the type of generation we need to meet the challenges of renewables generation."

Asked about the effect of solar's variability on the APS system, Albert said that the utility is starting to see a fairly heavy penetration of distribution feeders by rooftop solar systems. "In non-summer months, when customer demand on feeders is relatively low, but rooftop production is high, we see high voltage conditions that cause inadvertent tripping of rooftop systems." And on some feeders, he noted, APS has seen net backflow onto the sub-transmission system.

APS does not participate in an organized market, rather acting as its own balancing authority. But, Albert noted, "we do sit on the doorstep of the California ISO and we conduct a number of transactions in its market structure." APS watches for negative pricing as a result of solar overgeneration. "If the price pressures are great enough, we curtail our grid-scale solar facilities because it's a better deal for our customers." And, if the utility sees it coming on a day-ahead basis, it adjusts the commitment of its generation units.

"Given California's aggressive renewable energy targets, I think negative prices will only become more substantial," said Albert.

## About the Author

**Alice Clamp** is a technology writer for the Cooperative Research Network, a service of the Arlington, Virginia-based National Rural Electric Cooperative Association. With more than two decades of experience in the energy field, she has researched and written articles on renewable energy, nuclear energy, fossil fuels, grid reliability, environmental issues, energy efficiency, demand response, and emerging technologies.

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