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Features

'As for my HRSGs, I wish I didn't know now what I didn't know then'

A maintenance manager from an F-class plant sharing his challenges with the editors at the Combined Cycle Users Group 2017 meeting at the end of August borrowed that thought from Bob Seger's "Against the Wind" to illustrate the unappreciated changing behavior of his plant following a gas-turbine upgrade.

The "behavioral changes" he mentioned included high gas temperatures deep into the boiler, deteriorating catalyst performance, and duct burners not operating the way they used to. This did not come as a surprise to the editors, who attend about a dozen user-group meetings in a given year. Speakers—users and vendors alike—with cycle expertise have urged attendees for the last two or three years to evaluate the impacts of increasing GT exhaust flow and temperature on downstream components before making changes. Many users listened to the message, but only some heard it.

The editors' perspective is that because most attendees at user-group meetings have responsibilities associated with gas turbines they pay little attention to much else—except safety. That's not a criticism: GT upgrades can deliver faster starts, more power, increased turndown, and other favorable outcomes. They're all good ideas, as long as you don't compromise the operation of the heat-recovery steam generator and other downstream components.

Might plant reliability and performance be affected adversely by engine upgrades that have failed to consider cycle impacts? An immediate answer of "yes" came from the chairman of the HRSG Forum with Bob Anderson, who has decades of related experience from his time as both a plant manager and corporate subject matter expert (SME) for Progress Energy, and from recent consulting assignments—including O&M assessments of more than four dozen HRSGs worldwide.

Anderson told the editors that the impacts of GT upgrades on HRSG reliability and performance is a cornerstone of the technical program for the 2018 HRSG Forum, March 5 – 7 at the Hyatt Regency Houston, adding that he recently attended the European HRSG Forum (EHF) where a boiler expert addressed that very topic. Anderson regularly participates in/helps organize HRSG meetings worldwide to keep current on global technology developments and to engage the leading SMEs for input to the annual forum here bearing his name.

If low-load turndown is your goal, the EHF speaker began, be aware that the resulting reduction in exhaust-gas mass flow and increase in exhaust-gas temperature may impact attemperator capability, superheat temperature, temperature differential between tube bundles, and cold-end issues such as flow instability and steaming economizer. He went on to discuss the effects on the HRSG of increasing GT output and of enlarging the engine's operating envelope to increase plant flexibility. Get all the facts at the Houston meeting.

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Presentations scheduled for the 2018 HRSG Forum include the following:

- Update on the evolving issues with creep-strength-enhanced steels.
- 3D printing of custom parts and scaled mockups of HRSG components for planning repair activities.
- Latest developments in drum-level instrumentation and code requirements.
- F-class plant experience in replacing high-pressure- and reheat-steam attemperators.
- Update on the use of film-forming products in HRSG cycle chemistry.
- Managing combined-cycle and HRSG chemistry fleet-wide.
- Why FAC continues to be the No. 1 problem in HRSGs.

The last is particularly important given its possible personnel safety implications. Most puzzling is that there's no reason for flow-accelerated corrosion to exist in any plant today; the solutions for both single- and two-phase FAC are well known and relatively easy to implement and maintain. Listen to Dr R Barry Dooley on the short podcast giving the three actions to avoid FAC and the repair costs and downtime associated with it. Simply scan the QR code with your smartphone or tablet and listen for five minutes. . .then register for the HRSG Forum.

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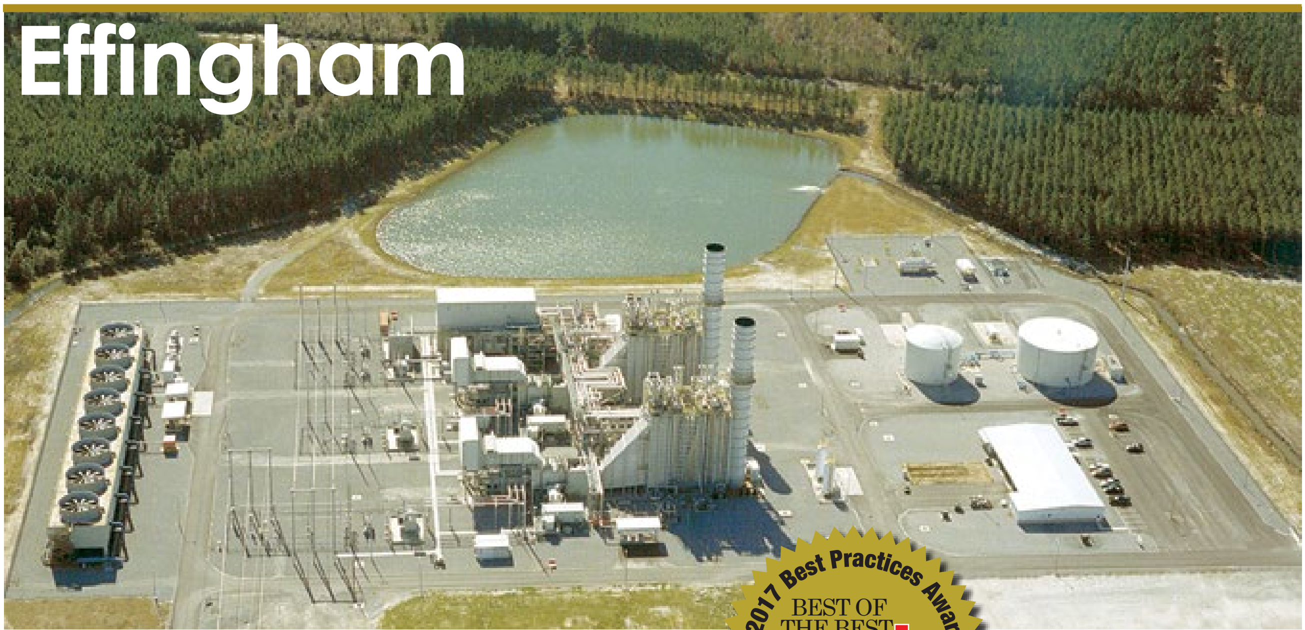
Effingham



Effingham County Power gets its fifth Best of the Best Award—tops in the industry

The Best Practices Awards program for owners and operators of generating facilities powered by gas turbines, sponsored by CCJ ONsite and its companion quarterly print edition, and their user-group partners, celebrates its 13th anniversary in 2017. Over the years, more than 600 Best Practices entries have been received from 200 or so individual plants and fleets; the accomplishments of more than 100 have been recognized with awards. County Power receives its fifth Best of the Best Award—tops in the industry

There are two levels of awards to acknowledge the achievements at individual plants: Best Practices and The Best of the Best, as voted by a team of highly experienced judges who evaluate the submittals with weighted consideration of the following characteristics:

- Business value.
- Degree of complexity.
- Staff involvement.
- Duration of value.

The five most successful plants over the years in numbers of awards received are Effingham County Power, Klamath Cogeneration Plant, and Tenaska Virginia Generating Station and its sister plants Lindsay Hill and Central Alabama. Effingham, today owned by Carlyle Power Partners and operated by Cogentrix Energy Power Management, was the only one of the five recognized in the 2017 program and it came away with the facility's industry-leading fifth Best of the Best Award.

The 2 × 1, 7FA-powered Rincon (Ga) combined cycle, rated a nominal 525 MW, began commercial operation in August 2003. Plant Manager Nick Bohl's team—including Bill Beahm, Cheryl Hamilton, and Bob Kulbacki—submitted four entries this year. The first one below was the most popular with the judges.

1. Ground hanger studs were purchased and mounted on top of the insulators (arrows) on the "H" structure serving the two GTs. This provided a fixed point of attachment for the ground clamp, which can be hung from ground level using an HV stick

Safe grounding of a generator step-up transformer

When maintenance is required on the high-voltage system, conductors must be effectively grounded to earth so the potential difference between the conductors and other grounded components is zero. The temporary protective grounds used are 4/0 Cu "C" style; they vary in length from 8 to 25 ft. In the past, they were connected directly to the conductors and an approved grounding point using a manlift.

There were several issues with this

2-4. Relocation of flow transmitter eliminates freeze-up, fouling

approach, including the following:

- Damage to cables.
- Use of a manlift.
    - A manlift is not rated for electrical use. Even if personnel in the manlift are using the proper electrical PPE, the workers at ground level are in danger if they touch the manlift because of the induced voltages from exposed conductors.
    - The plant doesn't own a manlift. This means it would be necessary to lease one at a cost of about $1400 per week.
    - Operating a manlift within the close confines of the HV yard increased the potential for damage to insulators and arrestors.

The most practical place to install grounding cables on the low side (18 kV) of the GSU serving the gas turbines at Effingham is where the generator transitions from solid bus to ACSR cable (aluminum-clad reinforced steel). Because the bus and the GSU are at different heights, the ACSR cables are angled at approximately 45 deg.

Even if a bucket truck with a dielectric boom were used to assist in hanging the grounds, the angle and weight of the ground cable would put excessive stress on the aluminum conductors, causing the strands to separate. This was confirmed during an annual outage inspection of the substation.

A new way to hang grounds safely and economically was needed. First, plant personnel tried using a step ladder positioned on the loose gravel. The weight of the grounding cable and the uneven surface made it unsafe. Next, technicians tried working off an extension ladder positioned against the GSU. The close proximity of the workers to the transformer, and the weight of the clamps, increased the possibility of component damage.

Ideas then were solicited from technicians who had performed this task in the past to determine a safe alternative. An employee with transmission-line experience recommended using grounding posts installed on the low-side insulators. He researched the various designs available and whether they were compatible with the voltage that would be present on the insulators.

Ground hanger studs were purchased and mounted on top of the insulators on the "H" structure serving the two GTs (Fig 1). This provided a fixed point of attachment for the ground clamp, which can be hung from ground level using an HV stick. Studs were installed by electrical contractors during a planned outage.

After installation of the grounding posts, technicians practiced hanging the ground clamps; all feedback was positive. Technicians liked the safety of being able to hang grounding cables from the ground versus climbing onto a ladder or using a manlift. Plus, use of the grounding posts means grounding cables no longer are clamped to the aluminum HV cable, eliminating the resultant wear and tear.

Success! Grounding posts are located directly above the technician's head. This means the weight at the end of the stick is straight up and not at an awkward angle, making it easier to control the grounding cable being installed.

A longer HV stick (shotgun) was purchased, allowing the technician to hang the grounding cable from the ground without use of a ladder or scaffolding. The benefit: A more stable platform for the grounding process.

The grounding posts provide a defined grounding location and are clearly visible from the ground, enabling personnel to verify grounds are removed prior to closing any breakers. The grounding posts are bolted in position, so if there's any damage they can be replaced easily during an outage.

Finally, eliminating the need for a manlift saves thousands of dollars annually.

Relocation of flow transmitter eliminates freeze-up, fouling

A condensate flow transmitter is critical to proper operation of Effingham's hot-reheat (HRH) dump valve. It regulates condensate flow to control the temperature of steam dumped to the condenser.

The transmitter was located directly off the condensate process line with carbon-steel piping and valves (Fig 2). It is insulated with both lag pads and heat tracing. In winter it would freeze, damaging the instrument and causing plant upsets. Damaged transmitters would have to be replaced at a cost of $1500 per.

During the summer, buildup of biological matter would clog the short process lines. It caused the transmitter to indicate flow even when the condensate system was shut down and the condensate block valve would not open because of this false indication. This was an issue when the HRH dump valves were placed in service, because steam temperature would increase until condensate flow demand was high enough to overcome the false indication.

Result: Several high steam-temperature alarms and potential damage to the condenser exhaust-hood spray. This required that the transmitter be re-zeroed and calibrated numerous times during the summer. Also, process lines had to be flushed periodically to remove any build-up in the sensing line.

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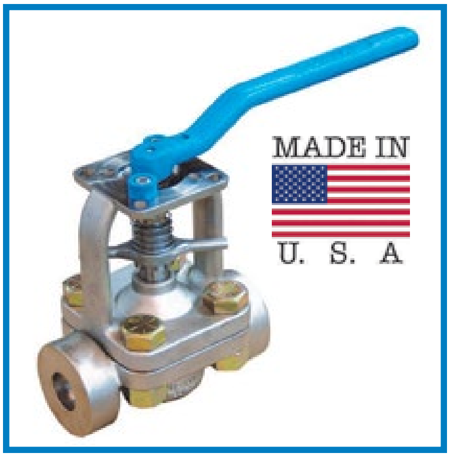

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5. Exhaust-duct pressure switches before modification (left), after (right)

A new location was identified for the transmitter and the instrument was relocated (Fig 3). The material costs were approximately $4500; all work was performed by plant personnel during a routine maintenance outage. The transmitter was placed in an insulated box with a heater to prevent freeze-up and damage (Fig 4). The transmitter's process lines were extended and placed below the process piping. They are insulated and protected with heat tracing.

Success! Relocation of the transmitter eliminated the threat of freeze damage and the longer process tubing mitigated biological growth. The latter reduced the possibility of plant upsets. Also eliminated is the need for flushing out the lines and/or zeroing the transmitter prior to startup.

Empowered technicians, inexpensive mod boost reliability

By design, there is a transmitter that senses the exhaust-duct pressure of Effingham's gas turbines and provides an input to the Mark VI control system. Also, there is one pressure switch that activates an alarm when its set point is exceeded.

There are two additional pressure switches that provide a trip signal to the Mark VI system if their set points are exceeded. The GT is designed to trip if any two out of three exhaust-duct pressure switches exceed their set points.

These switches and a transmitter were connected in series. Because there was only one test connection installed in the sensing line to calibrate the switches, they had to be tested together. But if tested together all three switches would exceed their set points, activating a turbine trip signal. Thus the only time the switches or transmitter could be checked or calibrated was when the unit was offline.

After a major outage while the plant was ramping to 525 MW, the operator received an exhaust-duct high-pressure alarm, Twenty-four seconds later GT1 tripped because two out of three pressure switch set points had been exceeded. The exhaust-duct pressure at the time of the trip was 21.9 in. H_2O. Staff determined that set points for one or both of the trip pressure switches had drifted down since the last time they were tested. Lost generation for this event was 100 MW.

On a second occasion, while at steady state, GT2 tripped on high exhaust-duct pressure, which occurred at 23.7 in. Prior to restarting the GT, the set points for the exhaust-duct alarm and trip pressure switches were checked. All three pressure switches were set at 23.6 in.—the two trip-switch set points had drifted down by almost 2 in. The switches were last calibrated 45 days prior to the trip. Lost generation for this event was 147 MW.

For each lost megawatt of generation the plant is charged $150; therefore, trips can result in thousands of dollars in lost revenue. It was important to find a way of checking pressure-switch set points easily and to check them frequently during the year to prevent trips.

Space constraints militated against installation of individual sensing lines. Other switches on the GT roof had a separate isolation valve and calibration ports for their sensing lines, allowing calibration of switches without disassembling sensing lines to connect test equipment. Based on that knowledge staff decided to install a separate isolation valve and calibration port for each of the exhaust-duct switches.

For about $100 a unit, technicians purchased the needed components to complete the sensing-line mod (Fig 5). With the GTs offline, technicians installed the isolation valves and calibration ports. At the completion of the modification, the tubing was leak-tested with air and the isolation valves were closed to ensure complete isolation to the instrument being calibrated.

In the short amount of time since this modification was completed, spurious exhaust-duct high-pressure alarms have decreased significantly. The ability to check the set points of switches has increased plant reliability.

Success! The ability to check and calibrate switches while the GTs are online has made this project noteworthy. For example, last June the plant remained online for 28 out of 30 days. During that time, personnel were able to check the switch set points weekly. A spreadsheet was developed to monitor the amount of drift and any adjustments required. Installation of improved switches has virtually eliminated trips attributed to drifting set points.

Lay up chillers dry in winter to protect equipment, save money

The GT inlet chiller system normally is taken out of service when daytime temperatures are consistently below

6, 7. Chiller condenser head as installed (left), removed (right)

8. Head is stored alongside condenser for the winter

60F—typically December through March. When Effingham commissioned its chiller system in 2010 there was minimal experience on staff with winter layup. Plant personnel reached out to the chiller manufacturer and the chemical supplier for recommendations on how to prevent biological growth and minimize corrosion.

The first method used was to keep the system full and circulate the water for four hours, adding chemicals every three days during the off-season. The annual cost in chemicals and electricity for this approach was about $3300; plus, there was the possibility of freeze damage when the system sat idle.

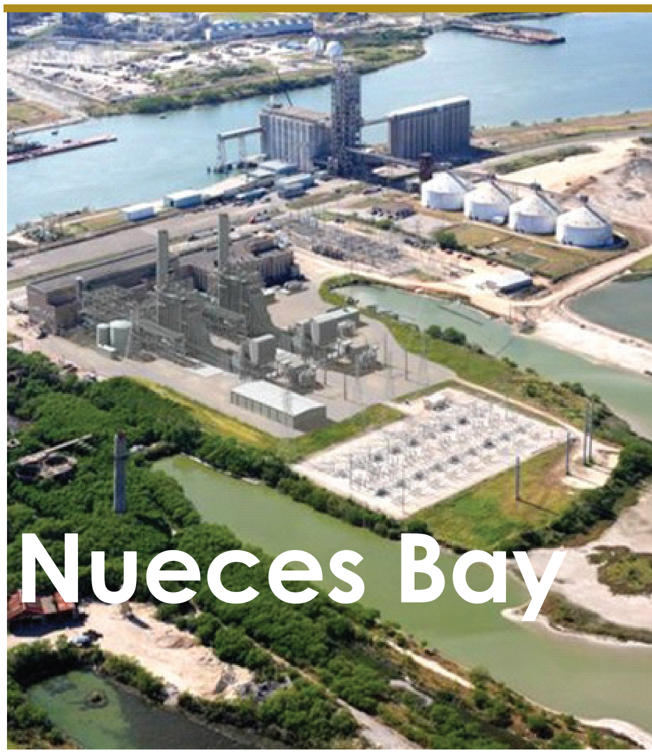
The second method tried was to drain the entire cooling-water system by opening the vent and drain valves on the condenser and cooling-water pump. Once the system was drained, a nitrogen cap was placed on the cooling-water header. Adding one cylinder of nitrogen daily from a 12-pack was the direction provided to the operators, but it was not an effective solution for preventing corrosion. Leakage of nitrogen was one reason.

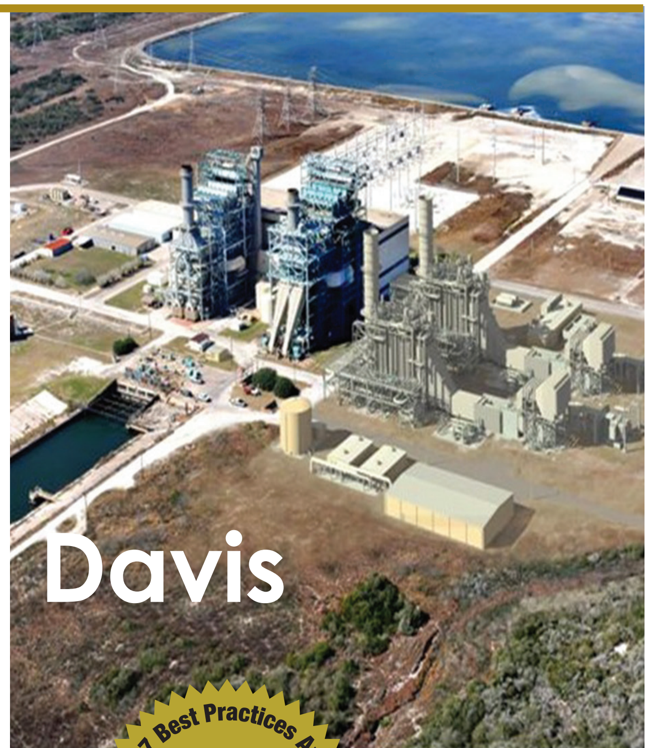
A quarterly service contract for the inlet chiller was the next solution tried and the one adopted. It calls for three operational inspections and one shutdown inspection annually. The shutdown inspection and condenser tube cleaning are conducted in the first quarter. To do the cleaning, one head must be removed from each of the condensers (Figs 6, 7). Since the layup methods described earlier were expensive and failed to prevent biological growth and corrosion, staff decided to pull a head and keep it off for the duration of the winter layup period.

The current plan: Once the chillers are no longer required, the cooling-water system is drained and a condenser header from each chiller unit is removed and stored (Fig 8), allowing for complete drying of the system. Next, the service contractor is contacted and tube cleaning and inspection are scheduled.

The vendor responsible for the chemistry program also inspects the cooling-water system. Based on its findings, the effectiveness of the chemistry program is evaluated and changes made as needed.

Since instituting the practice of drying the chiller condensers during the winter, the corrosion rate has been reduced. In addition, no cooling-water tube leaks have occurred and no electricity and chemical costs incurred. Finally, since the entire cooling-water system is drained during the layup period, there is no need for additional insulation or heat tracing. CCJ



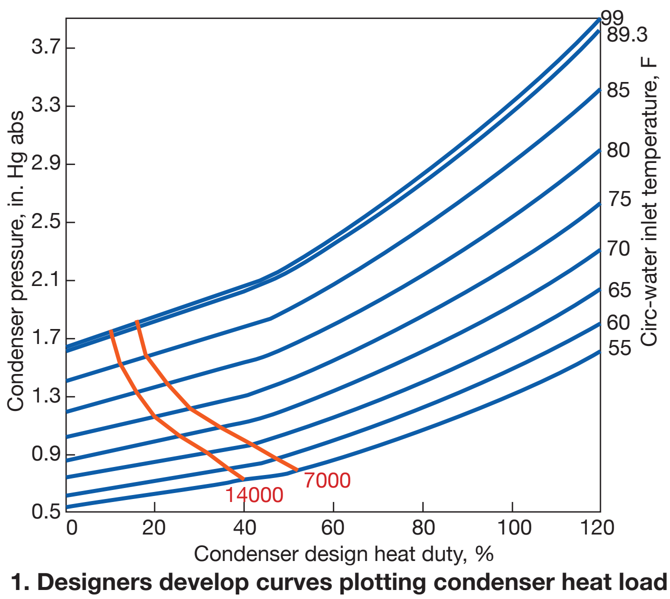


Healthy condenser makes for an efficient plant

Main-condenser vacuum is a primary driver of steam-cycle efficiency. Powerplant designers develop curves plotting condenser heat load and cooling-water temperature at an assumed tube cleanliness to arrive at a calculated condenser vacuum (Fig 1). These curves then can be used by the O&M staff to verify operation at or near design conditions. However, the curves, as provided by the condenser manufacturer/EPC contractor, are of limited practical value to operations personnel. For example, they do not provide the following:

- Data that are easily accessible during transient conditions. Many units in Talen Energy's combined-cycle fleet, like the 2 × 1 F-class Nueces Bay (670 MW) and Barney M Davis (648 MW) Energy Centers, both located in Corpus Christi, Tex, change load frequently to follow market opportunities. Plus, inlet circulating-water (CW) temperature can vary by several degrees throughout the day because of ambient conditions.
- Historical data to trend changes in deviation from design curves over time. This could provide valuable information to plant management for determining when to perform condenser maintenance as well as to quantify the effectiveness of maintenance performed.

The challenge was to develop an operating metric that could improve upon the design curves provided. The Nueces Bay and Barney Davis staffs came together to develop the solution described below. It can be implemented fairly easily at many other plants, possibly yours, to improve performance and predict maintenance needs.



1. Designers develop curves plotting condenser heat load and cooling-water temperature at an assumed tube cleanliness to arrive at a calculated condenser vacuum

The condenser heat duty presented on the abscissa of the design curves is proportional to steam turbine/generator (ST) output. The performance improvement team's first step in developing a practical operational metric was to convert the heat duty on the x-axis to applicable ST output values in megawatts. The curves then were converted to mathematical formulas that could be programmed into the plant's distributed control system (DCS).

The DCS can interpolate between the discrete curves to allow analysis at any CW inlet temperature. By inputting the actual ST output and CW inlet temperature into the appropriate formula, an as-designed condenser vacuum can be calculated. This then can be compared to the actual vacuum.

The difference from actual to design is called the condenser design vacuum deviation (CDVD). As a DCS-generated value, CDVD can be used by operators to gauge condenser efficiency in real time during both steady-state and transient operations.

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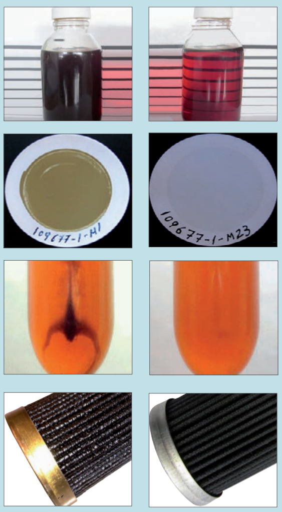

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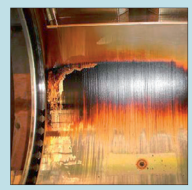

Varnish on journal bearing, gas turbine

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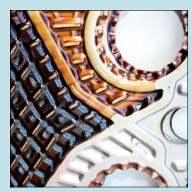

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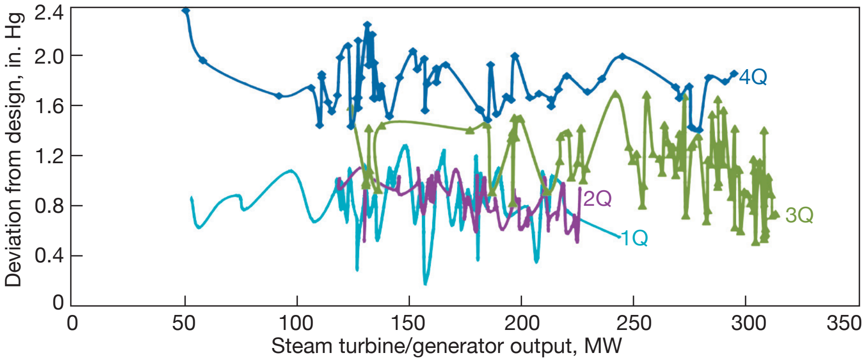
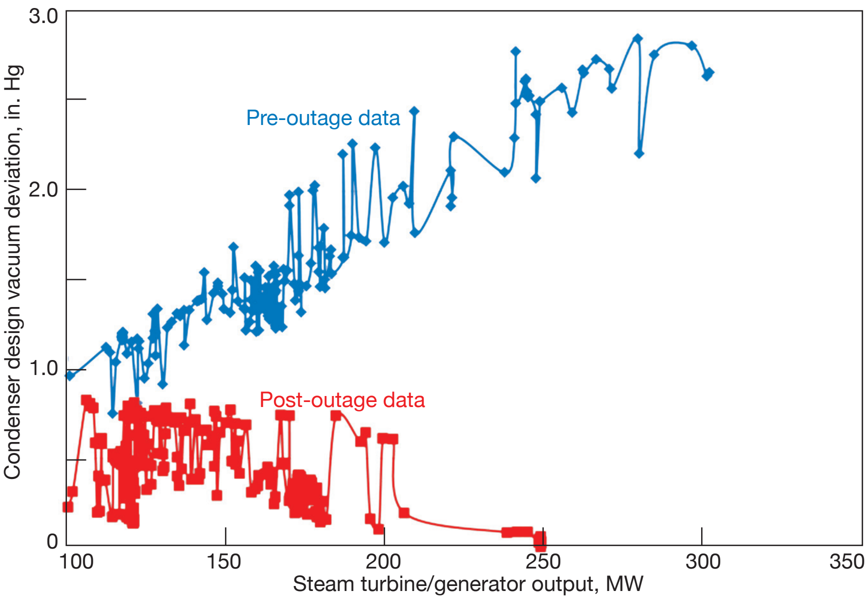
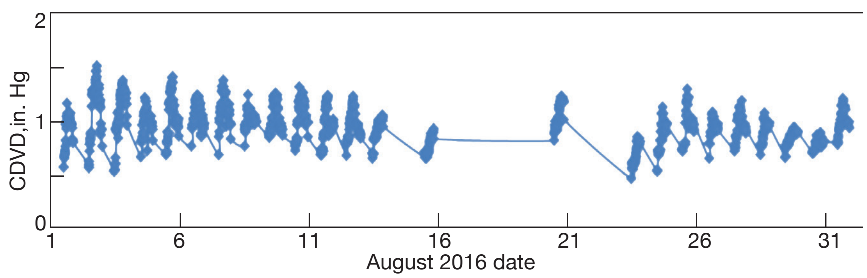


2. Condenser vacuum was continually worsening quarter over quarter in 2015. Impact of repairs is shown in the table



3. Performance improved dramatically following outage to repair plant's circ-water filter system and clean condenser tubes and tubesheet



4. CDVD data show vacuum running well and within normal specification

Condenser repairs boost performance

Parameter	Before repairs	After repairs
Plant output, net MW	243.3	244.4
GT8 output, net MW	68.3	63.0
GT9 output, net MW	65.5	63.2
ST output, net MW	109.4	118.3
Circ water inlet temp, F	58.4	58.9
Condenser vacuum, in. Hg abs	2.77	1.02
CDVD, in. Hg	2.03	0.24
Vacuum pump air flow, cfm	90	<20
Combined-cycle heat rate, Btu/kWh	8546	8200
Power cost, $/MWh	21.37	20.50

In addition, the CDVD can be logged in the plant data historian to trend condenser performance. This can be used by maintenance team members to determine loss of condenser performance, or restoration of performance post-maintenance.

The performance-improvement team cited several instances of CDVD being used for determining vacuum leakage problems. They are:

Case 1. During 2015, condenser vacuum continually deteriorated. Given the long timeframe, cycling operation, and varying CW temperatures, the deviation was suspected, but not verified. When CDVD was graphed on a quarterly basis, the movement away from design was easy to see (Fig 2). Corrective action was taken and performance improved dramatically (table).

Case 2. Prior to the fall 2016 outage, the plant's CW filtering system failed. The decision was made to continue operating until the scheduled outage. During the outage, significant resources were expended to restore the CW filtration system to good condition, as well as to clean the condenser tubes and tubesheet. Before and after CDVD values are shown in Fig 3.

Case 3. During a summer run, operations staff thought condenser vacuum was running high. An analysis of CDVD data showed vacuum was running well within normal specification and there was no increase in CDVD (Fig 4). This precluded chasing a nonexistent vacuum issue.

Case 4. Condenser performance curves also are developed by designers for operation on one CW pump. When one of two 50% CW pumps is unavailable for operation, it is typical to de-rate the plant to half load. But by using these curves and knowing nominal CDVD values, when one pump is unavailable, actual CW temperature can be used to determine available condenser duty—hence, plant output. This may mean the plant can operate at a higher capacity on the single CW pump than it otherwise might. CCJ

Project participants:

Norm Duperron, plant manager, Nueces Bay
Bill Smith, plant manager, Barney Davis
Eric Mui, senior ICE technician, Nueces Bay
Robert L Garza, operations manager, Barney Davis
Vince Powers, plant performance manager

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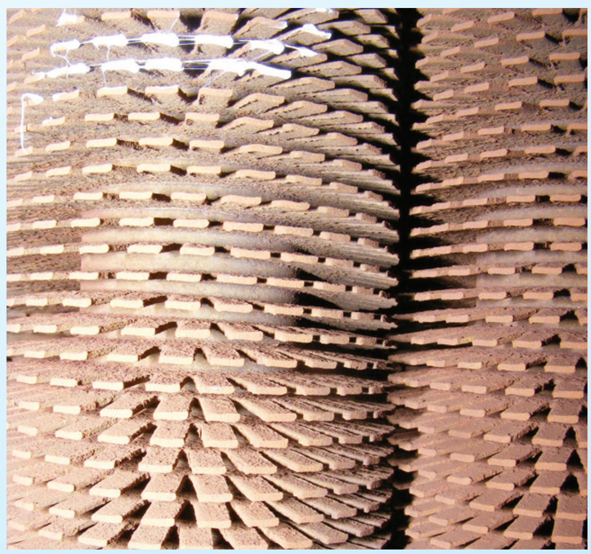

After

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Athens

Reconfigured heat-trace system assures accurate drum-level measurement

Heat-tracing challenges faced by plants in cold climes often are a discussion topic at user-group meetings. There are many suppliers of heat tracing and many different approaches to preventing freeze-ups. Beyond the obvious proper design and installation, critical to success is reliable operation of the control system and instrumentation charged with turning on and off sections of tracing as necessary and alerting where failures have occurred so they can be corrected before damage occurs.

While manufacturers have a wealth of experience to share in design, install, and system troubleshooting, don't expect them to understand your facility's specific needs. Plant personnel have to pick up the ball after the contractor leaves the site and do the customizing necessary to accommodate the idiosyncrasies of weather and operational requirements. The best practice described here illustrates the value of experienced personnel in such problem-solving. The process illustrated and the road to the solution identified can serve as a model for others.

At Athens Power Plant in the Albany (NY) area, cold winters and cycling operation challenged the facility's heat-trace system—in particular the drum-level heat-trace system serving the heat-recovery steam generators for the three 1 × 1 G-class combined cycles.

Drums for the HRSGs are located 100 ft above the level transmitters; sensing lines run down the boilers into heated cabinets where nine drum-level transmitters are located. Because of the length of the sensing lines and change in water density, any difference in temperature between a variable leg and reference leg causes an inaccurate drum-level reading.

The sensing lines were run in Tracepaks—the product name for an insulated, weatherproof jacket offered by one manufacturer—with their heat tracing controlled by resistance temperature detectors (Fig 1). The RTDs provided input to a heat-trace panel that would turn the Tracepak bundles on and off. If the RTD did not turn off the reference and variable legs of each transmitter at exactly the same time, drum levels would deviate because of the temperature difference.

These deviations were exacerbated by ambient temperature and unit run status. If a unit was offline and ambient temperature 30F, all the heat tracing had to be on. Drum levels typically were fine in this condition. If the unit was started up, heat from the unit and the location of the RTDs would cause heat tracing to cycle on and off, contributing to the drum-level deviations.

Plant Engineer Hank Tripp and I&C Technicians Eric Van Zandt, Todd Wolford, and Bob Robinson considered several possible solutions, including the following:

- Installing one RTD per Tracepak.
- Pairing each drum-level transmitter with a single RTD.
- Combining sensing lines into a single Tracepak.

None of these alternatives produced consistently reliable levels during the winter months, causing several forced outages and forcing numerous de-rates

1. Sensing lines were encapsulated in the Tracepaks shown along with heat tracing

2. New heat-trace contactor and control panel eliminated drum level deviations

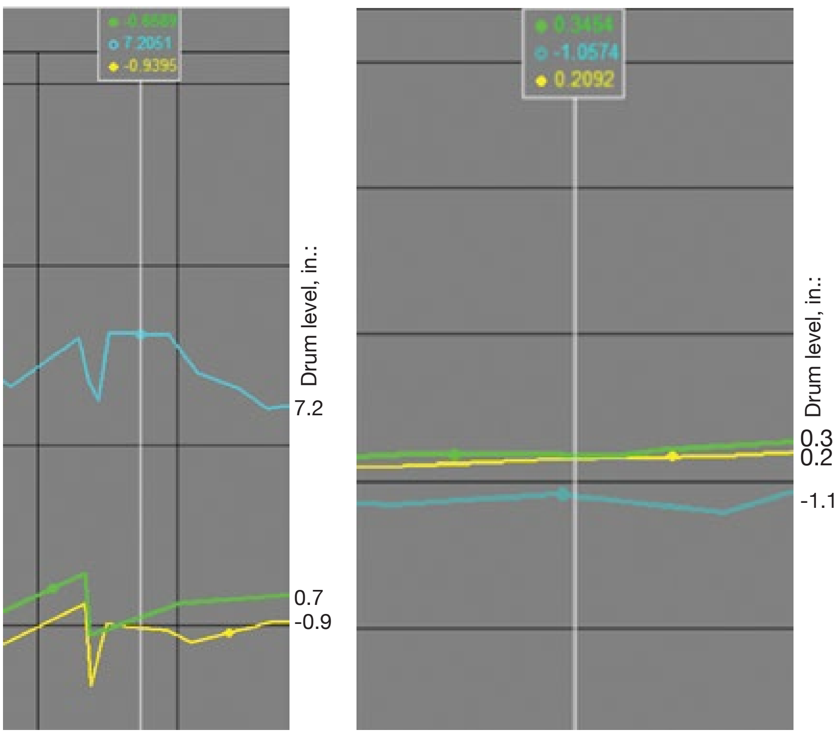
to correct the level deviations.

Plant personnel believed the drum-level heat-trace system had become too complicated. They decided to simplify it by using a single contactor operating by ambient temperature via the plant's DCS (Fig 2) to ensure all drum-level heat tracing was turned on and off at exactly the same moment, thereby eliminating temperature deviations among the sensor lines.

Using the DCS allowed staff to build logic into the control system that would factor in run status and ambient temperature. The solution ensures that the heat tracing operates only when necessary and also alerts operators with an alarm if the contactor is not energized when the heat tracing should be in operation.

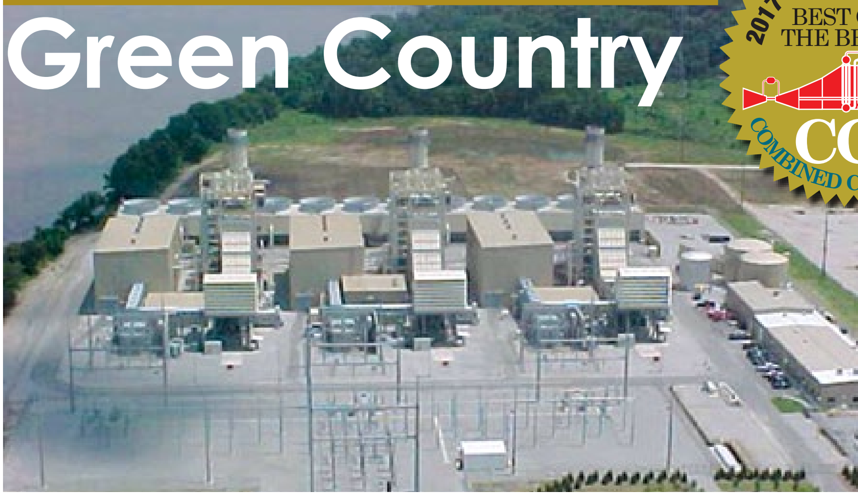
Success! The heat-tracing contactor and control logic were installed in October 2015. Since then, the plant, owned by Talen Energy and operated by NAES Corp, has experienced no unscheduled call-ins, de-rates, or forced outages related to drum-level heat tracing. Plus, drum levels across all units—whether running or shut down—are consistent.

Fig 3 shows drum-level deviation before the new system was installed. One channel indicates 7.2 in., the other two approximately ± 1 in. Ambient temperature was about 30F. As shown in Fig 4, drum levels following system reconfiguration ranged from plus 1 to minus 1 in. at an ambient temperature of about 25F. CCJ



3, 4. Poor control of drum level is in evidence before upgrade of the heat-trace system (left), tight control at right after the modification

Green Country



Recovering 'non-recoverable' megawatts

Under its capacity agreement, Green Country Energy, Jenks, Okla, is incented to maximize capacity up to 795 MW, corrected to contract conditions. When new and clean, the facility was capable of producing the 795 MW from its three 1 × 1 F-class combined cycles, but after several years, capacity had declined by approximately 20 MW, depending on ambient conditions. The reason: Normal degradation of the gas turbine (GT), steam turbine (ST), and heat-recovery steam generator (HRSG).

