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COMBINED CYCLE Journal

User Group Reports

Ovation Users Group 4

Users ponder big issues, knuckle down on knotty problems. Meeting topics included training, power supplies, simulators, control-system replacement, steam-valve actuator issues, hydraulic versus pneumatic actuation, cybersecurity.

Combined Cycle Users Group 20

Adapt to survive the coming sea change in industry structure. Conference program covered the gamut of challenges facing plant personnel—from boulder- to pebble-size issues. Grid-scale storage, safety, electrical faults, cyber and physical security, in-house NO_x mitigation solution, and headaches shared during open discussion sessions are the focus of this report.

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Register now for 2018 user-group meetings

2018 Conference and Vendor Fair
February 25 – March 1
Hyatt Regency Grand Cypress
Orlando, Fla
Contact: Tammy Faust,
tammy@somp.co
http://501f.users-groups.com

HRSG Forum with Bob Anderson
March 5 – 7
Hyatt Regency Houston
Houston, Tex
Contact: Alan Morris,
amorris@morrismarketinginc.com
www.HRSGforum.com

28th Annual Conference and Expo
March 18 – 21
Renaissance Hotel/Palm Springs
(Calif) Convention Center
Contact: Charlene Raaker
craaker@wtui.com
www.wtui.com

Spring Conference and Trade Show
April 8 – 12
Hyatt Regency Greenville
Greenville, SC
Contact: Ivy Suter
ivysuter@gmail.com
www.ctotf.org

INDEPENDENT VOICE OF THE GAS-TURBINE-BASED GENERATION SECTOR

2018 meetings: Gas and steam turbines, HRSGs, generators

January 15-16, EPRI TGUG Workshop, Orlando, Fla, Disney's Coronado Springs Resort. Contact: Bill Moore, bgmoore@epri.com.

February 25-March 1, 501F Users Group, Annual Meeting, Orlando, Fla, Hyatt Regency Grand Cypress. Chairman: Russ Snyder, russ.snyder@cleco.com. Conference information at http://501f.users-groups.com. Contact: Tammy Faust, tammy@somp.co.

March 5-7, HRSG Forum with Bob Anderson, Second Annual Meeting, Houston, Tex, Hyatt Regency Houston. Chairman: Bob Anderson. Details/registration at www.HRSGForum.com. Contact: Alan Morris, amorris@morrismarketinginc.com.

March 18-21, Western Turbine Users Inc, 28th Anniversary Meeting, Palm Springs, Calif, Renaissance Hotel/Palm Springs Convention Center. Chairman: Chuck Casey, ccasey@wtui.com. Details/registration at www.wtui.com. Contact: Charlene Raaker, craaker@wtui.com.

March 20-22, Second International Conference on Film Forming Amines and Products, Prague, Czech Republic, Hotel NH Prague City. Chairman: Barry Dooley, bdooley@structint.com. Contact: Ladislav Bursik, ladi.bursik@bht-gmbh.com.

April 8-12, CTOTF 43rd Spring Conference & Trade Show, Greenville, SC, Hyatt Regency Greenville. Chairman: Jack Borsch, john.borsch@ihipower.com. Details/registration at www.ctotf.org. Contact: Ivy Suter, ivysuter@gmail.com.

May 7-11, 7F Users Group, 2018 Conference & Vendor Fair, Atlanta, Ga, Atlanta Marriott Marquis. Details/registration at www.powerusers.org. Contact: Sheila Vashi, sheila.vashi@sv-events.net.

May 15-17, European HRSG Forum, Fifth Annual Meeting, Bilbao, Spain, Meliá Hotel. Chairman: Ladislav Bursik, ladi.bursik@bht-gmbh.com. Details at http://europeanhrsgforum.de.

June TBA, 501D5-D5A Users, 21st Annual Meeting, decision on venue pending. Chairman: Gabe Fleck, gfleck@aeci.org. Registration and other details at www.501d5-d5ausers.org when available.

June 11-14, Frame 6 Users Group, Annual Conference & Vendor Fair, Ponte Vedra Beach, Fla, Marriott Sawgrass Golf Resort & Spa, Co-chairmen: Jeff Gillis, william.j.gillis@exxonmobil.com, and Sam Moots, smoots@coloradoenergy.com. Details/registration at www.Frame6UsersGroup.org. Contact: Greg Boland, greg.boland@ceidmc.com.

June 18-21, T3K Annual Conference, Orlando, Fla, Hilton Orlando Buena Vista Palace. Meeting is co-located with the Siemens Customer Conference for F, G & H Technology. Chairman: Bob Lake, bob.lake@fpl.com. Contact: Elizabeth Moore, elizabeth.moore@siemens.com.

June 18-21, Siemens Customer Conference for F, G & H Technology, Orlando, Fla, Hilton Orlando Buena Vista Palace. Meeting is co-located with the T3K Annual Conference. Contact: Kelly Lewis, kelly.lewis@siemens.com.

July 29-August 2, Ovation Users' Group, 31st Annual Conference, Pittsburgh, Westin Convention Center Hotel. Register for membership (end users of Ovation and WDPF systems only) at www.ovationusers.com and follow website for details. Contact: Kathleen Garvey, kathleen.garvey@emerson.com.

August 27-30, Combined Cycle Users Group (CCUG), 2018 Conference and Discussion Forum, Louisville, Ky, Louisville Marriott Downtown. Meeting is co-located with the Steam Turbine Users Group and Generator Users Group. Chairman: Phyllis Gassert, phyllis.gassert@talenenergy.com. Details at www.ccusers.org. Contact: Sheila Vashi, sheila.vashi@sv-events.net.

August 27-30, Steam Turbine Users Group (STUG), 2018 Conference and Vendor Fair, Louisville, Ky, Louisville Marriott Downtown. Meeting is co-located with the Combined Cycle Users Group and Generator Users Group. Vice Chairman: Bert Norfleet, bert.norfleet@dom.com. Details at www.stusers.org. Contact: Sheila Vashi, sheila.vashi@sv-events.net.

August 27-30, Generator Users Group (GUG), 2018 Conference and Vendor Fair, Louisville, Ky, Louisville Marriott Downtown. Meeting is co-located with the Combined Cycle Users Group and Steam Turbine Users Group. Chairman: Kent Smith, kentn.smith@duke-energy.com. Details at www.genusers.org. Contact: Sheila Vashi, sheila.vashi@sv-events.net.

September 10-13, V Users Group, 2018 Annual Conference, Denver, Colo, Hilton Denver Inverness. Contact: Kelly Lewis, kelly.lewis@siemens.com.

September 16-20, CTOTF Fall Conference & Trade Show, Chandler (Phoenix), Ariz, Sheraton Grand at Wild Horse Pass. Chairman: Jack Borsch, john.borsch@ihipower.com. Details/registration at www.ctotf.org. Contact: Ivy Suter, ivysuter@gmail.com.

October TBA, ACC Users Group, Tenth Annual Conference. Details at www.acc-usersgroup.org. Chairman: Dr Andrew Howell, andy.howell@xcelenergy.com. Registration/sponsorships: Sheila Vashi, sheila.vashi@sv-events.net.

October 7-11, 7EA Users Group, Annual Conference and Exhibition, Garden Grove, Calif, Hyatt Regency. Details/registration at http://ge7ea.users-groups.com.

December 4-6, 501G Users Group, Mid-Year Meeting, Orlando, Fla, Hyatt Regency Orlando International Airport. Chairman: Steve Bates, steven.bates@dynegy.com.

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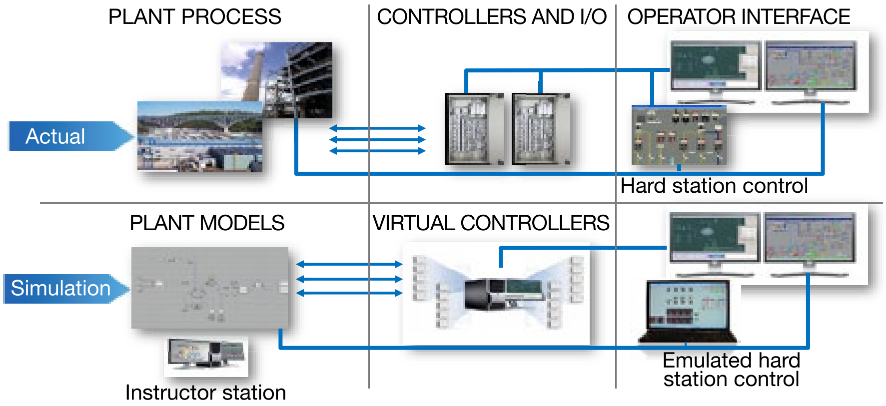
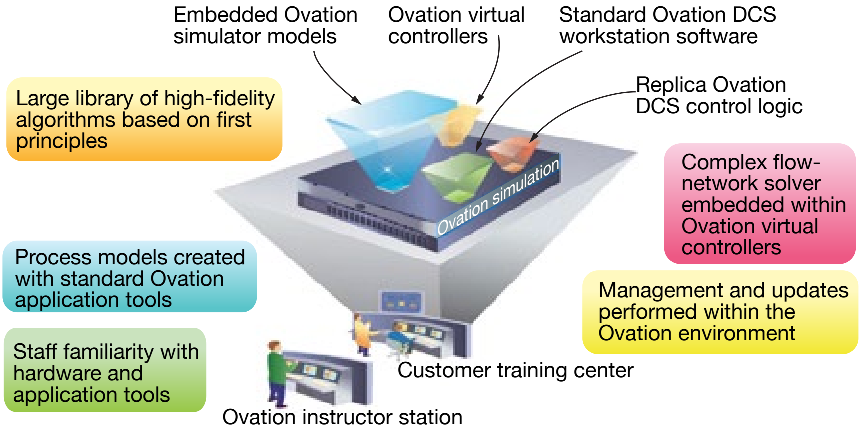
Users ponder big issues, knuckle down on knotty plant problems



1. Embedded simulation in Ovation™ (above and below) leads to a "virtual" plant and, in five years will be used as much by operators as the actual controls in plant control rooms, according to Emerson Automation Solutions Power & Water President Robert Yeager



Encompassing 1300 GW of global capacity, 450,000 MW of that in the US, and 120,000 MW of combined-cycle capability, the Ovation control system platform, according to Robert Yeager, president of Emerson Automation Solutions Power & Water, is Number One in global power generation control systems. But Yeager, in the traditional "bragging rights" opening remarks at the Ovation Users Conference, clearly wanted to put his competitors on notice that he is gunning for more.

