Business & Technology Strategies

TechSurveillance

Integrating Renewables: Fossil Generation Options Available to G&T Cooperatives

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This *TechSurveillance* article is the second in a three-part series examining the impacts of variable generation and the options that can help electric cooperatives integrate renewables in an affordable and reliable manner.

This article discusses two options — new and upgraded equipment for thermal plants and new, more flexible generation — that can help electric cooperatives address the impacts of renewables variability. The first article discussed the impacts of renewables variability on electric cooperative operations and the grid system. The third article will examine additional options to facilitate safe and affordable integration of renewables, such as energy storage and demand-side management.

While this series highlights the challenges and various options that cooperative utilities have to address variable integration, NRECA is exploring how to assimilate this information into co-ops' comprehensive resource planning processes. Please visit our Business and Technology Strategies website for updates, and sign up for our newsletter, TechUpdate, to stay apprised of new information.

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. Among the drivers of this growth have been federal investment tax credits for solar PV, federal production tax credits for wind, and state renewable portfolio standards, as well as reductions in the cost of large-scale wind and significant reductions in the cost of residential, commercial, and utility-scale solar PV.

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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 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, often during the passage of a weather system. 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 — especially wind — can present operational, reliability and economic challenges for generation and transmission (G&T) cooperatives. Among the operational issues is the need to ramp and cycle fossil-fuel-fired generating plants. Reliability issues for distributors include voltage fluctuations, increased fault current, feeder imbalance, and unintentional islanding, plus potentially 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.

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, or who are experiencing substantial investment by others in intermittent resources within balancing authorities where the G&T owns or operates generation resources.

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 (SPP), G&Ts may face periods of negative locational marginal pricing (LMP) — which reflects the value of electricity at different locations on the grid. The negative LMP can be as much as a negative $40 per megawatt-hour during wind generation's maximum output, which causes oversupply in a region as well as transmission congestion, primarily during off-peak periods and "shoulder" seasons. Oversupply of wind can cause coal-fired power plants to quickly reduce output, which could affect their profitability.

What do cooperatives need to know and/or do?

Those G&Ts that operate wind and/or solar PV facilities, purchase wind or solar energy under a PPA, or have distributed solar generation within their service territory have a number of technical and economic options that can help integrate renewable generation by mitigating the impacts of its variability. They include new or upgraded equipment to reduce the effects of thermal plant cyclic operation and new, more flexible quick-start generating units.

INTRODUCTION

A previous *TechSurveillance* article **Variability and Uncertainty in Renewables' Generation Pose Challenges for G&T Cooperatives** discussed the impacts of renewable generation variability. For examples of wind and solar ramping, see the sidebar *Plotting the unpredictable* in that article.

For this article, NRECA talked with representatives of G&Ts that own wind facilities and/or buy wind or solar PV 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, South Texas Electric Cooperative, Tri-State Generation and Transmission Association, Inc. in Colorado, Basin Electric Power Cooperative in North Dakota and Lea County Electric Cooperative in New Mexico. NRECA also talked with representatives of Denton Municipal Electric in Texas and Arizona Public Service.

The article focuses on wind generation issues faced by G&T cooperatives that either own wind farms, buy wind or solar energy through a power purchase agreement (PPA), or both; or who are experiencing substantial investment by others in intermittent resources within balancing authorities where the G&T owns or operates generation resources. Many of these co-ops are located in the Midwestern 'Wind Belt,' which runs from the Canadian border in North Dakota to Texas.

The technical options for fossil generation include: new or upgraded equipment to mitigate the impacts of cyclic operation of coal- or natural gas-fired generation and the addition of more flexible generation technologies, such as reciprocating internal combustion engines (RICE) and aeroderivative gas turbines (AGT).

As a rule, solar penetration has not yet reached levels in cooperatives' service territory that pose reliability issues.

OPTIONS FOR MITIGATING THE IMPACTS OF RENEWABLES VARIABILITY

NRECA has identified several technical and economic options that can help to integrate renewable generation by mitigating the impacts of variability. Not all options are equally viable nor universally applicable, but each co-op may want to explore their suitability to its circumstances.