Plant owner J-Power USA and its operator, NAES Corp, teamed up to find a cost-effective way to recover the lost megawatts. Several possibilities were evaluated within the time constraints imposed by equipment suppliers offering discounts for quick decision-making, including the following options:

1. GT advanced gas-path technology.
2. GT combustion-air enhancements.
3. GE's OpFlex model-based control system upgrade package.
4. Increased duct-firing.

The Green Country team (sidebar) weighed these options in terms of five criteria:

- Financial.
- Environmental impact.
- Contracts evaluation, including the project's contractual service agreement (CSA) with the OEM.
- Technical feasibility study, including input from an engineering firm and the HRSG manufacturer.
- Operations and maintenance impact study, to consider future O&M benefits and risks.

Options 3 and 4 were selected by the evaluation team: The OpFlex control system plus additional duct-burner equipment and a modified permit to increase heat input.

The OpFlex upgrade consists of an advanced model-based control (MBC) software platform that increases GT output, efficiency, and flexibility (figure). OpFlex removed the legacy control methods— exhaust temperature control, for example—and replaced them with a more flexible solution, one offering greater capability to optimize performance.

It identifies operational parameters such as exhaust temperature, firing temperature, and emissions and creates specific control loops for each parameter to ensure that the turbine as a whole is always operating within the intended design space.

Among the OpFlex offerings, Green Country selected peak fire, cold-day performance, AutoTune, and enhanced alarm help. With OpFlex installed, operators can select a megawatt value above base load—up to 100% peak-fire capability. However, once peak fire is enabled, an increased hot-gas-path (HGP) maintenance factor is incurred.

AutoTune removes the combustion restrictions of the legacy control system that limited baseload output in cold ambient conditions, providing cold-day performance increases in GT output. AutoTune also provides constant tuning of NO_x and combustion dynamics, reducing the need to perform seasonal tuning. Cold-day performance requires no operator action, and it incurs no increase in the HGP maintenance factor.

Green Country also installed enhanced GT transition pieces, flow sleeves, and Stage 1 buckets to minimize the effects of peak fire on GT

Green Country evaluation team

J-Power USA

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Masaru Sakai, VP of engineering

Justin Sperrazza, assistant director of asset management

Makoto Kaneko, assistant director of engineering

NAES Corp

Rick Shackelford, operations director

Danny Parish, plant manager

Michael Anderson, maintenance manager

Daniel Barbee, contracts administrator

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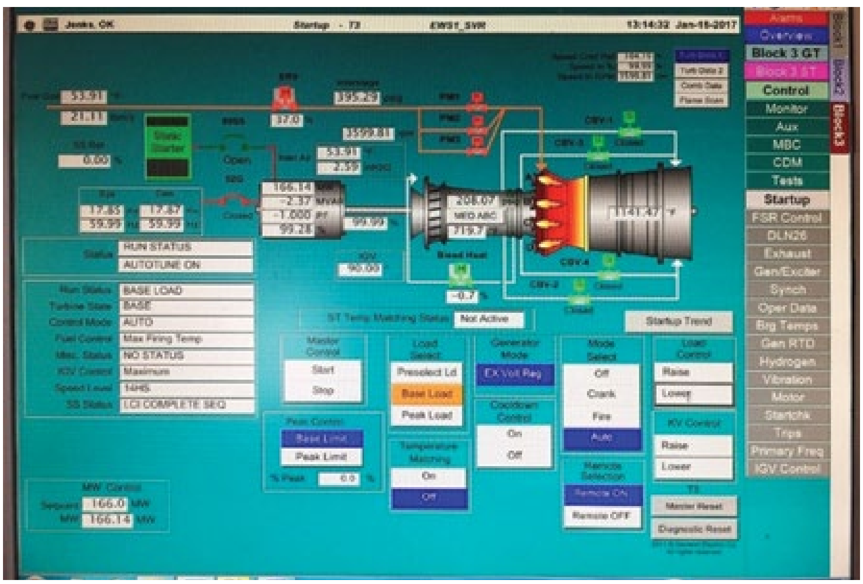
Derek Hale, lead operator



OpFlex is an advanced model-based control (MBC) software platform that increases GT output, efficiency, and flexibility maintenance intervals. The evaluation team expected a capacity increase for the facility of about 17.5 MW, as well as an improved combined-cycle heat rate.

As mentioned earlier, duct-burner hardware and controls also were added to enable increased duct-firing. This included addition of one burner element, four baffles, and upgraded pressure-reducing stations to each HRSG. These additions were projected to yield up to 3 MW more output per unit, or 9 MW total for the three-unit facility.

There were some concerns about deploying the peak-fire provisions in concert with the additional heat input from the duct-burner modifications, so the potential risks were evaluated:

- The HRSG components could reach metallurgical temperature limits when both systems were fully deployed, especially during summertime ambient temperatures.
- The additional burner element and related baffles could increase the HRSG pressure drop, which would negatively impact GT exhaust pressure, especially when deploying OpFlex cold-day performance during the winter months.
- Existing equipment might not provide sufficient desuperheating capability to adequately control HP steam temperatures during the summer.
- Relief-valve capacity (with required margins) might not be sufficient to respond to a baseload trip during deployment of both peak fire and maximum duct-burner heat input.

After weighing the risks and benefits, the evaluation team determined that GE OpFlex together with the duct-burner modifications would provide a technically sound solution with limited commercial and technical risk. An overall increase of 17 to 20 MW was believed possible, depending on ambient conditions.

Success! The OpFlex and duct-burner projects met or exceeded expectations. Once the permitting requirements were finalized and the projects commissioned, Green Country conducted a capacity test that measured 801 MW. This achieved the maximum contract capacity of 795 MW with some margin.

In addition to restoring the megawatts lost through equipment degradation, the upgrades improved combined-cycle heat rate. Plus, the higher GT output and greater mass flow through the HRSG produced by OpFlex at both high and low ambient temperatures reduced the amount of duct-burner output needed to meet the plant's normal deployment, resulting in fuel savings. CCJ

2017 Best Practices Award
BEST OF THE BEST
CCJ COMBINED CYCLE Journal

Woodbridge

The powerplant may be 'commissioned,' but extensive work remains to get it shipshape

Woodbridge Energy Center is a nominal 725-MW 2 × 1 combined cycle powered by two of the first 7FA.05 engines to achieve commercial operation (2Q/2015, p 92). It is owned by Competitive Power Ventures and operated by Consolidated Asset Management Services (CAMS) with Plant Manager Ken Earl at the helm. Given the leading-edge technology implemented at this facility, Earl and his team have been deeply engaged in plant activities since well before first fire.

The veteran manager is a believer of "owning" the operation of the plant from Day One. What he means is not to be in a position of blaming someone else for punch-list items after commissioning. To keep on top of things, Team Woodbridge implemented a formal process of system walk-downs during construction to correct as many oversights as possible before first fire. This level of involvement fostered the development of many best practices to ensure lessons learned would not be relearned.

Earl and team members Michael Armstrong, Justin Hughes, and Ryan Bullock share four of the plant's best practices here. The first profiled below, Comprehensive plant heat-trace guide, received Best of the Best honors. This is the fifth Best of the Best Earl has had a hand in. The other four were awarded to Effingham County Power when he managed that facility for CAMS.

Coincidentally, Effingham, under new ownership, also was recognized with a Best of the Best this year—its first under Nick Bohl (p 4), who was promoted to plant manager when Earl accepted the challenge at Woodbridge.

Comprehensive plant heat-trace guide

Plant personnel found that poor installation practices coupled with the lack of documentation made it difficult to troubleshoot Woodbridge Energy Center's heat-trace system. This required staff to spend roughly 60 man-hours per week identifying and fixing issues with heat-trace circuits not functioning as designed. The poor performance of the heat-trace system jeopardized reliability and operability by allowing critical equipment to freeze-up.

The central New Jersey facility was constructed as an outdoor plant with everything—including instruments, pumps, piping, control valves, etc—installed outside. Equipment must endure the elements of a Northeast winter, where temperatures may be below freezing for days on end. Obviously, equipment reliability depends on a functioning heat-trace system.

Woodbridge was constructed by a single EPC contractor with multiple equipment suppliers. Design of the heat-trace system was subcontracted to a reputable supplier while installation was handled by the EPC contractor's craft electricians, who had little or no experience with heat-trace equipment.

1. Microprocessor-based temperature control and monitoring panels maintain equipment temperature at 40F when ambient is -8F

The various scope-of-supply boundaries and types of heat tracing proved problematic. Many field changes were required to complete the installation—changes performed without the knowledge of the designer and poorly documented.

Heat tracing was designed to maintain an equipment temperature of 40F at an ambient of -8F. The heat-trace supplier implemented the use of microprocessor-based temperature control and monitoring panels (Fig 1) which required other new equipment—including various temperature sensors, new alarm capability, DCS integration, self-testing circuit cards, and programmable RTD outputs.

The lack of qualified oversite from the heat-trace designer during equipment installation and in preparing documentation of as-built conditions proved challenging for the plant operator once it took possession of the facility.

First step in fixing the problem was to bring back the original heat-trace designer to audit the entire system and identify and correct any deficiencies. This required all 612 individual circuits to be reviewed to ensure the correct materials were used along with the correct installation practices. Next, all the documentation was updated to reflect as-built conditions. This information and a thorough review ensured the system was designed and installed as originally intended.

With the proper installation and operational techniques identified for the new technology, the plant operator developed a heat-trace guide to provide a laymen's approach to better understanding of equipment and operational requirements. In the guide, details which had been segregated because of scope breaks are included in one location, eliminating the need for multiple sources of documentation. The guide is written in plain language and includes pictures of installed equipment to better acclimate the reader and facilitate troubleshooting.

The guide includes the following major sections:

- *Equipment and location* defines what the pieces of equipment are, along with their associated location.
- *Operational overview* describes the system from beginning to end.
- *General alarm and troubleshooting* describes typical steps to take when an alarm is received. This section also advises the operator what information must be recorded to facilitate a work order in the event they are unable to troubleshoot the issues seen.
- *Examples of equipment onsite* describes with pictures each piece of equipment.

Success! Using the original design team to identify and fix the installation issues the heat-trace system achieved its specified objectives. System performance now is aligned with the original design intent, ensuring safe and reliable operation of plant equipment during times of inclement weather.

Upon release of the guide, personnel were immediately able to reference site-specific information for heat-trace issues in a timely manner. Today, only about 10 man-hours per week are required to properly troubleshoot system issues, down from 60. The guide also helped personnel identify equipment improperly installed, before it adversely impacted heat-trace performance.

In sum, the guide's effectiveness has shifted the response from reactive troubleshooting to proactive analysis and has removed any uncertainties associated with the new technology installed at the facility.

Logic changes reduce blowdown quench-water use, save $30,000 per month

At Woodbridge Energy Center, blowdown and drains from each heat-recovery steam generator are directed to a dedicated blowdown tank where they are cooled with potable service water supplied by the local water authority. Quenched steam and water drains from the blowdown tank into a blowdown sump and is then forwarded to the cooling-tower basin via HDPE piping, temperature-limited at 140F.

The blowdown tank and drain sump have independent temperature control valves. The blowdown-tank control logic was programmed to maintain a temperature below 140F using service water for quenching. The sump was programmed to maintain 120F using a separate but similar quenching setup. Each of the blowdown tanks required 65 gpm of quench water, the sumps an additional 25 gpm each.

To reduce potable-water use, the blowdown tank temperature control logic set point was raised to 220F, allowing blowdown to flash off and leave through the outlet piping to the muffler with minimal or no need for quench water. The elevation of the muffler provides enough exposed piping that steam entering the blowdown tank can cool naturally and condense, reducing the need for quench water. The new alignment reduces the temperature of water remaining in the blowdown tank to less than 120F, eliminating the need for quenching in the drain sump.

Big saving. Service-water consumption has dropped by approximately 125 gpm since implementing the logic changes. This translates to a monthly saving of $30,000.

2. Separate kits are maintained for each arc-flash level, including properly rated PPE in sizes large and extra large

Safety program minimizes the potential for arc-flash injuries

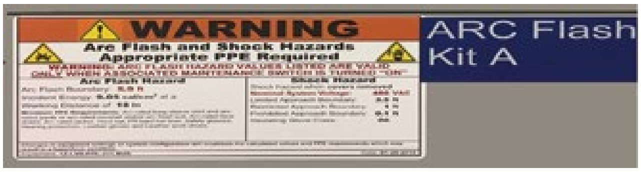
Determining the appropriate arc-flash personnel protective equipment (PPE) was extremely difficult at Woodbridge Energy Center because of the complex nature of the installed arc-flash PPE and various scope breaks in arc-flash protection. The plant's power distribution system was designed to restrict the incident energy level to a maximum value of 25 cal/cm^2.

Differential protection, fiberoptic arc-flash detection, high-speed overcurrent protection, and maintenance switches were used to satisfy this requirement. Depending on the voltage and current rating of a particular piece of equipment, any one of these methods could have been employed.

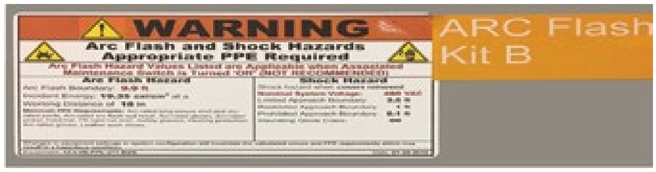
The arc-flash rating for equipment with a "maintenance switch" could be changed dramatically by turning the switch on or off. Adding to the confusion, the arc-flash study performed by the EPC contractor during construction referenced NFPA 70E-2012 guidelines, which changed shortly after the study was completed when NFPA 70E-2015 was released.

Adding to the difficult nature of the protection was an arc-flash study over 300 pages with results for the incident-energy levels described not in alignment with NFPA 70E-2015 or the site's arc-flash safety procedure.

Furthermore, the NFPA 70e hazard labels provided by the EPC con-



3. Kit A for equipment rated 1.2-12 cal/cm² has blue label with white lettering

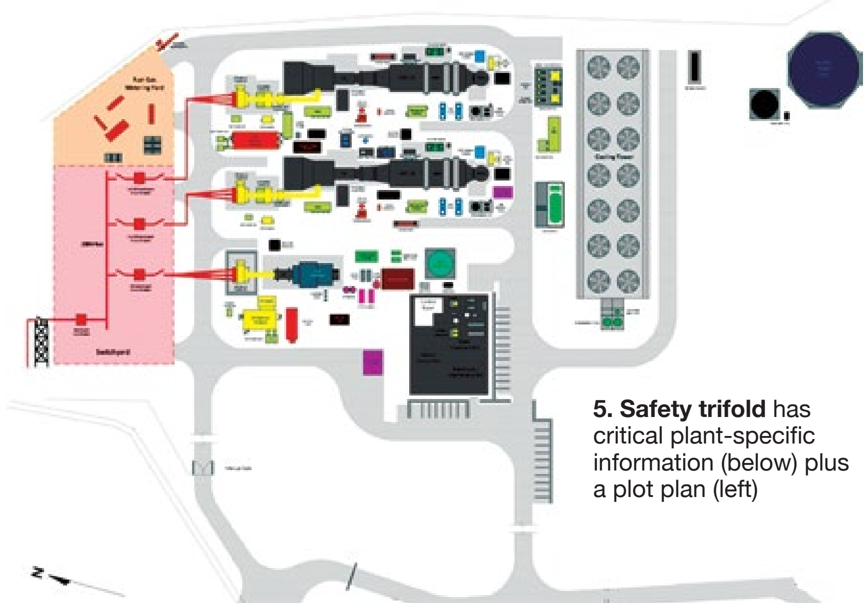


4. Kit B for equipment rated 12-40 cal/cm² has yellow label with white lettering

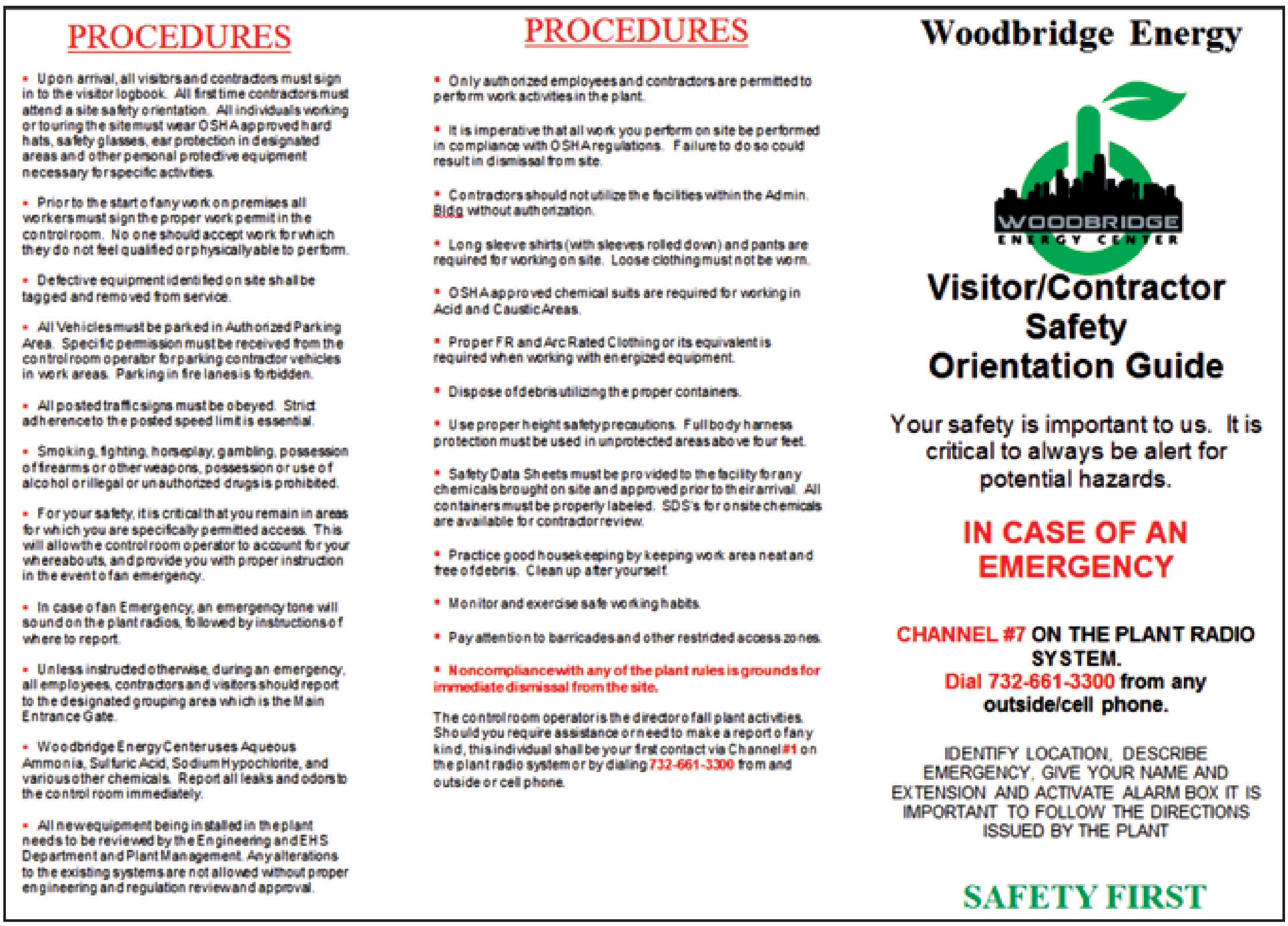
tractor did not specifically call out a recommended level of arc-flash PPE, requiring the person performing the work to locate the piece of equipment in the arc-flash study and cross reference the incident energy level with the site's safety procedure and NFPA 70E-2015. With so many different documents being used to accomplish one task, the risk of human error increased significantly; potentially hazardous situations could occur.

The first step in reducing the confusion regarding the hazard ratings was to ensure the site arc-flash safety procedure included easily understood PPE classifications. Following NFPA 70E-2015, site personnel aligned the plant's arc-flash PPE with these three incident-energy levels: 0-1.2, 1.2-12, and 12-40 cal/cm^2. For the 0-1.2 cal/cm^2 range the company determined arc-rated uniforms and arc-rated face shield (as necessary) would be required and made them available.

For the higher incident-energy levels, separate kits were created for each arc-flash level and included all of the properly rated PPE in sizes large and extra-large. The kits are contained in a clear storage bin stored in a designated



5. Safety trifold has critical plant-specific information (below) plus a plot plan (left)



PROCEDURES

- Upon arrival, all visitors and contractors must sign in to the visitor logbook. All first time contractors must attend a site safety orientation. All individuals working or touring the site must wear OSHA approved hard hats, safety glasses, ear protection in designated areas and other personal protective equipment necessary for specific activities.
- Prior to the start of any work on premises all workers must sign the proper work permit in the control room. No one should accept work for which they do not feel qualified or physically able to perform.
- Defective equipment identified on site shall be tagged and removed from service.
- All Vehicles must be parked in Authorized Parking Area. Specific permission must be received from the control room operator for parking contractor vehicles in work areas. Parking in fire lanes is forbidden.
- All posted traffic signs must be obeyed. Strict adherence to the posted speed limit is essential.
- Smoking, fighting, horseplay, gambling, possession of firearms or other weapons, possession or use of alcohol or illegal or unauthorized drugs is prohibited.
- For your safety, it is critical that you remain in areas for which you are specifically permitted access. This will allow the control room operator to account for your whereabouts, and provide you with proper instruction in the event of an emergency.
- In case of an Emergency, an emergency tone will sound on the plant radios, followed by instructions of where to report.
- Unless instructed otherwise, during an emergency, all employees, contractors and visitors should report to the designated grouping area which is the Main Entrance Gate.
- Woodbridge Energy Center uses Aqueous Ammonia, Sulfuric Acid, Sodium Hypochlorite, and various other chemicals. Report all leaks and odors to the control room immediately.
- All new equipment being installed in the plant needs to be reviewed by the Engineering and EHS Department and Plant Management. Any alterations to the existing systems are not allowed without proper engineering and regulation review and approval.

PROCEDURES

- Only authorized employees and contractors are permitted to perform work activities in the plant.
- It is imperative that all work you perform on site be performed in compliance with OSHA regulations. Failure to do so could result in dismissal from site.
- Contractors should not utilize the facilities within the Admin. Bldg without authorization.
- Long sleeve shirts (with sleeves rolled down) and pants are required for working on site. Loose clothing must not be worn.
- OSHA approved chemical suits are required for working in Acid and Caustic Areas.
- Proper FR and Arc Rated Clothing or its equivalent is required when working with energized equipment.
- Dispose of debris utilizing the proper containers.
- Use proper height safety precautions. Full body harness protection must be used in unprotected areas above four feet.
- Safety Data Sheets must be provided to the facility for any chemicals brought on site and approved prior to their arrival. All containers must be properly labeled. SDS's for onsite chemicals are available for contractor review.
- Practice good housekeeping by keeping work area neat and free of debris. Clean up after yourself.
- Monitor and exercise safe working habits.
- Pay attention to barricades and other restricted access zones.
- Noncompliance with any of the plant rules is grounds for immediate dismissal from the site.

The control room operator is the director of all plant activities. Should you require assistance or need to make a report of any kind, this individual shall be your first contact via Channel #1 on the plant radio system or by dialing 732-661-3300 from and outside or cell phone.

Woodbridge Energy

WOODBRIDGE ENERGY CENTER

Visitor/Contractor Safety Orientation Guide

Your safety is important to us. It is critical to always be alert for potential hazards.

IN CASE OF AN EMERGENCY

CHANNEL #7 ON THE PLANT RADIO SYSTEM.
Dial 732-661-3300 from any outside/cell phone.

IDENTIFY LOCATION, DESCRIBE EMERGENCY, GIVE YOUR NAME AND EXTENSION AND ACTIVATE ALARM BOX IT IS IMPORTANT TO FOLLOW THE DIRECTIONS ISSUED BY THE PLANT

SAFETY FIRST

location at the site and are labeled to reflect the arc flash rating and designation by color and letter (Fig 2). The color code and letter designation labels also are applied to each piece of power distribution equipment adjacent the NFPA 70e label. Specifically:

- Equipment rated <1.2 cal/cm^2 is identified with a green label having white lettering stating, "Arc Rated Uniform."
- Equipment rated 1.2-12 cal/cm^2 has a blue label with white lettering (Fig 3) stating, "Arc Flash Kit A."
- Equipment rated 12-40 cal/cm^2 has a yellow label with white lettering (Fig 4) stating, "Arc Flash Kit B."

These same labels then were placed on the outside of the clear storage bins containing the corresponding PPE. Note: Equipment rated >40 cal/cm^2 has a red label with white lettering stating, "No Energized Work Permitted."

Safety made easy. Site personnel now can walk up to a piece of power distribution equipment and easily identify the hazards and proper PPE required to perform energized work, greatly reducing the risk of incorrectly determining the required PPE. In addition to significant increases in arc-flash safety, this best practice has reduced the time required to evaluate energized work requirements—from hours to minutes. Man-hour reductions could save $150,000 over the life of the facility.

Trifold for contractors keeps critical site information readily available

Combined-cycle outages require a large skilled workforce to complete a substantial amount of work in a short period of time. It is not uncommon to have over 150 contractor personnel working during a major outage, increasing the risk of a safety or environmental incident.

To mitigate this risk, all contractors are required to participate in an onsite safety orientation prior to beginning work.

This orientation covers the site safety and environmental requirements and procedures along with all of the applicable plant policies. Most contractors participate in dozens of site-specific orientations per year so keeping track of which policy/procedure applies to the current worksite is nearly impossible. Additionally, contractors may have little knowledge of the equipment and processes they are working on, and may be expected to carry out tasks that are not routine for them.

After the relatively short orientation, contractors are expected to recall vital safety information including evacuation locations, emergency contacts, locations of equipment, and hazards. Tall order.

So Woodbridge personnel developed a contractor safety orientation trifold pamphlet (Fig 5). Upon completion of orientation, each contractor receives a hard-hat sticker and a copy of the pamphlet, which they are required to have on their person when onsite. The sticker tells plant personnel who should have copy of the trifold.

The trifold, printed on durable cardstock material, includes critical plant-specific information—including emergency phone contacts, plant radio system channel, what to do in the event an emergency, summary of safety policies and procedures, and a plant plot plan that identifies contractor parking, smoking areas, restrooms, and the evacuation muster point, plus major plant equipment.

The safety trifold was inexpensive (less than $350) and has provided immediate results in improved awareness and safety culture. To date, the plant has not experienced a safety or environmental incident attributable to contractor personnel. The trifold makes critical safety information presented during contractor orientation accessible at all times. CCJ

Check turbine wheels for cracks during HGP and major inspections

Mike Hoogsteden, Advanced Turbine Support LLC's director of field services reminded the large gathering of owner/operators at the company's booth during the 2017 7F Users Group vendor fair, May 15-19 in San Antonio, about the importance of proper F-class turbine wheel inspections.

To increase the probability of detecting flaws of critical size, he recommended thoroughly cleaning dovetails after buckets are removed (Fig 1) for hot-gas-path (HGP) and major inspections. The preferred methods of preparing dovetails for inspection are steam cleaning or CO_2 blasting.

The inspection technique proven to best detect wheel flaws, Hoogsteden said, is eddy-current array using specialty probes which allow technicians to scan a large area and collect data for analysis and characterization. He added that Advanced Turbine Support has worked with several vendors to optimize its inspection methods to best meet fleet needs.

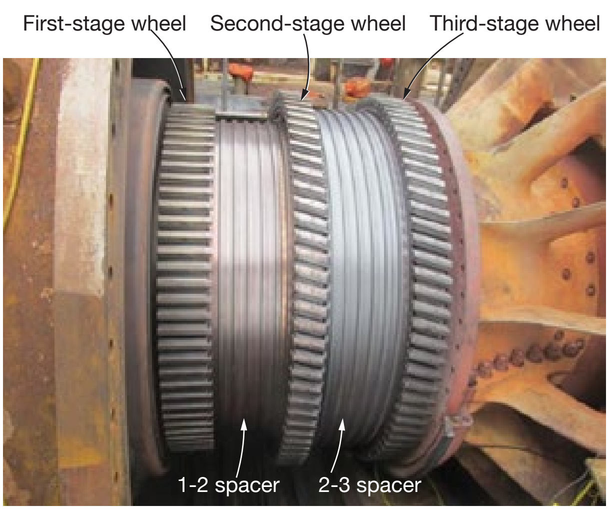
Cooling slots. Hoogsteden went on to say the company's technicians have identified 16 cracks ranging from 0.04 to more than 2 in. in length propagating from first-stage cooling slots (original configuration) in 7F engines since 2013 (Figs 2 to 4). He added, "In 2017, three units were found to have conditions which condemned wheels and component replacement to enhance unit reliability and safe operation."

Owner/operators of units with the original cooling-slot configuration can minimize the possibility of cracking, the field service director said, by way of a blend/polish/peen procedure that results in a component radius and compressive stress in accordance with best engineering practice. Fluorescent dye penetrant inspection is used to confirm the absence of indications.

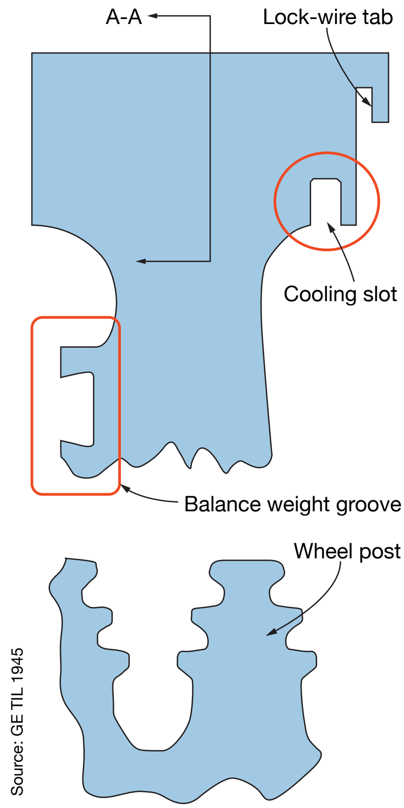
Lock-wire tabs. Cracks propagating from the edges of first- and second-stage turbine-wheel lock-wire tabs are another concern (Fig 5). Typically, cracks in these locations are viewed as less critical than those in the cooling-slot area. Here's why: An affected tab can be blended off in-situ (Figs 6 and 7). A caveat: If three or more consecutive tabs on a given wheel are cracked, tab removal is not an OEM-approved solution. That turbine disc would require engineering disposition and most likely would be condemned.

Background. The importance of turbine-wheel inspections should not come as a surprise to most 7F owner/operators; the subject has been a discussion topic at user meetings for two decades, or more. However, given the recent rash of retirements, the continual shuffling of personnel among plants, significant numbers of O&M personnel joining the staffs of 7F plants, etc, "refreshers" are important. No plant manager can ever assume "everyone knows this."

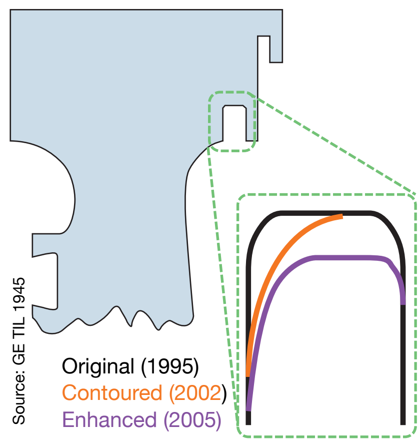
Users might consider perusing the OEM's library of



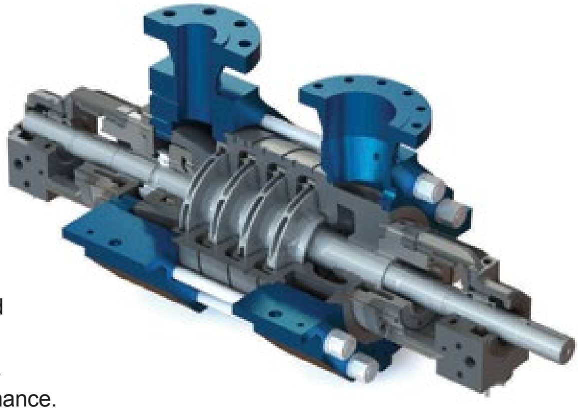
1. 7F gas turbines have three turbine stages. After buckets are removed for hot-gas-path and major inspections, dovetails should be thoroughly cleaned—steam and CO_2 are the preferred alternatives—and checked for cracks

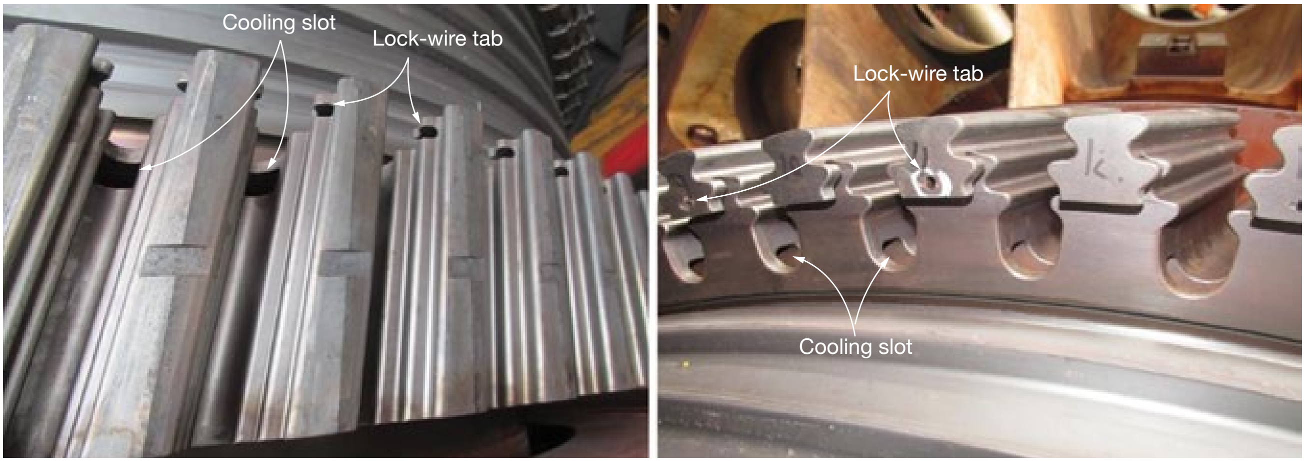


2. Wheel features illustrated here point to important inspection areas: lock-wire tab, cooling slot, and balance-weight groove



3. Cooling-slot profile has changed over the years as the diagram inset shows. The original configuration is most prone to cracking. Hoogsteden told 7F users that Advanced Turbine Support offers blend/polish/peen (BPP) services to reconfigure that slot profile to make cracking less likely



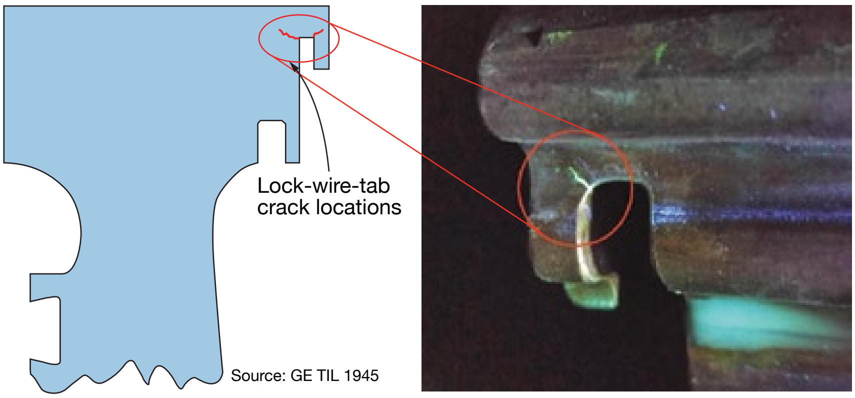


4. Actual lock-wire tabs and cooling slots are shown looking down at first-stage dovetails (left) and from the side of the wheel (right)

Technical Information Letters (TIL) to gain the foundational knowledge required for objective decision-making. For example, the subject of wheel cracking in early 7F rotors is addressed in TIL 1945, "F-class Turbine Wheel Inspection and Maintenance Recommendations," as well as in other GE documents.

Here are some take-aways from TIL 1945 pertinent to the foregoing discussion:

- Turbine buckets are retained axially by a snap-ring type of lock wire located in a machined groove passing through the buckets and turbine wheel. The portion of the wheel retaining the lock wire is known as the lock-wire tab.
- Cooling air is provided to first- and second-stage buckets via cooling slots at the bottom of the turbine-wheel dovetails.
- 7F turbine rotor discs are made of a high nickel alloy sensitive to surface imperfections. The high-stress/high-temperature operating environment is conducive to intergranular crack initiation and propagation.
- Rotors operating in regions of high ambient temperature and humidity, or where other corrosive conditions exist, have increased risk of crack initiation and propagation.
- A process of continual improvement has reduced the sensitivity of turbine rotor wheels to cracking, inoculating late-model engines against some of yesterday's concerns.
- Rotors manufactured prior to 1997 did not have full shot-peen coverage of turbine wheels. Recall that shot peening leaves a residual compressive stress and decreases the risk of crack initiation—such as in the region of the dovetail slots. After 1996, all F-class turbine wheels shipped fully shot-peened.
- During operation, the intersection of the cooling slot and dovetail slot is subjected to high temperatures and tensile stresses caused by turbine bucket pull. The high temperatures and stresses, in conjunction with an adverse edge condition, have been known to initiate cracks in this location.
- Cracking has been found in several rotors at the balance-weight groove, initiating at an adverse edge condition (refer back to Fig 2) influenced by the balance-weight retention method and other variables. CCJ



5. Typical locations for lock-wire-tab cracks are shown in the sketch at left. Photo at right shows an actual crack illuminated by penetrant

6. Cracked lock-wire tab can be blended off in-situ to avoid possible liberation of the tab and resultant downstream damage. Sketch at left shows portion of the dovetail typically removed. Photo at right shows fluorescent penetrant check of blended area to ensure cracks have been removed

7. Blended area after peening to mitigate cracking

'CliffsNotes' on design, O&M of stator-bar insulation systems helps improve reliability

By Clyde V Maughan, Maughan Generator Consultants

Generator stator-bar insulation systems have experienced a steady evolution since the beginning of central powerplants in the early 1900s. Initially, 1900-1915, natural products were used—for example, shellac, mica flake, paper. These materials apparently worked well on small, low-duty units, but were inadequate beyond perhaps 10 or 15 MW.

As units grew in size, problems developed and during the period 1915-1950, "asphalt-mica" was the common system. These systems used mica, with a paper or cloth carrier, and vacuum pressure impregnation with carefully selected asphalt compounds. Initially, they performed well, with minor problems associated with puffing and asphalt bleeding if operated at too high a copper temperature—above roughly 95C.

But as generator size increased, the "tape migration" issue described in Ref 1 became so destructive that use of asphalt-mica systems was discontinued in the 1950s for generators rated higher than about 25 MW.

Problems with asphalt-mica systems led in the 1950s to the transition to thermoset resins, first polyester and then epoxy, for impregnating the mica tapes. From the 1950s to the present time thermoset systems have evolved upward in mechanical and electrical capabilities.