"We're going to knock the wind out of our competitors," he said, referring to the relatively new OCC100 product, designed to compete head-to-head with the traditional programmable logic controller (PLC). The OCC100 also forms the backbone for Ovation-based microgrid control systems.

Features now fully integrated into Ovation, such as embedded simulation (Fig 1), vibration and condition monitoring, and predictive analytics obviate the need for separate packages—and separate vendors. Yeager claimed that the company is working on 35 active embedded simulator projects around the world. "In five years, operators will spend more time in the 'virtual' plant residing in the 'cloud' than with the real plant controls," he predicted.

Underscoring the challenge cybersecurity poses to highly connected digital systems, Yeager also noted that the Ovation cybersecurity team has ballooned from three to 50 members in the last few years. "We're providing cybersecurity services on competitor control systems, too," he added.

Steve Schilling, VP of technology, and head of the Ovation Technology Team, amplified some of Yeager's comments. Ovation's "remote node interface module," a/k/a Ethernet I/O, is in final testing, he said. It can be used, along with the OCC100, not only for wind and solar facilities, but also for smaller, dedicated control systems for skid-mounted process units—the traditional purview of the PLC.

Two other remarks by Schilling were, well, darn right chilling. First, he noted that "storage is the wild card in the power equation." This is yet one more indication that grid-scale storage is seriously penetrating the power industry "psyche." Commercial storage facilities are already lopping off the peak of the peak demand in major markets around the country and thus compete with quick-start gas turbine units.

Second, he said that half of one large utility's 6000 employees are eligible to retire in five years. That's more than a brain drain; that's a potential vortex, at least in the time scales the electricity industry operates under.

Yeager had noted earlier that one-third of the attendees at the confab had never attended an Ovation User Group conference before. Hopefully, some of those newcomers represent youthful energy, not veterans who had to take over control system duties because someone retired.

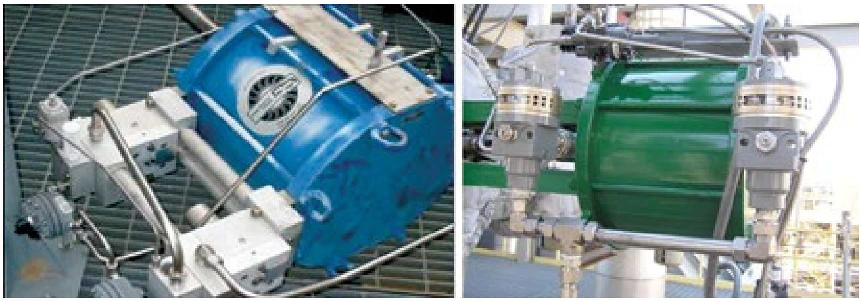
Schilling also put turbine vendors on notice, saying that Ovation now offers a "completely integrated turbine control solution incorporating new synchronizer, machinery health, and excitation modules." He also addressed cybersecurity, stating that certification under ISA/IEC 62443 is underway.

Modern to mundane

Up next in the general session was Emerson's Glen Heinl, director of customer services, who addressed mapping your journey with an Ovation system. He said Ovation offers more than 50 formal classes for employee development and advanced skills, and 20 webinars are available without leaving your desk.

One important question he had for the folks on the deck plates: "Are you checking your power supplies?" Because users often add I/O cards and capabilities, the existing power supplies can quickly become overwhelmed. A preventive maintenance guide, addressing power supplies and other critical items for Ovation systems is expected to be released "within six months."

2. Cabinet layout was an important consideration in replacement of GT OEM control system at this peaking facility; some panels were relocated to make the I/O flow more logically



3. Steam turbine bypass-valve actuator (left) was replaced with one far simpler to maintain, not prone to cracking at the weld between plug and stem, easier to tune, and more stable during startups (right)

Speaking of knotty problems, the modern simulator has come to the aid of the age-old mundane problem of inconsistent operator performance at one plant. Personnel there, suffering from the aging workforce challenge, committed to a formal operator training program anchored by the Ovation embedded simulator, replacing a simulator onsite for eight years but not used.

Plant representatives reported the program led to a 44% reduction in startup and shutdown times. The five operator crews, a mix of veterans and new recruits, had been doing things differently. Following training, the crews are consistently following startup and shutdown procedures, performing tasks simultaneously, getting qualified "expeditiously," and in general achieving more consistent performance.

Lucky sevens

Replacing seven gas-turbine control systems with Ovation in seven weeks could be like holding your breath at the casino, hoping for lucky sevens. What made this project more white-knuckle is that the seven turbines (at two different locations, one a combined-cycle facility, the other a simple-cycle peaker facility) were acquired from merchant owner/operators. Lacking experienced personnel in this area, the new owners essentially put their full trust in Emerson as system supplier and engineer—that is, not hiring a separate electrical contractor. All electrical demolition was also left to Emerson.

One of the objectives of the replacement at the combined-cycle facility was to automate the manual power augmentation and water injection NO_x control subsystem, dubbed SPRINT™ by the turbine vendor. In fact, this was the core of project justification. At the peaking facility, it was to achieve remote operation.

A few of the candid lessons learned include the following:

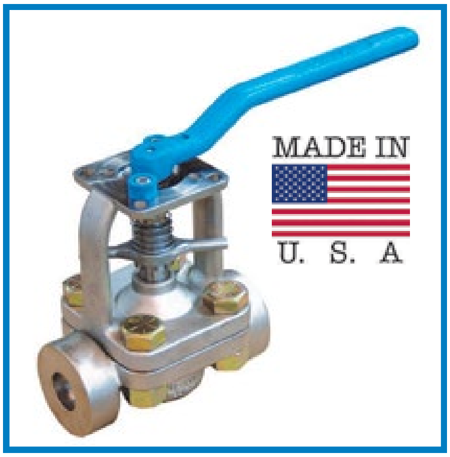
- The due-diligence team for the acquisition did not pay much, or any, attention to field instrumentation. Apparently, this is typical of due-diligence teams, and something others seeking to acquire plants should guard against.
- While generally pleased with overall outcomes, the site representatives did note the Ovation team's lack of experience with retrofits of machines from this type—for example, the turbine vendor locates I/O at the GT housing, while Emerson prefers to put the boxes in the control room (Fig 2).
- Resolving disputes around the HMI (human machine interface) graphics and high-performance screen layouts was also a challenge.
- The new owners discovered that the air permits for the peaking units were written in a way that prevented them from adequately conducting no-load tests. Only two starts per day were allowed if the units were not going to proceed to full load and compliance operation within 30 minutes.

Actuator acting up

Steam-turbine bypass systems and valves for combined cycles have been giving users fits for years. In one Ovation user's case, it was the actuators on the HP and IP bypass valves. It would do little good to show the list provided of what was wrong with the original actuator design, because essentially nothing was right with it. However, in fairness, it should be noted that this combined cycle, which came online in 2003, was originally designed for baseload service, but later began to cycle.

According to the facility reps, "the valve would go nuts" on a steam-turbine trip, and for good reason: It has to go from closed to 80% open (11.2 in. of valve stem travel), then throttle as if nothing happened, all in two seconds! Doing both well is difficult for a valve this size, they conceded. They also conceded that the actuator worked fine the first few years, suggesting that cycling may have been the root cause of their issues.

The original valve was fine, they said, but the actuator was poorly designed. For one thing, it was "full of O-rings, and other parts and pieces" and three derivative boosters (used with a positioner to increase stroking speed). Also, the rapid stem movement repeatedly broke the weld between the plug and stem.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The plant decided to go with pneumatic actuation because it would avoid oil leaks and fire hazards and the parts would be more readily available than for a hydraulic actuator. Emerson designed a bolt-on actuator (Fig 3), leaving the original valve in place, with far fewer parts and all the boosters of the same component. The new booster is three to four times the size of the original one.

According to these plant reps, the valve and actuator "haven't been touched since" and the weld cracking issue has been resolved. Tuning is much easier and more consistent, and the control loop is more stable during startups.

Sabers for cyber

Protecting against cyber-intrusions and keeping the "bad guys" out consumes more and more of the digital control system community's energy—and piles on costs. In addition, like environmental restrictions, there are multiple layers of compliance, standards, and jurisdictions.

During a cybersecurity panel, a representative from the US government's Industrial Control System Cybersecurity Emergency Response Team (ICS-CERT, part of DHS) referred the audience to the C-SET, a cybersecurity evaluation tool.

As described in a document available from ICS-CERT online, "it is a desktop software tool that guides asset owners and operators through a step-by-step process to evaluate their industrial control system and information technology network security practices." Available for free, users answer questions and the software generates a report comparing your practices to recognized government and industry standards and recommendations.

In addition to federal standards and recommendations, states are imposing their own, according to a consultant on the panel. New Jersey, for example, has mandated cybersecurity standards. He noted that costs for complying with mandatory requirements could be challenging for power producers in low-price markets. That includes most everyone in today's world.

An expert from one of the largest combined cycles in the country, built in the early 1990s, explained how his plant went from "25 years of connecting everything to disconnecting from the sins of the past." His plant had one supervisory control system for the entire plant, because it was designed to deliver all of its 1640 MW of capacity to one buyer as a baseload facility. The plant comprises 12 gas turbine/HRSG trains and three steam turbine/generators and, to complicate matters, two steam hosts and six packaged boilers.

Now they have to comply as a NERC CIPS 6 medium impact facility. "In the early days of compliance, we were patching one workstation every two to three days." Plus, they are planning to add an 800-MW 2 × 1 combined cycle at the site.

Plant practices reported to the group included these:

- Create action plans based on vulnerability assessment results.
- Patch monthly to keep current.
- Physical and electronic access control is key.
- Use E-ISAC for threat intelligence.