The technical options for fossil generation include: new or upgraded equipment to mitigate the impacts of cyclic operation of coal- or natural gas-fired generation and the addition of more flexible generation technologies, such as reciprocating internal combustion engines (RICE) and aeroderivative gas turbines (AGT).

This article will focus on the role of these two options in mitigating the impacts of variable generation.

New or upgraded equipment to mitigate impacts of thermal plant cyclic operation

G&Ts with significant wind penetration in their service territories or the markets in which they operate may need to cycle their fossil-fuel-fired plants much more frequently in response to variable output from wind and/or solar PV resources. 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, and auxiliary components go through unavoidably large thermal cycle fatigue and pressure stresses, which cause damage through thermal cycle fatigue, noted a report by the National Renewable Energy Laboratory, as well as reports prepared for NRECA by the Center for Energy Advancement through Technology Innovation (CEATI), which can be found on **www.cooperative.com**.

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

Coal-fired plant impacts, mitigation options

When a coal-fired power plant is required to operate with load and shift variations to accommodate the integration of wind and/or future solar PV output, there can be several impacts. The major problem is related to thermal cycle fatigue damage, which results in cracking caused by thermal gradients across thick-walled vessels during starts and stops. Other issues include environmental impacts, furnace/fireside corrosion, corrosion of electrostatic precipitator plates and wires, motor rotor bar cracking thermal fatigue and weld cracks in deaerator, thermal fatigue and cracking of high-pressure

A number of co-ops are required to provide automatic generation control (AGC) to their energy markets and to the reliability authorities to address the impacts of wind variability as well as pricing.

heaters and boiler tubes, and increased wear and tear to turbine and boiler drains.

Options for addressing the impacts of cyclic operation include:

- increased drainage capacity to promote steam flow through the boiler pipework
- improved combustion reliability and stability during turndown
- boiler offload and economizer recirculation,
- interstage drains in the boiler
- modification of tube attachments, condenser air extraction and vacuum raising

A detailed list of engineering strategies and solutions for addressing problems arising from thermal cycling and low load operation of fossil-fired plants is available in Appendix B of the CEATI Thermal Generation Interest Group (TGIG) report, ***Damage to Power Plant Due to Cyclic Operation and Guidelines for Best Practices***.

Natural-gas-fired combined cycle plant impacts, mitigation options

Older combined cycle gas turbine (CCGT) plants have less operating flexibility than conventional steam plants, which can be run down to 40 percent of rated output. Older CCGTs, on the other hand, have difficulty in getting below 60 percent, according to a June 2014 article in POWER magazine. Newer CCGTs can now drop to below 30 percent load, although plant efficiency is significantly reduced. An additional problem is the length of time required for the heat recovery steam generator (HRSG) and steam turbine plant to achieve full output from a hot start, as the gas turbine can be at full load in approximately 15 minutes (roughly 70 percent of capacity), while the HRSG and steam turbine cannot get to full power for 30 to 45 minutes.

The Electric Power Research Institute (EPRI) and CEATI have identified a number of common damage mechanisms related to cycling. They include: thermal cyclic fatigue causing material deformation and cracking, differential thermal expansion, erosion and corrosion, and impaired performance of environmental control equipment.

A detailed list of engineering strategies and solutions for addressing issues involving heaters, tubes, feedwater and connecting pipework, and other components is available in Appendix 4 of the CEAT TGIG report, ***Damage to CCGTs due to Cyclic Operation***.

The steps taken to limit cycling vary across utilities. Arizona Public Service (APS) has worked to get the minimum loading level at its natural gas-fired plants as low as possible, said Brad Albert, general manager of resource management. "If we get to that level, we can keep the plant on line and eliminate some of the start-stop cycles." For its coal-fired plants, said Albert, APS asks: Do we want to have a plant on line or is there a period when we can take it off line? "We look at those type of decisions regularly. This helps us minimize or reduce the number of starts and stops for the rest of the fleet."