But during this period, generator ratings also have gone up, with associated mechanical and electrical duties dramatically increasing. For example, generators manufactured prior to 1950 would have normal electromagnetic forces in the slots of perhaps 2 to 3 pounds per inch of length (0.35 to 0.53 kg/cm), and an electrical stress of up to 45 volts per mil (2 kV/mm).

In modern generators the slot forces range up to about 110 lb/in. and electrical stress to more than 90 V/mil. Thus it should be no surprise that, although the evolving new systems generally performed fairly well, problems continue to occur to this day. Some of these problems have been very costly and some have been very persistent.

Asphalt systems, with their low slot forces and soft, bounce-free groundwall insulation, never experienced slot bar vibration. Thermoset systems, with their higher slot forces and hard insulation, experienced severe slot bar vibration unless the bars were well restrained by slot wedging systems. These increased mechanical duties and challenges existed throughout the entire stator winding—that is, slots, endwindings, and connections.

The 2:1 increase in electrical stress from 45 to 90 V/mil may not seem great, except that electrical-stress duty is about a ninth-power function. Translation: The duty increase from 45 to 90 V/mil would be $(90/45)^9 = 512$. The huge increase of electrical duty shows up not only on the groundwall, but also as increased electrical duties everywhere throughout the entire stator winding.

Thus with increased mechanical and electrical capabilities of the stator-bar groundwall insulation came demands to increase mechanical and electrical capabilities on all portions of the stator windings—including internal components of the stator bar, slot bar surface grounding systems, endwinding electrical grading and electrical clearance requirements, phase connection rings, and series and phase connections insulation.

Note that there are also thermal and atmospheric duties on the windings. The duty from these influences has remained relatively constant, and generally is not considered in this article. But some of these influences are significant. For example, the influence of humidity on insulation systems, both stator and rotor, can be highly important, as discussed in Ref 2.

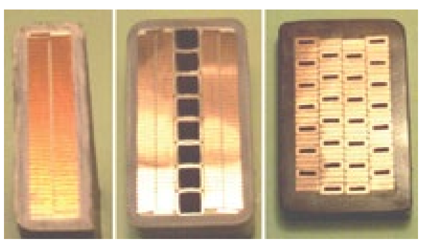
Design evolution

The insulation systems considered in this paper apply roughly to units 25 MW and above, high speed and low speed, polyester and epoxy.

Basic design of stator bars

Stator bars for large generators are made in three configurations (Fig 1): At left, "conventional" indirect-cooled; center, "direct-cooled" gas (air or hydrogen); right, "direct-cooled" liquid with hollow strands through which water flows.

The "bare bar,"—that is, consolidated insulated copper strand package, varies among cooling methods and unit size, but the groundwall composition normally is the same for all designs.



1. Stator-bar configurations for large generators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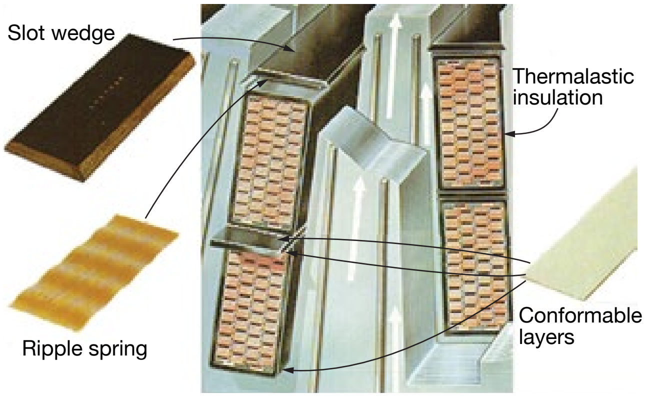


2. Typical slot assembly identifies major components, including ripple springs (above)

The groundwall typically is formed by applying mica tape layers to the bare bar. The number of layers depends on the voltage of the winding and the volts/mil the designer chooses.

The composite tape usually is made up of a layer of glass or polyester (Dacron) tape, a layer of mica paper and perhaps a third layer of unwoven material. Total thickness of the tape is around 7 mils. Two bars then are assembled into a slot, as shown in Fig 2.

Many manufacturers have not used side springs, although they are becoming more common on large units. A top spring under the wedge is now very common, except on small units.

Resin evolution

The initial thermoset systems generally used polyester resins to replace the asphalt, great progress having been made with polyesters during World War II. Other components remained largely the same, mica flake with paper or cloth carrier.

But from the beginning two very different approaches were taken as to how the resin was applied:

- In the VPI process, resin is applied to the mica-taped bars through an individual bar vacuum-pressure-impregnation (VPI) process.
- Resin rich. Resin is in the mica tape, as applied to the bare bar.

In the mid-1990s, global VPI systems became popular for generators of moderate size—roughly rated 200 to 500 MW. Some of these systems have performed very well, but others have not. All are very difficult to rewind. These units are not a topic of this article.

The initial mica was the natural mica flake splittings, pretty much as the mica comes from the ground. As the high-grade natural mica became harder to obtain, a conversion to "mica mat" occurred. This mica is a "paper" made from lower grades of mica by a mechanized process that breaks down the mica into tiny "platelets" which are extremely thin. These platelets of mica are sufficiently thin that they have high ratio between width and thickness as did the original mica flake.

Polyester systems performed fairly well—if installed and supported well—but they were subject to difficulties: difficult to cure correctly, soluble in hot water even if well cured, limited temperature capability, limited mechanical capability. Result: By the 1960s, most OEMs were working on new epoxy-resin-based systems.

As each of the systems was developed, the manufacturers issued technical papers touting the merits of their new system (Refs 3-6).

Quality considerations

Manufacturers touted the properties of each new resin system. But in the opinion of the writer, the resin itself generally does not have much impact on the intrinsic quality and performance of the stator winding system—even if the groundwall system is made perfectly to engineering specifications. This (controversial) observation is based on considerations such as those that follow.

Consider that stator-winding performance depends on many parameters, some directly related the groundwall resin system itself, but most not. For example:

Design parameters directly related to quality of the groundwall system

- Cure of resin.
- Mica content.
- Mica tape backer material.
- Internal voids.

Stator-bar design parameters not directly related to groundwall system

- Magnitude of vibrational electromagnetic forces.
- Volts/mil design stress.
- Strand crossover insulation.
- Internal grading systems.
- External grounding system.
- External surface armor material.
- End arm grading.

Winding and connections

- Connection between grading and grounding systems.
- Uniform end arm spacing.
- Connection insulation.
- Slot vibration prevention system.
- Endwinding vibration prevention system.
- Connection-ring vibration prevention system.

Based on the complexities of the design of the various stator winding systems, is it possible, and likely, that the manufacturing facility and personnel will be able to meet the engineering requirements of the stator winding design.

Root causes of performance problems

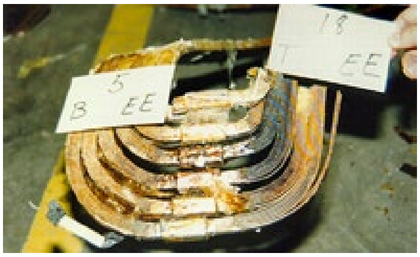
Polyester groundwall insulation

Problems with groundwall insulation have been relatively few. In the very early days of the polyesters there were a few cases of cure failure that apparently permitted tape migration. Other lesser but important cure difficulties were associated with failure to obtain resin with correct components, resin pre-cure, incorrect cure temperature, and failure to adequately remove volatiles.

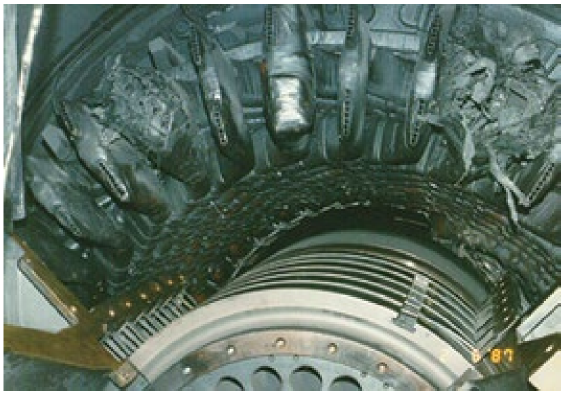
One OEM wedged its initial production of polyester windings with the same loose, clearance techniques as used with asphalt; these windings had severe and destructive bar vibration. This same OEM initially had bar cross-section issues, including dog-ear corners. This made reliable wedging of the bars in the slots impossible and resulted in numerous major winding problems.

At least one unit with water-cooled bars developed water leaks; the hot water destroyed the polyester groundwall insulation and resulted in winding failure. Also, polyester windings seemed vulnerable to high humidity which made drying of the windings difficult.

In general the polyester systems performed satisfactorily. However, the problems were sufficiently important as to cause early transition to the more stable and reliable epoxy resins.



3. Two shorted groups of strands (above)



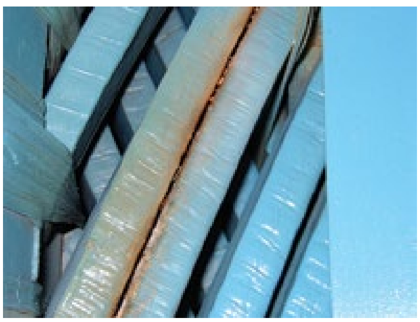
4. Destruction of winding (right) caused by group shorts (refer to Fig 3)

5. Gross overheating from shorted strands (above)

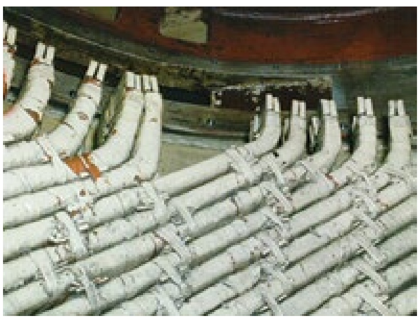
6. Slot grounding paint completely destroyed by partial discharge (right)

7. Grounding paint destroyed only at hot end of unit, illustrating the effect of temperature on partial discharge

8. Burning (not partial discharge) at junction of grading and grounding paints



9. Partial discharge at narrow gap in endwinding



10. Winding has bare joints and a large gap at phase break. Failure was caused by a sudden short circuit, not partial discharge

Epoxy groundwall insulation

Epoxies eliminated most of the problems associated with polyesters. The groundwall concerns then focused on obtaining maximum performance from the groundwall. Brief comments follow on the parameters mentioned previously:

Curing of resin. If the cure is imperfect, obviously less than optimum mechanical and electrical capability resulted.

Mica content and tape backing material. The greater the uninterrupted mica content of the groundwall the better will be the electrical behavior. This suggests a thin carrier for the mica, and if a woven fabric such as glass or polyester is used, select a fine thread for the fabric.

Internal voids. These are difficult to avoid, particularly at the corners and between the bare bar and groundwall. Internal semi-conducting paints often are applied to address the latter.

Non-groundwall insulation

These problems are many and varied and carry low relationship to the groundwall system selected. Some have been experienced by all manufacturers. Some occur on only the VPI systems, some on only the resin-rich systems. Of the problems tabulated in the previous section, a few brief comments:

Magnitude of vibrational EMFs. Electromagnetic force is established simply by the design: It is essentially proportional to the armature reaction and inversely proportional to the number of slots. Armature reaction tends to increase with an uprate associated with cooling methods—air or hydrogen—and indirect or direct stator-bar cooling. And how hard the designer is willing to push the duties on the physical components.

Volts/mil. In a laboratory voltage endurance test, a good groundwall will be severely damaged by partial discharge and fail after many hundreds of hours at a stress greater than about 200 V/mil. Most of today's systems are designed at less than about 70 V/mil and will not fail in 100 years. At 90 V/mil, "good windings" may eventually begin to fail electrically, but not until after many years of service.

Strand insulation. The voltage between strands is very small, but important. At the crossovers it is reinforced by additional insulation. Still, insulation failures occasionally occur (Figs 3-5).

Internal grading systems. These systems can be simply paint applied to the bare bar, but can also be very complex. (The writer it is not certain that internal grading systems are well understood.)

External grounding system. These are always a semi-conducting paint applied directly or via tape carrier. But they are often a troublesome item, primarily on air-cooled generators (Figs 6 and 7). Some experts also are not sure that external grounding systems are well understood.

External surface armor material. Usually some "armor" tape is applied over the mica groundwall. If vibration occurs it will quickly wear off. Also, if a large-thread material is used, such as polyester, the threads

11. Failure at phase break is insulated with non-mica materials

12. Minor loose-wedge vibration

13. Bar-side vibration caused by air-gap flux not shielded from bar current because of end-of-core iron setback

14. Severe end-of-slot vibration

15. Severe side-vibration sparking caused winding failure

may not fully impregnate and cause the condition shown in Fig 6.

End-arm grading. These materials perform the important duty of grading off the abrupt voltage discontinuity at the end of the slot grounding paint. The end-arm grading systems usually are not troublesome.

Connection between grading and grounding systems. Energy collected in the grading paint must be bled off to ground. This is done by connecting the grading paint to the end of the grounding paint. This connection often is not made well and gives a local peripheral mark on the bar. This is a burn (Fig 8), not partial discharge (PD).

Uniform end-arm spacing. If end-arm bar shape is not uniform and spacing between bars at the phase breaks is less than about 0.375 in., severe PD indications may be observed (Fig 9). But with mica in the groundwall, failure may never occur.

Connection insulation. The electrical voltage between series bars is small and the insulation here can be limited in capability—non-mica or even air. But the voltage between phase connections often is line-to-line and mica insulation, or a large air gap, is needed (Figs 10 and 11).

Slot vibration prevention. Slot bar vibration has been a relatively

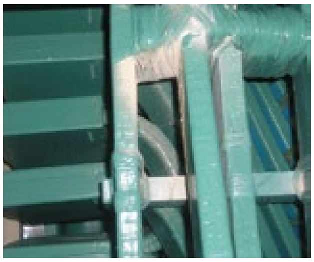
16. Minor vibration with noticeable dust generation

17. Failing electrical connection caused by endwinding vibration

18. Failed half-bar attributed to vibration

19. Open stator bar cracked and burned

20. Loss of clamping pressure on rings caused vibration



21. Vibration attributed to bond failure between rings and ties

common deterioration and failure mechanism on thermoset windings (Figs 12-15).

Endwinding vibration is a common, costly failure mechanism on thermoset windings (Figs 16-19).

Connection-ring vibration is a common wear and failure mechanism with numerous causes (Figs 20 and 21).

Other winding duty mechanisms that can cause deterioration and failure are in Figs 22-27.

O&M recommendations

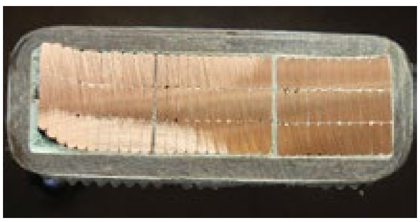
From an O&M viewpoint, all thermoset insulation systems are basically the same, although in a few important ways they are different from the soft asphalt systems. Thermoset windings are more vulnerable to cracking of the bar groundwall insulation from sudden short circuits, but more forgiving of over-temperature. Thermoset bars are vulnerable to cracking during winding installation.

A few cautions and special considerations relative to the thermoset windings are presented below. But O&M of the soft and hard insulation systems are not greatly different.

Operation

Nothing can be directly seen on the winding while the generator is in operation, and monitoring/ instrumentation capability is in general low. However, there are still important operational considerations, including the following:

Cleanliness. No insulation system likes contamination. On open, once-through cooling-air systems this can be a huge problem, depending on the local atmosphere. The



22. Strand displacement caused by insufficient flux shielding to top strands of bar in hydro generator (also see Fig 13)

23. Partial discharge occurring on exposed area at top of top bar

24. Cracking of bars caused by a sudden short circuit on winding

25. Tiny crack caused by sudden short circuit in winding. Since mica insulation cracks about like glass, groundwall is destroyed because crack essentially will go all the way through it

26. Severe arc damage to stator winding attributed to rainwater ingress

27. Foreign object (lost lock plate) damaged phase joint insulation

only solution may be constant physical monitoring of contamination build up.

Even on TEWAC generators, contamination will often slowly build up, depending on tightness of the ventilation system, quality of filtering of the inevitable air ingress, and local atmospheric conditions.

On hydrogen-cooled designs, contamination can still occur, particularly over long periods of time, and primarily during outages. Depending on the nature of the material—for example, coal dust or brush-wear carbon—contamination can be an issue.

Cleanliness issues are greater on the rotor windings, but can be a problem with stator windings as well. It is something that efforts should be expended to minimize, but is likely to continue even under the best of efforts.

Moisture is a sub-set of cleanliness. While dirt contamination, and correction, can be well understood, moisture contamination, and its correction, may not be. On open and TEWAC ventilation systems, no prevention really is possible beyond avoiding leaking coolers. On hydrogen-cooled units, humidity can still be an issue with cooler leaks or non-functioning dehumidifier equipment.

Direct water-cooled stator winding. These systems require constant monitoring during operation to maintain water purity, correct water oxygen content, water pressure, performance of coolers, and detect water leaks.

Overload. System demands may

call for overload of a generator. These situations should be limited because excessive load increases the electromagnetic forces on the stator winding as a squared function of current (load).

Asynchronous operation. Plant personnel may have little or no control in these situations, except during synchronizing. If the condition occurs at low power, no generator damage may occur. But if at high power, and persisting, total destruction of the generator may result.

Sudden short circuit. Except during synchronizing, the operator will have no control relative to short circuits. If synchronizing is off only a few degrees, no damage is likely. If a short occurs at 120 deg, maximum torque occurs and couplings may slip and other damage may occur. If the angle is off by 180 deg, maximum forces on the stator winding will occur and the stator winding almost certainly will be destroyed.

Winding temperature instrumentation

The recommendation of the OEM should be followed carefully relative to monitoring and responding to winding temperature readings. This may prevent a minor problem from turning into a major, costly, and long forced outage.

There is an inclination to want to load the unit based on slot RTD/TC readings. On indirectly cooled windings these readings are very indirect and inaccurate. Read an amalgamation of the temperatures of the cooling gas, the core, and the bar copper through a thick thermal blanket (the ground insulation).

On direct gas-cooled windings, cooling gas often is measured as discharged from individual bars. These values are an important and reliable indication of winding performance.

On direct water-cooled windings, many designs measure the temperature of the cooling water from each bar, and these readings are used to monitor winding condition.

But on a large number of water-cooled windings, cooling-water temperature is measured as it is discharged from pairs of bars. Using the discharge water temperature and the corresponding slot RTD/TC temperatures, some limited intelligence can be derived as to winding condition. But interpretation of winding condition based on these temperature readings is complex and inaccurate.

Maintenance

A well-designed, properly manufactured, and properly operated generator is unlikely to require rewind in 30 years of operation, and maybe never. But it will require regular maintenance. The frequency of OEM-recommended maintenance has evolved in the last 25 years (Ref 7).

But regardless of maintenance frequency, and considering the discussion in the root-cause section above, some basic principles apply. They are:

1. No work should be attempted without a qualified crew and supervision onsite.
2. The quality of the work and the rate of progress will be expedited if all necessary tools and equipment are on hand.
3. Item 2 also applies to all needed materials and parts.

These three items can be a huge challenge. In particular, skilled workmen are limited in supply and availability. The availability of capable supervision is limited as well. Also, often those sent onsite, even by the best of OEMs and vendors, are not well qualified. The result can be costly in dollars and calendar time, and in quality of work.

In the case of failure root cause

determination, if the lead investigative engineer is not highly skilled, incorrect determinations often have been reached and the result have been hugely negative in quality and cost.

Actual routine maintenance work constitutes a broad spectrum of often highly skilled effort. The work procedures have been documented by the OEMs and by others, and this documentation is broad and voluminous. No attempt has been made here to further document these procedures; but some special considerations are offered below on a few specific topics.

A good inspection by a qualified individual generally is the best assessment tool of a stator winding. It can reveal important information relative to deterioration associated with most of the conditions discussed previously in "Root causes of performance problems."

Thus the importance of a skilled inspection cannot be over emphasized. This inspection will consume time, maybe a full shift or more, but it must be done and done by a qualified individual. Many technical papers have been written on this important topic and two books with chapters on maintenance are included under Refs 8 and 9.

Test. Some stator-bar deterioration mechanisms cannot be detected by inspection—for example, general deterioration of groundwall, internal PD, strand or bare-bar vibration or displacement, and strand and group shorts. (Turn shorts on a multi-turn coil will normally be detected by winding failure.) Detection of some of these conditions may be possible by available tests, the most important of the tests being over-voltage test (hipot). Many papers have been written on the subject (Ref 10).

Hipot is a powerful test, but is controversial because of possible winding failure, which would likely force a long outage for bar or winding replacement.

Power-factor test can be performed, although this test has limited usefulness in determining winding condition, in the opinion of some experienced individuals.

Partial discharge and electromagnetic interference (EMI) may also provide some intelligence on winding condition. Expert assistance may be needed to interpret test results.

Finally there is the low-voltage insulation resistance test—the "megger" test. Both resistance and polarization index readings should be taken at every convenient opportunity.

Other maintenance considerations:

- Robotic inspection without rotor removal is widely recommended by OEMs, and these devices can perform rather well in an inspection of stator core areas. They can also do wedge tightness test and ElCid core insulation integrity test. However, a robotic inspection is expensive and may indicate the need to remove the rotor anyway.
- Re-wedging of the stator winding is recommended where it is not needed. Judgement of wedge tightness can be very subjective—for example, manual test by an inexpert individual, improper use of tightness test device, misunderstanding results of tightness device, etc. Re-wedging is expensive and time consuming, and can result in core and/or winding damage. Also, if only the end wedges are loose, only the end wedges should be replaced, not all wedges.

  It is essential that a qualified expert is involved in any wedge tightness assessment decision.
- Stator cooling-water systems involve many components: piping, valves, controls, storage tank, filters, deionizer, coolers—and the stator winding itself. Close following of the OEM recommendations for operation and maintenance of these systems is highly recommended and can avoid costly repair (Ref 11).

Wrap-up

The foregoing discussion of stator groundwall insulation and stator windings systems is intended as a general summary only. It is by no means complete, or even comprehensive. The reader is referred to the several references provided below, and to references within those documents. Also, the website www.generatortechnicalforum.org has a large collection of references in "Resources." The industry-wide library, open 24/7 at no cost to the user, is huge, variable in quality, and helpful if wisely and patiently used. CCJ

References

All but References 3 – 6, which predate the "electronic era," can be accessed via the QR codes provided by simply scanning the image with your smartphone or tablet. They are listed here to illustrate how long the industry has been dealing with insulation issues.

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QR1 QR2

QR3 QR4

QR5 QR6

QR7

How to design and care for reverse osmosis systems

By Wes Byrne, consultant, membrane technologies, U.S. Water

Pure water does not exist in nature. All natural waters contain varying amounts of dissolved and suspended matter. Osmosis is the process in which a solvent (water, for example) flows through a semi-permeable membrane from a less concentrated solution to one with a higher concentration. This normal osmotic flow can be reversed (*reverse osmosis*) by applying hydraulic pressure to the more concentrated (contaminated) solution to produce purified water.

There is no perfect semipermeable membrane. A small amount of dissolved *salt* is also able to diffuse through, but this results in relatively low concentrations compared to the feedwater values.

The benefits of reverse osmosis (RO) technology should be well understood in water treatment for power generation, particularly because of its potential to reduce O&M expenses. For most sources of water, RO will be the least expensive way to remove dissolved salts.

The term *total dissolved solids* (TDS) refers to these inorganic salts with some small amounts of organic matter, present in solution. The salts exist as cations (mostly calcium, magnesium, sodium, and potassium) and anions (mostly bicarbonate, chloride, sulfate, and nitrate). These positively and negatively charged ions can pass electrical flow, thus determining the conductivity of the water as a measurement of its TDS concentration. Pure water is a poor conductor of electricity.

For plants originally built using only ion exchange, adding RO can reduce chemical regeneration requirements by a factor of 20 or more. Complete removal of regenerable systems might even be considered.

With RO upstream removing the bulk of the dissolved salts, the polishing ion-exchange systems might be economically replaced with service demineralizer beds that are chemically regenerated by an offsite water service company, or they might be replaced by electrodeionization. EDI units use electricity to continuously regenerate their resins.

Some new and existing plants are now being required to remove dissolved salts from their wastewater streams prior to discharge. RO may perform this role so well that it may even be possible to re-use the water within the plant. The concentrated salt stream remaining after RO treatment might then be more economically hauled to a region that can better handle the environmental effects, or it could be evaporated or discarded in some other manner. The political and regulatory advantages of becoming a zero-liquid discharge (ZLD) facility can offset part of the capital and operating costs.

But the superior economics of RO operation are only achievable if the system and its upstream treatment components are correctly designed, operated, and maintained.

Analysis

Pulling a water sample for laboratory analysis is a good start in preparing an RO design. A comprehensive analysis provides data on the metals in the water (for example, iron, manganese, and aluminum), the dissolved salts (cations and anions), the water pH (acidity), and possibly the inorganic *total suspended solids* (TSS). A measurement of the *total organic carbon* (TOC) will often correlate with the potential for biological activity (Table 1).

A TSS analysis reveals the concentration of filterable solids in the water. The concentration of dissolved metals, such as iron, will change in the water sample as they react with oxygen introduced by contact with air. This will cause some of the metals to oxidize and become insoluble. The metals that stay suspended in the water may cause the TSS value to increase significantly with many well-water sources.

Table 1: Laboratory analysis report for water sample

Lab sample ID	Total	Dissolved
pH	7.4	-
Conductivity, μmho/cm	2440	-
Total organic carbon (TOC), ppm	3.76	-
P-alkalinity, ppm $CaCO_3$	0.0	-
M-alkalinity, ppm $CaCO_3$	400	
Bromide, ppm	<0.50	-
Chloride, ppm	26.4	-
Fluoride, ppm	<0.40	
Nitrate, ppm NO_3	<1.00	-
Nitrite, ppm NO_2	3.31	-
Sulfate, ppm SO_4	1117	-
Total phosphate, ppm PO_4	0.438	-
Ortho-phosphate, ppm PO_4	0.12	-
Total dissolved solids (TDS), ppm	2055	-
Total suspended solids (TSS), ppm	10.5	-
Ammonia-nitrogen, ppm NH_3-N	0.768	-
Total hardness, ppm $CaCO_3$	1325	1325
Calcium, ppm $CaCO_3$	913	913
Magnesium, ppm $CaCO_3$	412	412
Aluminum, ppm	<0.01	<0.01
Arsenic, ppm	<0.01	<0.01
Barium, ppm	<0.01	<0.01
Boron, ppm	0.215	0.215
Chromium, ppm	<0.01	<0.01
Copper, ppm	<0.01	<0.01
Iron, ppm	1.62	0.212
Manganese, ppm	0.447	0.447
Molybdenum, ppm	<0.01	<0.01
Nickel, ppm	<0.01	<0.01
Potassium, ppm	11.5	11.5
Selenium, ppm	0.057	0.057
Silica, ppm	24.9	24.9
Sodium, ppm	134	134
Strontium, ppm	2.44	2.40
Tin, ppm	<0.02	<0.02
Vanadium, ppm	<0.01	<0.01
Zinc, ppm	<0.01	<0.01

Notes: Results are listed down to the detection limit of the instrument used. Where results fall below these limits, they are reported as less than the detection limit. A dash indicates testing was not requested or was unable to be run

Table 2: Potential for scale formation

Parameter	RO concentrate
Langelier Saturation Index (LSI)	2.04
Stiff and Davis Index	1.72
Calcium Sulfate Saturation Index	9
Strontium Sulfate Saturation Index	8
Barium Sulfate Saturation Index	2495
Calcium Fluoride Saturation Index	126
Calcium Phosphate Stability Index	-8.97
%Calcium Silicate Saturation Index	-885.79
%Magnesium Silicate Saturation Index	-178.17
%Dissolved Silica Saturation Index	7.7

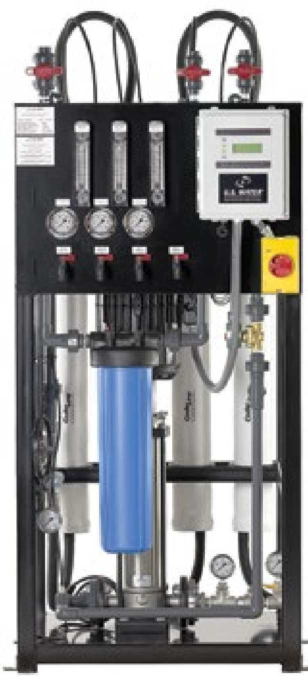
Note: Water sample described above would require 8.42 mg/L of USW RO-505 to inhibit scale formation

Biological fouling solids will not be well represented in the TSS results. The mass of these solids will typically become negligible when the TSS filter is dried prior to weighing for results. The water could be tested for its *silt density index* (SDI) if the metals are first separated out of the sample. This test will be highly sensitive to the ability of biological solids to coat and reduce the flow rate through its 0.45-micron test filter. Results will correlate with the fouling tendencies of a membrane system.

No analysis is perfect, and water quality can change over time. Even the characteristics of a well-water source will change if the well is relatively shallow.

Sampling methods affect results. Some concentrations will change between sample pull and analysis. Metals may attach to the container's inner surface. Ammonia and carbon dioxide may degas or carbon dioxide may dissolve from exposure to air. Any of these changes will cause the water pH to change. An accurate water pH is best measured onsite.

Chemical suppliers can use a water analysis to predict how much purified water (*permeate*) the RO might safely separate from the source before the dissolved salts become too concentrated in the remaining water and form scale within the membrane elements (Table 2). The water analysis is also used in designing the RO system, both in projecting the purified water quality and in assessing any effect of the salts on system hydraulics.



1. Pilot RO example

Pilot study

An RO system and its pretreatment equipment designed solely on one water analysis may not be fully optimized for the fouling characteristics of the source. It might be oversized or, of greater concern, it might not be ideal for water that has a high membrane fouling potential. This can best be determined with a pilot study (Fig 1).

A well-designed pilot study will use components that have been scaled down but still offer the same type of media and use similar flow velocities and exposure times. The pilot RO should duplicate the permeate recovery, the permeate flux rate (that is, permeate flow per unit of membrane area) and concentrate stream vessel exit velocities, along with the scale inhibitor dosage and shutdown flush methods.

When the pretreatment methods are piloted along with the RO, the system operation can be adjusted to minimize the rate of RO membrane fouling, such as by modifying the permeate flux rate or the rate at which water passes across the membrane surface and through the membrane elements. With the right equipment choices and sizing, it might even be possible to eliminate membrane fouling, which could then dramatically reduce operating cost and maximize membrane life (Fig 2).

The choice of membrane might also be evaluated. With large systems, demonstrating that a low-fouling membrane element performs better than a standard element will help justify its higher cost. Low-energy elements might be evaluated for their potential to reduce pump size and associated power consumption.

The pilot study also offers an opportunity to learn more specifically about what will foul the RO system. A membrane element from the pilot study might be pulled and autopsied. Analysis of the solids then makes it possible to choose cleaning solutions that are best suited for removing the particular fouling materials. The effectiveness of the solutions and cleaning methodology might then be verified with the pilot unit.

The longer the pilot system can be operated, the more information will be gained. A minimum of several months is recommended.

Upstream equipment

The success of a new RO membrane system is often directly related to its pretreatment. Piloting the upstream processes can be challenging in sizing these components for the pilot's low flow rate.

The most important role played by pretreatment is protecting the RO from incompatible substances. With the polyamide thin-film RO membrane commonly used today, the biggest concern is removal or destruction of any chlorine or other potentially oxidative compounds. This membrane has very little tolerance to free chlorine (present in many municipal water sources), and is only slightly tolerant of chloramines (in other municipal water sources).

The two most common methods for breaking down chlorine are reducing-agent injection and activated carbon filtration. The most common reducing agent is sodium bisulfite ($NaHSO_3$) which will react preferentially with free chlorine in breaking it down to the innocuous chloride ion.

2. Multimedia filter skid, low-flow pilot, is designed to test different media upstream of the RO system

Sodium bisulfite/sulfite injection systems can fail in ways that will degrade RO membrane elements if not quickly remedied. Examples: The day tank could run out of solution, or the injection pump could lose power or pump-head prime. The injection pump setting might provide insufficient chemical to handle the full range of chlorine concentrations, or might be set for such a low pulse speed that the chemical does not sufficiently mix with the feedwater.

The proper sodium bisulfite dosage should be injected any time that the RO inlet valve opens, even if this opening is for filling the RO or for flushing it out before a shutdown. There cannot be significant pipe length distance between the point of injection and the RO inlet valve, since this length will become fully chlorinated during shutdown by chlorine diffusion. The point of sodium bisulfite injection should be immediately upstream of the inlet isolation valve.

Activated carbon filtration may offer a more reliable means of breaking down chlorine. During manufacture, non-carbonaceous materials are burnt off, leaving porous granules with a substantial amount of pure carbon surface area. This has a high attraction for adsorbing almost any contaminant, including most organic materials and heavy metals, although there may be limited removal capacity for some contaminants that are shed into the effluent water.

The breakdown of chlorine by activated carbon involves an electrochemical reaction, which offers a high capacity for chlorine removal. The carbon gives up electrons to the chlorine atoms, forming innocuous chloride ions (Cl-) that remain in the water. In this reaction, oxygen atoms previously bonded with the chlorine atoms as hypochlorous acid (HOCl) now attach to the carbon surface. Because the carbon will also react with dissolved oxygen in the water, the carbon surface can become fully oxygenated. It will then lose its ability to remove additional chlorine, but this typically takes a few years with inlet chlorine concentrations less than 1 mg/L.

When ammonia is present naturally or when added by a municipality, chlorine will chemically bond with the ammonia to form monochloramine (NH_2Cl) or possibly dichloramine ($NHCl_2$). The chloramines are not as chemically reactive so require more carbon volume for their breakdown. A catalyzed carbon media is available at an increased cost that improves the carbon reactivity with chloramines and reduces the need for oversizing the carbon filters.

Carbon system valves cannot leak or otherwise bypass. They should be *normally closed* and driven by sufficient air pressure to not allow chlorinated water to reach the RO system.

Maintenance is critical to the success of either reducing-agent injection or carbon filtration. It is recommended that the activated carbon media be replaced annually or as based on an increase in its effluent concentration of TOC, to prevent the shedding of biological particles into the RO system.

Over-injection of sulfite will cause increased breakdown of dissolved oxygen in the water. This will increase the potential for heavy growth of slime-forming species of bacteria that can quickly foul an RO system if there is a sufficient concentration of organic food in the water source. This potential can be minimized by maintaining a residual sulfite concentration that is greater than zero but less than 2 mg/L as sodium sulfite, measured using a low-level test with sensitivity of 1 mg/L or less. As long as the sulfite concentration is greater than zero and it is well mixed into the feedwater, free chlorine will not be present.

Scale formation

There is typically at least one salt in any natural water source that will concentrate beyond its solubility and potentially form scale (Fig 3). Preventing scale formation should not be a major challenge unless the water source has an unusually high concentration of a slightly soluble salt, or unless the RO is being operated with an unusually high-percent permeate recovery.

Scale formation may be prevented by injecting an acid into the inlet water, by softening the water, or by injecting a chemical scale inhibitor. Usually the least expensive method is a scale inhibitor, which slows the rate at which the salt crystals grow when their solubility is exceeded.

3. Scale crystals are shown within the feed-side spacing material (top) and on the membrane (bottom)

Acid injection prevents calcium carbonate scale formation, but leads to an extremely high concentration of carbon dioxide. Carbon dioxide is not removed by the RO system and will place a high removal demand on downstream ion exchange processes. Also, acid injection alone will not offer much protection against the formation of sulfate or certain other scales.

Softening offers several advantages, but suffers from high capital and operating costs, unless there are particularly low concentrations of calcium and magnesium hardness in the water. The softener also will

4. Cartridge filters are fouled by biological growth

remove other potential scale-forming ions, like strontium and barium, and will remove metals that would otherwise foul the RO system (for example, iron, manganese, and aluminum). But the softening resin will also foul with the metals and then require periodic chemical treatment.

Scale-inhibition chemical suppliers often will use software programs to estimate the potential for scale formation. These programs will predict the concentrations of salts that will be present in the RO concentrate stream, as well as its pH, to determine how much scale-inhibition chemical will be needed.

The potential for silica scale is common with certain ground-water sources in the West. Inhibition formulations have shown varied success. Maintaining warmer water temperature will improve silica solubility, as will changing the water pH. Increasing pH is a common strategy, although the water must first be softened to prevent hardness scale from forming when a caustic chemical is injected to raise the pH.

When using a scale inhibitor, it is critical to rinse the RO system of its increased concentration of dissolved salts whenever the RO shuts down. Otherwise, scale particles will grow and stick to the membrane surfaces during the shutdown. This rinsing process should be automated and is often performed with low-pressure inlet water. Low pressure reduces the RO permeation that tends to concentrate the dissolved salts.

A better rinse might be performed with pressurized permeate water if a line can be plumbed back to the RO from a permeate storage tank system. The permeate is biostatic. Its use will reduce the formation of biological solids within the RO while shut down.

Membrane fouling

Fouling will not necessarily reduce RO membrane life if the RO is effectively cleaned. If the RO is allowed to foul too severely and cleaning is not effective, then the membrane will likely continue to lose performance.

It is common to include a filter housing on the RO inlet that contains 2.5-in.-diam cartridge filters whose pore size is nominally rated. The actual ability for removing smaller particles can vary greatly (Fig 4). Some (regardless of rating) will only protect the RO against large particles that might get caught within the membrane flow channels or damage the high-pressure pump. These are inexpensive and may last weeks before an elevated pressure drop indicates the need for replacement.

Tighter porosity filters that might remove more of the incoming suspended solids are more expensive and will also require more frequent replacement. Therefore, the use of these tighter filters becomes more economically viable if the concentration of suspended solids in the water has been minimized by upstream treatment.

Suspended solids often can be effectively reduced to reasonable concentrations for the downstream RO system with just a multimedia filter. Its inclusion in the RO water system might be sufficient to prevent a high RO fouling rate that could result in unmanageable cleaning requirements. Multimedia filters contain granules of two or more different types or sizes of sand, crushed rock, or anthracite (hard coal). Such a filter can be successful at removing most of the particles that make up the suspended solids if:

- It is sized for a downward flow velocity approaching 2 ft/sec.
- It has a lower collection lateral system designed to obtain uniform flow distribution across the media when the filter is operated at low flow velocity, while also allowing the entry of a sufficient backwash flow rate for a 40% bed expansion.
- The filter is backwashed before its previously removed smaller/fine particles are shed, which may occur before there is an appreciable buildup in filter pressure drop.
- After backwashing, the filter is forward-rinsed at its service flow rate

until its effluent quality is acceptable (such as based on effluent iron concentration, turbidity, or SDI).

The preceding points do not provide all of the filter design requirements, but were chosen because these particular guidelines often are not followed (mostly because they would increase the filter's cost).

Some water sources may contain unusually high concentrations of fine particles. In these cases, it may be necessary to send the water through large reaction tanks intended to give the particles more time to coagulate into larger particles that can then be more easily filtered.