The electricity information sharing and analysis center (E-ISAC) is operated by NERC but functionally isolated from its enforcement arm. It's a central repository for physical threats, vulnerabilities, and incidents. According to information available from the program online, the following benefits are described:

- Identify adversary campaign tactics, techniques, and procedures and share specific mitigation actions.
- Reverse-engineer malware to better understand events and develop predictive capabilities.
- Share tactical information to reduce cyber risk for all participants.
- Cross-benchmark and evaluate with other critical infrastructure sectors.

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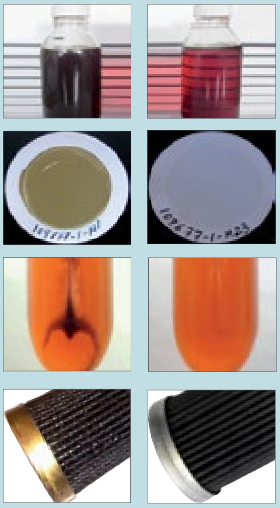

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Customer experience drives NV Energy's overall strategy

The changing nature of electric supply

Special to the COMBINED CYCLE Journal

Jason Makansi, chairman,
Editorial Advisory Board

GRiD TODAY

If your doubt lingers about the direction the electricity industry is headed, hopefully for your sake you're close to retirement. That direction is towards the customer end of the production and delivery value chain and away from "big iron," large centralized power stations and long transmission lines.

But while the direction is unmistakable, the velocity isn't. And the change is uneven across different regions and utilities, with an overall vector that is still a bit unclear. Any student of this industry knows that we've been through several iterations of electric utilities getting closer to their ratepayers over the last 50 years—the interest invariably coincides with low electricity demand growth (less need for centralized assets) and/or regulatory pressures from abnormally high electricity prices.

No question we are in a prolonged period of low and even negative electricity demand growth. This time, however, there are several other important drivers – renewable energy costs which are now on par with, or lower than, fossil energy prices, even without subsidies (although still not compensating for the intermittency); and digital data and communications technologies which facilitate instantaneous interactions with tens of thousands of customers.

One investor-owned utility embracing this path at a rapid pace is NV Energy, Las Vegas, Nev. In fact, it is blazing a trail for the rest of the industry. As you might suspect, the foundation for the shift isn't hardware; it's data—lots of data—and all the things you can do with data to enrich the customer experience, save ratepayers money, and avoid investing in big iron, in the short term anyway. It's called PowerShift, and the best way for readers to think about it is a shift from big iron to the customer's onsite energy infrastructure.

1. NVE's smart phone customer interface app helps engage and retain customers in the demand response program, and puts the utility in the company of savvy digital service providers, rather than a distant entity that simply sends a bill each month

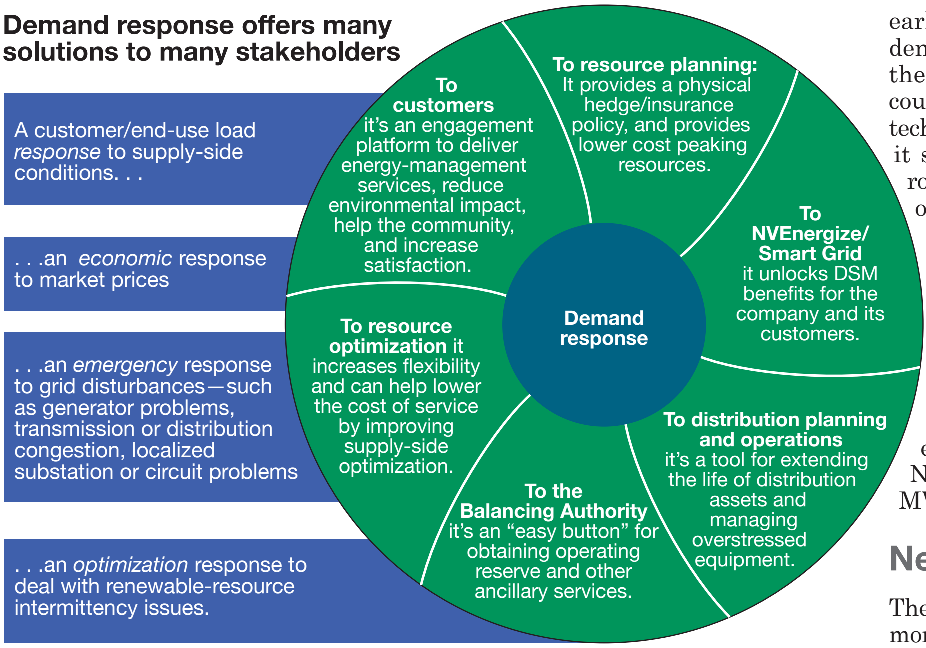
Why Nevada?

Before diving into the specific programs and activities, it is appropriate to ask, why Nevada? One of the foundation reasons is that NV Energy had the foresight several years ago to install "smart meters" at all 1.3 million customer locations. That's an advantage. There's also a regulatory component (naturally, NV Energy is a regulated utility) and an ownership component.

NV Energy is owned by Berkshire Hathaway, one of the most valuable companies on the planet, founded and managed by Warren Buffett. More specifically, Berkshire Hathaway Energy owns NV Energy, along with PacifiCorp, Pacific Power, Rocky Mountain Power, Kern River Natural Gas, MidAmerican Energy, Northern PowerGrid, AltaLink, BHE U.S. Transmission and BHE Renewables.

Anyone who has noticed Berkshire Hathaway HomeServices signs knows that the holding company also is big into real estate. Just what this impact might be on designing demand-side management programs and home energy options is anyone's guess, but the smart money would assume there are important synergies.

NV Energy also is confronting a regulatory climate pushing towards customer choice of electricity supplier. Nevada voters already passed an "Energy Choice Initiative" in 2016 and the initiative will be up for a second constitutionally required vote at the end of 2018. At the same time, regulators have denied the utility's recent plan to acquire an existing combined cycle located in adjacent Arizona. So, conscientiously managing demand downward gets the utility involved with its customers, addresses the regulatory threat, and avoids capex upstream in the system.



Demand response offers many solutions to many stakeholders

A customer/end-use load *response* to supply-side conditions. . .

. . .an *economic* response to market prices

. . .an *emergency* response to grid disturbances—such as generator problems, transmission or distribution congestion, localized substation or circuit problems

. . .an *optimization* response to deal with renewable-resource intermittency issues.

Demand response

To customers it's an engagement platform to deliver energy-management services, reduce environmental impact, help the community, and increase satisfaction.

To resource planning: It provides a physical hedge/insurance policy, and provides lower cost peaking resources.

To NVEnergize/ Smart Grid it unlocks DSM benefits for the company and its customers.

To distribution planning and operations it's a tool for extending the life of distribution assets and managing overstressed equipment.

To the Balancing Authority it's an "easy button" for obtaining operating reserve and other ancillary services.

To resource optimization it increases flexibility and can help lower the cost of service by improving supply-side optimization.

2. While demand response is laser-focused on the customer's premises, the benefits accrue throughout the traditional centralized grid supply and delivery operations

Catering to the customer?

According to NV Energy managers and executives interviewed for this article, the enabling piece of the customer experience are the smart meters installed essentially for every customer, all 1.3-million of them. But the crown jewel is the smart thermostat program, the largest two-way home thermostat program in the country, according to NV Energy.

Although the program began in 2006, the latest thermostats take customer data every 15 minutes, which is then plugged into a model that calculates energy consumption patterns specific to each home—based on such parameters as air temperature, fan operation, compressor load, and local weather data. In essence, the model creates a comfort profile for that customer's premises.

If the smart thermostats are doing all the work, then the smart phone interface (Fig 1) gets all the glory. "We had to design an end-to-end data and information system," Senior Vice President of Renewable Energy and Smart Infrastructure Pat Egan said, "and because the interface competes in the mind of the customer with retailers and other apps on the device, it better be comparable."

Traditional utility benefits were the natural draw to this customer-centric solution—as the company provided thermostats that can be remotely controlled to help balance demand with generation on hot summer afternoons when temperatures in Southern Nevada can go above 110F.

Although each demand response (DR) participant has the opportunity to override the automatic adjustment, NV Energy has the ability to adjust the temperature setting of customer thermostats to cycle their air conditioners on and off for short periods of time during an "event" (as it is called) on days when peak demand approaches the utility's maximum ability to meet that demand. This typically occurs during the afternoons between May and September.

With nearly 100,000 customers participating, NV Energy can shave demand to the equivalent of about 200 MW, the size of a small-to-medium fossil unit. In turn, NV Energy reports that customers save an average of 11% to 13% on annual heating and cooling costs, or approximately $100 annually.

The smart thermostat is free, and the participant receives a performance-based payment, based on comparing customer event load reductions to a customer-specific baseline that is comprised of the three highest load days out of the prior five non-curtailment days. And while the savings and the rebate may be modest, NV Energy notes that the mobile phone app "has driven the participation rates."

A new feature just being rolled out is pre-cooling. The customer premises can be pre-cooled to dampen the effect of the rise in temperature during the curtailment event.

The difference in the current program, compared to the one started in 2006, is that it is now under *active management,* and in real time. In earlier phases, the utility was dependent on the customer programming the thermostat; about half of them could be counted on to do so. The old technology/approach never could prove it saved energy for customers year-round. Importantly, the new program optimizes the customer's HVAC year-round. Thus, it's more of an optimization service that does not rely on customer activity driven by high price signals.

The benefits of the new program are far-reaching (Fig 2). When combined with other elements of the DR and distributed energy resource (DER) programs, NV Energy can actively manage 260 MW, or 3% of its peak demand.

New Maytag man?

The smart thermostats are also able to monitor the performance of the HVAC system. With the right software, NV Energy can then perform predictive analytics and send alerts about when the unit needs service or repair, filters cleaned, etc. Linked to this capability is NV Energy's high- efficiency AC unit replacement program.

The smart meters have functionality which disaggregates data such that electrical signatures of individual appliances can be broken out and analyzed. This allows NV Energy specialists to make recommendations and even conduct remote energy audits, and combine that intelligence with a field visit to the premises.