Sunflower Electric Power Corp. tries to limit the cycling of the major pieces of equipment at its coal-fired Holcomb Station through its resource offer strategies in the Southwest Power Pool's (SPP) Integrated Marketplace (IM), said Corey Linville, vice president, power supply and delivery for Sunflower and Mid-Kansas Electric Co. Such offers can be a combination of a resource's start-up offer, no-load offer, energy offer curve, regulation-up offer, regulation-down offer, spinning reserve offer, and supplemental reserve offer.

A number of co-ops are required to provide automatic generation control (AGC) to their energy markets and to the reliability authorities to address the impacts of wind variability as well as pricing. AGC adjusts the power output

The two main types of natural gas-fired quick-start technologies are RICE units and AGTs.

of multiple generators at different power plants in response to changes in the load. In the SPP IM, AGC is required for dispatchable resources providing regulating reserve [frequency regulation], said Sunflower's Linville.

Co-ops can take advantage of offering AGC capability into the MISO and SPP markets, said Matthew Greek, senior vice president of engineering and construction at Basin Electric Power Cooperative.

When asked if AGC might contribute to a thermal unit's damage from cyclic operation, Greek said: "It could be a source of wear and tear." But, he added, it is a user-defined parameter. "If you're allowing the market to have control and it picks up your offer, you still define the range of operations, say 10 MW up or down, and you can define the rate at which the market moves within that range, such as 1 MW a minute. That's information you put in your bid, and if the market picks up your bid, it accepts your constraints."

New, more flexible generating technologies
Flexible generating units — reciprocating internal combustion engines (RICE) and aeroderivative gas turbines (AGTs) — can provide fast-start backup generating capacity for intermittent renewable resources.

A growing number of cooperatives have installed, or plan to install, these flexible units to address fluctuating loads stemming from wind variability and to respond to market price volatility that comes with wind generation.

The two main types of natural gas-fired quick-start technologies are RICE units and AGTs. For an evaluation of these two technology types, see the sidebar: ***Comparison of new, fast and flexible response natural gas-fired generation***.

Golden Spread EC relies on the RICE technology at its 168-MW Antelope Station, consisting of 18 RICE units that can be synchronized to the grid and reach full output in 5 minutes.

The G&T's Antelope Station is designed to take advantage of price volatility, said Matthew Moore, the co-op's director of marketing operations. "But the ERCOT and SPP markets differ. ERCOT's market construct is based on price volatility, while SPP's market design and operator actions do not allow as much price volatility because its construct is built around reliability unit commitment." The Antelope units are valued more for energy in the ERCOT market, said Moore.

APS plans to install five fast-start 100-MW AGTs at the Ocotillo plant site in Maricopa County — but their purpose is to meet changing power demands caused by solar variability. The total output of three large PV plants in Arizona has ramping events of up to 40 percent to 60 percent of rated output power over 1-minute to 1-hour intervals, according to the Electric Power Research Institute (EPRI). With more than 200 MW of solar capacity in the county, between 165 MW and 310 MW of quick-start generating capacity is needed to back up the solar systems, said EPRI. APS has an extensive natural gas-fired

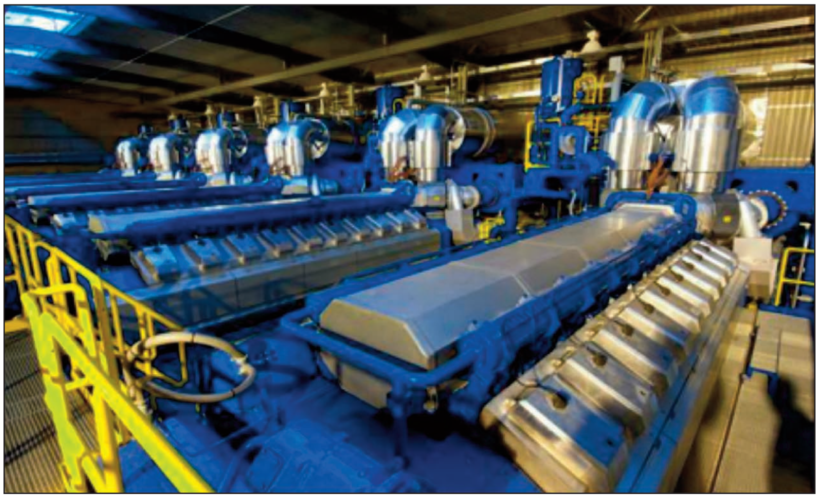

FIGURE 1: RICE units at Golden Spread's Antelope Station.
Source: Golden Spread Electric Cooperative, Inc.

fleet — combustion turbines and combined cycle plants — that provides some degree of flexibility, said Albert. "In the summer, the combined cycle units typically run all day. In the winter, when there is high solar output, they cycle a lot more, but still run 12 to 14 hours a day."