An inorganic chemical coagulant (never a cationic polymer) may be added to the water upstream of the tank to speed the coagulation process. The coagulant will be most effective if it is first well-mixed with the suspended solids. If soluble metals (like iron or manganese) are present in the water source, some percentage will be oxidized by allowing the water to contact atmospheric air in the tank, although this percentage will be small.

A chemical oxidizer like chlorine (bleach) can be added to the water to oxidize the metals into their insoluble oxides (actually into their hydroxides when present in water) prior to coagulation.

Membrane filtration

Membrane filtration is becoming more common in various applications including pretreatment for RO systems. Membrane filtration often can provide water that is more consistently low in its concentration of suspended solids than that provided by a pressurized multimedia filter. Therefore, these systems may be used as an alternative to multimedia filtration, or possibly downstream to further polish the water and minimize RO fouling.

The most common configuration is hollow-fiber technology. Fibers of an inert polymer are extruded with a hollow internal region called the *lumen*. The fibers may be relatively fine/small in diameter where the inlet water passes through the outside of the fibers, and the fiber lumen. It then moves toward one end of the module for collection.

Because the fibers are tightly packed, flow movement around them is not uniform. Feedwater particles will come out of suspension on the membrane surface as the water goes through the fiber. They are not concentrated within a passing stream as the particles mostly would be with spiral-wound reverse osmosis, so there is no concentrate stream. The systems are simply operated at 100% recovery, except for the water losses from frequent backwashing with filtered water, resulting in an overall recovery of 90% to 95%.

There also are modules with larger fibers that use an inside-out service flow direction. The fatter fibers offer improved membrane surface flow characteristics for better distribution of the fouling solids, while the finer fibers offer the cost advantages of more membrane surface area in the modules.

The membrane filtration systems (Fig 5) should be sized to keep the fiber pressure differential (*transmembrane pressure,* TMP) relatively low to prevent compaction of solids against the fiber and into the fiber pore structure, and to reduce the potential for fiber breakage. This may mean sizing the fiber for a filtrate flux rate of 30 gal/ft²/day or less.

The fiber modules are backwashed using the filtrate water at a frequency of roughly once every 30 minutes, again to try to keep the solids from compacting and to prevent particles from getting forced into the pores and subsurface structure. Some manufacturers will reduce the backwash volume by knocking the solids free with compressed air.

Backwashing alone may not fully restore the original TMP. A chemically enhanced backwashing may then be required. If this fails to restore original performance, a circulated cleaning for an extended period of time may be needed.

5. This membrane filtration system is automated

6. Two-pass RO system purifies the raw water twice, and requires about twice the number of control valves and monitoring instruments

Operation and monitoring

Large RO systems will include several membrane pressure vessels. These vessels will be staged so that the concentrated salt stream from one set of parallel-plumbed vessels will be plumbed into a smaller number of membrane vessels, then possibly plumbed to another stage with an even smaller number of vessels.

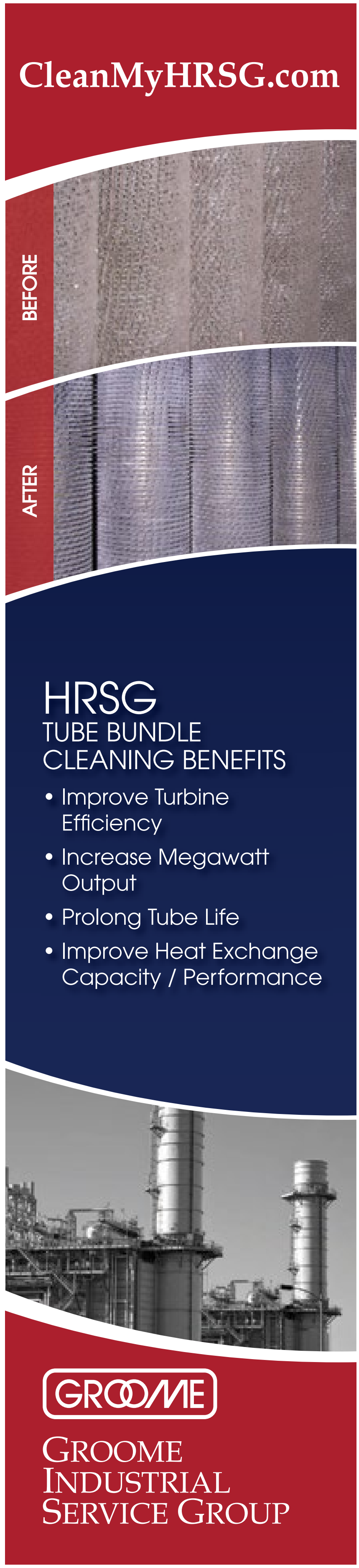
Staging is based on maintaining flow velocities sufficient to keep suspended particles moving and to assist dissolved salts in diffusing back into the bulk stream from the membrane surface (Fig 6).

RO systems usually are operated by adjusting the membrane feed pressure as needed to achieve the desired RO permeate flow rate. This may be done with a variable frequency drive (VFD) to control the high-pressure pump motor's rotational speed, or by using a throttle valve located directly downstream of the pump. With VFD control, the adjustment may be automatic. The RO system will also have a concentrate stream throttle system to achieve the desired concentrate flow rate. This may be a fixed system that uses an orifice plate, or more commonly a manual or automatic valve.

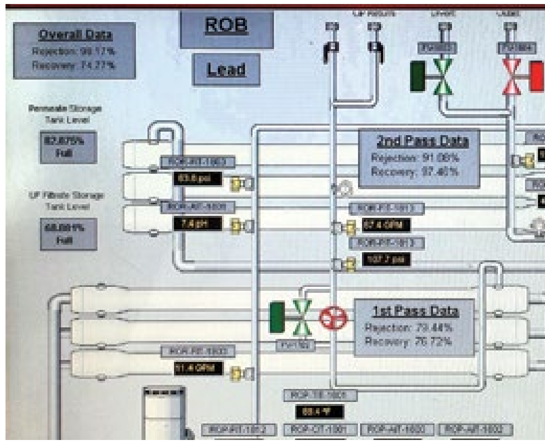
Along with the permeate and concentrate flow meters, pressure sensors are installed in the system piping to monitor the pressure entering the membrane elements, the concentrate pressure exiting the membrane, and possibly the pressures within the plumbing manifolds that connect the membrane vessel stages (Fig 7). A permeate pressure sensor may be needed, especially if there is significant or variable permeate backpressure on the system.

The electrical conductance of the water streams is used to monitor how well the RO is removing dissolved salts. The RO permeate water conductivity is monitored along with the makeup water conductivity.

A percent salt rejection for the system is calculated by subtracting the permeate conductivity from the feed stream conductivity and then dividing



7. Monitoring instruments can be panel-mounted or placed directly on the piping system



8. Large RO systems often include a display panel with all critical data captured by monitors

this value by the feed conductivity. The salt rejection percentage is probably the most commonly monitored performance variable.

Additional instruments may be needed if there is variability in the feedwater characteristics, or if a chemical is being added (Fig 8). If the water acidity changes naturally or through chemical addition, then the water pH should be monitored continuously.

The pH can have a dramatic impact on the RO salt rejection. If chlorine is being removed upstream, an online chlorine monitor or possibly an *oxidation-reduction potential* (ORP) monitor may be used to warn against its presence.

Key variables

Monitoring the percent salt rejection is important, but is limited in its ability to show the state of the RO membrane and is generally not a good gauge of membrane fouling or scale formation.

The relative ability for water to permeate the RO membrane can be tracked using a variable called the *normalized permeate flow rate*, which is the RO permeate flow rate standardized for the effects of operating pressures, dissolved salt content, and water temperature. The feed-to-concentrate pressure drop

tracks the resistance to water passage through the flow channels of the various membrane elements. This value may be calculated for the entire RO vessel array, or if inter-stage pressures are available, it can be calculated for the individual vessel stages.

If flow rates are not kept constant when operating the RO, it will be necessary to standardize the pressure drop for the effect of changing flow rates in calculating normalized pressure drop values. This then allows direct comparison of these values over time regardless of whether any flow rates have changed (Fig 9).

Small suspended particles or salt particles that coat the RO membrane surface will cause the RO normalized permeate flow rate to decline (Fig 10). Larger particles that get caught within the membrane flow channels and subsequently block the flow will cause the normalized pressure drop to increase.

If something in the water is chemically reacting with the RO membrane, the effect will likely be apparent in the normalized permeate flow rate, and possibly in the salt rejection. For example, if chlorine is allowed to come into contact with the RO membrane, the extent of membrane oxidation will be apparent as an increase in the normalized permeate flow rate soon followed by a decline in RO salt rejection.

A thorough understanding of the state of the RO system can thus be gained by routinely calculating and graphing the salt rejection and the two normalized performance variables. But their values may be misleading if any of the instrument readings are inaccurate. It is absolutely critical that monitoring instruments be routinely calibrated and repaired/replaced if in error (Fig 11).

When to clean

Chemical cleaning is a routine requirement for most RO systems. Frequency depends on the effectiveness of the pretreatment equipment.

As fouling solids or scale particles accumulate, their characteristics often change and they become more resistant to cleaning. Clay and biological materials will tend to compress against the membrane surface and become chemically resistant as water is squeezed out of their structure. Scale formations may change from being primarily calcium carbonate (relatively easy to clean) to calcium sulfate (difficult to clean).

The change in *normalized RO performance variables* can be used to determine cleaning needs. Most membrane manufacturers recommend cleaning before these variables change by about 15%.

Certain types of fouling solids or scaling salts may have a substantial impact on permeate quality. Aluminum salts may come out of suspension as a fouling particle, only to re-dissolve if the water acidity changes. This may then result in increased aluminum passage from the membrane surface through the membrane and into the permeate/purified water.

Calcium carbonate scale may leach a relatively high concentration of calcium carbonate through the membrane into the permeate stream and affect the conductivity. Most other fouling solids will not have a significant impact on RO salt rejection unless the fouling is extreme.

How to clean

Membrane cleaning involves passing a cleaning solution through the membrane system at conditions that promote the dissolution or delamination of the fouling solids from the membrane surface or from the spacing material along the membrane flow channels. The optimum solution will depend on the particular fouling solids or scale particles, and the relative ability to clean will often be limited by mem-

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- Manways and outer air seal removal
- Remove/inspect/replace bearings, seals, blowers and coolers
- Removal of generator rotor using Siemens advanced tooling
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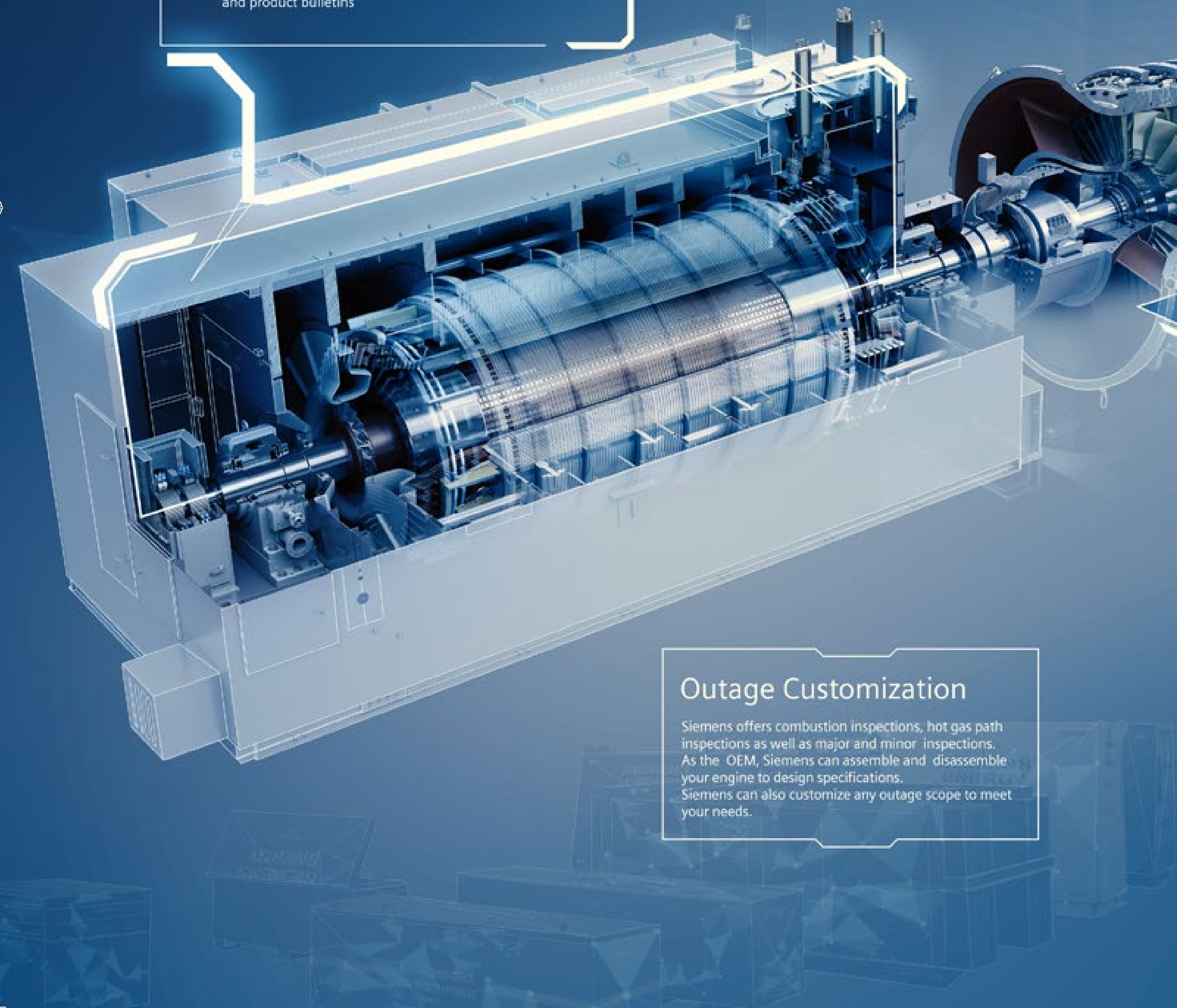

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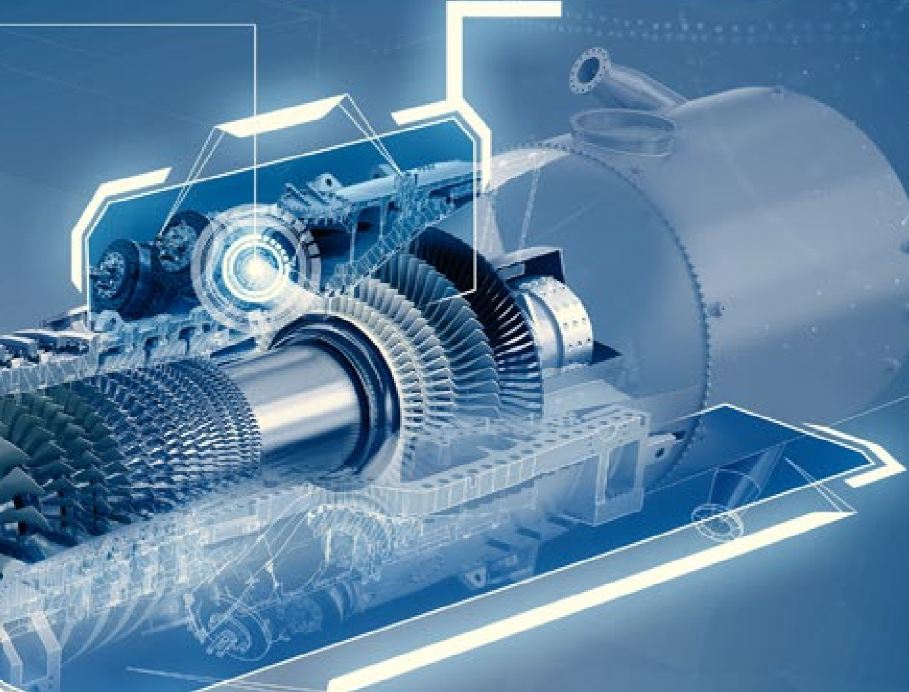
- Includes scopes as defined in the Combustor Inspection
- Removal of turbine cover
- Remove/inspect/replace hot gas path components based on operational history
- Borescope inspect compressor section via accessible ports



Flex Contract

This flexible approach uses Siemens reduced maintenance techniques incorporating advanced data collection,inspection tooling, procedures and analyses to define the specific maintenance solutions.

This allows for greater flexibility to make adjustments to address future needs with streamlined technology infusions. All while focusing on your specific operational environment and commercial drivers.

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- Remove inlet and exhaust covers
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- Optional removal of rotor and inspections based on operational history

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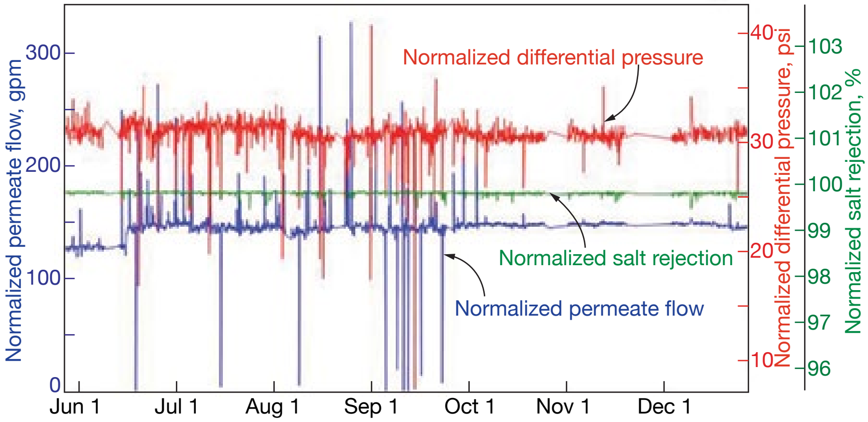
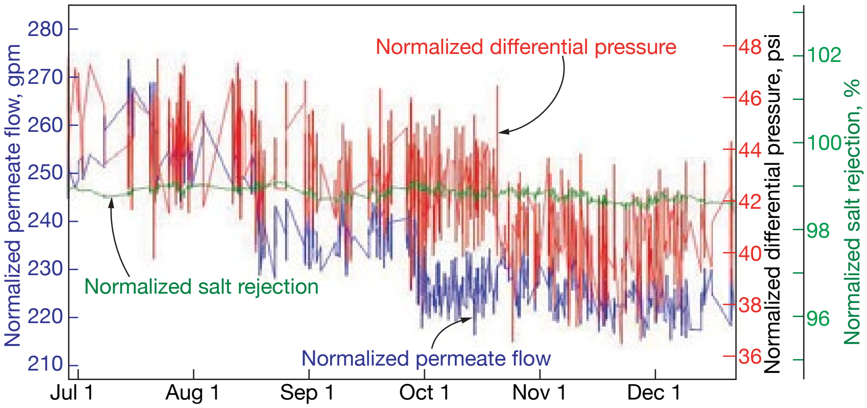


9. Internet-accessible graph of normalized performance variables indicates a stable RO system. Chart was developed from data captured during 9930 tests over a 215-day period. Normalized permeate flow was 146.6 gpm; normalized differential pressure, 30.9 psi; and normalized salt rejection 99.9%



10. RO system has a declining normalized permeate flow rate. Chart was developed from data captured during 1542 tests over a 184-day period. Normalized permeate flow was 235.7 gpm; normalized differential pressure, 42.3 psi; and normalized salt rejection, 98.9%

11. Proper instrument calibration is essential to RO system maintenance

brane chemical tolerance.

Most strong oxidizing agents that would typically be effective in cleaning biological solids are not going to be compatible with the RO membrane. There will also be limits to the pH extremes that should be used. In addition, while higher temperature will increase the rate of cleaning, the solution temperature will be limited to below 105F or as designated by the membrane manufacturer.

The most critical characteristic of a cleaning solution is its pH. Acidic solutions are more effective in dissolving metals and scale formations, while alkaline (high pH) solutions are more effective in removing clay, silt, biological, and other organic solids. Strongly acidic solutions may stabilize biological solids and therefore should not be used as a first cleaning step. Finishing a cleaning with a strongly acidic solution will tend to leave the membrane with increased rejection characteristics but somewhat reduced permeate flow, while finishing with a strongly alkaline solution will have the opposite effect.

The addition of specific cleaning agents often improves the solution's cleaning abilities. A chelating agent assists in pulling out metals from the fouling solids, while surfactants/detergents improve the solution's ability to penetrate the fouling solids and suspend oily substances. The use of surfactants may reduce cleaning time but will increase the time required for rinse up.

When the fouling solids are causing a flow restriction increasing normalized pressure drop, high cleaning flow rates (within the membrane manufacturer's guidelines) through the membrane feed channels will cause agitation that will assist in breaking up the deposits. When the solids coat the membrane surface and reduce the normalized permeate flow rate, the delamination of these solids will be most easily achieved if water is not permeating through the membrane during the cleaning process and creating a force that holds the solids to the surface. This means cleaning at low pressure.

Achieving a high cleaning flow rate that is balanced throughout all of the membrane vessels usually requires that each vessel stage be cleaned separately. This also helps minimize the pressure required to push the solution through the elements. Cleaning solution is therefore pumped at high flow rates, as recommended by the membrane manufacturer. It is pumped at the maximum pressure required to achieve the target flow rate, but may be limited to 60 psi to reduce the potential for crushing or otherwise damaging the membrane elements.

The solution is directed in the normal feed-end direction of flow and the exiting concentrate stream is then returned to the cleaning tank at minimal backpressure. The flow direction may occasionally be reversed so that the solution enters the concentrate end of the stage when fouling solids are blinding the face of the lead-end membrane elements.

There may be a small flow of permeate that should also be returned to the cleaning tank using a separate line. In spite of its low apparent flow rate, the permeate should never be valved off because this may put certain membrane elements at risk of physical damage.

Data should be recorded during the cleaning process. With membrane surface fouling, it is difficult to gauge when original performance has been restored until the unit is rinsed and operated normally. If the fouling solids were causing an increased pressure drop in the RO, then the cleaning inlet pressure can be used as a measure of cleaning progress. If the pressure keeps declining, the cleaning is still removing fouling solids. If the fouling is severe, it may require a number of hours of circulation before the inlet pressure stabilizes.

Cleaning success is confirmed when the normalized pressure drop and normalized permeate flow rate return to their startup values. CCJ

OEM hosts the only US user meeting focusing on V-frame engines

Music City or the Home of Country Music, whichever you call it, Nashville was the site of the 2017 Siemens V-frame Users Group conference, June 12 - 15. The meeting attracted attendees from across the world representing 37 power generation companies. As with previous V-frame conferences, the scope and design of the agenda provided a platform for sharing information among all parties.

This year's program focused on safety within the plant during all modes of operation, improvements to the reliability and efficiency of the equipment through improved maintenance processes and procedures, improved monitoring techniques (including new digitalization capabilities), and the implementation of new design components and upgrades to the operating systems.

Highlights of the Nashville meeting included:

- Exclusive user-only sessions integrated into the four-day program.
- An exhibition that showcased products and services for V-frame engines offered by Siemens and eight vendor partners. On display were the following:
  - Thermal insulation.
  - Exhaust and intake acoustic testing, emissions control, and inlet-filter-house and exhaust-stack repair.
  - Fogging and wet-compression compressor-inlet cooling technologies.
  - Hydraulic and pneumatic component repair for pumps, motors, and actuators.
  - Fabrication and repair options.
  - Fire detection and suppression systems.
  - Sensor and actuator repair/rebuild.
  - Babbitt-bearing repair and replacement.

Plus, Siemens displayed its repair and service network and technologies, and cybersecurity solutions. Attendees were able to experience a virtual reality assembly of a gas turbine which they could view from any orientation including from above or below the turbine deck.

Fleet update. The conference opened with a V-frame fleet update that reviewed performance data for the SGTx-2000E (known previously as the V94.2x and V84.2x) and SGTx-4000F (known previously as the V94.3x and V84.3x) engines. Both fleets showed similar availability and reliability numbers above 95% with the SGTx-2000F units slightly higher than the SGTx-4000E in starting reliability.

Introductory speakers Thomas Schmuck, for the SGTx-4000F, and Bernd Vonnemann, for the SGTx-2000E, got the audience engaged with a review of user questions and comments extracted from previous-conference user surveys and Siemens responses. Both presenters also provided an overview of new product upgrades.

Digitalization/product analytics. Siemens unveiled its Health Advisor as a part of the company's expanding digitization efforts. The performance-analysis tool evaluates and prioritizes solutions by cost and availability and displays potential availability and reliability improvements in unit configuration, diagnostic monitoring, operation, and maintenance. This helps owner/operators select options of greatest value to their plants.

Siemens' Continuous Plant Monitoring System also was discussed. It remotely monitors units and develops O&M plans based on the data provided. Such monitoring can support operation and maintenance planning and help users manage their plants optimally.

Tooling and field service. A new field service tool introduced to the group is designed to measure and monitor combustion dynamics to ana-

Products and repair services for V-frame engines were showcased at the Innovation & Technology Fair integrated into the user-group meeting

lyze combustion-chamber frequencies and help minimize the potential for acceleration events.

Outage-related safety tools used by Siemens' field service personnel were discussed next. They include a method for hand-turning and locking of the rotor during various stages of work—such as blade removal. This flexibility can allow sites with silo combustors to flip the combustion chamber in a controlled manner and allow for work to be performed in a different orientation.

Expanded combined-cycle solutions. While most users are familiar with Siemens products and services intended to improve plant startup metrics, the new Flex-Power Services™ product incorporates a variety of offerings for the entire powerplant regardless of the equipment suppliers. Example: Flex-Power Services offers a wide variety of services for the heat-recovery steam generator—including water-chemistry consulting, inspections, spare parts, and advanced engineering studies to assess the effects of gas-turbine upgrades on the HRSG.

Case studies

Plant optimization experience. Siemens engineers explained how they developed a solution to reduce emissions during "hot starts" (restarts within 12 hours after an engine shut down), while keeping the equipment within the manufacturer's startup recommendations for internal temperatures, steam pressures, and flows. This was accomplished with the following series of interconnected steps:

- Tuning.
- Control logic optimization.
- Incorporation of logic improvements with CEMS.
- Personnel training.

Result: A hot-start CO reduction of more than 40% and a startup time reduction of 35%, in round numbers.

Lift-oil hose update for the SGTx-4000F. A customer case study described the challenges faced when replacing a worn lift-oil hose for a compressor bearing. The main challenges of the hose-replacement effort were the limited access to the bearing-side connection with the rotor installed and the more rigid properties of the new hose. To dig deeper on this and other conference topics identified in this article, registered users are invited to access the Siemens Customer Service Portal.

Fuel-gas quality. The OEM discussed its view of the effect of the increase in the number of fuel-gas supplies (wellhead gas, shale gas, and LNG) on plant operations. Siemens believes this has led to fluctuating fuel-gas quality nationwide. The speaker said one reason for the quality differences, is that each supplier has its own processing steps which produce varying hydrocarbon and sulfur (H_2S) contents.

Siemens' experience has been that higher hydrocarbons can lead to a variety of problems—including clogged burners from coking. High levels of H_2S also can clog burner nozzles and/or contribute to burner corrosion.

For the user, fuel-gas sources and their mixtures should be considered simultaneously; operation outside of the OEM's fuel specs could lead to operational issues and void warranties. Fuel gases (mainly consisting of alkanes) may have the same Lower Heating Value (LHV) but a different Lower Wobbe Index (LWI). Among other adverse effects, gas with a low LWI has the potential to cause combustion instabilities, while gas with high LWI can cause both combustion instabilities and higher NO_x emissions.

While the SGTx-2000E and SGTx-4000F designs can operate over a range of conventional and unconventional liquid fuels, an automatic tuning system is available to accommodate changes in fuel-gas quality. The system can include, among other components, a fuel gas analyzer, liquid separation, coalescing filter, fuel gas preheating, aluminized burner and control logic upgrades to automatically adjust for changes in the LWI.

Generator update

Generator Frame Owner Scott Robinson presented to users on research results that concluded that multiple emergency starts from a standstill without lift oil in operation can potentially damage bearings. Inspections are recommended, based on the number of emergency starts.

Robinson also discussed new products and services, developed based on customer inputs, to help reduce outage duration and/or costs—including:

- Bonded stator core "donuts" which can provide the potential for a cycle time reduction from more than 100 to as few as 20 days or less.
- Auxiliaries upgrades:
  - Improved H_2 sealing, coolers, dryers, and skids.
  - Stator water skid control, instrumentation, and chemistry.
  - Automatic voltage regulator modernization.
- Ultra-low clearance inspection robot. A compact robotic inspection platform presented to the users is equipped with a high-resolution video and can eliminate the need to remove rotors for major inspections. Stator slot wedge tightness, in-situ stator core tests, and retaining-ring inspections also can be performed. Field removal still may be necessary based on findings from the robotic inspection.
- High-frequency loop test. Siemens has developed tooling and processes to perform the loop/thermographic inspection of stator cores without the need for a plant-supplied 4160- or 6900-Vac (100 to 700 amp) connection. This new tool also eliminates the need for multiple, large-diameter cables. The newly designed equipment includes an elevated-frequency power supply enclosed inside a 10 × 8 ft shipping container for easy transport to jobsites and requires only a 480 Vac (100 amp) supply.
- GVPI. The differences between the current, new-build generator manufacturing process of Global Vacuum Pressure Impregnation (GVPI) versus single VPI generators were discussed next. Since the global VPI manufacturing process was introduced in 1988, more than 1650 stator windings have been delivered and amassed 25.5-million operating hours, plus 322,000 combined start/stop cycles. To date, no stator failures attributed to insulation issues on Siemens generators have been reported to the company.

Robinson concluded his presentation with a review of the benefits and reasoning behind the modular design of the GenAdvisor™ Monitoring Platform. These include:

- The ability to monitor partial discharge, endwinding vibration, inter-turn short-circuit monitoring, and rotor shaft voltage and shaft grounding current.
- The allowance of concurrent monitoring of multiple generators and connection to the OEM's Power Diagnostics Center.
- Providing real-time information about the machine condition during operation (difference to offline tests).

Controls, digitalization

The I&C group reviewed its products and services designed to provide customers with optimal operation and security of their systems. These presentations detailed:

- Training. Siemens offers support, courses, and course extensions to owner/operators throughout the lifetime of the installed control system. Users can be instructed on I&C system planning, assembly and configuration, how to respond to alarms, diagnose faults, create system simulations, etc.

- SPPA View2 is an application that provides internet access to site data (not direct control) for remote viewing of I&C operation and can be used to display documents and other customer reference material.
- I&C Customer Portal allows users to input and track hotline tickets, request remote inspection services, and oversee software patch and malware protection. Customers can also use the portal to search operations manuals.

An overview of several SPPA T3000 applications was given including the plant performance and diagnostics overview or "Plant Health Display" option which allows plant operators to view plant-wide operations on a single screen. Several case studies were presented which outlined the implementation of these applications and how they helped customers.

Cybersecurity

Cyber attacks, past and current, were reviewed with an eye on how new international standards and government policies are helping to address increasing attacks via connected industrial devices added to the OT environment. This was followed by a presentation on Siemens comprehensive cyber security portfolio approach to combatting hacking was presented.

A case study of Darktrace technology, which uses artificial intelligence systems to identify and respond to in-progress cyber threats followed. In the presentation, the Siemens team discussed how they attempted to bypass the Darktrace technology by using a registered, properly configured company laptop. As reported, within seconds of connection, the technology recognized the authorized, but unfamiliar, presence of the laptop and logged an alarm.

Within a short period of time, the technology learned that the computer was new to the network but was properly authenticated and was performing the same tasks as the other computers already on the network and lowered the threat severity level to less than 5%.

Engineering session

RCIE update. Siemens reviewed the 100,000-EOH (equivalent operating hours) Rotor Casing Inspection and Evaluation (RCIE) findings aggregated from overhauls of more than 100 SGTx-2000E and 48 SGTx-4000F gas turbines since 2009. Evaluation of these findings produced the following conclusions:

- Statistical results have shown that, in some cases, there is a potential to reduce the component replacement scope at an RCIE outage.
- Component-specific recommendations at an RCIE may change based on changing electricity markets and more demanding operating regimes.
- Inspection programs are updated based on experience and the latest analytical results.
- Siemens has an established material aging strategy designed to determine the mechanical properties of aged materials and work toward extending the RCIE of 2000E baseload units to 200k EOH.
- Flexibility in timing of the RCIE and adaptation of the outage scope is possible and has been successfully implemented.

Repair update. A discussion of various state-of-the-art and/or patented repair processes available at the Winston Salem Service Center was conducted. In some cases, the repair technology was transferred from the 50-Hz to the 60-Hz design. These processes are focused on improving technologies to meet customer needs and meet or exceed the original component design criteria. Components that can benefit from these processes include:

- Refurbishment of blades and vanes. Inspection and repair using welding, blending and/or brazing, recoating of the airfoils, and final inspec-

tion which now includes rigorous cooling-hole measurements.
- R1 blade tip repair uses a patented, precise, automated laser welding process for tip findings and an automated laser re-opening process for cooling-air flow. The repair includes an improved coating designed to avoid spallation of the thermal barrier coating (TBC).
- R1 and R2 vane repairs. Advanced brazing processes reduce scrap rates with braze advancements through R&D. These components may also benefit from the implementation of an upgraded TBC coating.
- SGTx-2000E Si3D components. Updated repair techniques can increase inspection intervals up to about 41k EOH and 1500 starts.

Technical issues session

A review of the 2000E technical improvements developed in the past year included the following:
- Spoiler tile—Optimized clearances; retrofitable to all flame tubes.
- Hardface coatings of MC transition areas, tile support ring, IC transition to MC.
- Ceramic heat shield combustion-chamber material improvement.
- Compressor exhaust diffuser.
- Combustion chamber upgrades.
- Improved exhaust.
- Inner casing upgrades.

The 4000F technical improvements developed in the past year included these:
- Upgrade of the ceramic heat shield.
- Compressor vane carrier 1.
- ACC outer shell/TVC wear improvements.
- Compressor manufacturing process improvements.
- Improved lift-oil hose.
- HR3 burner improvements.
- 33MAC experience.

Mods and upgrades session

The most important M&U products for the SGTx-2000E at a glance:
- Flexibility—Part-load upgrade and 50-Hz turndown.
- Power—Increase in compressor mass flow (CMF+).
- Performance—Wet compression, Si3D Stages 1-4, power limit increase.
- Availability and lifecycle cost—New inner casing, new maintenance concept.

Most important M&U products for the SGTx-4000F:
- Power—CMF++, wet compression.
- Efficiency—Hydraulic clearance optimization.
- Power and efficiency—CMF+ and thermal performance upgrade.
- Flexibility—Reduced cooling down, load gradients in IGV range, fast startup/shutdown, part-load optimization.
- Performance—Advanced stability margin control.

8000H update

A short presentation of the latest Siemens gas turbine, the SGTx-8000H engine was included in the program. This engine combines the best features of the V- and F-frame designs, along with newly designed components and features—such as hydraulic clearance optimization.

Siemens/users open discussion

The conference concluded with a review of the following topics to answer user questions generated during the closed sessions:
- Foreign material exclusion.
- Rotor balancing.
- SGTx-2000E fuel control actuators with low-pressure hydraulic system.
- Knowledge transfer .
- IT and server. CCJ

Advisory document reflects OEM's changing maintenance philosophy over time

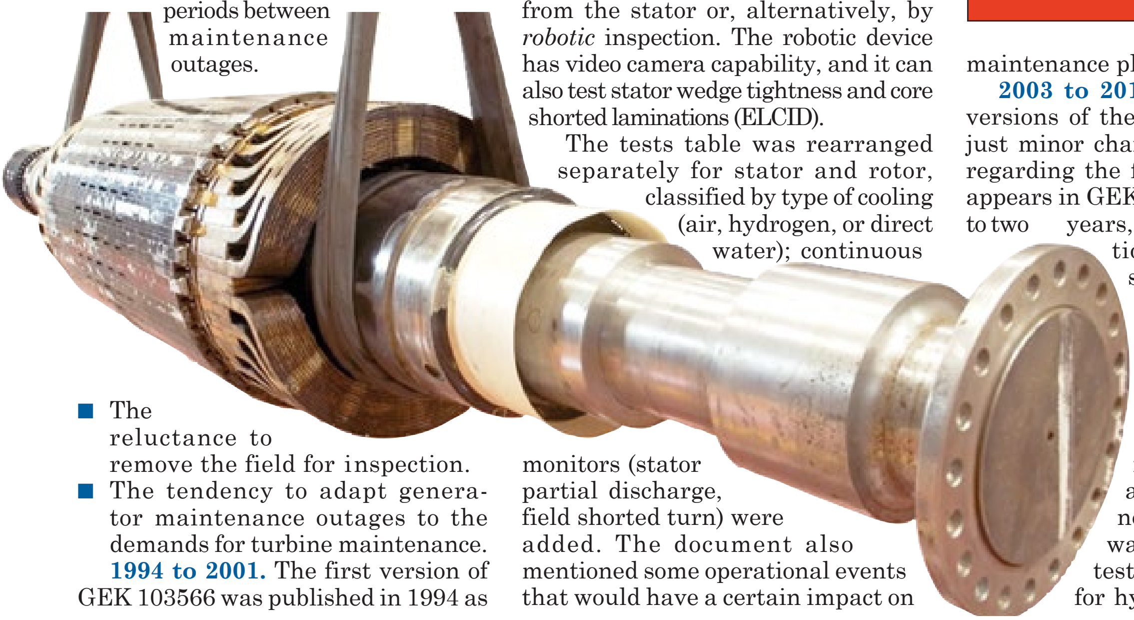
By Relu Ilie, Utility Electrical Engineering Manager

OEMs include generator maintenance recommendations in their O&M manuals. Sometimes they also issue general instruction documents, to be applied to their entire fleet, including machines already in operation. One such document is GE's "Creating an Effective Generator Maintenance Program" (GEK 103566), which recommends achieving machine reliability through consistent maintenance frequency, testing, and inspections.

This valuable document for generator owner/operators has been issued over the last 23 years and has evolved through about a dozen versions. Thus it can be used to illustrate maintenance philosophy changes that have occurred in the industry during the last quarter-century. Similar changes also have been implemented by other generator manufacturers and utilities.

The following brief review of GEK 103566 historical documents reflects these trends, among others:

- The industry evolution toward longer periods between maintenance outages.
- The reluctance to remove the field for inspection.
- The tendency to adapt generator maintenance outages to the demands for turbine maintenance.



1994 to 2001. The first version of GEK 103566 was published in 1994 as an attachment to the OEM's Technical Information Letter (TIL) 1154-3, "Generator Test and Inspection."

It recommended a time-based maintenance frequency: *minor* outages every 30 months (with end shields dismantled but field remaining in place) and *major* outages every 60 months (including removal of the field from the stator), with the first major outage scheduled a year after generator first operation. Note that inspections of old, long asphalt-insulated generators were recommended more frequently.

In principle, this time-based maintenance strategy matched the OEM's instructions issued prior to publication of GEK 103566.

The document included the standard and optional tests to be performed during each outage type, as well as the visual inspection areas.

2002. The revision GEK 103566A (2002) kept the above maintenance frequency but brought one significant change: A major outage can be performed as before by removing the field from the stator or, alternatively, by *robotic* inspection. The robotic device has video camera capability, and it can also test stator wedge tightness and core shorted laminations (ELCID).

