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Several Technical and Economic Options Can Help G&T Electric Cooperatives Integrate Renewable Energy into the Grid

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This is the third article in our TechSurveillance *series discussing issues with the integration of variable utility-scale wind and solar photo voltaic (PV) generation in the electric transmission and distribution grid. The* ***first article*** *in the series addressed the impacts of variable generation on utility operations of the grid, while the* ***second article*** *discussed new, more flexible fossil generation technologies for mitigating such impacts. This article examines additional options for addressing renewables' intermittency and variability impacts on generation and transmission (G&T) cooperatives.*

ARTICLE SNAPSHOT:

What has changed in the industry?

The installed capacity of renewable energy resources — primarily utility-scale wind and solar photovoltaics (PV) — has been rising 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 pose challenges for grid operators and utilities, including electric cooperatives. Output from

NRECA
America's Electric Cooperatives

these renewable resources can drop or rise suddenly. These rapid output changes — or *ramps* — can occur with little or no warning, affecting electric power operations and making the balancing of load and generation more difficult to manage.

What is the impact on cooperatives?

The sudden, rapid ramping up and down of renewables' output can present operational, reliability, and economic challenges for generation and transmission (G&T) cooperatives' coal-fired plants and natural gas-fired combined cycle gas turbines. Among the operational issues is the need to cycle, two shift, or even double two shift (and eventually start up and shut down twice a day). Fossil fuel-fired generating plants will need to respond to a rapid increase or decrease in renewable output. Reliability issues for G&Ts due to spikes and dips in power, voltage, and potentially frequency are inadvertent operation of relays and circuit breakers.

The economic issues include volatile and negative market prices due to fluctuations of under- and oversupply of power and energy. Because of negative prices in a number of markets caused by solar and wind output, many existing fossil generation plants may not be able to generate enough margin (differential between market price and total variable cost of operation) to pay for their fixed operating costs (primarily staff), potentially resulting in premature retirement and perhaps decommissioning.

In addition, fossil plant operation and maintenance costs could increase by 20 percent per year, due to temperature transients, which will cause significant thermal cycle fatigue and creep. This may result in increased rupture of coal-fired power plant boilers, rapid corrosion of air preheaters and erosion of steam turbines because of exfoliated corrosion products. It may also result in failures to combined cycle gas turbine hot gas paths, compressor and gas turbine blades, steam turbine blades, and heat recovery steam generators' boiler tubes, condensers, and air preheaters.

Research by EPRI and DOE suggests a substantial increase in O&M costs at hydroelectric facilities due to breaker cycling, which is occurring with increased renewable penetration.

Some G&Ts with significant penetration of wind energy have experienced several of these ramping impacts. 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, buy wind energy through a power purchase agreement (PPA), or both. But, as the cost for wind turbines continues to decrease with taller towers and longer blades – which also results in higher capacity factors, more wind turbines will be added throughout the Eastern United States.

What do cooperatives need to know and/or do?

G&Ts that operate renewable facilities, purchase wind or solar energy under a PPA, or have experienced significant growth in distributed solar generation within their service territory have a number of technical and economic options that can help them mitigate the impacts of renewable generation variability. These options may include energy storage and demand-side management. Currently, it is not known what percentage of renewables' penetration will overwhelm the ability of the existing fossil fleet (coal- and natural gas-fired power plants) to respond to the rapid up and down ramps and non-dispatchability of renewable resources.

The Southwest Power Pool (SPP), for example, was able to respond to wind penetration levels exceeding 50 percent for hours at a time in 2017 with existing fossil fleet resources. The SPP analyzed forecasted high wind operating days 4 to 7 days in advance using a Multi-Day Reliability Assessment (MDRA) and subsequent Reliability Unit Commitment (RUC) studies that account for errors in the wind and load forecast. Wind generation in the SPP has dropped by 70 percent to 80 percent in less than 2 hours, allowing adequate time for conventional fossil fleets to respond.

INTRODUCTION

Today, wind resources dominate the renewables' portfolio of electric cooperatives, with more than 6.7 GW of wind owned or under contract. A majority of cooperative renewable power comes from power purchase agreements (PPAs). An additional 850 MW of PPAs are planned over the next 2 to 3 years, according to research by NRECA's Resource Adequacy and Markets work group. (See the *TechSurveillance* article ***Growth of Wind Generation in the Electric Cooperative Community*** for more information.)

Although solar PV capacity in the electric cooperative community is growing quickly, it still lags behind the significant penetration today of wind energy. While the nation's wind resources currently are located mainly in the Midwestern "Wind Belt," which runs from the Canadian border in North Dakota to southern Texas, improving wind energy economics are supporting the expansion of wind energy to the rest of the United States. Wind tower heights now exceed 100 meters (nearly 330 feet) and greater blade lengths have improved capacity factors by 50 percent or more.