But, the challenges of solar overgeneration identified the need for more flexible assets, he said. The new AGTs, which can also be used for contingency response if there is a forced outage at a large baseload plant or a large, sudden drop in solar or wind production, will be operational in late 2018 or early 2019.

For years, Lea County Electric Cooperative, a distribution co-op based in New Mexico, has relied on Southwestern Public Service (SPS, now part of Xcel Energy) for all its power needs. But, when SPS decided against investing in enough new generation to meet Lea County's projected demand, the cooperative's board chose to meet growth and resource requirements by adding generation and negotiating a new, stepped-down agreement with SPS that would end in 2026.

One source of new generation was a nearby wind farm. To comply with the state's renewable portfolio standard (RPS) — which required the cooperative to provide 5 percent of its energy from renewable sources in 2015, rising to 20 percent in 2020 — Lea County signed a PPA with the wind farm developer, agreeing to take all the output from the 27-MW Wildcat facility. And to ensure reliability, the co-op decided to install quick-start natural gas-fired generating units.

"We evaluated several technologies on the basis of the RPS, and how thermal units would work with wind," said Gary Hurse, Lea County EC's president and general manager. "We found that reciprocating internal combustion engines were a better fit for our requirements, with the best overall cost per kilowatt." Five such units began operating in 2012. "The RICE units are mainly for the wind farm," said Hurse. "But we're part of SPP and we bid the units into that market every day." To meet the 2020 RPS requirement, the cooperative plans to sign a PPA in 2017 for energy from a 30-MW wind project. Lea County EC has also joined Western Farmers Electric Cooperative, said Hurse. "We have matched our capacity and energy requirements with the G&T, and joining Western Farmers takes some of the pressure off an individual co-op in terms of effort to meet its needs."

Like Lea County EC, Denton Municipal Electric in Texas has turned to quick-start resources to mitigate the impacts of wind variability. In response to a challenge from the Denton City Council to increase renewable energy without sacrificing rates or reliability, the city's municipal utility proposed the Renewable Denton Plan, said Brian Daskam, Denton Municipal Electric's manager of external affairs. The plan calls for increasing the renewables share of the utility's generation portfolio from 40 percent to 70 percent by 2019. To address this goal, the utility explored a number of technical and strategic solutions before deciding on a long-term renewable energy PPA and a new Denton Energy Center with 12 RICE units. Before the City Council voted on the plan, it asked The Brattle Group, an economic consulting firm, for an evaluation. In its assessment, the company looked at the cost of the plan, the size of the Denton Energy Center, and the timing of a decision. In its 2016 report, the group said that developing the Denton Energy Center would give Denton Municipal Electric access to flexible power that could firm its entire renewable portfolio. The center would significantly reduce future costs associated with firming renewables. In addition, potential revenue from energy and ancillary service sales in the ERCOT market would help pay for the center's debt service charges, said the company.

FIGURE 2: Mid-Kansas Electric's Rubart Station.
Source: Sunflower Electric Power Corp.

The ability to quickly start and stop is one reason why the utility chose RICE technology over gas turbines.

– Mike Grim, executive manager of Denton Municipal Electric

The RICE units can be quickly shut down during off-peak periods of low prices in ERCOT, while not incurring the O&M penalties typical of large combustion turbines or combined cycle gas turbines.

After issuing an RFP for the energy center's generators, the utility compared responses from different companies, opting for RICE units, said Daskam. The ability to quickly start and stop is one reason why the utility chose RICE technology over gas turbines, said Mike Grim, executive manager of Denton Municipal Electric. "Denton is changing the electricity generation paradigm by using renewables as our baseload power and then using highly efficient, quick-starting generation as needed, when the wind doesn't blow and the sun doesn't shine," said the utility's Grim.