Which of course lead to NV Energy's offer of free home energy audits, conducted by certified energy professionals and typically completed in one hour. While NV Energy was required to offer these audits by legislation, over the past year, the utility converted this into an opportunity to "touch" customers. Having reams of data on comparable homes also allows NV Energy to alert customers when their electricity usage is out of line with the aggregate characteristics of similar dwellings.

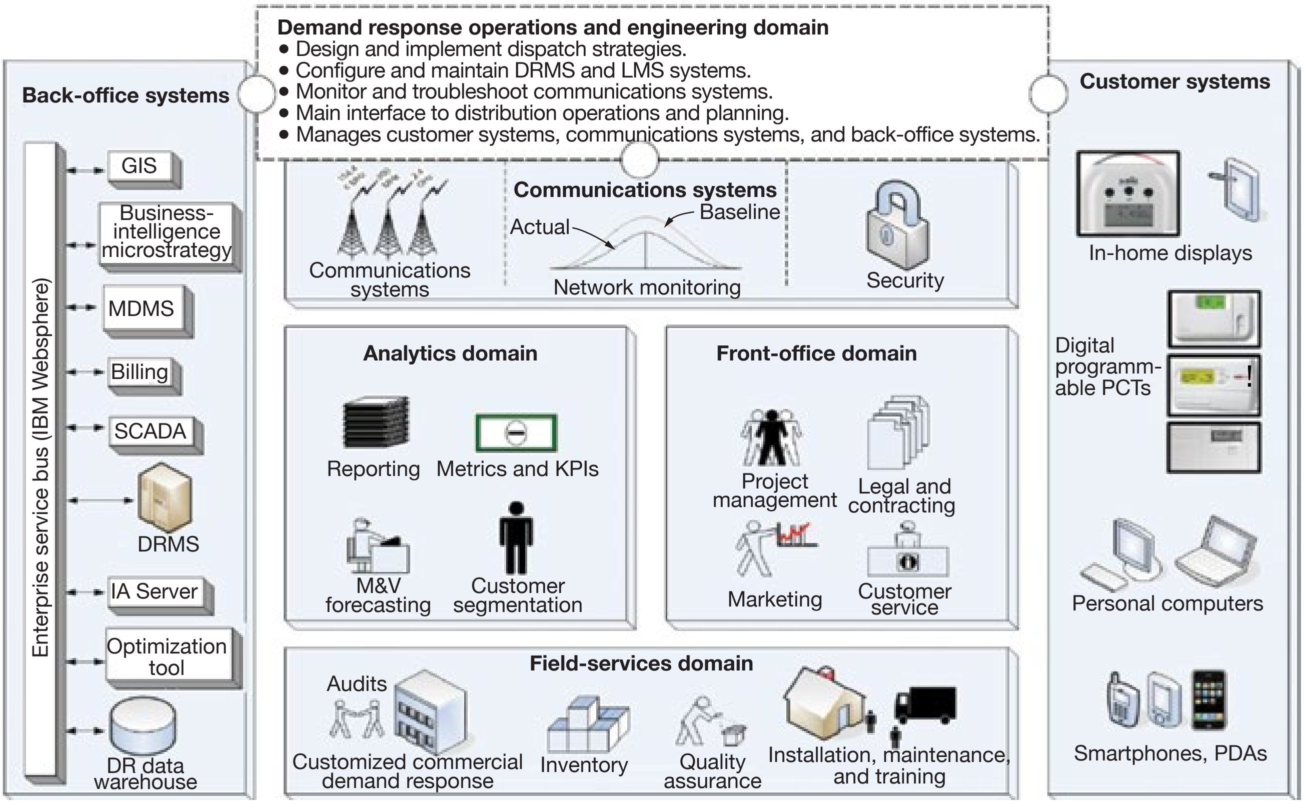
Solar photovoltaics systems and electric vehicle hook-ups will be added to the program in time, noted Michael Brown, manager of Demand-Side-Management Services.

Much of the data necessary to offer the services is stored and analyzed "in the cloud." EcoFactor, a cloud services firm, provides data analytics and optimization services for residential smart thermostats. Another cloud provider, Bidgely, provides smart meter data analytics. While the customer owns its data, NV Energy is, contractually, the steward of it.

Customers are able to access their data, see how much they have spent


Shaft Grounding Assembly
CUTSFORTH


CUTSFORTH
Shaft Grounding Assembly (RMP)
P/N EGSA-017
Shaft Voltage Test Point
Ground Rope
(Replace left rope if voltage present)
Meter Rope
(Replace right rope if voltage present)
Ground Current Test Point
(Use Clamp-on Ammeter)
High Voltage May Be Present - Authorized Personnel Only



3. The organizational requirements, skill sets, hardware, and software to manage load kilowatt-hour by kilowatt-hour at individual customer sites is disruptive to traditional utility management

to date in a given billing period, their kilowatt-hour usage to date, and other information. A Demand Response Management System (DRMS), built to NV Energy's specifications and run on its IT infrastructure, serves as a central hub to orchestrate the operation and integration of customer, program, device, and grid location information.

The information from all this customer data also helps NV Energy better monitor and manage the distribution circuits where these customers are located.

Monumental learning curve

Obviously, there are numerous challenges to overcome, both in transforming a "big iron" culture to handle individual customer services, and in hardware and software development (Fig 3). "At one point, we had 18 different types of technologies in the field—two way switches, one-way thermostats, firmware, and software," Brown observed, "and we had to streamline the equipment and learn how to integrate the software and maintain it."

The customer communication challenge is also serious. NV Energy had to educate its ratepayers on how to use the smart thermostats. According to Kelly Schackmuth, manager of DSM Customer Engagement, "the goal is to make it as seamless to the customer as possible." Different messages resonate with different customer classes. But keeping them retained and engaged requires frequent communication, such as messages sent the way they want to receive them—email, text, voice mail, etc.

The future is now

None of these challenges appear to daunt NV Energy. In fact, it is pushing DR and DER further. Coming programs will leverage lessons learned from:

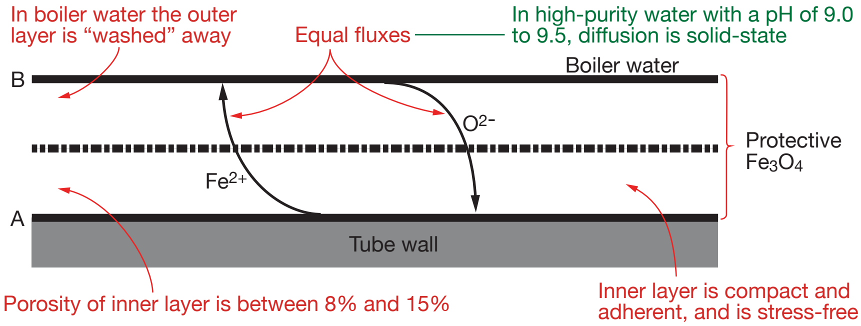
- A partnership with homebuilder Pulte in which 185 LEEDs certified (platinum) homes were built, each with 2-kW solar PV on the roof, demand responsive thermostats, smart meters, and automated intelligent agents. An ongoing pilot is testing the integration and control of 8-kWh Li-ion batteries at 10 customer sites.
- A statewide pilot that tested new dynamic rate, such as critical peak pricing (CPP) and enhanced time of use (TOU) pricing to further motivate demand response."

A variety of programs are also available for small, medium, and large commercial and industrial customers. One of the more innovative opportunities for commercial customers are agreements in which NV Energy sponsors investments in energy-efficiency upgrades and services in return for demand-response event participation. This provides more value for customers than standard cash rebates for DR event incentives.

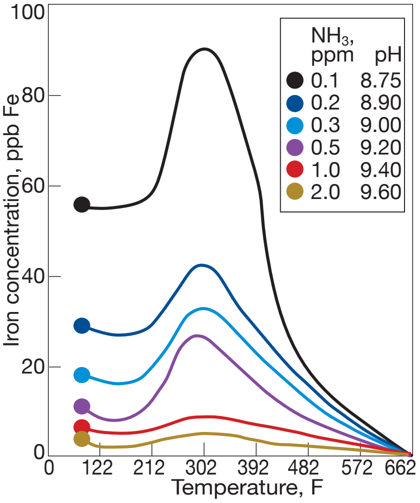
What NV Energy's transformation represents for the industry at large should not be under-estimated. Designing, constructing, operating, and maintaining a 260-MW generating unit, and delivering the electricity to thousands of customers, is quite different from avoiding the need for 260 MW by actively controlling assets at the customer premises kilowatt-hour by kilowatt-hour. CCJ

'Good tubes don't fail!'

By Steven C Stultz, Consulting Editor



1. Growth of protective magnetite in 680F boiler water is illustrated in tube section



2. Solubility of magnetite is influenced by temperature, pH, and ammonia concentration. Data here are based on the work of Sturla in 1973

3. FAC is the leading cause of pressure-part failures in combined-cycle plants

Reminded Dr R Barry Dooley at the Cycle Chemistry and FAC Workshop, sponsored by Structural Integrity Associates Inc (SI), June 27 - 28, 2017, in Cincinnati. Cycle chemistry drives many of the damage mechanisms that affect availability, reliability, and safety of conventional fossil and combined-cycle/HRSG plants, the respected chemist/metallurgist said forcefully. The ongoing battle against operational and financial losses was the motivation for the focused seminar.

"I am not here to make all of you experts in cycle chemistry," said Dooley who guided the two-day session. "I am here to share experience and insights, to look at strategies, and to give you some key indicators that I hope will reduce future equipment damage, plant downtime, and injuries.

"More specifically," he continued, "we'll talk about how all of this applies to your plant, and to your individual jobs."

And that's what we did. Interactively. This was a two-day workshop, not a lecture.

The intricacies

Electric power generating facilities are some of the most complex engineering achievements of our time. It's important to realize that cycle chemistry is equally complex, sophisticated, and at times unforgiving.

Every operating minute of every day adds to the wealth of global cycle-chemistry experience being analyzed by Dooley and the SI team.

Bad habits (poor common practices)

Participants examined what Dooley and his colleagues label *repeat cycle-chemistry situations* (RCCS)—circumstances that trigger damage. "A focus on RCCS is perhaps the industry's most powerful tool," he emphasized.

Dooley added: "Chemistry-influenced failure and damage can always be related back to these repeat situations in fossil and combined cycle/HRSG plants."