The tests table was rearranged separately for stator and rotor, classified by type of cooling (air, hydrogen, or direct water); continuous monitors (stator partial discharge, field shorted turn) were added. The document also mentioned some operational events that would have a certain impact on maintenance planning.

2003 to 2012. These subsequent versions of the document presented just minor changes. Some flexibility regarding the first major inspection appears in GEK 103566B (2003) of up to two years, depending on operation hours and starts/stops. Version B added details about robotic inspection capabilities and minimum possible air gap.

GEK 103566E provided separate tables for stator and rotor and, in between, a new table dedicated to water-cooled stator leak tests (with fewer requests for hydraulic integrity test skid—HIT skid—in case a high-performance stator leak-monitoring system is installed). Revisions G (2011) and H (2012) were almost unchanged, except for some minor notes about ELCID (optional in place of standard test) and wedge-tightness test criteria.

2014 to 2015. GEK 103566J (2014) was a completely rewritten revision, with significant changes. The recommended inspection intervals were no longer calendar-based; they were synchronized with the prime-mover schedule.

Minor and major outages became defined in terms of gas/steam turbine hours and number of starts (whichever comes first) and according to the generator model. The first inspection requirement was also after a specific number of operating hours or starts. Instead of major outages every five years, the OEM recognized that some powerplants may run for extended inspection intervals of from six to 10 years.

The fretting wear caused by turning-gear operation was mentioned. The document also recognized that the robotic inspection may not eliminate the need to remove the rotor if an issue is discovered and should be corrected—for example, replacement of stator wedges. No significant changes appeared in the test tables, except they now included visual inspection and clearly distinguish between *robotic* and *rotor-out* major outages.

The preferred method for field shorted-turn testing is mentioned to be the flux probe. A new section and table presented recommended NDT frequency and opportunities to check for cracks in the rotor forging bore (if it has one) and slots, field wedges, and retaining rings—according to the applicable TILs. Revision K (2015) remained mainly the same, except for some clarifications about turbine hours and turning-gear limits.

2017. GEK 103566L, dated February 2017, is again a major revision. It declares the intention to remove the generator rotor only when a repair requires necessary access (but mentions that some generator designs may still require rotor removal).

A new table shows examples of events or trends predicting the need to remove the rotor. The historic generator terms *minor* and *major outages* are not used anymore and they are respectively replaced by *borescopic* and *robotic inspections.*

The difference is a borescopic inspection is typically done via a manhole or by removing a cooler (the end shields do not require removal). These inspections alternate in time; however, after many years or numerous starts, just robotic inspections are recommended.

A modified and simplified table indicates the first and subsequent maintenance intervals. A few examples of inspection-interval charts are included, and they reflect synchronization with gas- or steam-turbine outages. This version mentions other plant equipment that requires periodic servicing and adds over-speed to the list of abnormal operation events.

The test tables are updated and rearranged; tan delta test is added for stator windings, new remarks are added about bushing replacement and PD tests, etc. The water stator leak tests table still treats high-oxygen systems, but some details are given below it for low-oxygen (Alstom) systems.

Additional NDT examinations are mentioned for collector shaft, couplings, fan hubs, etc. New guidance is given regarding replacement or at least more frequent inspection of 18Mn-5Cr retaining rings. A new table describes the OEM's available monitoring systems.

A new section and table deal with chemical cleaning (of hollow conductors of water-cooled stator bars), mainly giving explanations about high- versus low-oxygen systems and monitoring for cooling-water flow restrictions.

Conclusions. The OEM's philosophy regarding generator maintenance (including existing machines) has changed over time. These modifications indicate the efforts of all OEMs to match their recommendations to changes in the industry, primarily pressures for budget cuts, by increasing the intervals between outages and by performing inspections without rotor removal, etc.

These changes do not come without potential costs—for example:

- A deteriorating condition found after five years may be relatively inexpensive to repair, whereas before 10 years is reached the unit may fail catastrophically.
- A robotic inspection is unlikely to meet the quality level of a direct visual inspection by a qualified individual. Also, findings detected during robot inspection may require immediate rotor removal for repair of conditions found; this sequence of effort will result in higher cost and a longer outage.

Finally, a large generator is an extremely complicated machine whose reliability is essential to the industry. It deserves suitable attention and attention may suffer from being considered just another element of the rotating train to be maintained in the shadow of the turbine. CCJ

Automating startup procedures can provide numerous benefits

To paraphrase a famous quote from the political arena, a dollar here, a dollar there, pretty soon you're talking about real money. And so it is with automating combined-cycle startup procedures. It doesn't take a genius to realize that the more times you start up the unit, the more opportunities you have to avoid losing money. And who isn't experiencing more unit starts these days?

If you still rely on manual startups with sign-off paper sheets, you are probably wasting fuel. Similarly, starts spread among different operators with different preferences and understandings of the boundaries around hot, warm, and cold starts can also lead to inconsistent performance. In other words, the more dynamic the operating modes are day-to-day, hour-to-hour, the more chances there are of losses from inconsistent and out-of-date procedures.

Jeff Williams, Emerson Automation Solutions, Power & Water, speaking at the 2017 7F Users Group conference in San Antonio, provided a laundry list of options offered for his company's Ovation™ platform to optimize combined-cycle operations by automating manual procedures, along with a few concrete examples of the monetary benefits to owner/operators.

Regarding the latter:

- A southern US utility reduced fuel use by 54% over 55 starts and 290 load transitions, saving over $1-million in a year.
- A mid-Atlantic utility reduced fuel use by 26% over 50 starts, saving $250,000 annually.

Most recently installed facilities likely have a high degree of startup automation built into their controls. So the options up for consideration (table) are probably more relevant to older facilities originally designed for more stable operating regimes—such as baseload.

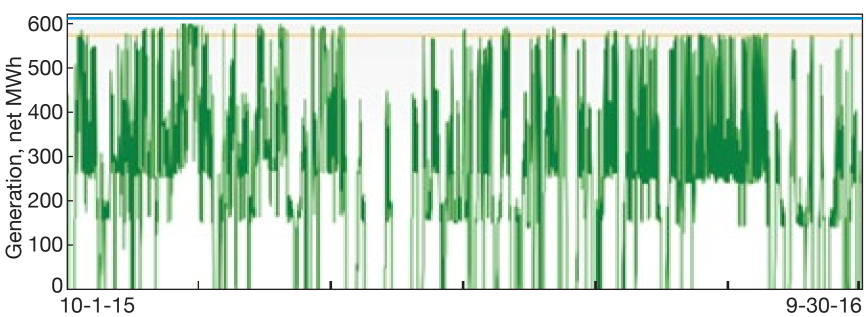
For example, according to Williams, what is "visible" at these plants are the number of starts from zero, the number of gas-turbine starts, capacity factor, heat rate, and minimum and maximum load points. What typically isn't so visible are the fuel use per start, time to start, starting reliability, dispatch time lost to starting, and AGC (automatic generation control) capability.

Extracting the added performance and revenue requires two things. First, the right metrics have to be installed. These include fuel used during hot, warm, or cold starts for your combined-cycle configuration; fuel used during load transitions and HRSG steam blending into the main header; instantaneous gas-turbine heat rate and overall plant heat rate; auxiliary (parasitic) megawatt-hour use; and fuel used during shutdown. These metrics are then used to generate reports and establish different plant operating profiles.

Second, you need to essentially convert your written start, transition, and shutdown procedures into live screens, or sequence function charts, in the control system. Tasks, steps, and actions are then shown in real time, with options for the operator to abort, hold, switch to manual, or override.

Other benefits from more consistent starts, shutdowns, and transitions include:

- Reduce stresses on equipment—such as less variance in steam temperature through model-based control, and less dynamic stress on spray valves. Up to a 50% reduction



Annual load profile (Oct 1, 2015 to Sept 30, 2016) for a 2 × 1 supplementary-fired combined cycle in Colorado reveals dynamic operating requirements. Duct-burner firing can increase output by up to 75 MW

Options for achieving more-consistent performance under dynamic operating regimes

Combined-cycle optimization apps: Start time and fuel

Application	Performance benefit	How it works
Pre-start automation	Faster, more-consistent starts and turnarounds	Uses sequence algorithm suite or sequential function chart to bring pre-start operations into the control system and off paper-based checklists. Embedded logic ensures all prerequisites are satisfied before proceeding to the next step
Procedural integration	Faster, more-consistent starts and turnarounds, reduced consumption of starting fuel	Same as "Pre-start automation," but focused on gas- and steam-turbine operations. Again, embedded logic ensures all prerequisites are satisfied before proceeding to the next step
Optimal load path	Reduced starting fuel consumption, faster starts	Custom logic characterizes HRSG steam production during startup to minimize heat loss from accelerated gas- and steam-turbine ramp-ups. Accurately matches HRSG heat input and steam production to HRSG and steam-turbine requirements. Note: "Procedural integration" must be installed before or with "Optimal load path"
Steam-header blending automation	Reduced starting fuel consumption, faster starts	Custom logic coordinates HRSG steam production via gas-turbine loading and bypass-valve management to produce desired steam-header pressures and temperatures automatically for faster starts with less fuel
Steam-turbine dynamic rotor stress	Reduced starting fuel consumption, faster starts	Custom logic characterizes and anticipates rotor stress levels and drives the process to minimize start time and fuel consumption while remaining below steam-turbine stress levels specified by the OEM

Combined-cycle optimization apps: Ancillary services

Application	Description	Performance benefit
Model-based steam-temperature control	Model-based superheat and reheat attemperator control	Faster ramping and heat-rate improvement
Duct-burner AGC	New mode added to coordinated control	Ancillary service ramping
Model-based load demand control	Model-based coordinated control	Faster ramping

Combined-cycle optimization apps: Emissions

Model-predictive SCR control	Model-based flow control	Reduced ammonia consumption

Combined-cycle optimization apps: Reliability

Freeze-protection alerts	Integration of smart devices to alert on device freeze-up	Fewer failed starts/trips from frozen impulse lines

in steam-temperature variation is possible, as well as 50% reduction in spray-valve movement and water flow.

- Minimize maintenance factors on gas turbines caused by balance-of-plant upsets.
- Detect problems with fuel system components, instruments, and other devices *before* a startup sequence is initiated—especially important as the time period between starts increases.
- Avoid issues with optimizing operations under seasonal temperature variations.
- Reduce reagent consumption to meet emissions limits under dynamic operating conditions.
- Universal access and visibility of procedures and performance under dynamic operating regimes.

Although today's plant load profiles can be quite dramatic (figure), shocking even, most forecasts point to even greater variability in operating regimes in the near future (CCJ 1Q/2017, p 24), as combined cycles are called upon to fill in around fuel-free renewable energy capacity and locational marginal prices decline. The plant represented by the figure is a 2 × 1 combined cycle with enough HRSG duct-burner capacity to add 75 MW of steam turbine/generator output when necessary.

Williams' presentation can be accessed by users registered on the 7F Users Group website at 7Fusers.org. CCJ

Aero combined cycle enhances reliability, flexibility for Pasadena

In California, it seems, the objectives with new supply capacity have to do with molecules and minutes—that is, minimizing "molecules" of NO_x emissions under all load and dispatch scenarios and shaving minutes off of dispatch response times. For the City of Pasadena Water & Power Dept, add a third objective: Addressing a long-standing reliability issue.

At the end of last year, the municipal utility replaced a 1965-vintage oil/gas "teakettle" boiler/steam turbine unit at its Broadway Power Plant with a new 71-MW combined cycle (named GT-5) at the adjacent Glenarm Power Plant. Anchored by a GE LM6000PG SPRINT gas turbine/generator, GT-5 includes an Innovative Steam Technologies (IST) once-through steam generator (OTSG) and Shin Nippon Machinery Co steam turbine/generator. The combined-cycle steam-side output was sized for an equivalent capacity replacement such that the existing emissions permit could be transferred. The old unit has since been decommissioned.

Like so many other owner/operators in the state, Pasadena needed faster response to dispatch signals, while avoiding the inefficiencies and emissions inherent in pressing old metal into service for current-day requirements. According to Plant Manager Arturo Silva, the facility might keep the old unit warm with a fire in the boiler for days so that its output could be available within an eight-hour startup sequence. Then the unit might operate at a load point between 20 and 71 MW, depending on what the California ISO called for and what the city needed internally.

The city's peak load is around 320 MW. While the utility has a 282-MW import capability, it comes from two lines connected with the Southern California Edison (SCE) system. However, both of those lines enter Pasadena's grid at the same point. In other words, there are three transformers, two transmission lines, but only one substation, one entry point for purchased power.

This created a reliability issue the city lived with for years. While the new unit doesn't remove this reliability constraint, it enhances overall system reliability for the utility by providing a generation resource within the city. In addition, it replaces 35 MW of purchased power sourced from a distant coal-fired facility.

Combined cycle, powered by an LM6000PG gas turbine at City of Pasadena Glenarm Power Plant, replaces capacity from 1960s-vintage oil/gas unit at adjacent Broadway plant (background) and displaces imported coal-based capacity

The new combined cycle reduces risk on several levels. First, it provides 71 MW from a state-of-the-art unit, rather than one that has seen more than five decades of service. Second, the 53 MW from the LM6000 can be online within 10 minutes and the full combined-cycle output within two hours (Sidebar), greatly enhancing the utility's ability to respond to CAISO dispatch signals, balance purchased power with its own supply, and substitute for purchased power under adverse or emergency conditions.

This is welcome flexibility especially since CAISO tends to either keep the unit at around 19 MW or frequently moves the load up or down, notes Silva. The unit typically experiences at least one start per day, and remains online for six hours, two hours in simple cycle, four hours with the steam cycle.

Early O&M challenges

Silva and the utility are "really happy" with the new unit. "It has come a long way towards alleviating our reliability issue," he said. Two persistent O&M challenges are dissolved O_2 in the steam cycle during startup and meeting NO_x emissions limits in both simple- and combined-cycle modes.

According to Silva, the water chemistry for the OTSG is extremely sensitive and the unit is above its dissolved O_2 limits until making steam, which then allows the condenser to most effectively remove oxygen. The plant plans to add a 3M LiquiCel membrane contactor for removing dissolved gases from liquid streams. According to 3M website info, this technology is replacing O_2 scavengers, forced-draft deaerators, and vacuum towers for removing O_2.

To meet the 2-ppm NO_x emissions limit (one-hour basis), the responsible vendors, IST and GE, implemented a variety of fixes. A combination of improved seals, static mixers, baffles, and reduced turbine emissions in simple-cycle operation improved NH_3/NO_x mixing and allowed the unit to achieve emissions compliance.

However, stack emissions still can be a challenge, says Dave Tateosian of Clean Power Consulting Partners, Martinez, Calif, when the unit is subjected to frequent significant load changes in response to CAISO dispatch orders, or is operating at low loads (down to 25%) when the mass flow through the OTSG is reduced, slowing its response to emissions changes. Tateosian served as the GT-5 project manager, and commissioning manager, for the final six months of the project.

Undoubtedly, Glenarm and Broadway's neighbors will breathe easier. The Glenarm and Broadway plants are an island of power generation within Pasadena, bisected by the Los Angeles County Metropolitan Transportation Authority's light rail tracks, and surrounded by built-out suburban and commercial neighborhoods and a high-end residential district that sits on a hill overlooking the plant.

The Glenarm powerplant dates back to 1906, exemplified by the historic building (now a city-designated historic monument) at the left in the photo. The original boilers, steam turbines, and condensers are still there, along with tiled walls, wrought-iron railings, etc—a monument to the days when generating stations were viewed as a sign of progress and held in high esteem. CCJ

Small aero-based combined cycles offer operational flexibility

Dave Tateosian, principal, Clean Power Consulting Partners, Martinez, Calif, respected for his decades of engineering experience on West Coast power projects, talked to the editors about the advantages in operational flexibility offered by aero-based combined cycles equipped with a once-through steam generator like the GT-5 project for Pasadena Water & Power Dept described in the main text.

In sum, he said, a 1 × 1 aero-powered combined cycle with an OTSG can offer the starting time and output of a simple-cycle unit with the full efficiency of a CC within a couple of hours. Here are some of the takeaways from the conversation:

- More than 50 MW in less than 10 minutes. The LM6000 for a unit such as GT-5 can start and reach full load in less than 10 minutes, providing about 75% of rated combined-cycle output. With condensate in spec, a cold startup of the steam plant takes approximately two hours to ramp to full capability.
- Turndown to 30% load. The 1 × 1 described by GT-5 offers a wide operating range, from 18 to 53 MW in simple cycle and 19 to 71 MW in combined cycle.
- Combined-cycle efficiency. With the ability of the OTSG to run dry, the generating unit can start in simple cycle and then transition to combined cycle on the fly, picking up an additional 15 MW or more.
- Steam plant upsets do not impact the gas turbine. The OTSG has two functions: Generate steam for the steam turbine and isolate gas-turbine operation from steam-plant upsets. Even in the worst case event of an OTSG trip, Tateosian said, the gas turbine continues to operate unabated. In the meantime, the OTSG is allowed to depressurize to less than 50 psig. Once the problem is corrected, the boiler is restarted, followed by a steam-turbine restart.

Adding big battery turns non-spin peaking GT into spinning reserve

The changing nature of electric supply

Special to the COMBINED CYCLE Journal

Jason Makansi, chairman, Editorial Advisory Board

On the one hand, if this Southern California Edison (SCE) facility is a harbinger, the industry could be entering a golden era of creative, innovative grid-scale storage applications. On the other hand, California is such an anomaly, this golden era, at least from a national or global perspective, could still be years away.

Either way, SCE gets credit for pioneering the world's first commercial applications of a hybrid 10-MW/4.3-MWh lithium-ion battery energy storage system (BESS) and LM6000 nominal 50-MW peaking gas turbine/generator, dubbed the hybrid enhanced gas turbine (EGT) by system supplier, General Electric Co, Schenectady, NY (Fig 1). Lest you think this is a BESS simply sited at a peaking GT facility, it's actually a fully integrated BESS/GT system, thanks to a control system having many proprietary details.

Wellhead Power Solutions LLC, Sacramento, rounds out the partnership for the project (Sidebar).

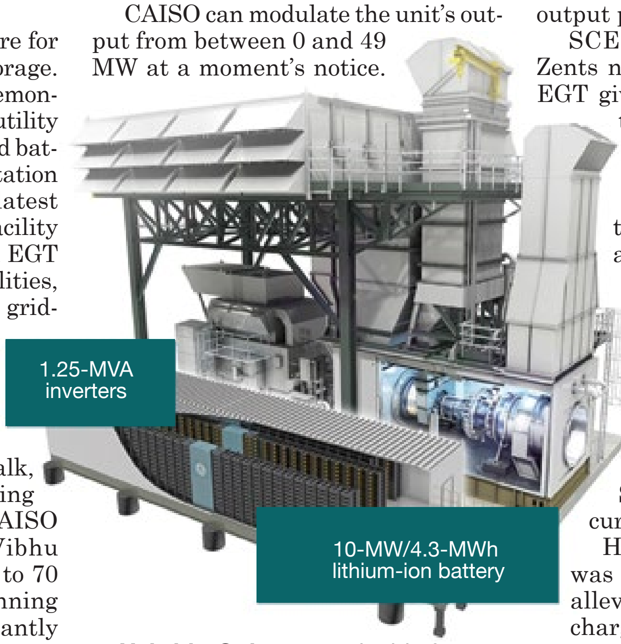
In a way, it's back to the future for SCE in pioneering grid-scale storage. The utility, with EPRI support, demonstrated what was at the time the utility industry's largest BESS (lead-acid battery chemistry) at its Chino substation from 1988 to 1996. With this latest system, at its Center Peaker facility (Fig 2), and a companion Hybrid EGT at another of its five peaking facilities, SCE is again at the forefront of grid-scale storage technology.

From non-spin to spin

The core value proposition for the hybrid EGT at Center, Norwalk, Calif, is capitalizing on the pricing for spinning reserves in the CAISO market, according to SCE's Vibhu Kaushik, which can be from 50 to 70 times higher than the non-spinning reserve price, while also significantly reducing emissions and optimizing the operation of other system assets. The LM6000 has been there since 2007 functioning as a peaker.

Essentially, the battery's main job is to dispatch power immediately upon receiving the CAISO dispatch signal to the plant, and keep delivering power for the first few minutes as the GT/G starts up. Typically, the GT begins its startup sequence once the battery achieves 250 kW output. Once the GT/G is delivering significant power to the grid, it also begins to recharge the battery.

CAISO can modulate the unit's output from between 0 and 49 MW at a moment's notice.



1. Hybrid EGT's most valuable function is, perhaps, its ability to respond instantaneously to grid needs

The battery is able to take load swings while the GT/G remains at max output, it's most efficient and lowest emissions operating point. Another aspect of the project was to reduce the LM6000 start duration from 10 minutes to five minutes. Thus, the BESS delivers megawatts immediately and ramps extremely fast, while the gas turbine takes the first two minutes to synchronize, and then less than three minutes thereafter to achieve full output of 49 MW.

In the absence of the BESS, the GT/G could be "spinning," ready to put megawatts onto the grid when called, but this practice consumes fuel and discharges emissions while not being productive. Other units around the system also function non-optimally; combined cycles, for example, could be producing at 90% of capacity, holding 10% back as spinning reserve. Having BESS units take up this slack allows combined cycles to continue to operate at their optimum design/maximum output point.

SCE Project Manager Matthew Zents notes, "essentially, the hybrid EGT gives us a more efficient asset that can participate in a market 'sweet spot' for dispatch below 49 MW."

The other big factor in justifying the project was the catastrophic leakage from the Southern California Gas Co's (SoCalGas) Aliso Canyon gas storage field and subsequent shutdown of the facility. When that occurred, the LA Basin, and southern California in general, was at risk of natural-gas shortages. In fact, SCE was under a threat of gas curtailment most of last winter.

Having a BESS at a peaker was seen as a means of partially alleviating that risk. Since a fully charged BESS didn't require a gas fuel feed, unlike a peaking GT/G, it could at least supply critical loads for short periods of time.

2. Center Peaker facility's battery dispatches power immediately upon receiving the CAISO dispatch signal and continues to provide power while the gas turbine/generator starts up

Although spinning reserves and mitigating the Aliso Canyon risk were mainly how the project was justified, Kaushik and Zents concede that neither CAISO nor SCE can fully predict how the hybrid EGT will be dispatched. "This is new territory," said Zents, "we're all going to learn how such a unit best contributes to grid management."

In grid-scale storage parlance, the Center BESS is what's known as a "power" application. The battery's output can be drained in 20 minutes. In "energy" applications, the battery's output is available over several hours or more.

As for the one challenge which plagues even the strongest advocates of Li-ion BESS for grid-scale storage, the risk of catastrophic fire, SCE indicates Center is equipped with Fike Corp's FM200 clean-agent fire suppression system, which is now considered the standard for a large-scale BESS. According to Fike literature online, it uses HFC 227ea suppression agent and is able to discharge in 10 seconds or less.

Switchgear, controls challenge initial ops

Zents and Operator/Mechanic Rick Snyder reported that the unit has met all of its performance obligations and technical objectives since commissioning in March. The plant staff is still tweaking the control system, the source of the project's most important lessons learned. The facility can be remotely controlled from SCE's Eastern Operations Generation Control Center in Redlands, but also controlled locally should the need arise.

Center proved what many other grid-scale storage projects have experienced; controls, automation, and digital communication are the greatest challenges with grid-scale BESS. "We learned that getting the main controller to 'talk' to the Mark VI GT control system, the Woodward system, and other sub-systems was anything but straightforward," observed Zents.

In addition, there are numerous communication interfaces: The control system handles battery operation and life management, interfaces with the grid, modulates between the BESS output and the GT output, and optimizes among everything on a sub-second basis. Fine-tuning digital communications among all the components and functions took time and patience.

As just one example, the battery contains 18,000 prismatic cells, and is designed as eight 1.25-MVA subunits, each containing 13.8 kV-480 V switchgear plus inverter apparatus and associated battery bank. The proprietary controls decide in real time which of those sub-units to call upon to meet the ISO demand signals, such that battery cell life is maximized. Each of those 18,000 cells has its own voltage monitor and every other cell has a temperature monitor!

One interesting aspect of controls/automation is that they were too sensitive initially. According to Zents and Snyder, the system was so effective responding to frequency droop, the battery would sense small variations on the grid and respond with output. However, those responses unnecessarily counted as unit "starts."

Starts are a precious commodity for a peaker in the LA Basin having to comply with South Coast Air Quality Management District (SCAQMD) emissions restrictions. Center is only allowed 356 annually. In the peak seasons, the unit could be called upon to start twice a day, so they can get tallied quickly.

The other big "pain point" during commissioning and early operation was the medium-voltage switchgear. One might think the associated relays, breakers, switches, and protection products would be off the shelf.

However, concedes GE's application engineer for the project, Shanon Kolasienski, the *design* necessary for this first of a kind facility was not solidified far enough in advance. "Site details and relay protection schemes were not completely vetted ahead of time, so the equipment was shipped without secondary wiring, heaters, and communication devices," he noted.

Zents and company expresses the medium-voltage switchgear headaches this way: "We took that hit for the next customers of hybrid EGTs."

Beyond fast track

Given the schedule for this project, dictated in part by the anticipated emergency posed by SoCalGas' Aliso Canyon, GE has been easily forgiven by the SCE project team. Other aspects of the project were deemed "lessons learned" but also originate in such an ambitious schedule. Zents and Kaushik agreed that air permitting did not start early enough. Local permitting issues, such as for safety and fire protection, were also challenges. After all, the local regulators had never experienced a project such as this.

Cybersecurity issues were also mentioned as an area for greater attention earlier in the project. Even though Center is low on the NERC CIPS asset classification scale, cybersecurity issues are still legion, especially with third-party vendors having access to

Wellhead's role in integrated GT/battery development and implementation

Wellhead Electric Co is a small, 30+-year-old IPP developer, owner, operator, and constructor, based in Sacramento (65 employees, 400 MW). Affiliate Wellhead Power Solutions LLC (WPS), performed the installation of the Hybrid EGT and designed and managed the related upgrade of the SCR at SCE's Center Peaker facility. WPS has been granted the patent for the hybrid technology embedded in the SCE Center project (U.S. Patent No. 9,722,426 for the Hybrid Energy System and Method).

The patent covers the company's innovative hybrid system integrating gas turbines with battery power systems that enable electrical generating stations to provide advanced grid stability. The specific GE LM6000 Hybrid Electric Gas Turbine (EGT) controls were co-developed by WPS and GE based on Wellhead's hybrid patent. GE's LM6000 Hybrid EGT is governed by a Hybrid Control System (HCS) which produces a blended high-performance output while managing the Battery State of Charge (SOC) and GT starting/stopping, and providing precise megawatt (net) control.

Wellhead has a commitment to powerplant and electric industry technology development with four additional technologies in the pipeline. It began developing and experimenting with EGT concepts on its LM6000 units in 2010. The development effort was prompted by a dramatic increase in variable operation of its peaker fleet for grid reliability reasons (versus peak energy) as renewables generation increased in California.

For the hybrid functionality to be fully effective, the system must ensure that the unit provides the same droop response with or without fuel burn, and complex programming is required to allow for the necessary bidirectional sequencing, adaptive synchronization, precision megawatt control, advanced emissions controls, and modified fuel shut-off/purge system of the gas turbine. This integrated control approach allows for superior grid support with a P_{min} of 0.0 MW and no minimum up time or down time requirement on the gas turbine.

the equipment for remote monitoring and maintenance.

But with two hybrid EGTS now under their belt, SCE is contemplating similar upgrades at the other three peaking facilities in its service territory. "From a revenue perspective, we could have selected any one of the five SCE peaker sites," Kaushik said. In part, this is because spinning reserve is a zonal value, not a locational one. "Center posed the fewest complications in terms of necessary modifications, upgrades, footprint, permitting, etc," he added, "so it was selected based on the cost side of the equation."

Every molecule counts

It is common knowledge that every molecule of emissions avoided is important to the State of California. Thus, one of the great benefits of the hybrid EGT is that it is expected to cut the number of starts on the LM6000 by 50% and reduce overall run time by 60%, thereby avoiding the equivalent number of operating hours, associated emissions, fuel consumption, and noise.

This being the strictest air quality district in the country, that wasn't enough. The LM6000 NO_x and CO control systems were upgraded, with assistance from catalyst vendor Cormetech Inc, Durham, NC. By increasing the catalyst cross-sectional area (within the same outside dimensional footprint) and thereby exhaust gas-reagent contact area, and bolstering the strength of the aqueous ammonia concentration from 19% to 29%, the GT can now operate between 0.5 and 49 MW output and still meet a 2.5-ppm final NO_x limit from the unit's stack. The water injection algorithm was also modified, so that less water would be consumed.

This may seem like overkill to those in other parts of the country, but consider that the Center peaker site sits adjacent to a major transmission substation literally surrounded by commercial establishments, shopping centers, busy thoroughfares, and residential areas. The Target superstore just across the street is emblematic of the location.

Other commercial aspects

Although the power application (as opposed to an energy application) batteries were supplied by Samsung, GE holds the bundled performance and lifecycle guarantees on the hybrid EGT. SCE signed a 20-year LTSA with GE, with off-ramp opportunities after five years. The batteries are designed for a 20-year life.

The battery also adds a wrinkle to SCE's resource adequacy (RA) requirements stipulated by the California PUC. RA means that SCE is obligated to maintain supply that is 115% above its summer peak demand. RA resources have to be able to deliver their maximum output for at least four hours. Dividing the BESS' 4.3-MWh capability by the four-hour deployment period means that it contributes 1.075 MW of additional RA capacity.

To recap, the hybrid EGT adds these market services to the original non-spin reserve capability of the peaking GT:

- Spinning reserve.
- Regulation up, regulation down (battery can serve as load and supply).
- RA resource.

By doing all this while significantly reducing fuel consumption and emissions unlocks additional value from SCE's peaking GT fleet. Such capital investments for assets which will rarely operate more than 10% of the hours in a given year may seem surprising, but it reflects where electricity grid management is headed as more fuel-free but highly variable renewable resources are added.

One might wonder how CAISO "accounts" for the electricity needed to charge the battery. There are no meters onsite at Center to monitor parasitic power consumption. CAISO instead assumes a constant parasitic load that is factored into the real-time price it pays for the electricity. The BESS' inverters (true for all inverters) constantly consume some electricity from the grid even while the hybrid EGT is offline, but that's the nature of the component.

The bottom line, notes the SCE project team, is that the value of non-spin assets has declined, mostly because so many quick-start GTs, as peakers or part of combined cycles, can now be online within 10 minutes. Investing to make the SCE peaking units spinning reserves, which will show some diminishing returns across the fleet (the grid needs a limited amount of spinning reserves), justifies such investments in grid-scale storage. Flexibility while avoiding incremental emissions has extremely high value in California.

The next peakers to be upgraded may feature even larger batteries, which will only enhance all the aforementioned benefits, according to SCE.

As a final note, major maintenance overhauls on the LM6000 GT/G can be extended because it will operate fewer hours and the combustor will experience much less water injection, prolonging its life. CCJ

Breakout sessions dig into the nitty-gritty of engine O&M

If you're involved in the management, operation, maintenance, and/or overhaul of one or more LM2500, LM5000, LM6000, or LMS100 engines and haven't participated in an annual meeting of the Western Turbine Users Inc, ask yourself this question: Why did about 400 users from 20 countries and 41 states attend the organization's 27th Annual Conference & Exhibition at the South Point Hotel & Spa in Las Vegas, Mar 19 – 22, 2017?

Answer, if you can't guess: It's the largest, most comprehensive technical meeting in the world for these engines. You can't help but learn from colleagues in the breakout sessions for each machine, from top engineers at GE and the OEM's Authorized Service Providers (ASPs), and from representatives of more than 150 suppliers of products and services for these specific gas turbines. Note that the ASPs were known previously as "depots."

If you're scratching your head thinking "well, I just attended a year or two ago and I'm up to date," scratch some more. To keep your plant competitive in today's challenging world of must-take renewables, of serious financial penalties for not satisfying grid contractual requirements, and of mandated shutdowns for relatively minor emissions excursions, your mind must be as finely tuned as the equipment in your charge.

Register November 1 for the next meeting in Palm Springs, Calif, March 18 - 21, 2018 (box).

This is the second CCJ report on WTUI's 2017 meeting; the first appeared last issue (1Q/2017, p 52). Here the editors offer an overview of the opening presentations by the ASPs and then walk you through some of the details shared during the LM6000 and LMS100 Breakout Sessions. Acronyms are used frequently in those sections; if you're not familiar with them, refer to Sidebar 1. The report concludes with a review of the vendor fair.

W.T.U.I.

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For the latest information on technical and social programs, exhibit space, sponsorships, conference and hotel registration, etc, visit www.wtui.com.

To reserve exhibit space and sponsorships, contact
Bill Lewis: wclewis@wtui.com, or
Jermaine Woodall: jwoodall@wtui.com

ASP profiles

ANZ Gas Turbines. The joint venture between Air New Zealand and Consolidated Asset Management Services, Houston, created a world-class field service organization for North America, based in Bakersfield, Calif. Frank Oldread is GM of the company, Jimmie Wooten is manager of turbine maintenance, and Bob Cox heads up marketing and sales. All are well known in the aero community; in fact, Oldread and Wooten were WTUI board members when users.

The company supports LM2500, LM5000, and LM6000 gas turbines. Plus, ANZGT is responsible for managing the aftermarket needs of the LM5000 fleet, which numbered more than 100 engines 10 years ago and only three dozen today.

To provide timely, quality service, the Bakersfield group is reaching out to owner/operators to develop a clear strategy for each power producer in the near term. It's no longer possible to run a traditional field/services/spare parts strategy given the wind down of the fleet. Several owners are not planning any maintenance/overhaul before decommissioning their engines.

IHI GM Takashi Yamamoto reviewed the company's deep connection with the LM6000: parts manufacturing (CRF), package and control-system design (for the PC, PD, PF, PG, PH, and PF+ engines supplied by GE), BOP design, EPC contracting, and maintenance (in the field and in the shop).

The company's aftermarket network includes two Level 4 shops—Kure Works (Hiroshima) and Mizuho Works (Tokyo)—plus service centers in Thailand, Australia, and Cheyenne, Wyo. Yamamoto stressed the Level 2 Cheyenne shop's ability to respond quickly and effectively to unscheduled events. Its assets include rotable exchange components, shipping containers, critical parts, and lease engine.

The GM next introduced attendees to the company's other business units in the US, including the following:

- Overland Park, Kans. HRSGs, SCRs, duct burners, and related equipment.
- Chicago. Energy storage (batteries), control software.
- Aliso Viejo, Calif. Aero GT operations, O&M contracts.
- Houston. LNG, oil and gas plants.

MTU Maintenance focused on its facilities—a Level 4 service center in Germany and five Level 2 service centers worldwide, including one in Dallas. The company's experience is vast—hundreds of LM engines have been repaired in the German shop, thousands when you add in the CF6 because of the company's large aircraft business.

The modern test facility in Berlin-Brandenburg with Mark VIe controls operates under real-load conditions using a generator. The facility can handle all types of LM engines, including the 2500+G4 and the 6000PF.

TransCanada Turbines (TCT). Dale Goehring and Darcy Simonelli handled the presentation duties. The company has an aggressive health and safety (HSE) program. It's the

1. Acronyms to remember

AGB—Accessory gearbox (also called the transfer gearbox)
AVR—Automatic voltage regulator
BACT—Best Available Control Technology
CBV—Compressor bleed valve
CCM—Condition maintenance manual
CCR—Customized customer repair
CDP—Compressor discharge port
CFF—Compressor front frame
CI—Combustion inspection
COD—Commercial operating date
CPD—Compressor discharge pressure
CPLM—Critical-parts life management
CRF—Compressor rear frame
CSA—Contractual services agreement
CSM—Customer service manager
CT—Current transformer
CTD—Compressor discharge temperature
CWC—Customer web center (GE)
DEL—Deleted part
DLE—Dry, low emissions combustor
DOD—Domestic object damage
EGV—Exit guide vane
EHS—Environmental, health, and safety
EM—Engine manual
EOL—End of life
ETS—Exhaust temperature spread
FFA—Front frame assembly
FFH—Factored fired hours
FMH—Flexible metal hose
FOD—Foreign object damage
FPI—Fluorescent penetrant inspection
FSNL—Full speed, no load
GCV—Gas control valve
GG—Gas generator (consists of the compressor and hot sections only)
GT—Gas turbine (consists of the gas generator pieces with the power turbine attached)
GTA—Gas-turbine assembly
GTG—Gas turbine/generator
HCF—High-cycle fatigue
HEPA—High-efficiency particulate air
HGP—Hot gas path
HGPI—Hot-gas-path inspection
HHV—Higher heating value (of fuel)
HMI—Human/machine interface
HPC—High-pressure compressor
HPCR—High-pressure compressor rotor
HPCS—High-pressure compressor stator
HPT—High-pressure turbine
HPTN—High-pressure turbine nozzle
HPTR—High-pressure turbine rotor
HRSG—Heat-recovery steam generator
IGB—Inlet gearbox
IGV—Inlet guide vane
IPT—Intermediate-pressure turbine (LMS100)
IRM—Industrial repair manual
LM—Land and marine
LCF—Low-cycle fatigue
LHV—Lower heating value (of fuel)
LO—Lube oil
LOTO—Lockout/tagout
LPC—Low-pressure compressor (not on LM2500; just LM5000 and LM6000)
LPCR—Low-pressure compressor rotor
LPCS—Low-pressure compressor stator
LPT—Low-pressure turbine
LPTR—Low-pressure turbine rotor
LPTS—Low-pressure turbine stator
LTSA—Long-term service agreement
MCC—Motor control center
MCD—Magnetic chip detector
MERV—Minimum efficiency reporting value (air filters)
MI—Major inspection
MOH—Major overhaul
NGV—Nozzle guide vane
OEM—Original equipment manufacturer
OST—Overspeed trip
PAG—Power augmentation
PB—Product bulletin
PM—Planned (or preventive) maintenance
PN—Part number
PT—Power turbine (turns a generator, pump, compressor, propeller, etc), potential transformer
PtAl—Platinum aluminide
RCA—Root cause analysis
RFQ—Request for quote
RPL—Replaced part
RTD—Resistance temperature detector
SAC—Single annular combustor
SB—Service bulletin
SCR—Selective catalytic reduction
SL—Service letter
SRV—Stop (or speed) ratio valve
SUP—Superseded part
STIG—Steam-injected gas turbine
TA—Technical advisor
TAT—Turnaround time
TAN—Total acid number (lube oil)
TBC—Thermal barrier coating
TC—Thermocouple
TEAAC—Totally enclosed air-to-air cooled generator
TEWAC—Totally enclosed water-to-air cooled generator
TGB—Transfer gearbox (also called the accessory gearbox)
TIL—Technical information letter
TMF—Turbine mid frame and thermal mechanical fatigue
TP—Transition piece
TSN—Time since new
VBV—Variable bleed valve (not on LM2500; just LM5000 and LM6000)
VBVD—Variable bypass-valve doors
VIGV—Variable inlet guide vanes
VSV—Variable stator vane
VSVA—Variable-stator-vane actuator

first subject TCT discusses each year at WTUI. Goehring seemed almost apologetic in Las Vegas because two HSE "events" were recorded in 2016 for more than 475,000 man-hours worked. Perhaps that was because there were no "events" recorded in 2015 when more than 480,000 m-h were worked.