The characteristics of utility-scale wind and solar ramping differ significantly from one another. Wind ramping 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, according to the National Renewable Energy Laboratory (NREL). Over a 10-minute period, for example, NREL found that the ramp rate change can be equivalent to 4.5 percent of total wind capacity. Over an hour, this percentage can reach 26.6 percent. Figure 1 is an example of the significant impact of changes in wind output within minutes (which notably is greater than 4.5 percent change) and its impact on the frequency on the electric system of the island of Maui, Hawaii.

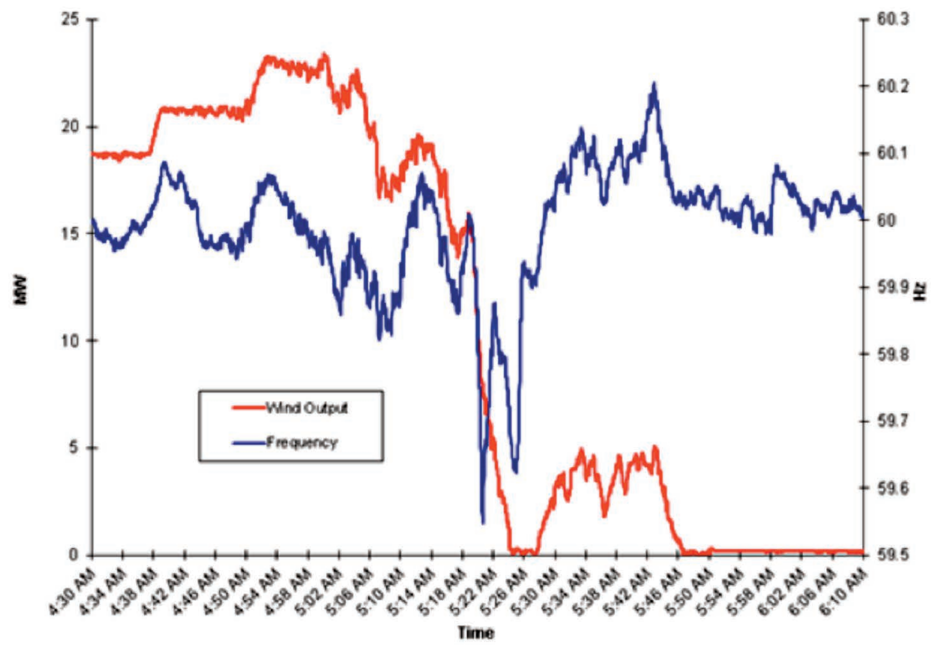


FIGURE 1: Example of wind variability and its effect on frequency. *(Source: **https://www.mauielectric.com/clean-energy-hawaii/clean-energy-facts/wind-energy-integration**)*

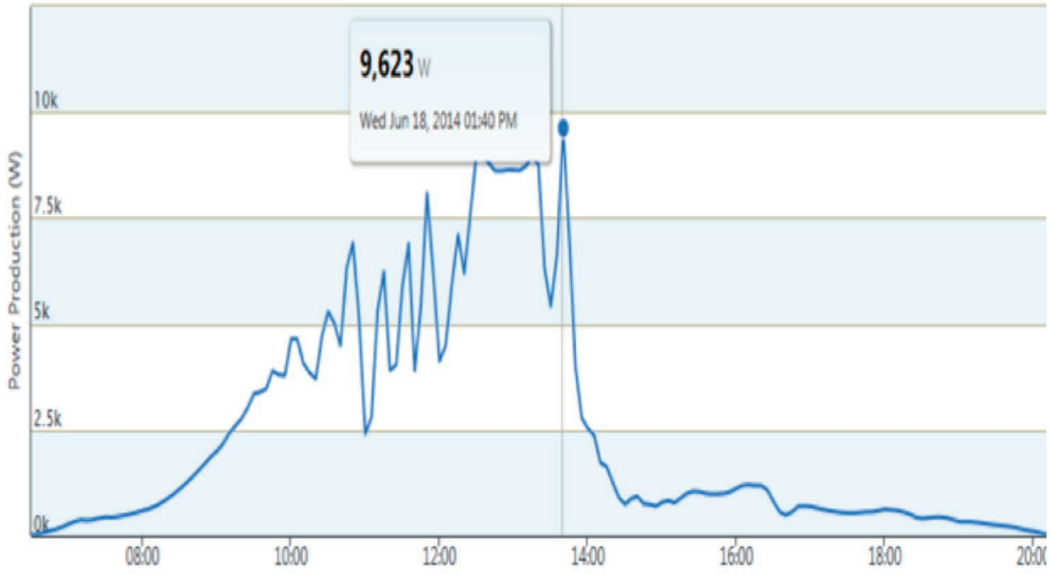
***Uncertainty* relates to a deviation in actual production from forecast production, while *variability* refers to the nature of the energy source.**

solar PV generation tends to begin about 9:00 a.m., peak at noon, and drop off rapidly about 3:00 p.m. This produces a distinctive bell curve for solar PV systems that face south. Like wind, solar PV output can vary from minute to minute and on an hourly basis. But, while multi-hour and daily wind ramps can vary significantly, the typical daily output curve for solar PV can be more predictable, except on cloudy days or during inclement weather. Solar PV can cause significant ramps at a specific location, as is evident from Figure 2.