With that, he listed the 10 most common scenarios:

1. Presence of corrosion products.
2. Drum carryover.
3. Fossil waterwall/HRSG evaporator deposition.
4. Improper chemical cleaning.
5. Contaminant ingress.
6. Air in-leakage.
7. Lack of online alarmed instrumentation.
8. Failure to challenge plant status quo.
9. Inadequate shutdown protection.
10. Lack of action plans (or simply, lack of action).

Each was discussed in detail.

Consider No. 7, for example, proper instrumentation is clearly outlined in the Technical Guidance Documents (TGDs) available at no cost from the International Association for the Properties of Water and Steam (IAPWS) through the organization's website at www.iapws.org.

"Very few powerplants throughout the world," explained Dooley, "meet even the minimum requirements." Lack of proper instrumentation tied with corrosion products as the leading (and preventable) damage-causing condition.

Summing up the discussion, Dooley emphasized: "We should be able to do something about this, and we can!"

Oxides and growth

It was important to review oxides and their growth (Fig 1) by discussing feedwater, boiler/evaporator water,

HRSG FORUM
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Registration Opens This Summer!

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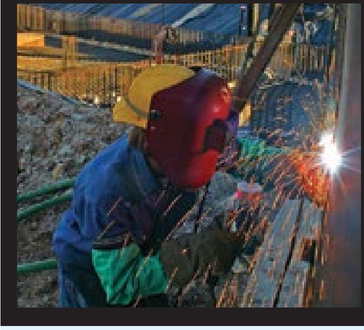
"We offer carefully chosen presentations on topics designed to help owners/ operators and maintenance professionals be more successful."

– Bob Anderson



What 2017 attendees say:

"Unique, very interactive"

"There are a lot of people here from power plants and corporate."

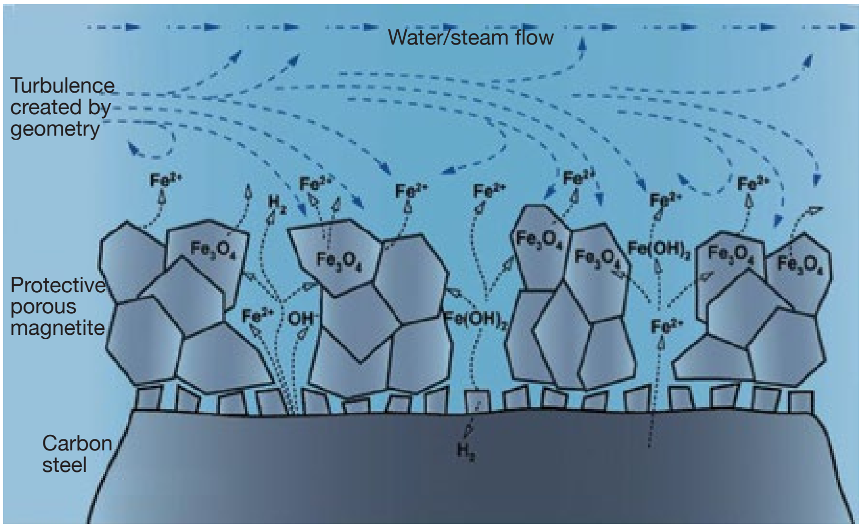
"It's hard to beat Bob Anderson and this forum for information-sharing and getting people involved."

"HRSG Forum has helped me a lot— I know HRSGs but this is where I get the practical information I need."

Key topics from this year's forum:

- Drones for HRSG Inspections
- Optimum Cycle Chemistry Control of CCPP/ HRSG & How to Achieve It
- ASME Code Issues Relating to Advanced Materials & What You Should Know about P91
- Design Challenges for 600°C (1112°F) HRSGs
- Automatic Control of HPSH / RH Drains Using Ultrasonic Technology

Registration Opens Summer 2017 at www.hrsgforum.com

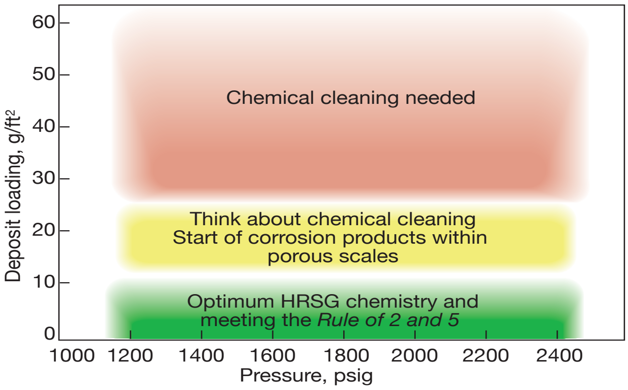


4. Two-phase FAC (steam and water) is a consequence of a flow-accelerated increase in mass transfer of dissolving and reacting species at a high-flow or highly turbulent location

steam, and deposit formation. A lengthy look at the mechanism of magnetite (Fe_3O_4) growth showed the importance of feedwater and condensate chemistry. Dooley then focused on magnetite in the LP circuits of both horizontal and vertical HRSGs. This led to discussions of various water treatment programs (Fig 2).

Specific mechanisms of magnetite dissolution, iron oxide solubility, and corrosion-product transport followed.

Copper alloys and their impact on the HP turbine were included, along with a review of supercritical units.



5. Deposition map for HP evaporators was developed by IAPWS and appears in the organization's 2016 Technical Guidance Document, "HRSG HP Evaporator Sampling for Internal Deposit Identification and Determining the Need to Chemical Clean," downloadable at no cost from www.iapws.org

FAC—a complex adversary

Significant time was spent on flow-accelerated corrosion (FAC), a complex yet comprehensible phenomenon in today's power systems. FAC is the leading cause of failures in combined-cycle plants.

These discussions centered on:

- Single- and two-phase FAC.
- Mechanisms and parameters (very important; solutions are different).
- Alleviation through cycle chemistry and materials.

Dooley offered specific examples of both single- and two-phase FAC in fossil and combined cycle/HRSG plants. The principal point: FAC continues to occur in more than 70% of fossil plants, and represents nearly half of all tube failures in both horizontal- and vertical-gas-path HRSGs.

Fundamental conditions for FAC (formerly known as erosion/corrosion) are processes occurring in the laminar boundary layer on the metal's surface.

Some details:

- Magnetite is the oxide that grows on carbon-steel surfaces in the feedwater up to about 535F to 572F under low-oxygen (reducing) conditions.
- With laminar flow, this is protective and its growth is balanced by its dissolution.
- Below 302F the layer can be very thin, and is controlled by local cycle chemistries.
- With turbulent conditions (because of local geometries), the dissolved ferrous ions are removed more rapidly.
- This faster removal equates to a more rapid overall corrosion process (FAC) and thinner remaining magnetite.
- FAC only occurs in water and water/steam mixtures, NOT in dry steam.
- FAC is a chemical mechanism.

He then clarified the process. "The normally protective magnetite layer on carbon steel dissolves in a turbulent stream of flowing water (single-phase) or wet steam (two-phase). This process reduces the oxide layer thickness and leads to a rapid decrease in thickness of the base material until the pipe, tube, or pressure vessel bursts (Figs 3 and 4).

"The rate of metal loss depends, in a very complex way, on three main factors: local water chemistry, material composition, and fluid hydrodynamics."

Specifics of these processes were clearly illustrated and reviewed, setting the stage for later critical discussions on inspection, appearance, detection, and identification.

FAC in air-cooled condensers also was discussed, including specific examples and a review of the Dooley-Howell Air-Cooled Condenser Corrosion Index (CCJ 1Q/2015, p 110). It is used to categorize the degree of corrosion and to track improvements made possible by use of better water chemistry. The relevant IAPWS TGDs were referenced.

Good tubes don't fail

"Chemistry can be optimized to reduce damage inflicted by FAC," continued Dooley, as well as that caused by the following damage mechanisms:

- Under-deposit corrosion (UDC).
- Hydrogen damage (remains prolific today).
- Corrosion fatigue.
- Thermal fatigue.
- Pitting.

As Dooley clearly stated, in all cases you must identify the damage and understand the root cause. "You never have a good tube fail," he said. The key is to understand the damage mechanisms.

Hydrogen damage, based on contaminants, continues to be a major powerplant concern. Damage examples were traced throughout the steam system, followed by chemical cleaning criteria. Another important point: Cycle chemistry influences 70% of all HRSG tube failures.

Various rules of thumb also were discussed, including the Rule of 2 and 5, and an IAPWS-generated graphic on deposition in HP evaporators (Fig 5).

The Rule of 2 and 5 applies to optimum total iron levels in the condensate/feedwater (<2 ppm) and in the evaporator/steam drum (<5 ppm).

A few conclusions about underdeposit corrosion:

1. Visual examination of a tube is generally not sufficient to distinguish among hydrogen damage, caustic gouging, and acid phosphate corrosion.
2. Metallography and deposit analysis are necessary to determine the correct mechanism.
3. Once the mechanism is identified, a root cause analysis is needed to eliminate future damage.
4. Identifying RCCS is key to avoiding UDC mechanisms.

Discovery

Stressing again the need to clearly identify and define the damage mechanisms, Dooley emphasized the need to link visual inspection with plant chemistry. "Include the chemists," he said. A proper, complete inspection program should also involve someone at the VP Operations level to give it proper weight. "Develop a corporate mandate," he recommended.

And identify the vulnerable systems:

- Look at all susceptible systems that contain the following:
  - Carbon steel.
  - Flowing water or wet steam.
- Consider system design and operating features.
  - P&IDs, heat-balance diagrams.
  - HRSG circuit design and thermal performance.
- Review water chemistry.
  - Current and past practices and guidance.
  - Parameter analysis compared to IAPWS
  - Instrumentation compared to IAPWS
- Document the review.

"Look closely at all the interfacial areas of fluid and materials," he said.

Bringing it home

Near the end of Day Two, participants were asked some specific technical questions. The questions were designed for thought, for ideas, for discussion, and for analysis. All were verbatim inquiries from operating plant personnel asked of Dooley and his colleagues.

Participants walked through the thought path for each, adding focus and meaning to the two days of discussions.