Goehring spoke briefly about the numbers of training hours, management visits to work areas, and inspections it takes to achieve such an enviable record—huge. Commitment squared. Training alone last year totaled some 3500 hours (round number). Still, 241 safety observation cards were issued to identify concerns, need to stop work, potential for an incident, unsafe acts/condition, and quick fixes. More than half of those cards were issued at customer sites. All SOCs are tracked and trended; both positive and negative observations are recorded.

The focus on people continued. The steady and experienced workforce averages 20 years in the industry, 10 at TCT, and has a turnover of less than 3%, Goehring said. The field-service team numbers more than 50 to serve 124 customer sites in 34 countries, each member averaging more than 50 hours of training annually.

LM6000

The LM6000 is the most popular of Western Turbine's four breakout sessions, attracting more participants (300 plus at the 2017 meeting in Las Vegas) than the LM2500, LM5000, and LMS100 breakouts combined. Andrew Gundershaug, plant manager of Calpine Corp's Northern California Peakers, chairs this group.

Gundershaug's day job is to manage seven LM6000 peakers at different sites, so there isn't much in the way of "issues" with these engines that he hasn't experienced firsthand. That, plus two decades of work on LM engines, exposure to problems faced by others as a WTUI conference attendee since 2001, and excellent speaking and audience-engagement skills, place Gundershaug among the most capable of user-group floor leaders.

The primary responsibility of breakout chairs at WTUI is program development. While that's true for steering committee members of other user groups as well, at Western Turbine this is pretty much a second full-time job; the work is year-round, with no financial remuneration of course.

Gundershaug works collaboratively with subject matter experts at the Authorized Service Providers and the OEM, as well as Western Turbine colleagues, to develop the annual

TICA presents awards for excellence at Western Turbine

The Turbine Inlet Cooling Assn (TICA) recognized Riverside Public Utilities and Princeton University at the 27th annual meeting of the Western Turbine Users Inc with its 2017 Excellence Award for successful implementation of turbine inlet cooling on GE aero gas turbines.

Riverside received the award for its 3500-ton centrifugal chiller system, which cools inlet air to the four LM6000PC engines at the Riverside Energy Resource Center from 110F to 48F. TICA Executive Director Don Punwani (at left in photo) said the TIC system, supplied by TAS Energy, enables the plant to produce an additional 66 MW in hot weather. He presented the plaque to the utility's Generation Manager Chuck Casey.

The Energy Plant at Princeton was recognized for implementing a chiller-based TIC with thermal energy storage to serve its LM1600 engine 42F air on a 98F day. TICA members CB&I and The Cool Solutions Company were major participants in the project.

WTUI golf tournament brings users, vendors together

The Western Turbine Users' 27th anniversary golf tournament drew 117 players to the 6909-yard course at Rhodes Ranch Golf Club in Las Vegas, Sunday, March 19. The popular social function, held annually before the conference officially begins, was organized this year by Jim Bloomquist and several members of the Western Turbine leadership committee.

Awards sponsors: SSS Clutch Co, GE, Protec Services Inc, NYCO, Turbine Technics Inc, AAF, Olympus America, Clarcor Industrial Air, and WTUI.

Individual achievements

Ladies' long drive: Lynda Riley
Closest to the line (hole 9): Steve Han
Closest to the line (hole 15): Michael Leon
Closest to hole 3: Bill Trefethen
Closest to hole 7: Clark Schwieger
Closest to hole 14: Binh Tran
Closest to hole 16: Wes Knapp

Team achievements

First place: Andy Stewart, Glenn Knight, Kristian Norheim, Joe Tirrenno.
Second place: Bob Parent, Mark Leara, Dan Arai.
Third place: Steve Han, Gary Martin, Mike Roesner.
Fourth place: David Flake, Part Williams, Brian Hulse, Donald Cho.
Fifth place: Shane Riley, Lynda Riley, Al Simon, Michael Tuck.
Sixth place: Joe Ennis, David Richardson, George Tater, John Vermillion.

"LM6000 O&M Bible" presented to each participant in the breakout session to facilitate learning and note-taking. This year's 200-page full-color book had three major sections:

- ASP findings in the shop, and in the field, the previous year.
- Details on the OEM's efforts to resolve fleet issues, plus mods and upgrades available to owner/operators to improve performance, safety, etc.
- Notes on topics for the package discussion integrated into the busy agenda.

The first three hours of the breakout was devoted to presentations by ASP representatives who compiled the drawings, photos, and notes on significant issues identified in 2016—vital for users looking ahead to the next overhaul and all those responsible for engine operations. The presenters:

- Ken Ueda of IHI Corp, 17 years of experience on LM6000 engines—including roles in R&D, maintenance engineering, customer support.
- Ralph Reichert of MTU Maintenance, 21 years of GT experience—including aircraft mechanic, field service engineer, maintenance shop engineer.
- Steve Willard of TCT, 15 years of LM engine experience, with involvement in component repairs, test-cell operations, project management, and engineering.

In all probability, nowhere except Western Turbine would you find such a capable "faculty" for sharing their knowledge on one of the world's most popular gas turbines for electric generation. Today, the fleet totals 1250 engines in round numbers—one-third of them equipped with DLE combustion systems.

As you read on, important to keep in mind that the editorial goal was to profile some of the session's highlights, not to compile a comprehensive summary of the proceedings. You can get that via the Western Turbine website, where all the ASP and OEM presentations are posted along with a 35-page chronology of the LM6000 sessions, compiled by Steven Giaquinto of Strategic Power Systems Inc. SPS engineers help support the WTUI mission by taking notes for the membership during the breakout sessions. Note: Conference materials are available only to registered WTUI user members. Not a member of Western Turbine Users Inc? Sign up today at www.wtui.com.

After opening remarks by Chairman Gunderson, including the all-important safety message on how to evacuate in the unlikely event of an emergency, TCT's Willard got the session rolling. He reminded attendees of the value proposition associated with the three Level 4 ASPs serving the LM6000 community:

- Access to GE technical documentation.
- Access to GE parts and service support as defined in the license agreement.
- Approved vendor list for component repairs.
- Departure records from GE to cover minor deviations to O&M and repair procedures.

Mention of the service bulletins (total of 17) and service letters (five) released since just before the 2016 meeting was made came next. Willard noted that it was a busier year than usual concerning document release.

He then passed the mic to IHI's Ueda, who presented on CRF vent duct improvement, engine monitoring, IGB housing deformation, and a No 4B bearing event. See Sidebar 1, "Acronyms to remember" if you're unfamiliar with the shorthand.

The CRF vent duct has experienced cracking (attributed to high levels of stress) at the fillet weld that joins the wear sleeve to the duct body. Oil leakage is a possibility. A smoky condition in the package would suggest

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TransCanada Turbines (TCT) is an OEM-licensed global service provider for aero derivative industrial gas turbines manufactured by GE and Siemens. TCT provides complete support for the Siemens industrial Avon, RB211, RB211 DLE, and GE LM2500, LM2500+ and LM6000 gas turbines under one roof.

In July 2011, TCT opened a new, custom-built overhaul and repair facility in Airdrie, Alberta. Conveniently located 20 minutes north of Calgary, Alberta, the new facility houses production, project management and support staff for both TCT's General Electric Level 4 services and Siemens MROC services. This purpose- built facility is 220,000 square feet and is complete with state-Of-the-art equipment and tooling. TCT is proud to offer all of its customer's immediate induction for all engine types.

TransCanada Turbines does performance test runs at TransCanada Turbines' owned and operated test cell, located in Calgary, Alberta beside the Calgary International Airport. This 930 m² (10,000 ft²) facility was constructed in 1999 and is capable of testing all marks of the Industrial Avon and Industrial RB211 as well as the LM2500 Base SAC engines using a calibrated test nozzle. In 2013, TransCanada Turbines expanded its engine testing facility to better support the LM6000 PA, PB, PC, PD and PF engine lines with the addition of Test Cell #2. The new facility offers emission mapping and monitoring services and is also the new base of operations for its Canadian Field Service teams.

TCT Field Service Office Locations: Houston, Texas; Syracuse, New York; Bakersfield, California; and Cumbernauld, Scotland

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that. Service bulletin (SB) LM6000-IND-320, "Improved CRF vent duct," eliminates the fillet-weld wear sleeve and identifies a material change from Type 321 stainless steel to Inconel 625 (to increase the strength margin).

An increasing T3 (HPC discharge temperature) difference among the four sensors provided (A/B/C/D) was detected; the T3-D signal was abnormal. Inspection of cable, connectors, and T3 sensors were recommended by Ueda. A user mentioned that one of his engines exhibited discrepancies in T3 signals but they couldn't identify the cause.

Another attendee reported seeing black marks in connectors that were removed by cleaning but reappeared a few months later. That led to the question, "Is there another cable design to improve this? We are getting oxidation in there." An OEM representative said he was not fully aware of repeated issues on connectors and asked that users provide more information on these occurrences.

Cabling can be problematic. Yet another user said engine oscillations can cause connectors to wiggle loose, sometimes resulting in an engine trip. A colleague said a robust maintenance program was required to mitigate cable issues. At his plant cleaning and tightening is done twice annually.

No. 4B bearing failure. A B-sump alarm alerted to high scavenge oil temperature and high Δp across the scavenge oil filter. Metal particles were found in the sump. Engine sleuths went to work, identifying deep flaking on the outer race of the No. 4B bearing at the 6 and 12 o'clock positions. They said such deep flaking at these positions indicated damage was done while the engine was not running. The root cause: An air-ride truck was not used for ground transportation and the damage occurred from excessive and repeated vertical shocking.

MTU's Reichert was next to the podium. He addressed the following:

- CRF oil leak, SB 307/308.
- TRF D/E sump, SB 323.
- SB 322 HPT second-stage nozzle retainer update.
- High C-sump oil temperature/pressure.
- DLE combustor improvement.
- LPT second-stage blade shroud deformation.
- Peak versus baseload component degradation considerations.

Again, if any of these speaking points of interest to you are not summarized below, consult the presentation materials available on www.wtui.com. Access is denied to all but user members of the organization.

CRF oil leaks got considerable attention from the group. Here's the background: Service Bulletins 233 and 236, issued September 2008, superseded SB 154 with the objective of mitigating the risk of oil leakage in the sump area. Shortly thereafter, some engines were found to have deformed J-tabs; three had oil leaks in the C sump area. J-tab distortion was attributed to an interaction between thermal expansion in the sump area and oil-tube (manifold) vibration.

In January 2015, SB 307 (SAC)/308 (DLE) replaced 233 and 236, specifying the following: removal of the heat shield, a wider wear sleeve, and a wider P-clamp for the affected oil manifold. SBs 154, 233, and 236 were canceled.

However, while the recommended fixes in SB 307/308 stopped the leaks, they were not without issues. Bent J-clamps were found after about 300 to 500 hours of operating time on a couple of engines. The good news is that the OEM does not view distorted clamps alone are a reason to pull the engine. Periodic monitoring of the J-clamps is recommended.

Significant discussion ensued. A user asked, "Can you fix clamps in the field?" An ASP representative replied, "This is a Level 4 service bulletin and not recommended for the field." A follow-on comment made by someone else at the front of the room, "The clamps move and then fretting occurs and tubes leak; then the engine smokes. Important to recognize, an ASP rep said, is that you can monitor the clamps with a borescope. If a clamp bends, he continued, don't worry; sometimes clamps stop bending. The important thing is look for oil, which will tell you when to think about repairs.

Yet another question: "Which is worse, a twisted clamp or a broken one?" ASP response: "With a twisted clamp, the support is still there. However, there have been some cases where the clamp was removed and the engine came back to the shop with no adverse effect."

Peak versus baseload operation. An important presentation; it was made last year as well (CCJ 2Q/2016, p 44). Photos of damage attributed to "hard" operation are available online and offer valuable lessons for the O&M staff. The takeaway for owners of peakers is that they will cost you more to operate because hardware takes more of a toll than it does on baseload units. The LM6000 can handle the service, it was said, but the frequency of shop visits might increase.

Reichert passed the mic to TCT's Willard, who began by discussing experience with HPC airfoils, covering SB 310 in the process. TCT would make nine additional presentations that afternoon. Those listed below of interest to users registered with WTUI can be accessed on the organization's website:

- HPC fifth-stage lever-arm event.
- HPC glass-bead findings.
- SB 301 and G33 combustors.
- DLE-combustor ferrule events.
- HPTN1 leaf seals, SB 306.
- LPT mid-shaft crack update.
- VBV door bushing wear.
- PB/PC PCC manifold.
- SB 313 RDS housing and clamp update.

Case history: Third-stage HPC blades. S3 blades on the unit under discussion were removed in the field and heavy wear was noted on the faces of the dovetail coating. The engine was removed from service and sent to a repair facility for evaluation.

Most blades in Stages 3-5 were scrapped because of heavy wear that penetrated the coating and continued into the parent material. The 3-9 spool was declared non-repairable at this time. Blades for Stages 3-5 can be replaced in the field or shop following the guidelines in SB 310. Many attendees indicated by show of hands that SB 310 had been implemented at their plants.

Several airfoil options are available to owner/operators implementing SB 310—standard single-intensity peened (SIP), the OEM's new dual-intensity peened (DIP), and overhauled SIP-to-DIP blades—but all have 1500-hr start limits. This not a guarantee of no event occurring below 1500 starts, but the risk of failure increases beyond 1500.

Note that blades older than "K" (T, A, and C) cannot be upgraded through the SIP-to-DIP process. Also, converted SIP blades become "M" type with a part number change. The new part numbers are noted in the presentation.

Background: Multiple HPC S3-5 dovetail events have been reported over the last several years. According to the OEM, there are two primary causes of this: VSV off-schedule and so-called edge of contact (EOC). The latter is described this way:

- Dovetail coating wears.
- An indication develops in the blade-to-spool EOC area.
- Dovetail liberates driven by LCF and HCF.
- A stall event and secondary damage typically are experienced next.

The OEM solution to resolve the S3-5 issues was presented during its podium time the following day. The "enhancement plan" reflects a change in the blade material from titanium to Inconel 718 and a more generous dovetail geometry (airfoil geometry remains unchanged). These changes are said to improve the resistance to dovetail pressure-face fretting and reduce peak EOC stresses.

LPT mid-shaft crack. This was a follow-up to the presentation made last year on the subject, which was not covered in CCJ. Background: At least 10 LP mid-shafts have been found with cracks/indications within the threads;

they can be located with white light. Pitting corrosion also was found following removal of the nickel plating on the threads.

Separate investigations by TCT and GE and by MTU reported similar findings, including the following:

- Multiple crack origins.
- No inherent material defect.
- No over-torqueing of the coupling nut.

The probable cause is corrosion attack on the base material where the nickel plating was depleted. Cause of the depleted nickel plating has not yet been identified.

Corrective action: ASPs are inspecting exposed threads in the shop during overhauls regardless of repair scope. Threads can be inspected in the field as well.

Important: Repair procedures have been changed. Removal of nickel plating as part of the inspection process is now mandated, with re-application after repairs are complete. There is no repair plan for cracked or highly pitted/corroded threads at this time.

GE presentations the following day covered the following engine topics:

- HPC S3-5 blades.
- LPT S1 blades.
- VSV bushing durability.
- CRF CDP customer bleed gasket.
- Bleed-valve durability.
- VSV/VBV actuator control module upgrade.

Once again, registered user members can access this material on the Western Turbine website.

LMS100

The first LMS100 began commercial operation at Basin Electric Power Co-op's Groton (SD) Generation Station 11 years ago. As of January 2017, 61 units were operating, according to Charlotte-based Strategic Power Systems Inc (SPS), which tracks powerplant equipment performance for the industry.

The OEM reported that through Dec 31, 2016, its LMS100 fleet had accumulated more than 525,000 hours of operation and more than 78,500 starts. Interestingly, the fleet leader accounted for nearly 10% of total fleet operating hours, the starts leader 8.5% (round numbers) of total fleet starts.

Fleet availability up. SPS engineers told participants in the LMS100 Breakout at the 2017 Western Turbine Conference & Exhibition in Las Vegas that fleet availability continues to improve, based on operating data gathered from 37 of the 61 units participating in the company's Operational Reliability Analysis Program (ORAP®) program.

More specifically, the 23 ORAP participants in peaking service recorded 95.7% availability for the November 2015 – October 2016 survey period. Additional *simple-cycle* plant data for this group of engines:

- Forced outage factor (percentage of time the unit is in a forced outage), 1.7%.
- Maintenance outage factor (percentage of time the unit is in a maintenance outage), 0.3%.
- Planned outage factor (percentage of time the unit is in a planned outage), 2.2%.
- Service factor (percentage of time a given unit is producing power at any level), 12.3%.
- Service hours per start, 4.5.

Jason King, O&M manager at the eight-unit Sentinel Energy Center LLC in North Palm Springs, Calif, and the LMS100 breakout chair, developed the technical program with the OEM and Western Turbine colleagues, but was unable to attend the meeting. Board Member Rick McPherson, plant manager of NRG's five-unit Walnut Creek Energy Park in the Los Angeles Basin, and former LMS100 Breakout Chair Don Haines, managed the sessions in King's absence.

Users representing operating

assets, and owner/operators interested in the LMS100, were among the more than 50 participants in this breakout. Haines reminded those in the first group that their commitment to information-sharing was necessary to drive continuous improvement across each plant and the overall fleet.

To support this effort, the LMS100 Users have established, and strongly recommend, using the following two avenues for ongoing communication:

- Monthly conference call (first Wednesday at 1 p.m. Pacific). Contact the chairman for details.
- Yahoo LMS100 Users Group, (visit to http://groups.yahoo.com/group/LMS100UG) facilitated by SPS, to help users stay current on technical and logistical issues impacting the fleet.

SPS analytics. Information-sharing was a theme of the SPS presentation to the group by Tom Christiansen, who also was responsible for taking the session notes posted at www.wtui.com for registered user members of the organization. He urged those not currently participating in the ORAP program to do so, a larger sample ensuring that the metrics provided users are meaningful and statistically representative of fleet performance.

SPS's Analytics Portal™, Christiansen continued, allows ORAP users to view their plant data in an Internet-based, on-demand business intelligence interface highlighting KPIs (key performance indicators) of interest. He encouraged users not already using the portal, which is updated quarterly, to contact SPS and get signed up.

The lion's share of Christiansen's presentation focused on the leading causes of LMS 100 forced outages, both in numbers of occurrences and their duration in hours.

Forced-outage incidents in the November 2015 – October 2016 evaluation period were split this way: station equipment (BOP), 37%; package, 33%; supercore, 15%; LPC (a/k/a booster compressor), 10%; generator, 4%; power turbine, 1%. The hot SCR was charged with the highest number of incidents, 66—nearly three-quarters of which were at three sites unable to control emissions and engines were shut down to avoid air-permit violations. Another 13 incidents were attributed to issues with ammonia systems at five sites.

Not surprisingly, perhaps, controllers and software were cited for 45 incidents, second on the list of top contributors. Third through fifth places: the LPC (VBV issues dominated), power distribution (breaker and relay issues dominated), and emissions monitoring.

Next were 19 incidents at four sites related to NO_x water injection, 17 lubrication incidents (half attributed to leaks), combustion (10 incidents at two sites related to flame-outs and failures to light), hydraulic control-oil (package), fire protection, and engine hydraulic control.

WTUI user members can access the details on the organization's website, where the non-OEM presentations are posted along with Christiansen's 16-page chronology of the LMS100 sessions. GE presentation materials are available on the company's services portal.

Top contributors to forced-outage hours during the evaluation period were divided this way: package, 41%; station equipment, 31%; LPC, 17%; supercore, 10%; generator, 1%. The LPC was charged with the highest number of forced-outage hours. About half of the 917-hr total was assessed against VBV trips caused by solenoid trips, broken gearwheel, servo malfunction, etc.

Package lubrication issues were second in FO hours, three-quarters of those caused by oil leaks and another 10%-plus by chip detector problems. Controllers and software, power distribution, and emissions monitoring were the No. 3, 4, and 5 top contributors in terms of hours.

Outage experiences and lessons

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QR 19 QR 20 QR 21 QR 22 QR 23 QR 24 QR 25 QR 26 QR 27

QR 37 QR 38 QR 39 QR 40 QR 41

Exhibitors

AAF International (QR 1)
Advanced Chemical Technology Inc
Advanced Filtration Concepts (QR 2)
Advanced Turbine Support LLC (QR 3)
Aero Controls & DLE Consultant
Aero Land & Marine LLC
AGTServices (QR 4)
AGTSI (QR 5)
AHM Associates, Div of Bay City Boiler & Engineering Inc
Air Hygiene
Air New Zealand Gas Turbines (QR 6)
Airflow Sciences Corp
Airgas Specialty Products
Ameridrives
AMETEK Power Instruments
AP+M
Arnold Group (QR 7)
Babcock & Wilcox (QR 8)
Baseload Power and Generation Parts & Services LLC
BASF Corp (QR 9)
Beamex
Borri Power (US) Inc
Braden Manufacturing LLC (QR 10)
Bradly Griffin LLC
Bremco Inc (QR 11)
Brush Aftermarket
Caldwell Energy (QR 12)
Camfil Power Systems (QR 13)
CEMTEK Environmental
Champion GSE
Chromalloy
CLARCOR Industrial Air (QR 14)
CleanAir Engineering
Clean and Science Co Ltd
Combined Cycle Journal
Concord Management Services/ Concord Engineering (QR 15)
Crown Electric Engineering & Manufacturing LLC (QR 16)
Cust-O-Fab Specialty Services LLC (QR 17)
Danfoss High Pressure Pumps
Dekomte de Temple LLC (QR 18)
Detector Electronics Corp
Doble Engineering Co
Donaldson Company Inc (QR 19)
Drake Controls LLC
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ECT Inc (QR 20)
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Environex Inc
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Evoqua Water Technologies
Filtration Group (QR 23)
Forney Group
Fossil Energy Research Corp (FERCO)
Fusion Inc
GasTOPS Ltd
Gas Turbine Controls Corp (QR 24)
GE
GE Inspection Technologies
GE Power
Global Industrial Solutions
W L Gore & Associates Inc
Groome Industrial Service Group (QR 25)
GSF Services
GT Ice
Hach Company
Haldor Topsoe Inc (SCR Group) (QR 26)
Hilco (QR 27)
Hill Brothers Chemical Co
HRST Inc (QR 28)
Hy-Pro Filtration (QR 29)
IHI (QR 30)
Innovative Steam Technologies
Integrated Turbomachinery Inc
Iris Power-Qualitrol
Jet Aviation Specialists Inc
Johnson Matthey
Kidde Fire Systems

learned surfaced several times during the two-plus days of breakout sessions. Interestingly, much of the information shared also is applicable to other aero models as well as frames. The takeaways are summarized below.

The performance of field-service organizations is a frequent topic of discussion at user-group meetings. The editors have observed over the years that it is not unusual for plant managers to review the lineup of service personnel scheduled for a given outage and possibly postpone work until people with a good track record at their facility are available.

If you're successful in this regard, consider taking the extra step during negotiations to lock in key personnel for the duration of the outage—in writing. One user at the meeting experienced a so-called "hand-off." Despite an agreement in principle, the service provider pulled the plant's primary contact within two days of the outage. In this case, the user's perseverance paid off and the promised staffing was reinstated.

An example was shared during one of the LMS100 breakout sessions by a user who had two very different experiences with one service organization during consecutive annual outages. In the first outage, all the variable-geometry hardware was pulled and on install a blade was inadvertently turned 180 deg. It came lose in operation and trashed the engine. A different team performed well during the next outage and the site will request that group for future work.

Another attendee suggested adhering to the cardinal rule of always checking the work done by any supplier because when they leave the site it's still your engine and you have the responsibility for its performance. This, of course, means that your "checker" must have the knowledge and experience to know when something might be wrong with the work done.

Yet another participant said he always assigns a person to work directly with field-service personnel to oversee what they are doing. Hold points may be of value, too. Work can proceed to a specified point and then must stop until what has been done is inspected and signed off by the plant. Once again, it is incumbent on you

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QR 28 QR 29 QR 30 QR 31 QR 32 QR 33 QR 34 QR 35 QR 36

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Kobelco Compressors America Inc (QR 31)
Koenig Engineering Inc
M & C Tech Group NA
Maximum Turbine Support Inc (QR 32)
Mee Industries Inc
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Metrix Instrument Co
MFE Rentals
Mitsubishi Hitachi Power Systems Americas Inc
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Protec Services Inc
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Wellhead Construction Inc
WK Enterprises
Woodward Inc
World of Controls Corp (QR 49)
Wunderlich-Malec
Zokman Products Inc (QR 50)

to provide a capable person for that assignment—in-house or from outside your organization.

Specific to the LMS100, a site reported having to replace two low-pressure compressors within a period of only a few months. The service provider, which was affiliated with the OEM, was said to have been good with the supercore, but not as experienced with the LPC side, which was derived from the MS6001FA frame. In prior outages, the attendee continued, tooling also was lacking for the LPC. Apparently, better communication between the OEM's aero and frame engineers would have benefitted this owner.

Two points of view during open discussion about the value of CSAs, contractual services agreements:

Case 1. CSA signed by previous management. Although the fee was thought reasonable, expectations were very high and not always met.

Case 2. Site ran without a CSA for several years and it was difficult. Once a CSA was in place, the user felt GE had "skin in the game" and things got better at the site.

FOD prevention and awareness. Foreign object damage is not unique to any engine model. The OEM reported that there were five FOD events in the LMS100 fleet in the last year, usually discovered during a periodic borescope inspection. Findings were throughout the engine: booster compressor (LPC), HPCR, IPTR (second-stage blade), and power turbine. A GE engineer offered insights on how to mitigate FOD risk. One: Vigilance by site personnel is critical to preventing FOD events. Maintaining combustion-air flow path cleanliness is especially important.

Lube-oil best practices received some discussion. Points made included these:

- Sample lube oil quarterly, maintaining a level of consistency on how the fluid is sampled and tested. Be aware, the group was told, that inconsistent sampling and test procedures can skew results.
- Replace loose Swagelok-type fittings when leaks are in evidence, never retighten.
- Two reports of significant oil losses, one plant lost 350 gal and the other about 1200, both attributed to loose

connections. The OEM recommended periodic inspections of oil connections.

Hydraulic pump leaks were mentioned. Most of these were said to occur at the pump inlet seal. If you see drips beneath the pump, the O-ring likely is damaged and should be fixed immediately before the problem gets worse.

Engine-specific (and other) maintenance tips/recommendations shared:

- Inspect for loose bolts on intercooler picture-frame seals because they work loose over time.
- Water chemistry is important in the intercooler. Protect against corrosion of inlet piping with an appropriate inhibitor and use a yellow-metal inhibitor in the intercooler tubes.
- An informal poll of the users revealed those with Bafco Inc VBV actuators are still having problems, but those using the newer Woodward model seem to be operating without issues.
- Keep a spare NO_x water pump at the plant to minimize downtime when problems arise.
- Turbine vent fans: Check belt tension (these are not direct-drive units) and grease bearings as part of your regular maintenance tours.
- Generator: Review historian data on a regular basis to analyze temperature and vibration changes.
- Fire protection: Keep a spare set of CO_2 bottles on hand to speed recovery in case of an accidental dump.

  A user introduced a new topic during this portion of the session, saying his plant's insurance company requires a fan pressure check every time the package roof is pulled to ensure that CO_2 will not leak out. The site had to purchase testing equipment for this purpose. By show of hands, no one else reported having the same requirement—yet.
- Inspect all grating onsite regularly and particularly prior to outages.
- Keep the package clean; it makes working in there better.
- Certify Yokagawa fuel flow meters just prior to installing them because the certification is only good for one year.
- A site reported using a jockey compressor to manage air requirements when the unit is not operating. ROI was two years—lower electrical costs, less wear and tear on the large air compressor. Jockey sizing can be tricky, so plant personnel rented until they found the correct size and then made the purchase.
- Turning-gear failures were reported by several sites because of water in the oil. One plant's solution: Install a desiccant breather on each machine. Another's: Change oil semi-annually.
- Leakage by gas compressor mechanical seals: Replace the seals, do not spend time trying to fix the leak. Ditto for lube-oil seals.

GE presentations. The OEM put considerable effort into content development for the LMS100 Breakout, with emphasis on the following:

- Product safety.
- Updates of product improvement initiatives.
- Field service capabilities and upgrade opportunities.
- Descriptions of recent engine issues and how to protect against them.

The product improvement programs appeared to attract significant interest. Here are some highlights:

Booster compressor. Some sites have experienced booster airfoil distress and liberation events from impact damage. Root cause: The original carbon steel vane rings corroded, reducing dampening and the tolerance of vanes from impact damage. This is not an aero-only phenomenon, some Frame 7 engines face similar challenges.

Corrective/preventive actions: Implement the software upgrade recommended by the OEM in SB 147 and the specified hardware changes outlined in SB 144. It was said that since the introduction of SB 144 no booster airfoil fracture or liberation event has been caused by impact damage. This is similar to the results achieved for affected frame engines.

HPC blades in stages 3, 4, and 5 and VSV system. Engineering and field testing complete, the OEM suggested the following fleet containment actions at the first opportunity and then after every 2000 hours or 225 starts—or annually:

1. Inspect VSV system hardware.
2. Check VSV lever arms for off-schedule condition.
3. Check torqueing of nuts on IGV lever arms according to SB 184.
4. Inspect the IGV, S1, and S2 inner shrouds and bushings.

Obviously, keep the OEM informed about any findings.

SAC combustor durability. SAC combustors have not met original operational life goal of 25,000 hours. Cracking of the outer and inner liners are cause for engine removal. Analyses indicate cracking was initiated by thermal fatigue and propagated in HCF. Access SB 133 to learn about the more durable replacement G14 combustor (thicker liners, improved cooling).

HPT S1 blade/S2 nozzle. Mid-span trailing-edge erosion and/or cracking of S1 HPT blades (see SBs 70 and 135). Recommended action: Replace blades with ones described in SB 175 during shop visit for hot-section maintenance. New airfoils have improved cooling and other benefits.

Stage 2 nozzles also benefitted from better cooling technology; new components are described in SB 174. Coating was improved as well.

Controls upgrades (Block 7.0). Significant improvements are identified in this presentation—such as an 8-min start when the control upgrades are supplemented with an optional "Fast Start" feature. Interested users should visit the GE Services portal for more detail.

Vendor fair

Vendor fairs at user-group meetings are win-win events: Plant personnel learn about products and services they otherwise might not be exposed to and suppliers gain access to those who might benefit from their solutions. Given today's small staffs, and the high cost of visiting plants, such venues may offer the only practical way for buyers and sellers to connect face-to-face. This is particularly true concerning peaking facilities powered by remote-start aeros at locations without permanent staff.

At the Western Turbine Users Inc's 2017 conference, there was the traditional high visibility and robust representation in the exhibit hall by the OEM and the four ASPs licensed by GE to inspect and repair the engines addressed by the group: ANZGT, IHI, MTU Maintenance, and TCT.

However, these companies were only the proverbial tip of the "exhibitor iceberg" and generally well known to attendees—at least by name. There were another 150 companies in the hall, many virtual unknowns to plant employees—about one-third of whom were attending their first WTUI meeting.

Sidebar 2 lists the exhibitors at the Las Vegas event, with 2016 CCJ print and CCJ ONline electronic advertisers highlighted in boldface type. You can access information from these companies by simply scanning the accompanying QR code with your smartphone or tablet. Never has it been so easy to aggregate information.

The organization's officers and directors recognize the challenge of trying to get through the exhibit hall to identify the vendors of greatest interest at the moment and to at least have a brief discussion with each. That's why the WTUI vendor fair is open for nearly 20 hours over three days. Most user groups just allow users and suppliers to connect for three or four hours on one evening. CCJ

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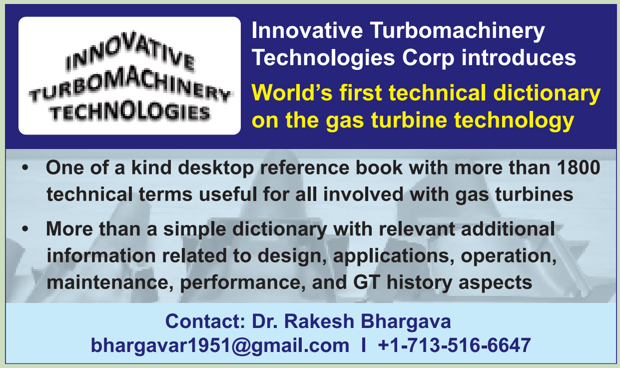
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How to select the optimal inlet air filters for your engine

By Dale Grace, Electric Power Research Institute, and **Chris Perullo** and **Tim Lieuwen,** Turbine Logic

A typical 7FA in baseload service ingests 3.5-million lb_m/hr of air containing a significant amount of particulate matter. How much? Based on data compiled by EPA nationwide, more than 1300 lb of particulates smaller than 10 microns likely will enter your gas turbine in one year of operation (8760 hours). While this may seem like a relatively small amount compared to the total amount of air ingested, such fine dirt can wreak havoc on efficiency and reliability.

However, there are multiple options available to owners and operators to prevent unit degradation. This article reviews filtration basics and offers a guide for choosing the preventive strategy to optimize the performance and health of your engine. Finally, results of a four-year study suggest the performance gains you could expect from several popular filtration options.

The basics

Choosing the right filter is based upon several factors, including these:

- How clean is the air around the plant?
- What is the right level of filter efficiency for your plant?
- How often should you water wash?

Table 1: Nominal concentration of particulate matter under 10 and 2.5 microns by region, in μg/m³

Region	PM10	PM2.5
Central	47.6	8.4
Upper Midwest	48.8	7.4
Northeast	41.3	7.6
Northern Rockies and Plains	NAv	NAv
Northwest	47.3	6.8
South	50.6	8.2
Southeast	34.13	7.8
Southwest	80.83	7.0
West	75.66	8.9

Particle size matters

It is important to understand the impact of the size of the dirt particles on unit performance and reliability. Choosing the right filter strategy requires that you know the cleanliness of the air around the plant. Here are some things to keep in mind:

- Particles larger than 5 microns have the capability to erode critical compressor and turbine parts. Resulting degradation can be recovered only through repair or replacement. Fortunately, most filters readily remove such large particles.

  Particles smaller than 1 micron contribute the lion's share of compressor deposits responsible for performance degradation. The actual loss depends on the efficiency and condition of the filters installed. While deposits of fine particulates reduce compressor efficiency, partial recovery of performance is possible with online water washing, full recovery with offline washing.
- In coastal environments, salt also can be an issue. Salt mists tend to be smaller than 5 microns and may cause compressor corrosion. They can be captured by filters but can also migrate through the filter system. Frequent online water washing may help mitigate salt-induced corrosion in the forward stages of the compressor.
- Small particles—such as metal oxide, smoke, carbon black, smog, and fumes—may be smaller than 1 micron and pass through all but the highest efficiency filters.

To find out the amount of airborne particulate matter at your plant, a first step might be a detailed air sampling onsite; in the absence of this, the EPA provides average PM10 and PM2.5 trends by region, county, and city (visit https://www.epa.gov/air-trends/air-quality-cities-and-counties). PM10 and PM2.5 data report the concentration of particulate matter under 10 and 2.5 microns, respectively, in micrograms per cubic meter.

While site-specific conditions, such as a coal unit or nearby farming, can impact the local concentration of particulates, the EPA data provide a good baseline. Table 1 summarizes 2016 EPA data by region. Operators at sites with high PM10 concentra-

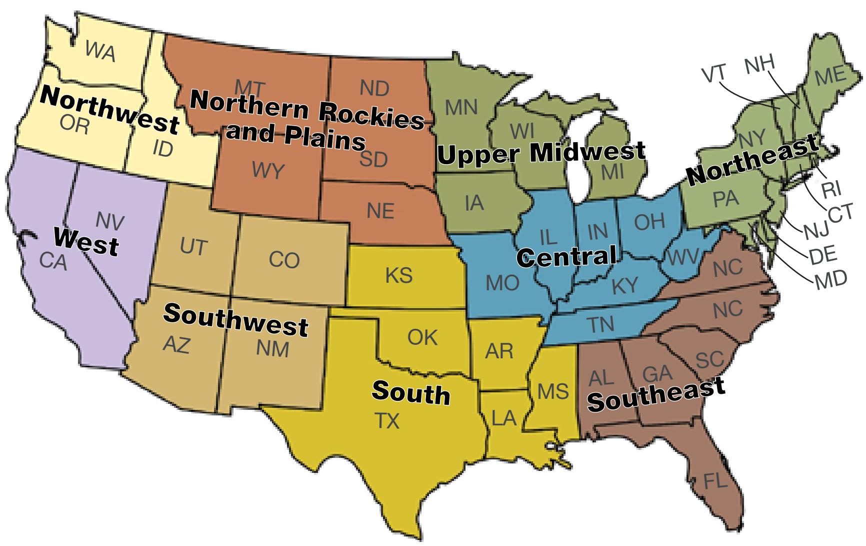


Table 2: Filter selection chart

Best use	ASHRAE filter class	ASHRAE 52.2: 2007 Collection efficiency (percent) by particle size (microns)			EN filter class	EN 1822: 2009 Total filtration separation efficiency, %
		E1	E2	E3		
	MERV	0.3 – 1.0	1.0 – 3.0	3.0 – 10.0		
Pre filter	1			<20	G1	
	2			<20	G2	
	3			<20		
	4			<20		
	5			20 – 35	G3	
	6			35 – 50		
	7			50 – 70	G4	
	8			>70		
Pre filter (very dirty environment)	9		<50	>85	M6	
	10		50 – 65	>85		
	11		65 – 80	>85	M7	
	12		>80	>90		
Final filter with regular washing	13	<75	>90	>90	F7	
	14	75 – 85	>90	>90	F8	
	15	85 - 95	>90	>90	F9	<85
Final filter with no washing	16	>95	>95	>95	E10	85
					E11	95
					E12	99.5

Table 3: Options for filter selection and wash type/frequency

Pre filter	Final filter	Offline wash?	Online wash?
G4 or above	MERV 13 – 15 (EN F7 – F9)	Yes, nominally quarterly, adjust through performance monitoring	Yes, if capacity is critical
G4 or above	MERV 16 (EN E10 - E11)	Yes, annually	No appreciable gain
G4 or above	MERV 16 (EN E12 or higher)	Only as needed through performance monitoring or inspection	No appreciable gain

tions may want to choose filters with a high dust-holding capacity to avoid frequent change-outs. At sites with high PM2.5 concentrations, the best strategy may be to choose high-efficiency second-stage filters to reduce compressor fouling.

Filter selection

To choose the optimal filters for your site, it's important to understand selection criteria. In a conventional two-stage static panel filtration arrangement, the pre filter serves to remove the large, erosion-causing particles and reduce the loading on the final filter, thereby extending its life. The final stage removes the remaining large particles and a majority of the small particles that contribute to compressor fouling. A simplified way to think about it is that the pre filter captures the PM10 particles and the final filter captures the PM2.5 particles.