Note that Solar PV variability can be significantly worse than solar PV forecasts, as shown in Figure 3.

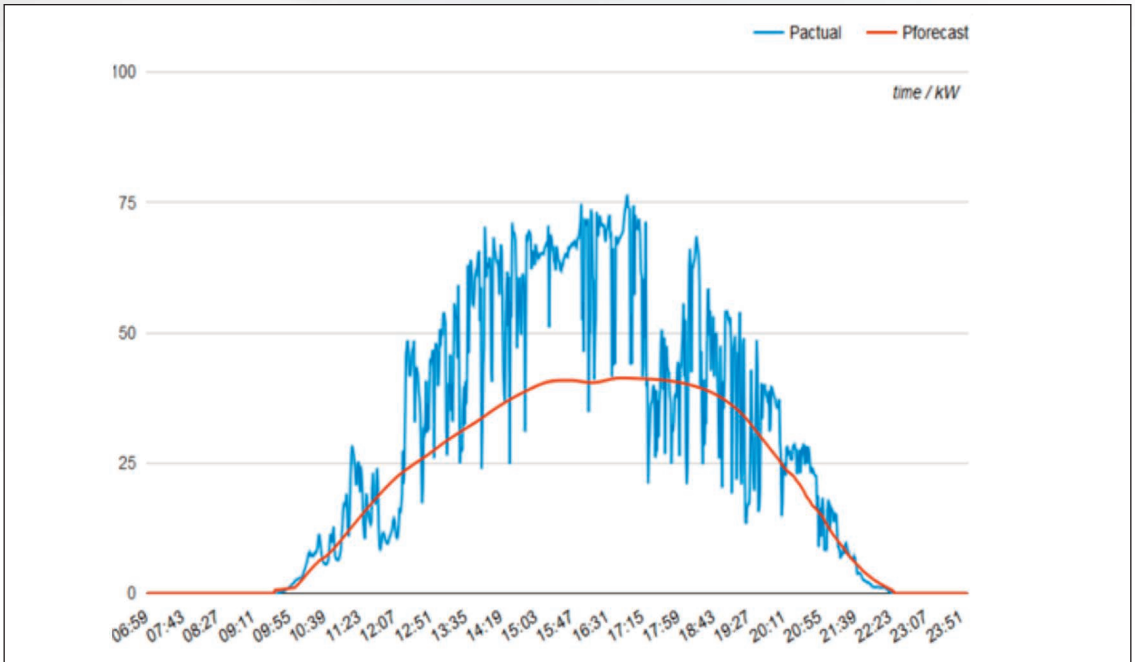
Wind and solar resources also have distinct characteristics that increase the need for flexible resources, such as gas-fired reciprocating internal combustion engines or gas-fired aeroderivative gas turbines. These resources can reach full load in less than a minute or up to 5 minutes, depending on whether the reciprocating internal combustion engines or gas-fired aeroderivative gas turbines are hot or cold during startup.

In general, wind and solar can both be characterized as having some levels of variability and uncertainty, according to NREL. *Uncertainty* relates to a deviation in actual production from forecast production (forecast error), while *variability* refers to the nature of the energy source. Wind has a higher level of uncertainty, but a slightly lower level of variability than solar. Conversely, solar has a lower level of uncertainty and more predictable output day to day and hour to hour. Solar has a marginally higher degree of variability, as solar resources produce zero power every night, and near peak power in the middle of the day and during seasons when loads are low. Wind, however, has fewer times when there is either zero power or near peak power, so overall there is less variability.



Source: Impact of Cyclic/Two Shift Operation on the Reliability, Economics, and Emissions of Fossil Generation (Coal and Combined Cycle Gas Turbine" by Dan Walsh and Dale Bradshaw, PowerGen international 2015, Las Vegas Nevada

FIGURE 2: Typical Solar PV production with significant down ramp in minutes caused by a thunderstorm which is typical for solar PV production in the Eastern United States in the spring and summer time



Source: JudithCurry.com

FIGURE 3: Actual solar PV production versus forecasts showing significant variation in ramping in solar PV production

In its *Western Wind and Solar Integration Study*, NREL pointed out that more grid integration studies have investigated high wind penetrations than high solar penetrations, as there are more grid systems facing high wind penetration than solar, though this may change in the near future.

A number of options — including the optimization of the economic and technical performance of a wind or solar PV facility — are available to promote the integration of renewables in the grid.

ELECTRICITY STORAGE

Energy storage systems — including batteries, flywheels, supercapacitors, compressed air, and pumped hydroelectric storage, as well as traditional hydroelectric systems with pondage (water storage) — have the potential to assist in integrating renewable energy in the grid and help optimize grid operation. Energy storage systems such as batteries, flywheels, and super capacitors respond in seconds to the need to ramp up or down, while compressed air and pumped hydroelectric storage systems take minutes to respond to ramp-up or ramp-down capacity demands.