This was real-world stuff to carry home to real-life jobs. CCJ

Adapt to survive the coming sea change in industry structure

The Combined Cycle Users Group's (CCUG) 2017 Annual Conference, held in Phoenix the last week of August, left few stones unturned with respect to plant O&M and management issues. Plant managers, consultants, insurers, vendors, and even an executive or two moved from immediate "pebble" subjects—such as Belleville washers for HRSG manways—to "boulder" size trends like grid-scale energy storage and electric-vehicle (EV) infrastructure which promise to upend in the coming years the industry as we've known it.

Boulder issues

A senior director for generation from an area utility set the stage in the keynote. He focused on three topics: safety, which should never go out of style; asset management; and regulatory and technological trends. While much of the talk was the typical "how great are we," a few golden nuggets were discernible.

The speaker's team implemented a safety program focused on counting "active" things, not reactive incidents. In the active category are training events, observations, drills, and actions which lead to positive reinforcement. "When you are good at safety," he said, "you get good at lots of other things." While no startling revelation, it's something that's easy to forget, as an incident case history later in this article reveals.

In the area of asset management, his team and facilities are focused on detection and prevention of significant equipment mishaps, rather than reacting to problems as they arise. Part of this effort is to carefully place equipment in priority. Most readers will understand this as reliability-centered preventive or predictive maintenance strategies, and immediately get the connection to safety.

Don't be reactive, in other words, be *proactive*.

He concluded by reviewing several of the overarching trends affecting the utility business, including these:

- Aggregators and resellers inserting themselves among utilities, generators, and ratepayers.
- Consumers renting rather than owning.
- Thirty percent of today's workforce doesn't work for a specific company.
- Climate-change events.
- Digital "platform" companies changing the business interface with consumers.
- The general decline in per-capita electricity consumption.
- Expansion of EVs to a predicted 50% of the vehicle fleet by 2040.
- Reduction in cost of grid-scale lithium-ion type batteries from $1000/kWh to $270/kWh over the past few years.

1. A vibrant commercial market for grid-scale storage in the US is still a few years out, despite declining cost curves for the prevalent technology option and a supportive legislative framework in key US markets and ISOs. Shown here is a DOE-funded demonstration project

Storage

Of these, grid-scale storage probably has the best chance to rock the world of gas-turbine facilities because they are envisioned to compete directly for peak-load supply and ancillary services.

Much later in the program, Jason Makansi, consultant and president, Pearl Street, Tucson, Ariz, offered a status report on grid-scale storage. In particular, he noted the variety of functions large-scale batteries (Fig 1) are being deployed and demonstrated to undertake around the country—including as part of microgrids, frequency regulation, black-start capability, avoiding NO_x emissions and priority pollutants from gas-fired peakers, filling in around renewable generation, and others.

Makansi also noted that the business is maturing, albeit in fits and starts, and reported on the bankruptcy of a major European battery supplier who only entered the US market with ambitious manufacturing plans just a few years ago. "Affordable home- and commercial-based storage begins to separate ratepayers from the grid," he said.

For existing gas-turbine and combined-cycle facilities, the key threat is that as more fuel-free electricity, subsidized or otherwise, is offered into the grid, locational marginal prices decline

2. Transformers fail regularly, an insurer told users attending the CCUG Conference

3. A death was attributed to an explosion suffered during the unloading of hydrogen

while combined cycles are forced into greater cycling and dispatch, escalating maintenance costs.

With economic home and building storage on the cusp of commercial expansion, competitive kilowatt-hours from rooftop solar PV, and so-called smart home and building design and devices (for example, smart thermostats), Makansi posited the emerging world of the "YouTility," where behind-the-meter electric producing and consuming infrastructure challenges the "size of wire" required from the grid to every building, and perhaps disintermediates the utility itself.

Makansi urges utilities to consider such infrastructure as simply an extension of the grid itself, especially because of the two-way interface, and apply the traditional rate-of-return infrastructure business model which has worked well over the last century.

Risk management

A representative from a major powerplant insurance firm delivered some foreboding words and statistics at the CCUG's 2017 Annual Conference. In particular, he stated that 40% of transformer faults occur regardless of any prevention or inspection techniques. Transformers, he said, fail regularly (Fig 2). He added that 70% of all losses are equipment breakdown.

He further noted that process safety culture in the US "lags behind Europe and Australia," and urged the audience to download his company's loss-prevention data sheets. A quick review by the editors of the two sheets he referenced as examples shows it's a good idea: They are loaded with good information and procedures.

Users can access this informative risk-management presentation in the FORUM on the Power Users website at www.powerusers.org. It offers valuable guidance on fire protection and prevention and on maintaining the integrity of lubrication systems. Note that Power Users is the umbrella organization for managing and coordinating the technical programs for the 7F, Combined Cycle, Steam Turbine, and Generator Users Groups.

4. Batteries demand your attention. A thermal runaway can occur when a battery is being charged and the heat generated exceeds the rate at which it can be dissipated through the battery case to the environment

5. Clashing damage to the trailing edges of R1 rotor blades can range from rub marks shown at left to torn and displaced metal (right)

The speaker also identified other good sources of information. Example: OSHA, which publishes its findings after investigating significant catastrophic events. He referenced an OSHA news release from Sept 27, 2013 as an example. The document describes an explosion that occurred during the unloading of hydrogen for generator cooling at a large powerplant in the Southeast and the 17 serious safety violations the owner/operator was cited for (Fig 3). While the resulting proposed fines totaled over $100,000, the scope of the violations screams negligence.

To underscore the need for broad programs like systems knowledge and management of change, he recounted the failure of DC power supplies (Fig 4) at a plant which affected the AC side of the electrical system and caused a loss of lubrication on coast down, which went on to impact the entire turbine. "Check your batteries!" he urged. This kind of failure apparently occurs at least once a year, with an average equipment loss of $20-million.

He labeled such failures routine events with severe consequences, as contrasted to routine events, including transformer failures and, as another example, clashing damage in Frame 7 compressors (and also in some Frame 5 and 6 units) attributed in part to vane lock-up in carbon-steel vane carriers (Fig 5).

Some of his other points and suggestions include these:

- OEMs are known to have installed parts which were condemned.
- Greater oversight is required of third-party independent component suppliers.
- Identify single points of failure and address them.

What the OEM and the FBI said

During GE Day at the CCUG Conference the big trends reported above were reinforced. One speaker bluntly told the audience that the trends in


UNISON
Ignition Exciter

demand growth, capacity additions, and load shape "sucks" for this community. Most of what the OEM presented, at least in the first segment of its program, sounded like GE talking to itself about how to respond to tectonic market forces.

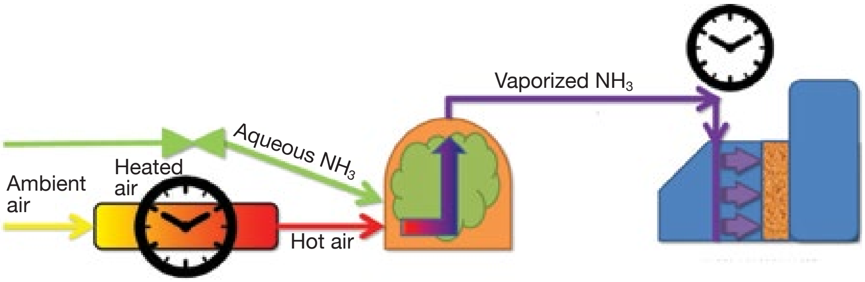
One speaker mentioned the need for a part-load maintenance factor. Yet another said "we need to rethink asset life," for example, building a database of performance from units experiencing two-start days. "What do we need to do differently?" he asked. Another mentioned service agreements which "flex with you" as well as "outcome-based multi-year agreements."

And such a discussion would not be complete without debating how digital technology is changing the O&M game. Putting the control-room information and indicators on remote digital devices was mentioned. In connection with that, one GE leader referred to a plant in California running at 10% capacity factor that has gone down to a single operator at night.

Cybersecurity was addressed by a representative of the regional office of the FBI. He observed that *physical* access is still the key to many security problems. Several pearls of wisdom:

- Wall off anything that cannot be patched from the Internet.
- Don't trust Microsoft patches.
- If you have Kaspersky anti-virus software, get rid of it. Kaspersky software has gotten caught up in the nation's current love of all things Russian.

Another FBI agent discussed the ideology of Islamic terrorism, though it was unclear whether anything was directly applicable to US powerplants. Both agents suggested that plants consider a visit from the FBI/Dept of Homeland Security (DHS), through the Arizona Cyber Threat Response Alliance, to walk down the site and provide an evaluation and recommendations.



6. Peaking facility with four LM6000 gas turbines reduced startup NO_x emissions 40% by reprogramming the SCR process control scheme to reflect the current operating tempo

User shares best practice for reducing NO_x in-house

It's only partly facetious to say that every molecule of NO_x avoided in California means something. A representative of a plant with four LM6000 units reviewed its innovation program for reducing startup NO_x emissions by 40%. That's significant, because startup NO_x mass can be three times that of a full operating hour at full load. Reducing NO_x emissions has the welcome byproduct of increasing operating time for each unit, at least in that state.

"We developed this program ourselves because the OEM wasn't interested in working with us," he told attendees at the CCUG Conference.

After implementing the obvious steps of tightening up maintenance, tuning up the system, and upgrading the NH_3 curve, the key to the program was to focus on the many points in the startup sequence when you wait—such as warmup, breaker synch, SCR coming up to temperature, combustion entering the "zone," and water injection coming on.

The specific steps proved to be (Fig 6):

- Reduce the SCR/NH_3 injection interlock temperature.
- Lower the SCR temperature NH_3 block interlock.
- Lower the NH_3 injection heater temperature interlock.
- Alter the NH_3 motive heating scheme.
- Add a megawatt-based feedforward capability to the normal NO_x-ppm feedback loop and fuel feedforward process control loops.

As one example of the reasoning, the system had been programmed to wait for the SCR catalyst to reach 550F, before starting NH_3 injection. Discussion with the supplier suggested 450F was acceptable. However, ammonia salts vaporize at 310F, so the owner's team agreed that 350F would be acceptable. Essentially, the mods were based on rethinking the process control scheme to iron out much of the design margin so it more closely reflects the current operating mode of the units—that is, more time in startup mode than anticipated in the original design.