In response to wind ramping, the most flexible resources that Sunflower Electric Power Corp. offers into the SPP market are its quick-start resources, said the G&T's Linville. Those include the 110-MW Rubart Station, which consists of 12 RICE generator-sets. "This resource, together with our combustion turbines, can help regulate wind deviation."

Asked if he foresees the need for additional quick-start RICE units, Linville said: "As more wind gets added to the SPP footprint, there will likely be a greater need for more quick-start, fast-ramping RICE units. However, the current market prices for energy make it very hard to justify investment in new generating facilities."

Another G&T, Basin Electric Power Cooperative, installed 12 RICE units earlier last year, said the co-op's Greek. "We added them for capacity, and we see flexibility as a great asset in the SPP system." But, he added, Basin won't know if they'll be used a great deal until they've been in the market for a while. Does the co-op see a need for more quick-start units? "We continue to have load growth, so we'll need to add capacity," said Greek. "But, you don't get one for one, wind capacity for marketable capacity. If you need 100 MW of capacity, you cannot build a 100-MW wind project to meet that demand. We will still need to build additional natural gas peaking units, as they would be the backup generation of choice — for wind — in this low-price natural gas market."

South Texas Electric Cooperative, which has PPAs for 175 MW of wind, also has chosen to install RICE units. Twenty-four generators provide 202 MW at the G&T's Pearsall plant and 12 generators provide 225 MW at its Red Gate plant. "Our system needed peaking capacity, so we evaluated various technologies and resources," said John Packard, STEC's manager of power supply. "RICE looked like the best fit." Packard noted that STEC did not install the RICE units in ERCOT to just "balance out the wind." The RICE units can be quickly shut down during off-peak periods of low prices in ERCOT, while not incurring the O&M penalties typical of large combustion turbines or combined cycle gas turbines. "This allows STEC to purchase the lower cost electricity for its members and then, during the peak periods, the RICE units can be quickly started and dispatched to earn margins to cover our fixed costs, as well as protect our members from sustained high pricing or short-term price spikes."

CONCLUSION

Those G&Ts that operate wind and/or solar PV facilities, purchase wind or solar energy under a PPA, or have distributed solar generation within their service territory have a number of technical options — including new and upgraded thermal plant equipment and new, more flexible generation — that may help them integrate renewable generation by mitigating the impacts of variability. These two options are likely to be the more viable solutions.

The next *TechSurveillance* article in this series on Renewables Variability will consider additional options to facilitate safe and affordable integration of renewables, such as energy storage and demand-side management. ■

COMPARISON OF NEW, FAST AND FLEXIBLE RESPONSE NATURAL GAS-FIRED GENERATION

Currently, if a G&T electric cooperative needs fast and flexible response natural gas-fired generation to respond to increased ramping of its system load, reducing reliability and increasing operation and maintenance costs for existing legacy fossil generation, and opportunities for hourly or 5-minute spikes in wholesale market prices, it has basically two options for fast and flexible generation; aeroderivative gas turbines (AGT) or reciprocating internal combustion engines (RICE). Lately, G&Ts have overwhelmingly chosen RICE units for fast and flexible response. The reason is evidenced by the comparison of characteristics of AGT versus RICE in the table to the right, where the yellow shading is unfavorable and the green is favorable.

Over time, the all-in turnkey engineering, procurement, and construction (EPC) capital cost for a RICE unit has declined (excluding owner's costs). That cost is now 20 to 30 percent lower than an AGT (assuming non-union labor costs). However, if the capacity is purchased to meet the capacity needs at 100°F at ambient temperature, the cost differential on a $/kW basis widens significantly — by 30 to 40 percent — as an AGT is de-rated ~15 percent at 100°F ambient temperature. The deration that occurs at 100°F for an AGT can be partially restored with low-cost evaporative cooling, but that significantly