To complicate matters, several filter rating systems are used in the power industry. So, before discussing recommendations, a good understanding of filter lingo is needed. Key terms are below:

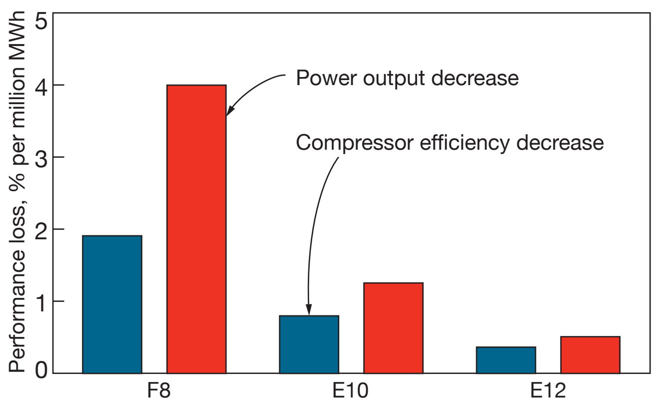
- Rated airflow. You want to be sure filter airflow is sufficient for your site. Filters can operate above or below their rated airflows, but operating at higher-than-designed flow rates can lead to increased pressure drop which hurts performance.
- Initial pressure drop. Most filter data sheets provide an initial pressure drop. This impacts performance. While every unit is different, a good rule of thumb is that every additional inch of pressure drop—in. H_2O a/k/a in. WG (water gauge)—decreases power output by 0.3% and increases heat rate by 0.1%.

  Filter pressure drop will increase as the filter loads. A fair assumption is that filter delta-p increases proportionally to the dust loading. So, if a filter has a 1-inch initial pressure drop and a 3-inch final pressure drop, the filter is approximately 50% through its life at 2 inches. For performance-impact estimates, users should assume the average of the initial and final pressure drops.
- Efficiency. This is the most confusing parameter since there are multiple rating systems. The ASHRAE filter class assigns a MERV rating from 1 to 16. As the scale increases, the filters become more efficient at filtering out larger, and then smaller particles. MERV ratings between 6 and 8 are appropriate for pre filters. These ratings filter out between 35% and 70% of particles between 3 and 10 microns—the size range most likely to cause unrecoverable damage to the rotating turbomachinery.

Choosing final filters requires additional rating scales. MERV ratings of 13 to 15 are good for basic filtration and will filter out more than 90% of the larger particles not caught by the pre filter. While this may seem low, consider that a 70%-efficient pre filter and 90%-efficient final filter means that only 3% of the large particles will make it through to the compressor.

MERV 13 - 15 filters still let through up to 25% of the small particles that can contribute to fouling. Thus they will help reduce the fouling rate, but water washing will still be necessary to retain performance. MERV 16, the highest ASHRAE rating, provides filtration of at least 95% across all particles sizes.

To distinguish among high-efficiency filters, you need to look at the EN



Data for 15 sites using at least G4 pre filters indicate the sharp drop off in power per million megawatt-hours when using an F8 final filter compared to an E10 or E12; note too that the E12's benefit over the E10 is not as significant

Table 4: Case-study data input to Air Filter Life Cycle Optimizer

Data/assumptions	F8 final filter	E10 final filter	E12 final filter
Gas turbine	7FA.04		
Plant configuration	2 × 1 combined cycle		
Service factor, %	90		
Hours at part load per day	4		
Avg load at part load, % of rated output	60		
Avg price of electricity, $/MWh	36.25		
Avg fuel cost, $/million Btu	2.75		
Inflation, %	2		
Discount rate, %	10		
US location	Southeast		
Pre filter	G4, change semiannually	G4, change semiannually	G4, change annually
Final filter	F8, change as needed	E10, change as needed	E12, high capacity/change as needed
Online wash frequency	Weekly	None	None
Offline wash frequency	Quarterly	Semiannually	Annually

Table 5: Case-study results using AFLCO based on input data/assumptions in Table 4

Financials, net present value	F8 final filter	E10 final filter	E12 final filter
Power produced, $	1,055,190,420	1,060,970,857	1,087,793,213
Fuel, $	(478,449,078)	(482,342,296)	(495,143,971)
Water wash, $	(240,185)	(120,244)	(61,288)
Filter change/installation, $	(1,091,051)	(1,263,080)	(1,240,219)
Total value, $	**575,410,106**	**577,245,236**	**591,347,735**

rating scale. Rather than identifying the average filtration efficiency for different particle sizes, the EN 1822 scale provides the minimum efficiency at the most penetrating particle size, which typically is about 0.2 to 0.4 microns for most filters.

The majority of filters with a MERV rating of 16, or a EN 1822 rating of E10 to E12, filter out more than 99% of all particles larger than 1 micron. A "cheat sheet" is provided to help you keep all of this information straight (Table 2).

Another common configuration for air inlet systems uses self-cleaning (pulse) conical/cylindrical filters. These typically are used in a single-stage configuration, or they may be followed by a very-high-efficiency stage. They can be more expensive than panel/V-bank filters, but have much higher dust-holding capability. This means they can operate longer at lower pressure drop, and therefore with less performance impact. However, over time they must be replaced due to wear and/or increasing pressure drop—the latter because some small particles are retained rather than released during cleaning.

Making your decision

Choosing a good pre filter with adequate dust-holding capacity is relatively simple. Selecting a final filter, which is impacted more by unit location, requires greater thought and analysis. Over the last four years, EPRI has led a systematic study—in cooperation with an EPRI-member utility and Turbine Logic—of 15 7FAs protected by two-stage panel filtration systems to identify the real-world impacts of final filtration efficiency.

Results indicate that the performance impact of high-efficiency filters can be summarized in terms of performance loss per millions of megawatt-hours of operation, which normalizes results across units of varying operating cycles and capacity factors because it accounts indirectly for the total mass of air entering a unit.

While the full results can be found in ASME paper "Evaluation of Air Filtration Operations for an Industrial Gas Turbine" (access by scanning the QR code with your smartphone or tablet), the bar chart compares results across the 15 sites. All the gas turbines in the study were equipped with pre filters with a rating of at least G4.

F8 filters are fairly standard across the fleet investigated and could be considered the default level of filtration. Notice the sharp drop in power per million MWh for the F8 over time. While the cost of better filters and the increased inlet pressure drop associated with them offsets this to some extent, there is also an aspect of diminishing returns.

The E10 final filters provide significant benefit over the F8; however, the E12 benefit over E10 is not as much. Nonetheless, plants in this study were able to run with E12 final filters for more than 12 months without water washing, significant performance impacts, or visual signs of fouling. In all of the studies conducted, offline washes were able to recover most of the performance degradation caused by fouling.

Proactive versus reactive maintenance

In addition to selecting the most appropriate filtration strategy, the plant operator must develop an effective maintenance strategy, which may be proactive, reactive, or a combination of both. Filtration is a proactive strategy, because it prevents dirt from entering the compressor; compressor washing is reactive, because it allows performance to degrade before cleaning the unit. Obviously, the two methods are not exclusive and can be used in combination. But keep in mind that while online washing allows the unit to remain operational, it is not as effective as offline washing at removing contaminants.

Optimizing among wash type and frequency, and filter type, requires an in-depth lifecycle cost analysis. Table 3 can help guide users without the time or resources for such a detailed study. However, the plant operator should have a performance monitoring strategy in place to adjust for site-specific conditions. Example: Sites with high PM10 loadings may choose pre filters with higher ratings.

EPRI publications focusing on inlet air systems

"Inlet Air System Procurement Guideline and Specification: For Gas Turbines in Power Generation Applications," assists owner/operators in the development of comprehensive and complete bid and procurement specifications. It enables users to understand the characteristics and important aspects of inlet air systems.

The specification will save staff time and money by providing a comprehensive template with all of the key aspects needed to assemble inlet air system purchase specifications. The template specification comes with a Microsoft Word document attachment that EPRI-member utilities can tailor to the specific needs of projects and corporate procurement procedures and policies.

"Inlet Air Filtration Assessment: 2016 Update" is a comprehensive, practical technical assessment of inlet air filtration and conditioning technology used in generating plants powered by gas turbines. As the main article shows, appropriate selection of inlet air filters can have a multimillion-dollar impact on plant profitability over time.

This report assists O&M personnel reduce lifecycle costs and improve plant performance. It provides a comprehensive description of various styles of filters for GT inlet-air applications, as well as a listing of filter manufacturers and their styles and brands of filters. Several assessments of remaining useful lives of filters removed from service are provided, along with laboratory test results based on ASHRAE 52.2 and EN 1822 standards. The background developed for this report also led to development of the "Air Filter Life Cycle Optimizer" software for economic analysis of filter selection as it interacts with GT fouling and performance impacts.

Case studies

Using the EPRI Air Filter Life Cycle Optimizer (AFLCO) software tool, a few detailed notional case studies have been assessed to provide users with estimates of the order-of-magnitude savings they can expect. A case was examined for a unit in the Southeast (90% service factor) operating most hours at baseload with evening turndown.

Three scenarios were examined. In the first, an F8 filter is used in conjunction with quarterly offline washes and weekly online washes. The same unit then was examined with an E10 final filter, a reduction in offline washings to two annually, and elimination of online washing. Finally, a high-capacity HEPA E12 final filter was evaluated with an annual offline wash.

Pre filters were assumed to be changed out every six months and the final filters were changed as required by the pressure drop. The E12 filters were assumed to be twice as expensive as the F8 on a per-filter basis.

Obviously, the price of gas, electricity, and other assumptions would change the results, but the pertinent assumptions are presented in Table 4. The analysis takes into account performance degradation attributed to compressor fouling using a detailed time-dependent analysis. The AFLCO model can be tuned to specific site data as required.

The results of these lifecycle (10 years) cost analyses are presented in Table 5. By moving from an F8 to E10 filter the unit can eliminate online washing, reduce offline washing frequency, and retain power output. Note that fuel costs actually increase because of increased power production at base load.

The impact of compressor performance retention tends to have a larger impact on power than on heat rate. As a result, increased power output often increases total fuel costs even though the unit is more efficient. Water wash costs in the E10 case are cut in half. The filters are marginally more expensive, but approximately 2-million current day dollars can be saved over 10 years.

Looking at the E12 case provides insight into the benefit of using filters of higher efficiency and capacity. Here, the filter change-out costs are actually reduced over the selected E10. This is because the higher-capacity filter requires less frequent change out. The increased efficiency also significantly boosts power production.

Final thoughts

While there are many avenues for proper filter selection, it is important to gather as much information as possible on candidate filters before making a purchase decision. Before fleet purchase decisions are made, A/B tests on sister units should be conducted—time and resources permitting—based on the results of a preliminary analysis. Finally, water wash schedules should be re-evaluated using performance data after any filter-efficiency change to ensure you're getting the expected value out of the investment. CCJ

About the authors

Dale Grace is a principal technical leader in EPRI's Gas Turbine and Combined Cycle Technology group. Contact DGrace@epri.com with any questions concerning the research organization's studies on inlet air filtration systems and published work.

Chris Perullo and Tim Lieuwen of Turbine Logic (http://turbinelogic.com) provide independent expertise, analytics, and services that help owner/operators optimize their gas-turbine assets—including inlet air filtration and wash scheduling. Contact them at connect@turbinelogic.com or by phone at 678-841-8420. CCJ

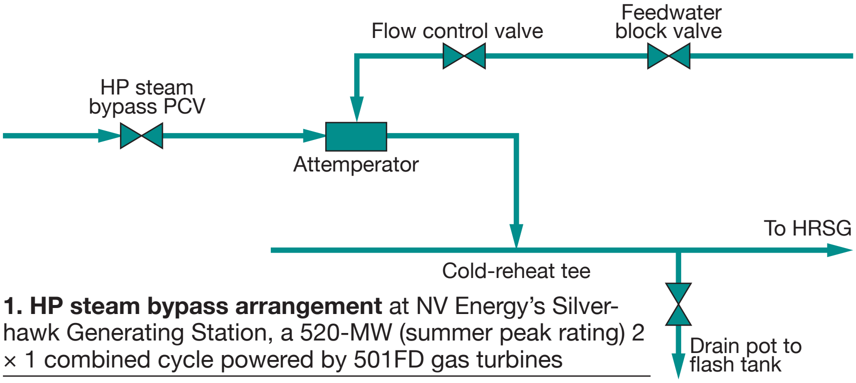
Track performance data from plant's historian to prevent piping failures

By **Rishikesh Velkar** and **Bob Ott,** NV Energy

NV Energy's Silverhawk Generating Station experienced repetitive failures of cold-reheat (CRH) piping which were attributed to quenching of the pipe caused by leaking attemperators. The cause of the first failure, in 2013, initially was thought to be a flaw in a shop weld. Three years later the plant suffered three more failures within a 12-month period and performance data were collected to determine the root cause of the problem.

The Silverhawk CRH piping failures occurred at the high pressure (HP) bypass to the CR tee, requiring multiple repairs at significant unbudgeted cost. The failures caused forced outages and loss of availability hours.

In a typical combined cycle, after the gas turbine is started and the steam begins to absorb energy from the exhaust-gas stream, it flows from the heat-recovery steam generator through the HP piping and is bypassed to the CRH line via the bypass pressure control valves (PCVs), as shown in Fig 1. The HP bypass lines have attemperators on the line to mix feedwater into the bypassed steam and control the temperature of the fluid in the line. Attemperator water flow is controlled using a flow-control valve and a block valve.



1. HP steam bypass arrangement at NV Energy's Silverhawk Generating Station, a 520-MW (summer peak rating) 2 × 1 combined cycle powered by 501FD gas turbines

Described below are the failures that the plant has experienced since 2013:

- **July 2013.** The cold-reheat tee failed on Unit A, identified by water and steam leaking from the piping. The loss in availability attributed to repairing and testing the piping was 55 hours.

  With the unit shut down, insulation was removed in the tee area and a visual inspection was conducted. The downstream weld connecting the tee to the CR piping had a clear indication of a crack, which was confirmed by magnetic-particle and dye-penetrant testing (Fig 2).

  The indication was 5 in. long on the pipe OD, 24 in. on the pipe ID. During radiographic testing of the weld after repairs, another crack (Fig 3) was found on the opposite side of the tee in the same weld that had been repaired. This 3-in.-long circumferential crack was repaired as well.

- **March 2016.** The CR tee on Unit A failed again on the downstream weld connecting the tee to the steam piping (Fig 4). Availability loss: 26 hours. The crack, confirmed using dye penetrant, was 8 in. long.

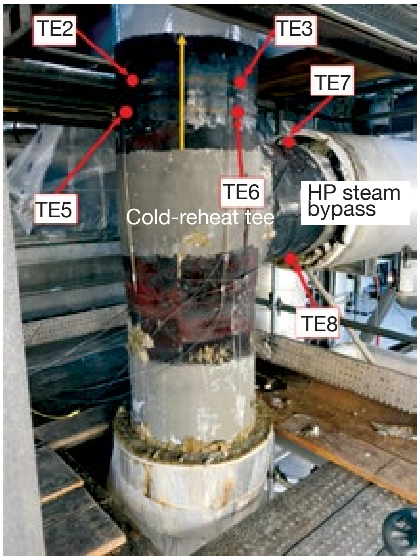
2. Mag-particle test results showing indication on the downstream weld of the tee

3. Radiographic testing revealed a crack on the opposite side of the same weld shown in Fig 2

4. Visual indication of crack 8 in. long

5. Another failure in the same area of the same downstream weld shown in Fig 2. Two cracks, each about 10 in. long were found using ultrasonic NDE

6. Cold-reheat tee on Unit B also failed on the downstream end (cracks in previous photos were found on Unit A). Crack ground out was 18 in.



7. Eight temporary thermocouples were installed (TE1 and TE4 are on the back side of the tee) to help get to the root cause of the failures

- **September 2016.** The CR tee on Unit A experienced its third failure, on the same downstream weld and in the same area as it did in July 2013. Availability loss: 18 hours. Two cracks, each about 10 in. long, were detected during an ultrasonic inspection. A visual indication of one crack is shown in Fig 5.
- **January 2017.** The CR tee on Unit B failed at the downstream end; availability loss was 20 hours. The crack, about 18 in. long, was found during an ultrasonic inspection (Fig 6).

Failure investigations

Investigation of the 2013 incident concluded the failure was caused by flaws in the shop weld and introduced during fabrication. Engineers believed that cycling of the unit could have exacerbated the problem because of thermal fatigue. After the second and third incidents in 2016, investigators confirmed that all three failures were caused by quenching of the metal by condensate.

Staff suggested two ways condensate might enter the CRH pipe and quench it:

The first, via the drain pot, by back-feeding through the flash tank header, which if unable to drain correctly would allow condensate to pool in the CRH line. This possibility was supported by a report from plant personnel who saw the flash tank overflowing a couple of years prior to this event.

However, backflow was ruled out after review of historian data. There was nothing to suggest the flash tank was overflowing and the drain-pot valve was functioning normally.

The second, via the attemperator and its associated block valve. This could not be verified by historian data because the feedwater flow meter was not working properly.

Engineers then decided to open a drain valve between the flow control valve (FCV) and block valve during normal operating conditions to see if the latter was leaking in the closed position. Water flowing through the drain valve confirmed this was the case. But it was not known if the FCV was leaking as well.

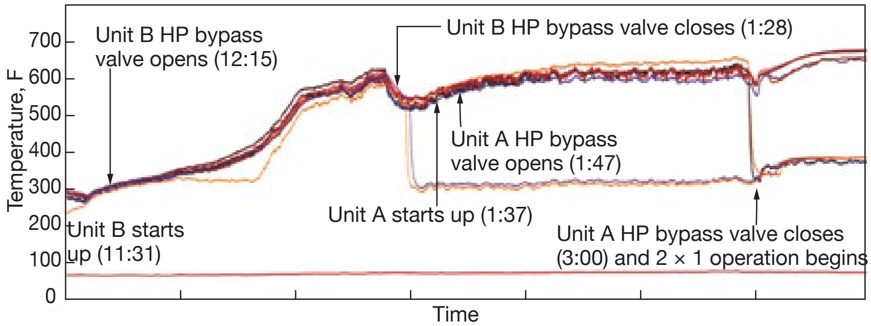
After the CRH tee on Unit B failed early in 2017, insulation was removed and eight thermocouples were installed temporarily on the tee to collect the data required for a true root-cause analysis (Fig 7). Six thermocouples were attached upstream and downstream of the weld, two of them near where the failure had occurred. The remaining two thermocouples were attached on the top and bottom of the HP bypass line connection to the tee.

Pipe temperatures were recorded during a Unit B start and when the plant was transitioning from 1 × 1 operation (Unit B gas turbine, its HRSG, and the steamer in service) to 2 × 1 service. Looking at Fig 8, note that as the unit heats up, the temperatures on the pipe slowly increase to 620F.

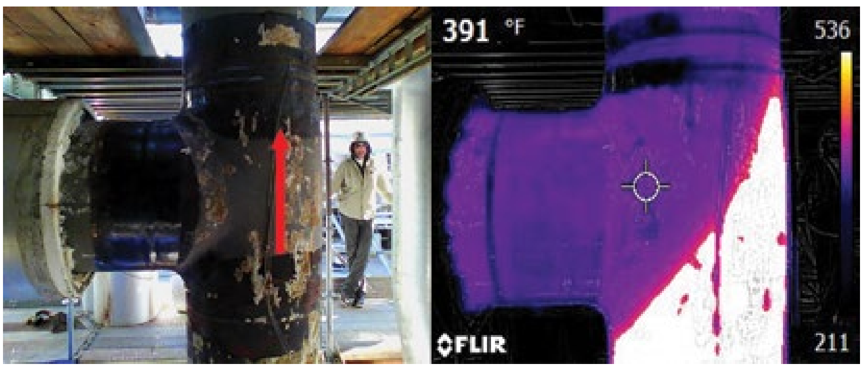
Now observe that during 1 × 1 operation, when the Unit B HP steam meets the required set point for it to flow through the turbine and the HP bypass valve closes, thermocouples TE7 and TE8 on the bypass side of the tee drop to approximately 300F. This confirms feedwater was leaking through the attemperator valves.

Furthermore, during the transition to 2 × 1 operation (when the Unit A HP bypass valve closes), thermocouples TE1 and TE4, where the failure occurred, drop down to about 360F. This means that during 2 × 1 operation there was a stream of water spraying in the area where the failure occurred, causing the metal to quench and contract.

Engineers decided to conduct a high-energy-pipe inspection during the spring 2017 outage. Prior to that outage, insulation was removed to prepare the surface of the pipe for an NDE inspection. An infrared camera was used to gain a better understanding of the temperature transients across the tee. The pictures clearly showed the attemperator leak was cooling a portion of the pipe (Fig 9).



8. Thermocouple data taken over a four-hour period confirmed what engineers believed to be the root cause—feedwater leaking by the attemperator valve



9. Infrared photo shows flow path of condensate; red arrow at left is direction of steam flow

Conclusion

A significant area of the pipe was cooled to around 350F to 400F, causing that section of pipe to contract while the remainder was expanding. The cool area overlapped the previous failure areas. Engineering analysis revealed the failures occurred from the inside surface outward in fatigue. The information gathered proved that the failures of the weld at the tee was from quenching caused by leaking attemperator valves.

Final steps. During the 2017 spring outage the following actions were taken:

- Attemperator block valves were replaced to prevent feedwater leak-by.
- Permanent thermocouples were installed on the HP bypass line downstream of the attemperator to alarm when steam temperature falls below saturation—this to alert operations personnel to potential attemperator block-valve leak-by and abnormal operating issues.

After these action items were implemented, the thermocouples on the bypass line indicated a steam temperature of more than 600F, confirming that the new block valves prevented feedwater from entering the steam pipe.

Finally, similar issues were found at another plant in the NV Energy fleet that had experienced piping failures—although the piping configuration was different. An infrared camera was used to confirm the quenching and isolation valves were restored to prevent these damaging conditions. CCJ

About the authors

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Frame 5PA upgrade motivated by forced outage

Planning for a major inspection in spring 2017 of the Frame 5 at a paper products plant in the Southeast was well underway Oct 10, 2016 when the unit tripped on high vibration, just as the day shift was arriving at the facility. An original Row 2 bucket failed and caused considerable downstream damage (Figs 1, 2).

The engineer responsible for the performance of major powerplant equipment at the mill huddled with management, which decided to begin necessary repairs immediately and to conduct the machine's third major inspection at the same time.

The Frame 5 cogen unit (turbine exhausts to an IST once-through steam generator) was a workhorse, having accumulated nearly 115,000 total fired hours and 1500 starts since commissioning in 1997. The GE MS5001PA engine was equipped with a DLN-1 combustion system and capable of dual-fuel firing. The 24.5-MW (gas) unit was one of the most advanced Frame 5s when installed: Only two such DLN-1 machines were operating in May 1999, according to the OEM.

Plant personnel told the editors that the bucket failure was the first major issue suffered by the engine in its lifetime. One reason for the machine's high reliability, staff believed, is the company's diligence in operating and maintaining the unit in accordance with OEM guidelines and industry best practices. Example: Lube-oil tests are run monthly to ensure a healthy unit.

The owner/operator did not make many significant modifications to the basic engine in its two decades of service; the 12 combustion, six hot-gas-path (HGP), and three major inspections since commissioning typically revealed little beyond normal wear and tear.

Improvements to the cogen unit over the years included retrofit of the CO_2 fire protection system, and upgrades of the Mark V controls, PI historian, and compressor bleed valves. Water-cooled flame scanners were a nuisance until an additional flame scanner was added and controls were modified to require two indications for a shutdown. Plus, all control wiring was rerouted outside the package to avoid the grounds that often tripped the unit following combustion inspections.

1. Two independent studies traced the root cause of the Row 2 bucket failure to stress corrosion cracking and fatigue

2. Collateral damage from the bucket liberation is in evidence at the trailing edges of the second-stage airfoils

SOS

Chris Mancini of Mechanical Dynamics & Analysis Ltd was informed of the unit trip and likely damage shortly after it occurred on Monday the tenth; MD&A had been working with the owner/operator's team to plan the spring 2017 major. Mancini and a superintendent were onsite two days later to assist in damage assessment.

Field service personnel and their tools/parts/equipment containers arrived Thursday. On Friday, the day shift completed its site/safety orientation, organized tools and work areas, and ran power and compressed-air lines as needed. The night shift received its site orientation, set up lighting, and began unit disassembly.

The project would proceed at an aggressive pace from that point forward given the black-start cogen unit's importance to mill production. However, safety and quality of work would not be compromised for speed. A confident owner knew the plant was prepared to handle such an emergency. Its two steam turbine/generators, bark and recovery boilers, 310,000-lb/hr standby gas-fired boiler, and electricity purchased from the local power company would satisfy process requirements. Note that with mill's assets at full capability, the plant could open the breakers on its two tie lines with the utility and be totally self-sufficient.

3. Atomizing air compressor, is removed from accessory gearbox

4. Blind flange seals opening in gearbox to accommodate the AA compressor

5. Combined SRV/GCV with hydraulic actuator was replaced with an electronic valve

6. Splitter valve also was replaced by an electronic valve

7. Existing gas-supply strainers and valves, located inside the compartment, were retained

MD&A was awarded a turnkey contract for repairs, the major inspections of the turbine and generator, and for some additional projects (Sidebar 1). Several specialty subcontractors were involved (Sidebar 2). As you scan the outage activities identified in Sidebar 1, keep in mind that several were far more complex than the few words used to describe them. Removal of the liquid-fuel and trip-oil systems is one of those. Likewise, outage participants identified in Sidebar 2 did not have equal responsibilities. The assignments for ACT, MD&A, and TTS were far more complex than those for the others.

Space limitations militate against meaningful coverage of all aspects of the mill's forced outage in this article so the editors looked to the plant engineer for guidance on what he believed might be of greatest interest to the user community. He suggested these three projects:

- Removal of the liquid-fuel and trip-oil systems and the replacement of hydraulically actuated gas valves with electric valves.
- Compressor/turbine rotor inspection and repairs.
- Refurbishment of the exhaust system.

Coverage of the generator major and some other projects identified in Sidebar 1 will appear in future issues.

Convert to gas only. The mill never had success operating on liquid fuel. Burning of fuel nozzles and liners were two outcomes of oil combustion. The most practical solution: Don't burn liquid fuel. This decision, made years ago by plant management, was easy given the ready availability of quality gas. Oil infrastructure remained until it ran afoul of the company's goal of continuous improvement.

The plant engineer told the editors it took three shifts to remove liquid-fuel components to conduct a combustion inspection and three to reinstall it before engine restart. The facility has been performing CIs at 8000-hr intervals, so the cost (labor and outage schedule impact) of this activity adds up quickly. The plant engineer is guardedly optimistic about doubling that interval given the more robust coating applied by ACT on hot-section parts in its LaPorte (Tex) shop during the outage. But this requires approval by the facility's insurer, which is currently considering the coating's merit.

MD&A was credited with developing the plan to eliminate oil capability (including fuel-nozzle mods) at less than half the cost estimated by an alternative supplier. This portion of the overall project would not have gone forward otherwise. Bonus: Eliminating the parasitic power associated with the liquid-fuel system increases unit output by 280 kW.

Issues with fuel valves equipped with hydraulic actuators motivated the mill to replace that equipment with electrically actuated valves when the change to gas-only firing was made. A bonus for this upgrade: Less gas is burned to produce a given amount of power than with hydraulic valves in the circuit.

Replacing the mechanical overspeed bolt and trip-oil system with an electronic overspeed trip enables operators to now verify trip functionality at 500 rpm without stressing the unit.

Rotor inspection and repairs, at the heart of ACT's capabilities, were relatively straightforward. The shop visit to fix the damage caused by the liberated second-stage bucket allowed Matt Lau and the ACT team to investigate every aspect of the rotor and upgrade all of its hardware for service up to 32k hours. Examples include oxidation-resistant coating of airfoils, hardfacing of transition pieces, and segmentation of second-stage nozzles. The last has given good results on Frame 6B and 7EA units.

The exhaust section of the unit, which did not get much attention over the years as is typical in the industry, was refurbished. Repairs and replacement seals were needed, as indicated by the 625F temperature in the load-gear area; with the unit disassembled, this was the ideal time to do the work. Temperature in the load-gear area is now in the neighborhood of 400F.

An exhaust system upgrade expected to pay dividends going forward was the installation of a hatch in the exhaust plenum to facilitate rotor removal, saving both time and money.

Today, gas-turbine performance meets expectations with one offline water wash yearly and annual change-out of filter socks (prefilters) for the primary cylindrical filters. The use of socks is a big cost saving. They are replaced quickly, economical to dispose of, and extend the life of the cylindrical filters—now at five years and counting.

Reliability is always on the plant engineer's mind. He believes in having "two of everything" for the Frame 5 because of its importance to the mill. It certainly helped having a complete set of second-stage parts for last fall's forced outage. He didn't have a spared first stage which is why those components were repaired by ACT and will be replaced in the future. One of the engineer's goals is to have a spare

1. Activities completed during the Frame 5 forced outage

- Turbine major inspection.
- Generator major inspection.
- Ninth-stage hook-fit modification.
- Replace second-stage buckets, nozzles, shrouds.
- Repair first-stage buckets, nozzles, shrouds.
- Clean/recalibrate inlet guide vanes.
- Shop inspect compressor/turbine rotor, blend compressor blade tips and FOD areas, apply anti-rock coating on turbine first-stage wheel dovetails, etc; low- and high-speed balance.
- Test and inspect generator field; high-speed balance.
- Test, inspect, clean stator, address areas with corona activity, install flux probe.
- Rebuild exciter.
- Remove liquid-fuel and trip-oil systems.
- Replace hydraulically actuated gas valves with electric valves.
- Refurbish exhaust system, install new expansion joints.
- Refurbish load gear and accessory gearboxes.
- Clean lube-oil tank and re-epoxy.
- Replace CO_2 fire protection damper.
- Refurbish enclosure.

2. Principal subcontractors

- ACT Independent Turbo Services Inc (inspect/repair/low-speed-balance compressor/turbine rotor and associated hardware, refurbish exhaust system).
- Advanced Turbine Support LLC (borescope inspection).
- Dekomte (expansion joints).
- EZ Filtration (remove old LO tank coating, re-epoxy).
- Industrial Metal Fabricators (reinsulate exhaust plenum).
- MD&A—Mechanical Dynamics & Analysis Ltd (overall project responsibility, generator inspection and related work, high-speed balance of both generator and compressor/turbine rotors).
- Timken Gears & Services Inc (refurbish gears/gearboxes).
- TTS—Turbine Technology Services Corp (convert dual-fuel capability to gas only).
- Turbo Parts LLC (turbine consumables).
- Young & Franklin Inc (fuel valves).

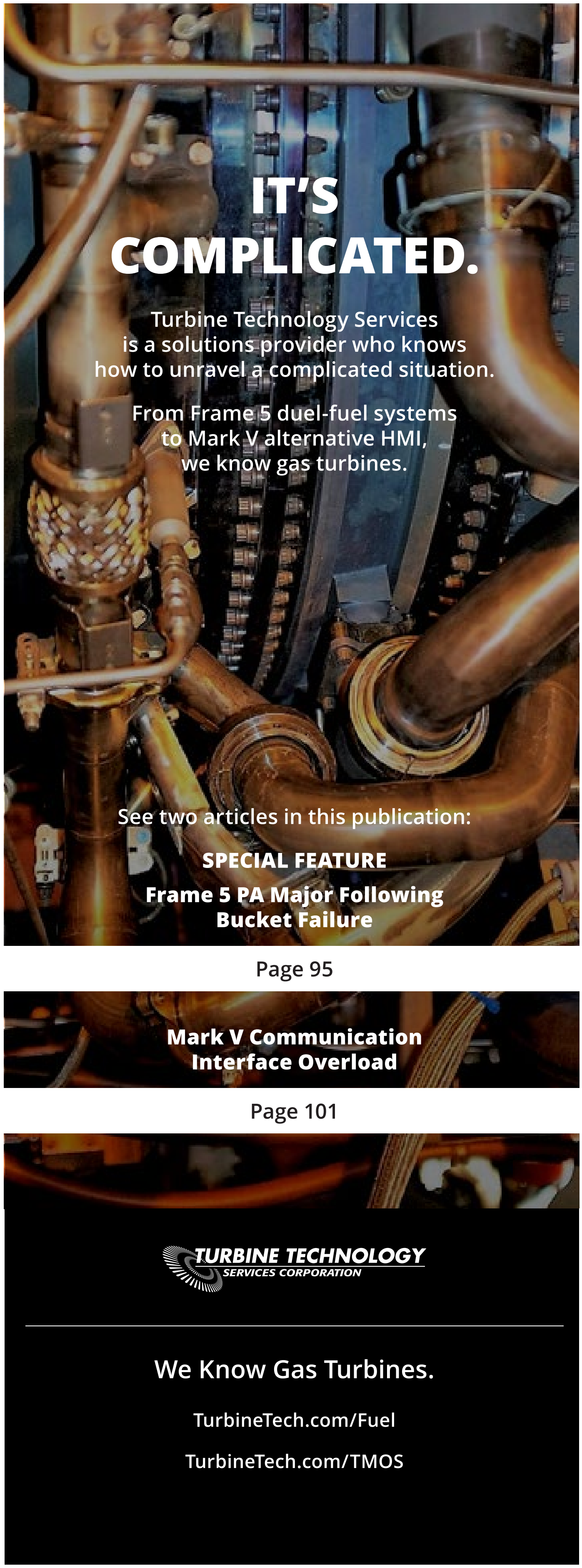
rotor in the plant warehouse and a second set of hardware to match.

The mark of a successful job: The unit was placed on ratchet November 27 and preoperational tests were conducted the next few days. Restart, synchronization, loading to spinning reserve occurred Thursday, December 1 without a hiccup. MD&A personnel packed up and left the site that weekend.

Converting from dual fuel to gas only

The liquid fuel system (LFS) for this Frame 5 included the following subsystems: primary and secondary liquid fuel and purge, atomizing air, and water injection and purge. LFS decommissioning, a first step in the conversion of the unit to gas-only operation, included deactivation or removal of all hardware associated with oil supply as well as of equipment in the subsystems noted.

During the forced outage, key components of the LFS were removed, but because of time constraints and the physical location of some hardware, it was not feasible to remove everything at that time. Others who have performed similar conversions told the editors it's important



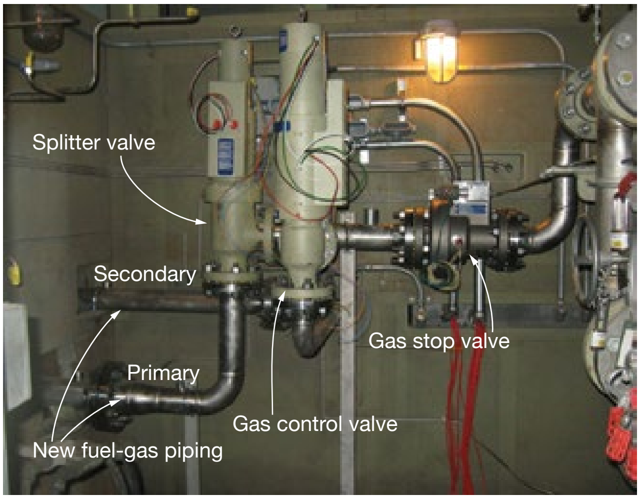
to disconnect/remove components that would consume power when inactive—such as the fuel pump and atomizing air compressor—and abandon in place piping that would have no adverse impact on gas-only operation.

The end covers and piping inside the turbine compartment were modified during the outage to reflect elimination of the LFS; Mark V controls software was reconfigured to accommodate the changes made.

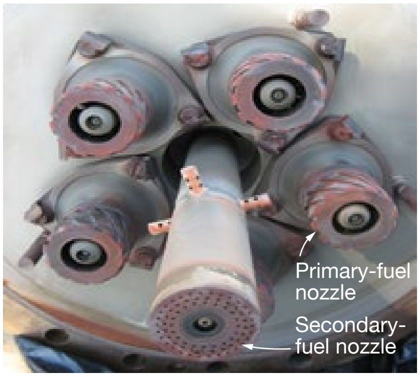
Here's a summary of LFS hardware *removed:*

- Primary liquid-fuel lines from the flow divider to the fuel nozzles.
- The accessory-gear-driven fuel pump—together with the electric clutch, coupling, bypass valve, and gear and its bearings. This task complete, a blind flange was installed to seal the pump-drive opening in the gearbox. Note that the liquid-fuel stop valve was not removed, neither was the piping from the stop valve to the fuel pump.
- The accessory-gear-driven atomizing air compressor—together with its drive gear and associated bearings. This task complete, a blind flange was installed to seal the compressor-drive opening in the gearbox (Figs 3, 4). Note that the atomizing-air filter was not removed but its inlet and outlet piping were blind-flanged.
- Extraction piping from the compressor to the atomizing- and purge-air subsystems. The extraction nozzle on the compressor shell was capped.
- Atomizing-air pre-cooler and its cooling-water supply piping. Source-air piping from the atomizing-air pre-cooler inside the turbine compartment also was removed.
- Atomizing-air booster compressor driven by the starting diesel, along with related piping and valves.
- Accessory-gearbox oil-vapor eductor; a desiccant breather cap was installed in its place.
- Gas-fuel purge system hardware.
- Water-injection piping to the fuel nozzles. Note that the water injection system for NO_x control was not operational because the unit was not run on liquid fuel; however, the necessary hardware had been installed from the water-injection compartment up to the fuel nozzles.

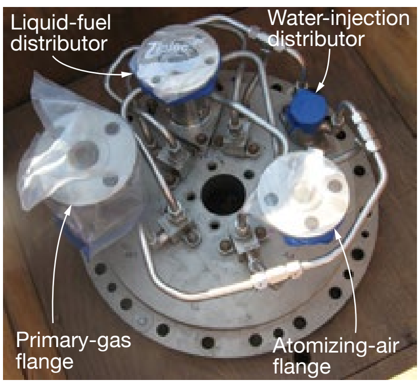
Finally, purge-system hardware inside the gas-turbine compartment for primary and secondary liquid fuel, and water injection—including solenoid valves, purge valves, and purge-



8. A stop valve was required in addition to electronic primary- and secondary-fuel control valves



9. Business side of an end cover showing the location of primary- and secondary-fuel nozzles



10. Original end cover with dual-fuel capability. Note that the secondary-fuel nozzle is not yet installed in the center hole

air pre-cooler—was not removed and supply piping blind-flanged.

Fuel valve upgrades. The mill's Frame 5 was equipped with a combined, hydraulically actuated gas stop speed/ratio (SRV) and control valve (GCV, Fig 5) and gas fuel splitter valve (Fig 6). Recall that the SRV and GCV are independent valves. Gas flows through the SRV to the GCV, which regulates the amount of fuel flowing to the ring manifold serving the 10 combustion chambers. The splitter valve serving on DLN machines divides gas flow between the primary and secondary fuel systems.

Turbine Technology Services Corp was retained to remove the liquid fuel system, as described above, and to replace the existing hydraulically actuated, 3-in. SRV/GCV and splitter valves with new electronic valves from Young & Franklin Inc. Existing gas supply strainers and valves were retained inside the compartment (Fig 7). A 3-in. stop valve was required in addition to electronic primary- and secondary-fuel control valves (Fig 8).

The company's Dave Simmons told the editors TTS has deep experience in this work, having removed liquid-fuel capability on about 50 GE Frame 5s through EAs over the years. Plus it has retrofitted electronic valves from different suppliers on perhaps 20 machines since 1991—including a valve of its own design which is no longer offered.