When the mods were concluded, operators measured the startup NO_x for the other three units in a range of 6.3–7.2 lb/hr; for the modified unit, it was 4.0 lb/hr.

And they aren't done. Coming mods include shortening the NH_3 heater "clamp" by 50%, programming warm standby on the NH_3 heater, reducing turbine warmup times and shortening breaker synch wait times and the turbine purge period. The mods can be extended to the other three units.

A death results when safety procedures are ignored

Although a presentation on the post-mortem analysis of an incident resulting in a worker death is somber, it's also a learning event and reminder that safety must always be reinforced, even if, as in this case, you've performed a task a hundred times before. Users were reminded of this at the CCUG Conference.

In the case described (at a hydro facility), the task was to clean a de-energized 13.8-kV bus. A veteran worker, who had performed this task 26 times before, was left alone as his team member left to retrieve an item they had forgotten for the job. He returned to find the veteran co-worker "energized" and lying on the ground.

Inexplicably, what happened was that the two of them had noticed a flat washer on the floor. While the veteran was alone, he wanted to "fix the problem" and put the washer where it needed to be. In doing so, according to the post-mortem, he violated multiple safety rules. He rolled stairs over, unlocked a locking mechanism (apparently every employee has a master lock key), removed rods, and opened the door to an *energized* 13.8-kV cubicle above the one they were assigned to.

He noticed a broken bolt, found a flashlight in the back of the top cabinet to shine on the bolt. They found his hard hat in the back of that cabinet. The top of his head apparently came in contact with the energized bus. The veteran proceeded on his own even though the two of them "had the conversation" that the top cabinet was energized. Not only should he not have worked alone, no out-of-scope work

should have been done unless workers had stopped to discuss it.

Organizationally, there wasn't much to do, other than reinforce existing processes and procedures. The owner/operator did eliminate master locks on this type of equipment and began a program to reward those who bring problems back for collective discussion, rather than solve them alone. However, nothing is going to stop someone from lapses of judgment or a determination to solve a problem on their own while no one is looking.

One audience member responded that energized gear "keeps him up at night." Sometimes equipment just malfunctions and you can't blame the person, and sometimes the person makes a mistake—especially when tired. Another attendee reported that they run safety drills at his plant unannounced weekly, and then evaluate responses and performance afterwards.

Perhaps the overarching lesson here is complacency can kill.

Others asked, "What constitutes emergent work?" and how to you handle it. Staff needs to be empowered to stop work to question and be certain, and be supported by management for doing so. One tool to assist in performing work safely that was mentioned may be the latest models of cameras, which can be used to troubleshoot problem areas and document tasks.

Attendees share their experiences

Two of the more insightful open-discussion sessions at the CCUG Conference had plant representatives, somewhat extemporaneously, tell the conference leaders (all veteran plant managers) what they needed help with and what problems they might solve, or at least address, during the meeting.

The following are some of the topics/concerns on the minds of users reported out in the first discussion session:

- We're seeing components fail for the first time; thermowells are an example. What are some of the other "one-offs" others are seeing, things not expected?
- The way we operate is changing. We're now *offline* during the peak of the day. We have six-hour minimum runs, instead of 12. We had a control valve split in half. Generally, we're experiencing more cycling and increased maintenance.
- Daily cycling is leading to cracking of steam piping (Fig 7), not leaks, but weld failures, valve seats cracking, etc. Strainer baskets are not catching foreign material going to the steam turbine (Fig 8).
- We are experiencing gas-supply issues, curtailments, and gas compressor issues.
- We tripped a 7FA offline and borescope inspection revealed fuel nozzle orifices coked up (this is gas-only plant). We had compressor station lubricating oil pouring out of everywhere. Eventually, we replaced five sets of gas-turbine fuel nozzles.
- We're having gas supply issues. We added diaphragm valves. We've had to step up line pressure because of low flow conditions, and experienced valve failures.
- Our plant doesn't have adequate cathodic protection because the original plant designers didn't think it was needed given the desert location (Fig 9).
- A significant recent problem for us focused on failure of the transformers for the steam turbine/generator. We ran for a month in simple cycle because of it.
- We've had all kinds of different brands of flowmeters for our attemperators. One model split in half. How often should we inspect them? Once a year? We found an obstruction in the liner after a borescope inspection (Fig 10). We got a good look at the 180-deg bend in the hot-reheat attemperator and found liner cracks and leaks in the gaskets between the valve body and attemperator. We must inspect these components often.

7. Mag-particle test reveals crack indication on the downstream weld of a tee

8. Hardfacing debris was removed from the strainer of a combined stop and control valve. Were the strainer to fail, as sometimes happens, this would wreak havoc in the steam turbine

During the second discussion session later in the program, new sparing and inventory programs sucked up a good portion of the oxygen. One utility representative spoke about a formal critical-parts risk matrix—including cost, location, turnaround times, potential suppliers, etc—conducted across their combined-cycle fleet. This led to increased inventory, especially for long-lead time critical spares at single-point-of-failure locations.

However, increasing spares adds to the tax burden. Another non-utility combined cycle shares parts with other owner/operators in the area, primarily a competing utility. A third user cautioned that equipment sourced overseas requires that you "document the hell out of stuff." Just because you specced out an in-kind replacement doesn't mean you're going to get it.

The discussion on spares necked down to thermocouples. One plant representative said that often one fails, then you put the installed spare in service, and forget about it. Now the practice has

9. Cathodic protection system test station, post-mounted and easily seen, is installed near where the natural-gas line enters. System is of the non-powered (sacrificial) type

MAXIMUM RELIABILITY

Water cooling technology to maximize capacity payment opportunities by providing reliable back up liquid fuel system operation

Water Cooled 3-Way Purge Valves

JASC water cooled 3-way purge valve is a bolt-in replacement for your standard 3-way purge valve. This design coupled with heat sink clamps keep fuel lines cool during extended periods of gas operation and will significantly improve both valve and fuel system reliability.

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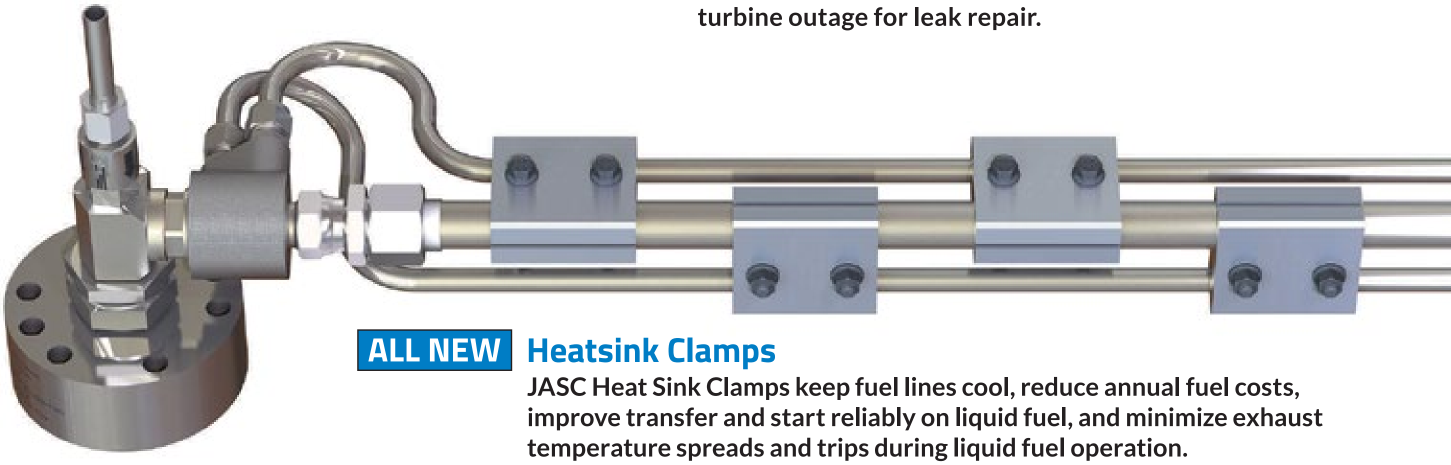

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Combined Cycle Users Group

Eighth Annual Conference and Discussion Forum

August 27-30, 2018
Louisville Marriott Downtown, Louisville, Ky

Steering Committee

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Vice chair: Brian Fretwell, *Calpine Corp*
Past Chair: Dr Robert Mayfield, *Tenaska Inc*
John Baker, *Clearwater Cogeneration Plant, Riverside Public Utilities*
Jimmy Daghlian, *NV Energy*
Robert Marsh, *Puget Sound Energy*
Steve Royall, *PG&E*

10. Regular borescope inspections are recommended for liners downstream of attemperators. Distress is clearly in evidence here

shifted so that the plant immediately orders a new one held as inventory.

Steam bypass valves and systems continue to give users fits. A plant attendee reported that the piston on one of his bypass valves broke in half, and they had to use another unit's bypass system to get the unit started up. Another participant said bypass valves are now inspected every outage because of Stellite seat failures.

Other miscellaneous points to ponder from the discussion include these:

- A user reported blowing out the guts of the silencer "more than once."
- A plant experienced multiple boiler-feed-pump failures and massive pitting on the pump shaft tied to an O-ring failure.
- A 3 × 1 plant designed for baseload had to significantly modify its zero-discharge water treatment system, originally designed to accommodate a five-day, 16-hr shift operating tempo. "The plant wasn't able to run in 1 × 1 or 2 × 1 configurations because of this limitation."
- If you operate under a two-starts-per-day regime, you need a robust vibration analysis program, and a vibration specialist, to anticipate when critical components may fail.

  Test motor breaker open/closing regularly, because internals have a limited defined life.
- Another plant caught relief-valve and thermocouple issues by implementing a commercially available advanced pattern-recognition software package designed for startup periods. CCJ

POWER USERS

Individual Achievement Awards

CCUG

Chuck Casey
Kevin C Geraghty
William J Gillis
Michael David Hoy

GUG GENERATOR USERS GROUP

Isidor Kerszenbaum, PhD, PE

STUG STEAM TURBINE USERS GROUP

Jimmy Baker
Donald D Hughes
Harold Parker
Tim Parsons

Individual Achievement recognition is earned by industry professionals who have demonstrated excellence throughout their careers in the design, construction, management, operation, and / or maintenance of generating facilities powered by gas and / or steam turbines.