In the future, energy storage systems may become the lowest cost option for managing the intermittency and non-dispatchability of renewable energy generation, potentially displacing the need to add natural gas-fired reciprocating internal combustion engines or aeroderivative gas turbines. Energy market barriers that have typically blocked energy storage have recently been removed by the Federal Energy Regulatory Commission's Order 841 (**https://www.ferc.gov/whats-new/comm-meet/2018/021518/E-1.pdf**).

According to Dale Bradshaw, technical consultant to NRECA:

> "Currently, battery energy storage systems' all-in installed capital costs have dropped to less than $400/kW per hour of storage and,

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Energy storage systems can readily buffer fluctuations in output from wind and solar generation and, therefore, provide firm, dependable peaking energy.

> thus, a 4-hour battery would cost about \$1,600/kW. But, it is expected that within the next 1 to 2 years, all-in installed capital costs could drop to less than \$300/kW per hour of storage, which would result in a 4-hour battery costing approximately \$1,200/kW, when it could compete with similarly priced aeroderivative gas turbines. It may be 2020 before all-in battery energy storage costs drop below \$1,000/kW for a 4-hour battery, when it would compete with reciprocating internal combustion engines as well as aeroderivative gas turbines.
>
> A key aspect of battery energy storage systems is the fact that they can be installed in months instead of years. They can be sited anywhere within the grid, they are easily permitted and when charged with renewable energy, there is no increase in CO_2 emissions. In addition, their variable dispatch cost may be lower than fossil fuel options, especially when wholesale market prices for off-peak generation are negative, with the result that the energy storage system is paid to charge up.”

Energy storage systems can be used for a variety of purposes, such as:

- Peak shaving or reduction in demand charges
- Improving system reliability and grid resiliency
- Energy arbitrage (by electricity for charging at low prices at night and discharged when prices are high during the daily peaks)
- New capacity
- Capital deferral of line and substation upgrades
- Relieving transmission congestion
- Spinning reserve
- Fast frequency regulation
- Ramping services (with nearly instantaneous response to ramp-up or ramp-down demands from the grid)

With a wide range of potential applications, energy storage can support integration of renewable energy in a variety of ways by:

- providing voltage support,
- discharging to the grid to increase generation when renewable energy resources ramp down (assuming that the energy storage is partially or fully charged),
- absorbing ramp-up in renewable generation by charging-up the battery (assuming that the battery has sufficient margin for charging and is not already fully charged, which needs to be planned and integrated with system dispatch) when renewable generation ramps-up,
- using spinning reserves as energy storage,
- mitigating any changes in system frequency,
- providing inertia to the system to mitigate the potential of dynamic/transient instability in the grid, and
- providing a means to shift renewable energy from off-peak to on-peak.

Energy Storage to Address Renewables’ Ramping

Energy storage systems can readily buffer fluctuations in output from wind and solar generation and, therefore, provide firm, dependable peaking energy. Storage provides the opportunity to maximize the production and delivery of wind energy during periods of high wind turbulence and ramping. Currently, operators sometimes must curtail production to ensure stability. In the future, energy storage will be able to manage the intermittency in the output of solar generation caused by cloud cover and inclement weather. In addition, energy storage will capture excess solar generation in the middle of the day and shift it to the late afternoon period of peak load. The California Independent System Operator (CAISO) had negative system prices 15 percent of the time in April 2016, resulting in “spilling” and dumping of excess solar generation to maintain system stability (https://www.utilitydive.com/news/prognosis-negative-how-california-is-dealing-with-below-zero-power-market/442130/).

Another niche storage opportunity for limiting ramping impacts is to coordinate wind production with hydroelectric production facilities, including pumped storage systems. In many cases, and especially at new pumped hydroelectric storage facilities or older facilities retrofitted with modern variable speed pumped hydroelectric technology, hydroelectric generators are able to respond in minutes to variations in wind generation output. The Bonneville Power Administration in the Pacific Northwest, for example, regularly uses hydro to moderate the fluctuations in wind power production for load, maintaining fossil, biomass, and nuclear sources at relatively stable levels of production.

In many cases, hydroelectric generators are able to respond in minutes to variations in wind generation output.

The availability of hydroelectric storage or pumped hydro is location specific, and investigations are underway around the country to find suitable sites to expand its use.

Battery storage facilities, on the other hand, may be deployed virtually anywhere on an electric system, near the renewable source or at the load. In one significant example of the versatility of energy storage, at Kodiak Electric Association in Alaska, battery energy storage has been used to serve as a coordination device for a combination of wind and hydroelectric generation, allowing the generating cooperative to optimize the renewable resources and fully displace fossil generation when adequate renewable energy is available. “We don’t want to operate fossil units as a backup, so we will be using the battery system as a bridge when wind slows down,” Darron Scott, KEA CEO, was quoted as saying on *Power Technology Inc.*’s website in 2012. KEA obtains 99.7 percent of its energy from renewable sources — a 30-MW hydroelectric facility and six 1.5-MW wind turbines.