Simmons said elimination of liquid-fuel capability on a non-DLN gas turbine is relatively easy, but experience counts when a DLN engine is involved. This project was unique: It was the first time to his knowledge that a Mark V-equipped DLN-1 machine was converted to electronic valves for fuel control—and it took only four weeks from initial request to startup.

TTS proved it could satisfy project goals by running tests on its reconfigured Mark V simulator. No empirical testing was involved. There were no surprises, Simmons said. The Y&F valves performed the way the company said they would.

He added that an increasing number of plants are investigating conversion to electronic valves and most projects can be justified based on opportunity costs. One of the first things to do, Simmons continued, is to determine the availability of physical space to accommodate the new equipment. This shouldn't be challenging for non-DLN machines, he said.

Some demolition and install of the new valves and electrical conduit/wiring are key elements of the physical project. The editors were told that most wiring generally can be reused; an exception might be that for an old non-DLN unit. Note: Shielded cable is strongly recommended for use with electronic valves.

Finally, if considering electronic

fuel valves for your plant, don't forget to audit the control system logic file to see if it can accommodate the switch from hydraulics to electric. At this mill there was no issue because so much liquid-fuel infrastructure was removed.

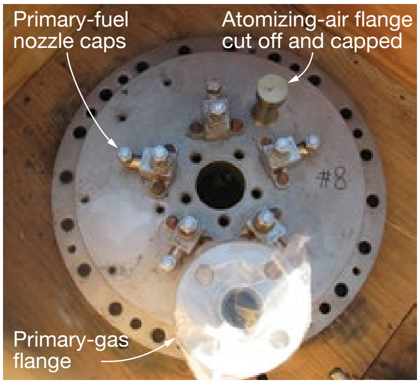
TTS modified the gas control software in the Mark V panel and HMI operator screens and then performed functional and operational tests of the new gas control system. Other activities required to complete the project included the following:

- Disable piping to the gas control valve for the existing hydraulic- and trip-oil systems. Note that the mechanical overspeed trip was disabled when trip-oil supply to the gas control valve was terminated.
- Install two magnetic speed pickups and independently connect to the Mark V overspeed "hardware" trip.
- Install an emergency-stop pushbutton inside the accessory compartment.

Combustion section. The Frame 5 fuel nozzles were in good condition with only light wear, according to experts. They were sent to a service shop for cleaning, flow testing, and conversion to gas only. At the same time, a set of DLN-1 end covers with refurbished primary fuel nozzles provided by the owner were converted onsite to gas only. The plant's back-up set of secondary fuel nozzles also was converted to gas. The modified components were installed in the gas turbine (Fig 9).

To convert the dual-fuel end covers to gas only, the liquid-fuel and water-injection distributors were removed (Fig 10 before, Fig 11 after). The tubing runs connecting the distributors to the corresponding five primary-fuel nozzles on each end cover also were removed and caps installed in their place at the openings created. Secondary-fuel nozzles attach to the center of each end cover; their liquid-fuel and water-injection connections also were removed and capped.

Combustion cans, liners, crossfire tubes and retainers, transition pieces and side seals, spark plugs, and flame detectors were inspected, found in generally good condition, and most returned to service with new hardware and refurbished wear surfaces.



11. End cover after modification to gas fuel only. Here again the secondary-fuel nozzle is not yet installed in the center hole. Note, too, that only the primary-fuel flange remains

12. Exhaust frame suffered extensive damage to its internal hot-gas flow-path surfaces—especially at the forward curved edge as shown in the photo

Rotor inspection, repairs

The GT rotor was shipped to ACT's shop for inspection, and repairs of the compressor and turbine sections as needed. Specific tasks conducted are summarized in Sidebar 1. Rubs and minor defects identified were corrected and consumables replaced as necessary. A low-speed balance at the LaPorte facility was backed up with a high-speed balance in MD&A's St. Louis pit.

Exhaust section

The exhaust frame suffered extensive damage to its internal hot-gas flow-path surfaces—especially at the forward curved edge that exposed the aft strut cooling air to hot gas (Fig 12). The upper and lower halves of the exhaust frame assembly were moved to ACT's service shop for repairs.

The exhaust frame was blast-cleaned in LaPorte to remove rust and corrosion. New or repaired layers of forward baffle seals were installed by the shop. The damaged second-stage aft wheelspace (discourager) seals also were repaired or replaced. The few cracks found at the support struts were weld-repaired.

Casing assembly repair work was done by ACT onsite. The No. 2 bearing housing was removed during disassembly and alignment work was performed on all the casings after reassembly.

The exhaust diffuser was removed from the unit and inspected. A crack found along the stiffener joint weld (hot gas path) was repaired by ACT onsite. A few cracks also were found inside the load-tunnel skin and were weld-repaired. All new hardware was used to marry the exhaust diffuser to the exhaust frame and the lock plates were secured.

The exhaust plenum was found corroded and in deteriorated condition both internally and externally, as most users might expect. The insulation panels had cracks and were deformed. Forward and aft flex seals were severely misaligned, allowing hot gases to escape to the turbine and load compartments. The plenum's forward and aft flanges were deformed and the misalignment between the plenum and turbine casing was large.

The exhaust plenum was removed from the unit and sent to Industrial Metal Fabricators Inc for repairs. Fit-up to the gas turbine casing during reinstallation met expectations and new flex seals were installed forward and aft without any stress. During startup and operational tests, the turbine and load compartments remained relatively cool with little to no exhaust leakage into either.

Expansion joints between the plenum and turbine compartment, and between the plenum and load compartment, were replaced by Dekomte. Installation included reconstruction of the internal hot-gas flow path that joins the plenum to the exhaust duct and prevents exhaust gas from directly contacting the expansion-joint material. Best practice: Dekomte recommended that the exhaust duct and expansion joint be inspected for integrity during combustion inspections.

The exhaust thermocouple radiation-shield holder ring and the radiation shields were removed, inspected, and reinstalled in the exhaust plenum; the TCs were replaced, however.

Practical idea: A small cutout was made at the top forward section of the exhaust plenum to facilitate removal of the gas-turbine rotor in the future. A bolted piece made from the cutout was installed in place. CCJ

BUSINESS PARTNERS

Thermal clamps help prevent coking in GT liquid-fuel lines

Reliable operation of dual-fuel gas turbines on oil demands that owner/operators protect against coking of oil in fuel-system valves and piping. Active cooling is one solution available to users for assuring both reliable starts on liquid fuel and reliable fuel transfers from gas to oil.

"Cool valves, piping improve engine reliability when called to burn oil," CCJ 1Q/2016 (p 69) and available at www.ccj-online.com (type headline into the search-function box), discusses several cooling options offered by JASC. One of these, the so-called "thermal clamp," was introduced as that article was in preparation.

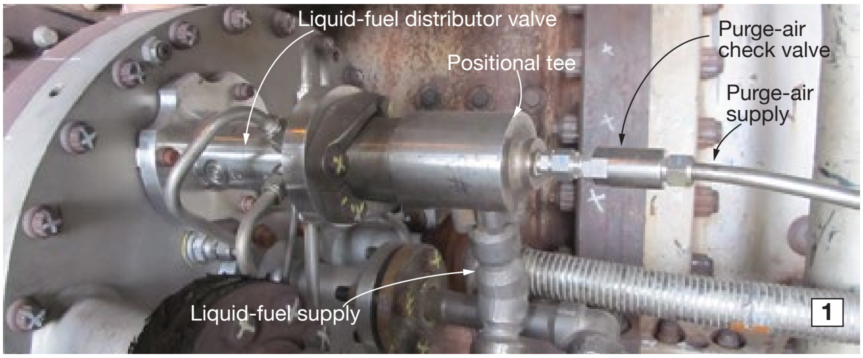
Early results available from the first commercial installation (Fig 1, *before;* Figs 2 and 3, *after* point to success both in protecting against coking and eliminating the need for "verification" firing of oil monthly to confirm liquid-fuel system reliability.

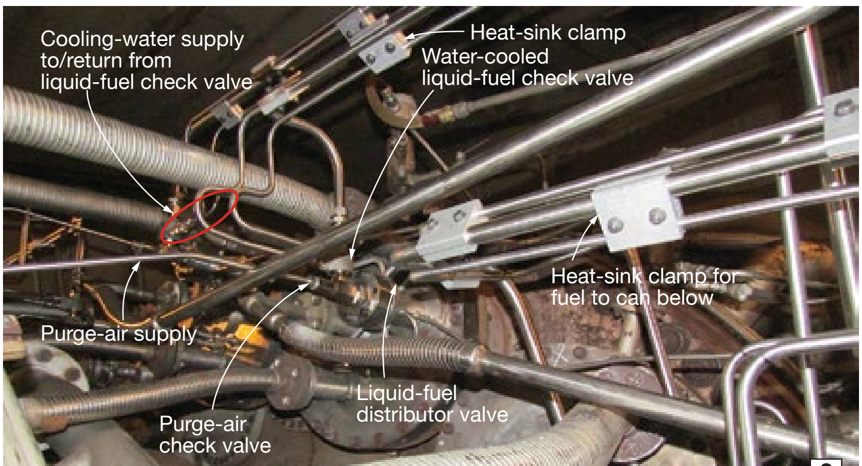
JASC's (Tempe, Ariz) Schuyler McElrath told the editors, "With our latest system configuration consisting of rerouting fuel piping, incorporation of heat-sink clamps to keep fuel lines cool, water-cooled fuel controls, and component connections which don't use O-rings, we are now offering the capability of running on liquid fuel at semi-annual intervals, or longer, without sacrificing back-up liquid-fuel system reliability.

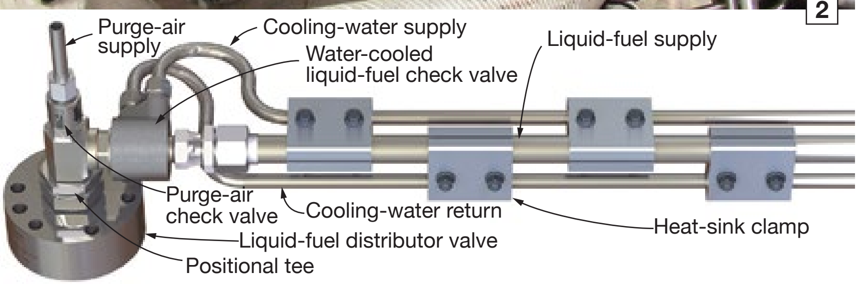
"In the first test of this latest configuration, the second of two 7F gas turbines operated on liquid fuel during commissioning of the fuel-system upgrade in April 2016. The site operated exclusively on natural gas over the next nine months, burning oil only during the second week of January 2017. The next run on liquid fuel was in July 2017. Both times, the turbines started and operated on liquid fuel without incident."

Thus the two-unit site burned liquid fuel successfully *twice* in the 15-month period ending in July. The typical site needing to confirm oil firing capability on two units would have paid approximately $60,000 each month the test was conducted. Thus, not having to run tests for 13 of the 15 months since the upgrade was completed saved more than three-quarters of a million dollars.

Based on this success, the owners of other sites currently are upgrading the fuel systems on some of their 7FA engines. These particular upgrades present a variation on the original concept in that they will be using JASC water-cooled 3-way purge valves to replace either standard 3-way purge valves or check-valve and purge-air-valve configurations. Piping modifications highlighted here will be incorporated.







Piping arrangement *before* the fuel-system upgrade is in Fig 1. Figs 2 and 3 show the system *after* the upgrade, from different angles. Note that the positional tee is an important part of the system: It can be rotated so connections to purge air and fuel can be made without having to modify existing piping. Not visible in the photos is that O-rings for sealing at the distributor-valve flange and check valves have been replaced with copper crush gaskets for long life. An advantage of the new sealing system is that check valves can be removed and reinstalled multiple times before the crush gaskets must be replaced

Updating the Mark V communication interface overload issue

"Mark V goes haywire, shuts down F-class units lube-oil pumps," caught many in the industry by surprise when it was published in CCJ ONsite May 3, 2017 judging from the social media and online user-group chatter we were told occurred the days following, a passing mention by a GE engineer at a recent meeting, and a call from Scott Muster of Turbine Technology Services (TTS).

What the editors learned recently came in too late to include in the article with the same title appearing in CCJ's 1Q/2017 print edition. The material that follows updates CCJ's coverage on the subject, which was based on the industry alert Abel Rochwarger, chief engineer at Gas Turbine Controls, shared with the editors for publication.

GE Power responded to the article with Product Service Information Bulletin (PSIB) 20170519A, "Mark V Communication Interface Overload—Loss of Lube Oil." The overview for that document states, "A recent loss of lubrication event on an F-class unit using Mark V controls has highlighted the need to communicate the capabilities of the Mark V controller in the context of today's demanding applications." The OEM said the Mark V controller was released in 1991 and has accumulated more than 200-million operating hours in a variety of applications with a good record for safety and reliability.

In basic terms, "heavy command traffic" was cited by the OEM as the cause of the accident described. GE said laboratory testing confirmed that symptoms similar to those observed can be recreated by increasing network traffic significantly above the recommended limit of 10 commands per second from all sources.

The PSIB recommended that owner/operators not make changes to lube-oil pump controls without first consulting GE. It also referenced four background documents on communications protocols. Plant personnel who do not have a copy of 20170519A should contact their GE representative for one.

Online discussion revved up after GE released the PSIB. TTS's Muster contacted CCJ after learning of customer concerns. He told the editors that his company's Turbine Monitoring System (TMOS), which is a direct replacement for existing Mark V <I> and <HMI> systems, actively manages and regulates the transfer of instructions from all site devices (BOP, DCS, SCADA, operator stations) to the Mark V, ensuring that the type of communication overload associated with the lube-oil failure is not possible.

Muster said the TMOS has been in the field since 2001 and has maintained an "outstanding record for safety and reliability for more than 60-million operating hours." More material pertinent to this discussion is available on the TTS website at www.turbinetech.com.

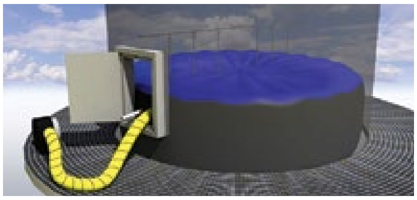
Stack-balloon design upgrade incorporates internal drain system

Gary Werth, the stack-balloon guy, called to tell the editors about the design upgrade for his product, which now features an internal drainage system. Werth listened to personnel at the many plants that have purchased the stack balloon since the first installation at Whiting Clean Energy (today Nipsco) in November 2004 regarding their ideas on how to facilitate installation, improve durability, and deal with rainwater accumulation.

And that intel contributed significantly to the stack balloon shown in the drawing. Note that the top surface is angled from the perimeter edge towards the center drain. As rainwater accumulates on the top surface, it is directed to the 4-in.-diam PVC pipe; latter can be connected to a gutter system or the stack drain.

This second-generation stack balloon, which includes a layer of heavy-duty fabric around the perimeter to increase wear resistance, is installed perpendicular to the stack.

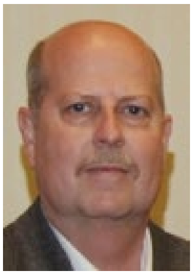
In retrofit applications, the access-door size must be changed from 30 ×



30 in. to 36 × 24 in. Werth reported that his company has been working with HRST Inc on access doors; HRST also can supply balloon support cable and hanger hardware.

Werth says his has sold five of the new stack balloons already, including one in the Tacoma (Wash) area—a good location to check drain performance. Feedback has been thumbs-up.

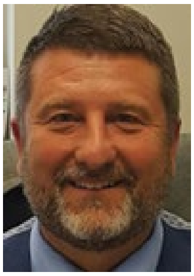
Eight Bells: Mike Gough, 61



"Sudden, unexpected" were the words used to describe the passing of Michael Collier Gough, general manager of Calpine Corp's Morgan Energy Center, Decatur, Ala, on July 9, 2017. He was held in high esteem by industry colleagues, including the CCJ editors, and the people he managed and worked alongside at power and process plants owned and/or operated by Calpine, NAES, Tenaska, Diamond Shamrock, and Occidental Chemical.

A maintenance manager told the editors, "Mike pursued excellence in everything that he did and installed that same pursuit in every person that he came in contact with." A plant manager said he was "a really good guy." Yet another colleague described him simply as "awesome." Gough's plant frequently shared its best practices with CCJ subscribers, receiving several awards over the years, including a Best of the Best.

Kohler launches Victory Turbine



Rodney W Kohler, a familiar face at user-group meetings over the last decade, recently launched Victory Turbine LLC to deliver owner/operators solutions for O&M and efficiency improvements. First business arrangements are with the following companies:

- Zokman Products Inc, to provide an environmentally responsible, water-based compressor cleaner and corrosion inhibitor to help maintain maximum efficiency and heat rate.
- Caldwell Energy, to offer fogging and wet-compression technology for OEM equipment.

By way of background, Kohler, like many others in power generation, got his start in the military—the US Air Force, as a ground equipment mechanic. A degreed enginer with a specialty in fluid mechanics, he got his industry work experience at GE, Whitton Technology, Gas Turbine Efficiency, Caldwell Energy, and Danfoss

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Products and services from over 100 companies support new unit construction, retrofit and maintenance activities at existing facilities, and plant operations. Solutions span gas and steam turbines, HRSGs, pumps, valves, piping, cooling towers, condensers, etc

AAF International

Global leader in the field of air filtration, meeting the most demanding conditions and the toughest environmental challenges. The company's filtration, noise abatement, and other turbine products are effective, durable, and crucial to greater efficiency and performance.

ABB

Leading power and automation technologies that enable utility and industry customers to improve performance while lowering environmental impact. Turbine-automation control systems are based on ABB's field-proven control platforms that deliver safe and reliable control.

Advanced Filtration Concepts

Offers new and innovative filtration products for the GT/CC power industry. Invest to save with inlet air filters that are high efficiency, low backpressure, and long lasting. As the largest stocking distributor of industrial air filters in the West, AFC is equipped to meet your most urgent GT inlet filtration needs. Turnkey installation available.

Advanced Indoor Air Quality Care

Specializes in cleaning heavy-duty equipment, power generation facilities, and electric utility plants. Options of cleaning include dry-ice blasting, soda blasting, and media blasting depending upon the project.

Advanced Turbine Support

Has delivered unbiased fleet experience and superior customer service for more than a decade. Company provides users high-resolution borescope inspections, cutting edge ultrasonic and eddy-current inspections, and magnetic-particle and liquid dye-penetrant inspections in accordance with OEM Technical Information Letters and Service Bulletins.

Aeroderivative Gas Turbine Support

AGTSI offers a full range of aeroderivative gas-turbine, off-engine, and package parts from the most basic to the most critical. An expansive inventory of spares and replacement parts is maintained at our warehouse for all models of GE LM2500, LM5000, LM6000, and LMS100, as well as P&W GG4/FT4.

AGTServices

Over 200 years of combined, proven OEM engineering, design, and hands-on experience; known in the industry for its schedule-conscious, cost-effective solutions with respect to generator testing and repairs.

American Chemical Technologies

Provides state-of-the-art synthetic lubricants to the power generation industry. Founded more than 30 years ago in the US, ACT has grown to become an international supplier of value-added lubricants that provide superior benefits to equipment, the environment, and are worker-friendly.

Apex Dry Ice Blasting & Industrial Services

Experienced provider of noncorrosive and nonabrasive cleaning services for all types of power generation equipment with no secondary contamination, significant reduction in downtime. Available nationwide, 24/7, using OSHA-trained techs, and registered with ISNetworld and Browz.

ARNOLD Group

With more than 550 installed insulation systems on heavy-duty gas and steam turbines, company is the global leader in designing, manufacturing, and installing the most efficient and reliable single-layer turbine insulation systems.

Bearings Plus Inc

Provider of repairs and custom technology upgrades for turbomachinery. Designs and manufactures an integrated solution to meet specific requirements for every operating environment, applying the latest fluid film bearing and high-performing seal technology to legacy equipment to optimize performance.

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Recommended, free, and easy-to-use apps:

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Braden Manufacturing

Designs and manufacturers air filtration systems and filters, inlet cooling/heating, silencing, exhaust and inlet ductwork, diverter dampers, simple cycle SCRs, expansion joints, bypass stacks, diffusers and plenums.

Bremco

Full-service industrial maintenance contractor since 1976. Company experience in combined-cycle projects includes header, tube, and complete panel/harp replacements. We also have significant experience in liner repairs/upgrades, duct-burner repairs, penetration seals, and stack-damper installations.

C C Jensen Oil Maintenance

Manufactures CJC™ kidney-loop fine filters and filter separators for the conditioning of lube oil, hydraulic oil, and control fluids. Our extensive know-how ensures optimal maintenance of oil systems and equipment reliability.

Caldwell Energy

Power augmentation, including inlet fogging and wet compression solutions, boosts the output and efficiency of gas turbines. With more than 400k hours of operating experience in power generation, these systems offer proven performance and are backed by a three-year warranty.

Camfil Farr Power Systems

A world leader in the development, manufacture, and supply of clean air and noise reducing systems for gas turbines. A correctly designed system minimizes engine degradation, leading to lower operating costs, optimum efficiency, and less environmental impact.

Chanute Manufacturing

Contract fabricator of HRSG products—including finned tubes, pressure-part modules, headers, ducting, casing, and steam drums.

CLARCOR Industrial Air

Formerly GE Power & Water's Air Filtration business, CLARCOR helps customers achieve air quality and plant performance goals with products and solutions for gas turbine inlet filtration, industrial filtration, and membrane technologies. Company is committed to improving plant performance and enabling users to realize their operating goals.

CMI Energy

Known globally for HRSGs and aftermarket solutions that are engineered to tackle the most stringent power industry demands, company serves its customers with experienced teams, advanced designs, and reliable operation. Count on CMI for proven technologies, expert project execution, and top-quality support for the life of every job.

Concord Engineering

Delivers end-to-end design solutions specializing in services that enhance performance, increase efficiency and reduce downtime. CEG delivers detailed engineering design for simple and combined cycles using aero and frame combustion turbines, with expertise in HRSG design and optimization.

Conval

Designs and manufactures high-performance valves for the world's most demanding applications, including power generation. Company has a series of power generation case studies that demonstrate the unique features and benefits of forged valves.

Cormetech

The world's leading developer, manufacturer, and supplier of catalysts for selective catalytic reduction (SCR) systems to control emissions of nitrogen oxides from stationary sources. Cormetech SCR catalysts are highly efficient and cost-effective where systems must be capable of reducing NO_x by more than 90%.

COVERFLEX Manufacturing

Offers superior removable insulation systems for an array of gas and steam turbines. Based on OEM turbine designs and feedback from plant managers, insulation systems are custom-designed to provide comprehensive thermal protection.

Creative Power Solutions

CPS is a group of engineering companies in the power generation and energy utilization sector. Its mission is to provide advanced, efficient, and customized technology solutions to clients ranging from OEMs to plant operators and energy consumers.

Crown Electric Engineering & Manufacturing

Engineers, designs, fabricates, and installs isolated phase bus, large bus duct systems, and outdoor switchgear. Specializes in rapid response needs such as IPB for GSU change-outs, quick-ship fabrication, and emergency on-site service needs.

CSE Engineering

Specializes in gas, steam, and hydro turbine control system upgrades, <ITC>® HMI replacement for GE Speedtronic™ MK IV and V, gas and steam turbine field services, Woodward parts and repairs.

Cust-O-Fab Specialty Services

Provides the latest technology in exhaust plenums, exhaust ductwork, and exhaust interior liner upgrades that will drastically reduce external heat transfer, making the unit safer and more efficient and easier to operate and maintain.

Cutsforth

Our experience and innovative designs have brought best-in-class brush holders, collector rings, shaft grounding, and onsite field services for generators and exciters to some of the world's largest power companies.

DEKOMTE de Temple

Manufactures fabric and metal expansion joints which compensate for changes in length caused by changes in ductwork temperature. Axial, lateral, or angular movements can be compensated for. Company has gained a global reputation for ingenuity of design and quality of products.

Donaldson Company

Leading worldwide provider of filtration systems that improve people's lives, enhance equipment performance, and protect the environment. Donaldson is committed to satisfying customer needs for filtration solutions through innovative research and development, application expertise, and global presence.

Dry Ice Blasting of Atlanta

Offers professional dry-ice contract cleaning services performed at your facility. Company provides a full range of dry ice blasting machines and capabilities to accommodate any size job by its team of trained, certified, and experienced operators.

EagleBurgmann Expansion Joint Solutions

Leading global organization in the development of expansion-joint technology; working to meet the challenges of today's ever-changing environmental, quality, and productivity demands. Company's flexible products are installed on equipment where reliability and safety are key factors for operating success.

ECT-Engine Cleaning Technologies

Offers R-MC and PowerBack gas turbine and compressor cleaners to eliminate compressor fouling. Additionally, ECT designs specialty nozzle assemblies and custom pump skids for the proper injection of chemicals and water for cleaning, power augmentation, and fogging.

Emerson Process Management

Ovation™ control system offers fully coordinated boiler and turbine control, integrated generator exciter control, automated startup and shutdown sequencing, fault tolerance for fail-safe operation, extensive cyber security features, and embedded advanced control applications that can dramatically improve plant reliability and efficiency.

Environmental Alternatives Inc (EAI)

Experts in CO_2 blast cleaning, surface preparation, and onsite dry-ice pellet production for HRSGs, SCR and CO catalyst, ammonia injection grids, gas and steam turbines, ACCs, and electric motors. Services also include scaffolding erection, sky-climber installation, deep bundle cleaning, and tube spreading.

EthosEnergy

This JV between Wood Group and Siemens is a leading independent service provider of rotating equipment services and solutions. Globally, these services include EPC; facility O&M; design, manufacture, and application of engineered components, upgrades, and re-rates; repair, overhaul, and optimization of gas and steam turbines, generators, pumps, compressors, and other high-speed rotating equipment.

Falcon Crest Aviation

Distributor of ZOK27 and ZOKmx gas-turbine compressor cleaning detergents. ZOK27 is a single cleaner and inhibitor in one that cleans and protects the engine—and also inhibits corrosion. ZOKmx is a power cleaner formulated to replace solvents providing exceptional cleaning without the health and environmental risks associated with solvents.

Federal Steel Supply Inc

Distributor of seamless HRSG high-energy pipe and power piping. Scheduled and heavier than scheduled walls in stock for headers, steam lines, etc. SA106 B/C and SA335 P11/P22/P91. Fittings to complement all pipe. Offering cut-to-length, custom fittings, specialty end preparation, supplemental testing, and emergency same-day shipments.

Filtration Group

Leader in manufacturing high-quality air filters from filter pads to final filters. Filtrair rigid pocket filters have high-performance properties and unique hydrophobic-treated air filters are the ideal solution for any environment with water droplet aerosol or high-humidity.

Frenzelit North America

Specializes in providing long-term expansion-joint solutions for gas-turbine exhaust applications. In addition to manufacturing superior quality expansion joints, Frenzelit also makes HRSG penetration seals, insulating materials, and acoustic pillows for silencers.

Gas Turbine Controls

World's largest stock of GE Speedtronic circuit boards and components for the OEM's gas and steam turbines. GTC stocks thousands of genuine GE-manufactured cards for the MKI, MKII, MKIII, MKIV, MKV, MKVI, and LCI controls, as well as EX2000, Alterrex and Generrex excitation.

Gas Turbine Efficiency

Provides solutions involving the application of electrical, mechanical, and process-related equipment and components for optimizing system performance. GTE's experienced team of engineers and designers has solid industrial process backgrounds with expertise in fluid systems, instrumentation, and system controls.

Gas Turbine Specialty Parts

Provides patent-pending products that are new, cutting-edge, add value, and promote a safer work environment. GTSP presently has two unique products designed for the utility industry: 1) flange leak detection and 2) open air exhaust thermowell.

GP Strategies

Provides training, engineering, and performance improvement services specifically designed for the power industry: The EtaPRO™ Performance and Condition Monitoring System and GPi-LEARN+™.

Groome Industrial Service Group

Offers a variety of SCR and CO catalyst cleaning and maintenance services nationwide and has formed strategic alliances with industry experts and catalyst manufacturers to ensure that Groome offers the most widely supported, comprehensive, turnkey service available.

GTC Services

Field engineering company offers gas-turbine owners and operators worldwide "Total Speedtronic Support." Engineers have decades of experience servicing and troubleshooting all GE Speedtronic systems.

Gulf Coast Filters & Supply

Keep your filter house and evap coolers operating at peak condition. GCF provides comprehensive, personalized filter-house products, field service, and maintenance, emphasizing safety, professionalism, efficiency, minimal job-site disruption, quality products, and thorough testing and inspections.

Haldor Topsoe

Our air pollution technology includes a series of unique catalysts for Selective Catalytic Reduction (SCR) systems for the control of nitrogen oxides (NO_x), and the reduction of carbon monoxide (CO) and volatile organic compounds (VOCs), from stationary and mobile sources.

Hilliard

The HILCO® Division cost-effectively brings fluid-contamination problems under control and engineers a full-range of filters, cartridges, vessels, vent mist eliminators, transfer valves, reclaimers, coolant recyclers and systems, and membrane filtration systems.

HRST

Specializes in technical services and product designs for HRSGs, waste heat boilers, and smaller gas or oil fired power boilers globally. Experience on over 200 boilers annually and able to provide quality inspections, analysis work, design upgrades, professional training, and more.

Hydro

Engineered solutions enable combined-cycle plants to achieve pump reliability and reduced O&M costs. As the largest independent pump rebuilder, Hydro works hand-in-hand with pump users to optimize the performance and reliability of their pumping systems.

Hy-Pro Filtration

Provides innovative products, support, and solutions to solve hydraulic, lubrication, and diesel contamination problems. Company's global distribution and technical-support networks enable customers to get the most out of their diesel, hydraulic, and lube-oil assets. ISO 9001 certified.

JASC

Engineers and manufactures actuators and fluid-control components for power generation, aerospace, defense, and research applications to improve operational capability and performance.

KnechtionRepair Tools

Manufactures tools designed to make thread repairs to both the female and male ends of cross-threaded compression fittings. In most cases, the repair will be accomplished without removing the tube from the system. This saves the O&M tech time and avoids additional downtime.

Kobelco Compressors America

Provides robust, high-efficiency fuel-gas compressors for use with all major types of gas turbines—including GE, Mitsubishi, Alstom, Siemens, Rolls-Royce, and Solar. Over 300 of the company's screw-type compressors have been supplied for gas turbines.

Liburdi Turbine Services

Advanced repairs employ the latest technologies and are proven to extend the life of components for all engine types. Company specializes in high-reliability component repairs and upgrades for blades, vanes, nozzles, shrouds, combustors, and transitions.

Mechanical Dynamics & Analysis

One of the largest turbine/generator engineering and outage-services companies in the US. MD&A provides complete project management, overhaul, and reconditioning of heavy rotating equipment worldwide.

Membrana, a 3M company

Market-leading producer of microporous membranes and membrane devices used in healthcare and industrial degassing applications. The Industrial & Specialty Filtration Group manufactures Liqui-Flux® ultrafiltration and microfiltration modules as well as Liqui-Cel® membrane contactors.

Mitten Manufacturing

Leading fluid system packager for numerous OEMs, EPC firms, utilities, and plant operators all over the world offering a number of value-added designs, spare parts management, and field services.

Multifab Inc (MFI)

Over 40 years of experience in design and manufacturing of products used for high-temp equipment along with air and flue gas applications. Offers a wide variety of services for all types of expansion joints, dampers, and high-temp products including installation, removal, repair, and splicing.

NAES

One of the world's largest independent providers of operations, construction, and maintenance services, provided through a tightly integrated family of subsidiaries and operating divisions. NAES services include O&M; construction, retrofit, and maintenance under dedicated long-term maintenance or individual project contracts; and customized services designed to improve plant and personnel effectiveness.

National Electric Coil

Leading independent manufacturer of high-voltage generator stator windings with expertise in design and manufacturing of stator windings for any size, make, or type of generator. This includes diamond coils, Roebel bars—including direct cooled, inner-gas, and inner-liquid cooled bars—and wave windings.

Nor-Cal Controls ES Inc

Provides control-system consulting, engineering, and training solutions and services to the power generation sector. Cost-effective solutions are based on proven technology and open-architecture design, eliminating the need for service contracts at the end of the project.

Parker Balston

Develops and manufactures nitrogen generators for all your power generation needs including boiler layup, gas seals, purging gas lines prior to service, blanketing demin water tanks, and LNG terminals.

Parker Hannifin

Reduce costs and optimize performance with the world's leading diversified OEM of motion, flow, process control, filtration, and sealing technologies, providing precision engineered solutions for the power generation market.

Praxair Surface Technologies

Leading global supplier of surface-enhancing processes and materials, as well as an innovator in thermal spray, composite electroplating, diffusion, and high-performance slurry coatings processes. Company produces and applies metallic and ceramic coatings that protect critical metal components such as in gas turbines.

Precision Iceblast

World leader in HRSG tube cleaning. PIC cleans more HRSGs than any other ice blasting company in the world. It ensures that HRSGs operate efficiently by providing the cleanest boiler tubes possible.

Proco Products

Supplies rubber expansion joints to the power industry in sizes ranging from 1 to 120 in. ID. Proco keeps joints up to 72 in. ID in stock at its Stockton (CA) warehouse and works through an agent/distributor network to supply products to combined-cycle plants.

PSM

Full-service provider to gas-turbine equipped generating plants, offering technologically advanced aftermarket turbine components and performance upgrades, parts reconditioning, field services, and flexible Long Term Agreements (LTAs) to the worldwide power generation industry.

PW Power Systems

Provides competitive, efficient, and flexible gas-turbine packages rated from 25 to 120 MW. PWPS offers a full range of maintenance, overhaul, repair and spare parts for other manufacturers' GTs with specific concentration on the high-temperature F-class industrial machines.

Real Time Power

Offers smart optimization solutions for power generation. Expertise spans machine learning, predictive modeling, diagnostics, and forecasting. Employs data scientists with unique domain knowledge of gas turbines to create realistic and practical algorithms, providing accurate predictions which improve plant operations.

Rentech Boiler Systems

International provider of high-quality, engineered industrial boiler systems. Rentech is a market leader in providing HRSGs for cogeneration and CHP plants. It is in its second decade of designing and manufacturing high-quality custom boilers—including HRSGs, waste-heat boilers, fired packaged boilers, specialty boilers, and emissions control systems.

RMS Energy

Performs all aspects of isolated phase bus duct maintenance, inspections, removal, installations, retrofitting and testing. Services also include cutting, aluminum and substation welding, transformer termination compartment removal, and provision of replacement parts.

Rotating Equipment Repair Inc

Specializing in high pressure multi-stage boiler feed pumps, RER provides its customers high quality engineering services, repairs, and parts for centrifugal pumps through the utilization of highly skilled professionals, cutting-edge technology, and proven work methodologies.

Sargent & Lundy

Provides complete engineering and design, project services, and energy business consulting for power projects and system-wide planning. The firm has been dedicated exclusively to serving electric power and energy-intensive clients for more than 120 years.

Siemens Energy

A leading global supplier for the generation, transmission, and distribution of power and for the extraction, conversion, and transport of oil and gas. Leadership in the increasingly complex energy business makes it a first-choice supplier for global customers. Known for innovation, excellence and responsibility, company has the answers to the sustainability, flexibility, reliability, and cost challenges facing customers today.

SNC Lavalin

Global engineering, construction, and project management company, and a major player in the ownership of infrastructure. Our passion for solving complex problems has allowed us to excel across many industrial sectors. We are a market leader in thermal power, having designed and constructed more than 50 GW of power capacity in over 200 locations.

SSS Clutch Company

Clutches enable operators to disconnect generators from simple-cycle turbines for synchronous-condenser service. Clutches also find application in CHP plants and in single-shaft combined-cycle facilities where operating flexibility is beneficial.

Strategic Power Systems

Provides products and services focused on capturing powerplant operational and maintenance data to develop reliability metrics and benchmarks for end users—including some of the most recognized organizations in the global energy market.

Sulzer

Provides cutting-edge maintenance and service solutions for rotating equipment dedicated to improving customers' processes and business performances. When pumps, turbines, compressors, generators, and motors are essential to operations, Sulzer offers technically advanced and innovative solutions.

TEC-The Energy Corp

Our skills and experience assist GT owners with front-end engineering, procurement of major equipment, and management of engineering, construction, and commissioning of new facilities. From due diligence to detailed design, TEC covers all phases of complex power projects.

TEi Services

Offers a full range of heat-transfer products and services and fully trained, certified maintenance personnel. Provides world-class emergency repair services, underpinned by a 75-yr history in the design and manufacture of condensers, feedwater heaters, and heat exchangers.

TesTex Inc

World leader in electromagnetic non-destructive testing (NDT). We continually define the state-of-the-art for the testing of ferrous and non-ferrous materials and structures through applied research and development.

Texas Bearing Services

Manufactures and repairs fluid film (babbitt) bearings and seals for turbomachinery including gas and steam turbines, compressors, generators, gearboxes, and more. Works with OEMs, distributors, and end-users all over the world and offer 24/7/365 emergency services for critical outages.

Turbine Technology Services (TTS)

Wide range of expert engineering and consulting services, conversion, modification and upgrade services, GT installation and reapplication services, and design and implementation of complete turbine management systems.

Universal AET

Designs, procures, and manufactures OEM and retrofit inlet and exhaust systems including filter houses, inlet duct/silencers, enclosure doors, diffusers, plenums, expansion joints, transitions, exhaust ducts/stacks, exhaust baffle silencers, and stack dampers.

Universal Plant Services

Specializes in the maintenance, repair, and overhaul of gas and steam turbines, centrifugal and reciprocating compressors, as well as all rotating equipment, with qualified millwright and field machining specialists.

Victory Energy

Offers all types of industrial boilers: watertube, HRSG, firetube, and solar-powered units. Company provides unprecedented support with its rental boilers, spare parts, field service, and auxiliary equipment—including water-level devices, economizers, stacks, expansion joints, and ductwork.

Vogt Power International

Supplies custom-designed HRSGs for GTs from 25 to 375 MW and has extensive experience in supplementary-fired units. Scope of supply includes SCR and CO systems, stack dampers, silencers, shrouds, and exhaust bypass systems.

USA Borescopes

Global supplier and repair service provider of borescopes, videoscopes, and pipe inspection cameras for today's turbine maintenance professional, offering a full complement of remote visual inspection equipment with a wide range of features and configurations.

World of Controls

Worldwide, low-cost provider of DCS circuit boards offering an array of ancillary services which include testing/repair of circuit boards, parts, DCS troubleshooting, Dos support, HMI upgrades/backup and field-based mechanical and controls training.

Young & Franklin

Premier fuel control supplier for combustion turbines for both long-term hydraulic solutions and, more recently, innovative all-electric controls solutions. Product scope supports natural gas, liquid, syngas, and alternative fuels as well as providing air controls to provide proper fuel to air mixtures.

Zokman Products

Distributor of ZOK27 and ZOKmx gas-turbine compressor cleaning detergents. ZOK27 is a single cleaner and inhibitor in one that cleans and protects the engine—and also inhibits corrosion. ZOKmx is a power cleaner formulated to replace solvents providing exceptional cleaning without the health and environmental risks associated with solvents.

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