TABLE 1: Comparison of fast ramping options

	AGT	RICE
EPC Capital cost in $/kW at ISO	$1,100	$750 to $850
EPC Capital cost in $/kW at 100 F	$1,294	$750 to $850
% derate at 100 F	15%	0%
% derate at 4000 feet	10%	0%
Variable O&M in $/MWh	$2.0	$5
Fixed O&M in $/kW per year	Check with vendor	$15
NOx emission in ppm	2 with hot SCR to 10	2 with SCR to 4.5
VOC emission as methane in ppm	~0	8
Water consumption	evaporative cooling	None
Time to Full load (minutes) from a hot start	5 to 10	2
Time to Full Load (minutes) from a cold start	10	Engine is always kept warm
Full load heat rate (Btu/kWh)	9000 to 9500	8104
Total Parasitic Losses (%)	0.1%	2%
Equivalent Forced outage rates (%) for a plant	1 % to 2%	<1%
Footprint	1X	6X

Continued

COMPARISON OF NEW, FAST AND FLEXIBLE RESPONSE NATURAL GAS-FIRED GENERATION (CONT.)

increases water consumption for an AGT. Alternatively, the AGT capacity can be fully restored by using HVAC chillers to avoid increased water consumption, but that will add $250-$350/kW to the cost of an AGT, and there will still be parasitic losses for the HVAC, which cause a partial derate. In addition to the deration of the AGT due to ambient temperatures, there is an additional 10 percent derate if the unit is installed at an altitude of 4,000 feet. Moreover, the deration increases as the altitude increases.

However, the most critical aspect that gives a RICE unit an edge for fast and flexible response will occur where the system load dramatically ramps up and down in short periods of time causing markets to dramatically increase prices for 5- to 60-minute intervals. A RICE unit can be at full load in 2 minutes when it is hot, which will be the case if the unit is operated every day (RICE units are kept warm, but this does increase parasitic load by 2 percent). This 2-percent increase of parasitic load is more than compensated by a 9 to 15 percent lower heat rate, which translates into a lower fuel cost for RICE. The maintenance intervals for AGTs and RICE units (not shown in the table) are comparable. RICE has maintenance requirements that translate into a variable O&M cost of about $5/MWh versus $2/MWh for an AGT, but the lower fuel cost for RICE will compensate for the increase in variable O&M.

The NOx emissions are comparable when an SCR is added to both the AGT (which will require an expensive hot SCR that is not included in the capital cost in the table) and the RICE (whose capital costs do include an SCR). The AGT has little or no emissions of volatile organic hydrocarbons (VOC), while the RICE has VOC emissions of about 8 ppm slip of methane (which currently is not regulated). The reliability of the AGT and the RICE, based on equivalent forced outage rates, is comparable and ranges from 98 percent to more than 99 percent.

However, if space is critical, the AGT will require six times less space to site on a per megawatt basis than a RICE unit. Recently, the one instance where an AGT won a bid over a RICE was at a location where the footprint was important and space in an urban area was very expensive. In addition, the site was in an environmental nonattainment zone that regulated NOx and VOCs. However, there are probably few if any situations for a G&T where space will be at a premium and the site will be in a nonattainment zone.

Today, if the power system or energy market needs fast response in 5 minutes or less at low capital and fuel costs, the RICE will be the natural gas-fired generation of choice. If the power plant is located in a region with high ambient temperatures in the summer and/or at high altitudes, the RICE will be the fast and flexible generation option of choice.

Large frame industrial gas turbines have not been considered for fast and flexible response, as their response is slower than AGTs (15 minutes to start). In addition, the large frame industrial gas turbines' O&M costs increase and reliability decreases not only with operating hours, but also with the number of starts. For both AGTs and RICE units, O&M costs and reliability vary only with operating hours and not with the number of starts.

In addition, combined cycle gas turbines (CCGT) can only respond quickly to ramps when the units follow the load to minimum load. But, if the CCGT is two-shifted, the CCGT may be too slow to respond to rapid ramping of the load, as the CCGT will take 30 to 45 minutes to achieve full load (while the gas turbine can restore 70 percent of the CCGT capacity in 15 minutes, which may still be too slow). Moreover, the CCGT O&M costs increase and reliability decreases — not only with the number of operating hours, but also with the number of starts.

About the Author

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