Energy Storage for PV Smoothing

Energy storage can smooth the output of photovoltaic systems by shifting solar PV generation in the middle of the day to the peak loads in the late afternoon, using the solar PV output that would have been clipped by insufficient inverter capacity. It can also buffer the effect of momentary power loss due to passing cloud cover. A recent example of this is the installation of the “dispatchable solar” system on the Hawaiian island of Kauai provided by Tesla. The solar array is dedicated to charging installed batteries during the daytime, which are then discharged in the evening hours to offset the evening peak load.

Because the output from a solar array is DC, it does not require the AC-to-DC conversion that wind energy needs. This can allow the direct connection of a battery to the solar DC bus through electronics using DC-to-DC choppers (devices that convert fixed DC input to variable DC output).

Variability in a PV system’s output can cause rapid fluctuations in grid voltage at both the transmission and distribution levels, potentially creating such problems as:

- consumer voltage excursions outside the acceptable voltage due to distributed solar PV in the distribution system,
- excessive cycling of voltage control devices (e.g., capacitors, voltage regulators, load tap changers),
- inadvertent tripping of relays,
- single phase imbalance in a three-phase system,
- reverse power flow at the distribution level, causing:
  - false trips
  - increases in fault currents
  - ground fault over voltage

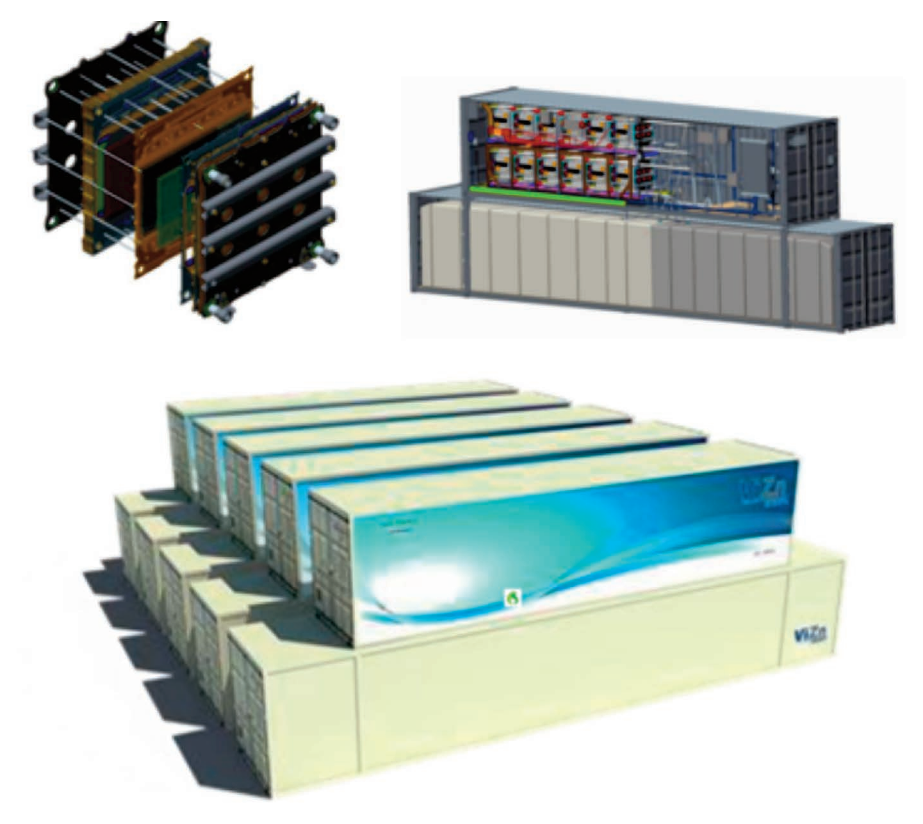
- increase in harmonics by the PV inverter
- increase in fast transients caused by cloud shading, resulting in dynamic interaction of transients with other conventional and nonconventional control devices.

As an example of large-scale energy storage for managing solar PV, Tucson Electric Power announced on May 23, 2017 that it would purchase power from a NextEra 100 MW solar PV array +30 MW and 4 hours of storage in a ViZn zinc iron redox battery. The project would have a levelized cost of electricity over 20 years expected to be less than $40/MWh when the solar investment tax credit of 30 percent is applied to the overall capital installation cost. But, since the ViZn zinc iron redox battery can provide both power and energy, it can bid into the CAISO Energy Imbalance Market (EIM) power and energy markets' ancillary services, such as spinning reserve and fast frequency regulation. It could do so when it is not time shifting excess solar production from the middle of the day to the late afternoon. As a result, the levelized cost of electricity could be further reduced to $25/MWh. The ViZn battery is one of the lowest cost batteries available and has a long 20-year life with the ability to charge and discharge 100 percent of its capacity over 10,000 times over the life of the battery — and unlike lithium-ion batteries, it does not require HVAC cooling. The battery is shown in Figure 4.

NRECA has developed a use case that focuses on the use of energy storage for **PV smoothing**. The rapid advancement and decreasing cost of PV systems, along with the expanded availability of new battery storage devices, suggests that while various storage technologies would provide for the integration and smoothing of PV, the battery may be the best option available to provide all the capabilities required.

Energy storage, and particularly battery energy storage, is seen increasingly as the means to moderate the effect of the so-called "duck curve" in high-penetration PV regions. For a discussion of the "duck curve," see the sidebar — *The Load Curve: If It Looks Like a Duck…* — to the *TechSurveillance* article ***Variability and Uncertainty in Renewables' Generation Pose Challenges for G&T Cooperatives.***

An example of a combination of energy storage technologies to successfully integrate renewable sources was demonstrated through the Public Service of New Mexico's Prosperity storage project. Prosperity investigated the technical performance of



Source: presentation at a CEATI TGIG meeting on November 12 in Fort Lauderdale Florida

FIGURE 4: ViZn zinc iron redox battery

a combination of a 500 kW/350 kWh lead-acid battery and an integrated supercapacitor (for energy smoothing), a 500 kW/1 MWh lead-acid battery (for energy shifting) and a 500 kW PV source. The project was effective in smoothing the intermittent PV output and the power and energy shifting system exhibited good round-trip efficiency, but the project cost at the time was high. The results also indicated the potential for additional control schemes to increase the value of the energy stored in the batteries.

DEMAND-SIDE TECHNOLOGIES AND STRATEGIES

With growing renewable generation, sufficient flexibility will be needed to respond to the variations and uncertainties of both load and variable generation, according to a paper presented on the role of demand-side resources in the integration of renewable power as part of an American Council for an Energy Efficient Economy (ACEEE) 2016 summer study.

Some demand response programs might be suitable to address the need for ramping upward, if the relevant load is active when ramping occurs, and it can deliver capacity at an increasing rate to balance the net load ramp rate. The difficulty with this strategy is that demand response, although flexible, is generally tied to specific end-uses, said the ACEEE authors. Since summer peak load is the typical target of demand response programs, air-conditioning and refrigeration loads are the most common end-use applications.

The nuances in variability and uncertainty for wind and solar lead to different flexibility needs on a given grid system.

The nuances in variability and uncertainty for wind and solar lead to different flexibility needs on a given grid system. In general, high penetrations of wind resources lead to needs for accurate forecasting as well as high reserve requirements, while high penetrations of solar resources lead to a need for resources that accommodate steep ramps or mitigate over-generation risk. Higher penetrations of wind lead to higher reserve requirements than for high penetrations of solar, because reserve requirements are largely driven by short-term uncertainty or when energy production is drastically different from the day ahead or hour(s) ahead forecast (Lew, et al., 2013).

To reliably address the upward ramping problem for a wind-rich generation portfolio, demand response would need to be available year-round, primarily in the evening. Simple, mass-market air-conditioning cycling or curtailment programs would not always be helpful. However, aggregators of automated demand response in the commercial and industrial sectors can harness year-round cooling and other loads through thermal storage applications, which may be able to deliver ramping to balance wind variations.

To contribute to up-ramping of renewable output, a demand-side resource (such as hot water heaters, air conditioners, and ceramic home heaters) must be available when ramping occurs. In addition, the demand-side resource also needs to be able to deliver power capacity up (ramping upward) or absorb power capacity down (ramping downward) in the needed direction and at a fast enough rate (in MW/minute) to balance the net load ramp rate, said the ACEEE authors. The only technologies capable of down-ramping are thermal ones (such as control of hot-water heaters and air conditioners), although even these systems are subject to limitations. For instance, controllable hot water heaters can vary the rate at which they charge during the off-peak hours, but once they are hot, they have limited ability in accepting additional energy throughout the day.

NRECA participated with Great River Energy (GRE) and two GRE distribution electric cooperatives in a DOE-funded Smart Grid Demonstration Project on “Energy Storage — The Benefits of “Behind-the-Meter” Storage” Adding Value with Ancillary Services, Initial Findings, January

2014. The demonstration deployed technology developed by the Steffes Corp. referred to as the Grid-Interactive Energy Thermal Storage (GETS) system (Figure 5).

GETS is a dynamic dispatch control system comprising a control panel with embedded microprocessor connected to current transformers and thermocouples in the hot water heater; it also had a hardwired high-speed Internet connection back to the head-end computer monitoring and control system. For this project, the water heaters were aggregated in the Microsoft Azure Cloud, and the head-end control system was located at GRE. The GETS units varied their charge during the 8 off-peak hours each night (11:00 p.m. to 7:00 a.m.) to charge at an average of 1.5 kW, for a total of 12 kWh. It could oscillate in response to the AGC or ACE signal by ramping or regulating up from 1.5 kW to 3 kW, or ramping or regulating down from 1.5 kW to zero per hot water heater.

FIGURE 5: Pictures of the installation of GETS system with two-way controller *(Source: presentation by Kelly Murphy of Steffes Corporation on Demand Response The Next Generation, September 23, 2015)*

The system was flexible enough that if the Mid-continent Independent System Operator (MISO) regulation market clearing price (RMCP) during any hour was projected to be higher at any point during the charging time, the system could swing from 0 to 4.5 kW until the tank hit the temperature limits of 170°F. In doing so, it would limit the time to provide quick ramping response and frequency regulation to less than 8 hours during the off-peak hours.

The demonstration was successful, but the connection to the Internet had to be hardwired at the time rather than using WiFi, significantly driving up the installation costs. As a result, the GETS system was not an economic option for providing fast frequency regulation service and ramping in the MISO market at that time. In addition, a large number of hot water heaters will have to be aggregated to significantly impact potential ramping from renewable energy resources. But, should energy markets develop a ramping product as well as increased prices for fast frequency regulation, and should the total installation cost of the GETS units decrease significantly through mass production, these types of units could be very effective for responding to rapid change in output from renewable generation during off-peak hours.

Finally, load ramping tends to peak during summer and autumn evenings, when load decreases rapidly as wind accelerates. It is perhaps surprising that during winter and spring mornings, when the solar resource increases, that the load rapidly decreases.

Depending on the season and the time of day, downward ramps in renewable generation can be handled by demand-side thermal storage (such as controllable water heaters, ceramic space heater storage systems, and ice energy storage for HVAC).

For the case of wind ramping in the warmer months, thermal storage would appear to be helpful. However, large numbers of thermal storage devices will have to be controllable, dispatchable, and be aggregated enough to provide adequate ramping services. A major uncertainty is the question of just how much of customer load is truly flexible and controllable. Specifically, in addressing downward flexibility, what is the technical potential for how much load could be controlled and shifted around or increased at specific times? Out of the total load, only a specific subset is controllable, and of that portion, only a certain amount can be shifted around or increased.

A major uncertainty is the question of just how much of customer load is truly flexible and controllable.

Asked how he sees the role of demand-side management (DSM) resources in mitigating the impacts of renewables' variability, Arizona Public Service or APS' Brad Albert, general manager of resource management, painted a changing picture. "We have been focusing on the energy efficiency and energy consumption aspects of DSM," he said. "But, with so much renewable energy in the region, we're in the process of evolving our DSM program toward peak period reduction."

Demand-side technologies are expected to play a growing — and increasingly important — role in the integration of renewables.

Natasha Henderson, manager of strategic planning at Golden Spread Electric Cooperative, noted that both the Electric Reliability Council of Texas (ERCOT) and SPP markets have programs that allow load to respond to price signals or, in ERCOT, to provide frequency regulation. "DSM could mitigate the price spikes associated with renewables, but the market constructs for this are not fully developed yet." Generation resources are typically more effective in responding to price signals than DSM, due to automatic generation control (AGC) with better dispatch granularity and often much lower costs, she added.

If there is no organized market to send price signals to a large group of generation and load resources, said Matthew Moore, director of marketing operations for Golden Spread EC, a utility won't have an indicator of what technology — quick-start resources, batteries or DSM — makes sense. "You have to have a properly designed market that is transparent and sends appropriate price signals, so a utility knows what to bring to the market."

Nonetheless, demand-side technologies are expected to play a growing — and increasingly important — role in the integration of renewables. "Optimization of demand-side resources will be crucial to keeping electricity reliable and affordable as large amounts of renewable generation are added to the grid," according to Keith Dennis, NRECA's senior director of strategic initiatives in Business & Technology Strategies, and Ken Colburn and Jim Lazar, both with the Regulatory Assistance Project, in a 2016 article in ***The Electricity Journal***.

In another article in *The Electricity Journal*, NRECA's Dennis wrote that by managing electric end-use load, utilities can fit the supply availability of renewable energy. With the growth of end-use electric-powered devices and vehicles by utility customers, end-use electrification will become an increasingly attractive and potential option for managing rapid ramps caused by renewable generation. Also NRECA is working to analyze and communicate the multiple economic and environmental benefits of electrification and dynamic control of end uses, such as electric vehicles, space and water heating, and commercial and industrial applications. The flexibility of electric loads is just one benefit of using electricity to power end uses that would otherwise be powered by fuels such as natural gas, propane, gasoline, diesel, and fuel oil. For more information about NRECA's research and work on beneficial electrification, visit Business and Technology Strategies on **cooperative.com**.

ENHANCEMENTS FOR UTILITY-SCALE SOLAR PV SYSTEMS

"Smart" components are being developed and will soon be implemented for utility-scale solar PV plants, which can help in part to address ramping issues. These include active power control (APC) of the inverter, which controls ramp rates and curtailment of the solar PV (obviously a last resort, a very expensive decision to "spill" and dump "free" solar PV power and energy), partial smoothing of intermittent and variable output, and partial compensation for frequency regulation, according to the National Renewable Energy Laboratory (NREL). Fast response by PV inverters makes it possible to develop other advanced controls, such as power oscillation damping and fast dynamic voltage response (which the inverter can provide even when the solar PV is not in operation in the evening hours).

In the future, as energy storage costs continue to decrease, the lowest cost option to provide fast frequency regulation and management of load ramps will be long life energy storage systems.

A key component of a utility-scale PV plant is the plant-level controller, according to a *T&D World* article. One of the functions provided by the controller is real power output curtailment when required, so the plant does not exceed an operator-specified limit. When the controller receives an active power curtailment command, it calculates and distributes power curtailment to individual inverters. Doing this effectively dumps the power (which today is more expensive than other options for managing solar PV ramps). Obviously a more effective option would be to dump the excess power into an energy storage unit that is not at 100 percent state of charge. The controller can minimize the impact of cloud cover by increasing the output of inverters in other locations not impacted by cloud cover in a large solar farm.

In 2016, the California ISO partnered with NREL and First Solar to evaluate whether solar PV systems could be used to provide ancillary services to the market. In the test, First Solar curtailed output of a 300-MW PV plant by 10 percent and used the excess capacity to partially provide frequency regulation while also providing significant voltage regulation, power factor regulation, and reactive power control over a 2-day period. However, this is an expensive form of frequency regulation, as solar PV systems are more expensive than natural gas fired reciprocating internal combustion engines, aeroderivative gas turbines, and even short duration energy storage systems. In the future, as energy storage costs continue to decrease, the lowest cost option to provide fast frequency regulation and management of load ramps will be long life energy storage systems.

A power purchase agreement (PPA) with a utility-scale PV plant developer can be structured to include these grid services, according to the Enhanced Capacity for Low Emission Development Strategies (EC-LEDS), a U.S. government program. But, the cost of this additional flexibility in service will need to be evaluated against other fast and flexible response options.

LOCATION AND SITING

The location and siting of renewable and distributed resources to address their ramping and power quality impacts are subject to multiple considerations and certainly subject to environmental and socioeconomic factors. Invariably, the siting decision takes into account a wide range of conditions associated with the availability of the resource in general. These conditions include wind regime, water conditions, solar insolation, the geographical features within the area of resource availability, and the electrical system topology of the transmission system to accomplish interconnection and effectively integrate with energy market opportunities. Nevertheless, certain siting decisions can be effective in alleviating some of the intermittency impacts, such as minimizing the displacement of offsetting resources and interconnection at points within the electrical system, whereby cycling, intermittency, and potential harmonic impacts will have minimal detrimental effects.

Increasing the size of the geographic area over which wind and solar resources are drawn can substantially reduce variability.

– NREL

Regional Influences (Geographic Diversity)
Increasing the size of the geographic area over which wind and solar resources are drawn can substantially reduce variability, according to NREL's 2015 *Western Wind and Solar Integration Study*. In an earlier study, NREL noted that there is a tradeoff between local resources that are closer to load but have lower capacity factors, and remote resources that have higher capacity factors but require long-distance transmission to access load.

Co-ops that plan to sign more than one wind PPA may want to consider whether there is value in seeking wind farms that are located some distance from one another and may not necessarily be subject to the same weather patterns at the same time.

Arizona Public Service has done just that, said the utility's Albert. APS has PPAs with two wind farms, one in Arizona and one in New Mexico. "The geographic diversity really helps a lot in dampening the overall ups and downs we have to manage."

Geographic diversity makes sense to some extent, said Dan Walter, senior manager, energy markets, at Tri-State Generation & Transmission. "It would spread the risk. And, if a co-op operates in a bilateral market or is its own balancing authority, it would make sense. But, in an RTO, the direct benefit is likely more economic than operational, in that geographic diversity could help mitigate congestion cost risk."

Matthew Greek, senior vice president, engineering and construction at Basin Electric Power Cooperative, said that the co-op would consider geographic diversity. "Its value would depend on how far apart the wind farms are. Can a cooperative transmit power at a reasonable cost, without interruption, to the markets where it needs to go?"

Another consideration is the profile of the renewable resource in a given geographic location, said John Packard, manager of power supply at South Texas Electric Cooperative. He noted that there are a lot of different profiles in geographic locations. "Our 100-MW wind farm is a coastal resource in South Texas. That facility provides more capacity during system peaks, as opposed to West Texas, where wind farms generate more capacity off-peak."

CONCLUSION

G&T cooperatives have a number of technical and economic options in addition to fast and flexible response natural-gas-fired reciprocating internal combustion engines or aeroderivative gas turbine that can help them integrate wind and/or solar PV generation in the grid. These options include energy storage, demand-side management, and enhancements to utility-scale solar PV facilities.

However, until low-cost energy storage is available, the lowest cost options to mitigate the intermittency and variability of renewable energy sources may be natural gas-fired reciprocating internal combustion engines and aeroderivative gas turbines, possibly coupled with short-term energy storage.

By exploring the benefits and drawbacks of these various options, as well as their effectiveness, G&Ts can determine which ones offer the best way of addressing renewables' variability. ■

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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BUSINESS AND TECHNOLOGY STRATEGIES
GENERATION, EMISSIONS, AND CARBON WORK GROUP

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