Power Users Group
Sheraton Grand, Chandler, Ariz
August 28-31, 2017

The Combined Cycle, Generator, and Steam Turbine Users Groups, all operating under the Power Users banner, presented their 2017 Individual Achievement Awards at the parent organization's Combined Conference, August 28 – 31, in the Sheraton Grand at Wild Horse Pass, Chandler, Ariz.

Individual Achievement recognition is earned by industry professionals who have demonstrated excellence throughout their careers in the design, construction, management, operation, and/or maintenance of generating facilities powered by gas and/or steam turbines.

Combined Cycle Users Group

Chuck Casey

Utility Generation Manager, *Riverside (Calif) Public Utilities*

Chuck Casey is responsible for the city of Riverside's generation assets (four LM6000 and four GE 10B1 peakers, and one LM2500-powered combined cycle) which provide a significant percentage of the 280 MW required to serve the municipal utility's more than 105,000 residential and business customers. He has three decades of generation experience—specializing in plant construction and commissioning, and regulatory compliance.

Before joining Riverside in 2004, Casey was a plant operator, I&E technician, plant manager, and consultant for Stewart & Stevenson, GE, and PurEnergy. He began his career as a nuclear electrician on US Navy fast attack submarines.

In 2013, Casey was elected president of the Western Turbine Users Inc, an all-volunteer organization of owner/operators of General Electric LM and LMS engines. During his 16 years with the user group, the world's largest such organization dedicated to land-based aeros, he held several leadership positions. Casey also serves as chairman (even years) of the Southern California Public Power Authority Generation Group, which he founded. Plus, he started the NetDAHS User Group (data-acquisition system environmental software).

Casey's plants have received several industry awards over the years, most recently the 2017 Best Practices Award (with Best of the Best recognition) from CCJ for the Riverside Energy Resource Center's creative, in-house efforts to reduce LM6000 startup NO_x emissions by 30% and dramatically improve engine operational flexibility (access by scanning the QR code with your smartphone or tablet).

Kevin C Geraghty

Senior VP of Energy Supply, *NV Energy*

Kevin Geraghty is one of relatively few senior managers in the industry who can trace his roots to the deck plates of generating stations where he began his career following graduation from the University of Pittsburgh with a degree in electrical engineering. That heritage has enabled

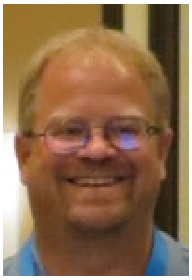
Kevin C Geraghty (left) accepts the 2017 Individual Achievement Award from Jimmy Daghlian, a member of the CCUG steering committee

Geraghty to become one of the most effective executives in the generation business today. His first-hand knowledge of what's important to run a powerplant is evident in Geraghty's support of user-group activities—an effective training ground for plant personnel.

He personally encouraged the formation of the Generator and Air-Cooled Condenser (ACC) Users Groups and provided the resources and meeting rooms for both organizations to conduct their first meetings. Plus, he has encouraged his generation engineers to learn from others with meaningful participation in various groups. Today, NV Energy employees are active on the steering committees and as session leaders for the Steam Turbine, ACC, Generator, CTOTF, and Combined Cycle Users Groups.

William J Gillis

Distinguished Engineering Associate, *ExxonMobil Research & Engineering Co*



Jeff Gillis is ExxonMobil's global technology lead for the company's frame gas-turbine fleet. He is a vibrant supporter of user-group activities and currently serves on the 7F Users Group steering committee (since 2007) and as the co-chairman of the Frame 6 Users Group. Jeff began his career working for Mobil Oil as a co-op student on the way to a BSME degree at Northeastern University. After graduation in 1982 he joined Exxon (at Linden, NJ, later moving to Houston) where he has specialized in engineering, operation, and maintenance of rotating machinery.

Gillis' global position allows him to learn/share technical information around the world. He shines in the all-important safety area and his detailed presentations and commentary at user group meetings reflect this. His knowledge of safety practices, rules, and regulations at plants in Europe, Asia/Middle East, and the Americas benefits all.

Michael David Hoy

Senior Manager, Major Projects Group, *Tennessee Valley Authority*

Mike Hoy's 40- year working career has been in the business of gas turbines and associated plant. The UK native's first job after graduation was with the National Gas Turbine Establishment, but it was too academic, so Hoy took a position with GE, spending nine years as an international field engineer in 20 countries. His next GE assignment, also for nine years, was in the US, where Hoy focused on gas-turbine projects in the Southeast.

Apart from a short stint as a subject matter expert with Duke Energy, Hoy has worked for TVA since 1998, initially as a GT site manager. Since relocating to the utility's Chattanooga's offices, he has held engineering management roles in the company's large operating gas fleet and later with the project group responsible for developing and installing TVA's new combined cycles—including H-class units.

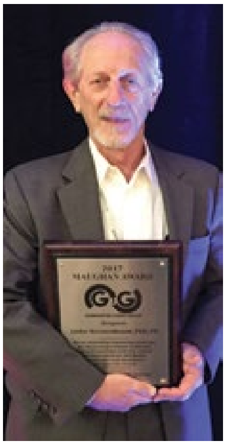
Hoy has been active in several users groups during his career. He was chairman of the CTC^2 organization from 2003 to 2005, chair of the 7EA Users Group from 2005 to 2008, and a member of the CCUG steering committee until 2014. Among his professional achievements, Hoy lists the promotion and improvement of user-group discussion forms and speaking truth to power. Most recently, he had a hand in getting GE to eliminate the need for a clutch between its latest aeros and generators for synchronous condenser operation.

If you know a person deserving of the CCUG's 2018 Individual Achievement Award, please complete the nomination form (access by scanning the QR code with your smartphone or tablet) and forward it to the steering committee for consideration.

Generator Users Group

Isidor Kerszenbaum, PhD, PE

Principal, *Izzytech LLC*, a consultancy specializing in electrical power engineering



Izzy Kerszenbaum has had a long and varied career in generators, motors, and transformers since receiving his BS in Electrical Engineering from the Israel Institute of Technology in 1978. He earned his PhD in Electrical Engineering from the University of Witwatersrand in South Africa five years later. Before founding IzzyTech in 2014 he worked for Southern California Edison, Edison Mission Energy, GE, and Israel Electric, among others.

In his efforts to help industry colleagues deal successfully with equipment challenges, Kerszenbaum has become a prolific author and lecturer on a wide range of technical subjects. He has written or co-authored nearly three dozen papers and a dozen books and technical reports, and since 1997 has conducted, or co-conducted, three- and five-day seminars for many hundreds of utility personnel.

He has been very active in IEEE, EPRI, and other engineering groups both as a participant and leader, and is a Fellow in two IEEE societies. Kerszenbaum was instrumental in introducing to North America the important Repetitive Surge Oscillograph test for field-winding shorted turns.

He has been, and continues to be, an exceptional contributor in the business in which we are all engaged—power generation equipment O&M.

If you know a person deserving of the GUG's 2018 Individual Achievement (Maughan) Award, please complete the nomination form (access by scanning the QR code with your smartphone or tablet) and forward it to the steering committee for consideration.

Steam Turbine Users Group

Jimmy Baker

President, *Jimmy Baker LLC*

Jimmy Baker has spent more than four decades working with steam turbines—including outage planning and execution, maintenance and repair, modifications and upgrades, performance testing, and vibration

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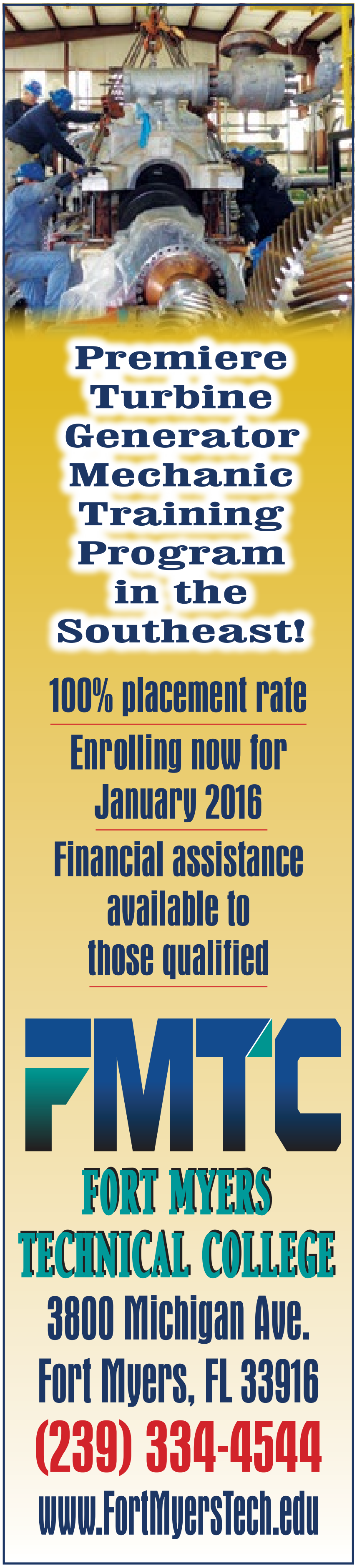

analysis and balancing. He joined Southern Company in mid-1976 and spent the next 34 years with the utility as a steam-turbine specialist. Among Baker's many accomplishments was his work in the development of Southern's strategy for steam-turbine reliability. He was an active member of the Vibration Institute (national organization and Georgia chapter) for years and represented his company on many EPRI projects.

Baker launched the consulting firm that bears his name in mid-2010 after retiring from Southern and he remains active in the industry solving steamer problems for customers. Colleagues consider Baker innovative and a true student of steam-turbine O&M. They value having his third-party eyes for guiding turbine maintenance projects.

Donald D Hughes

O&M Manager, *SRP*

Don Hughes has spent the last four-plus decades of his professional career with SRP, 31 of those years with direct involvement in powerplant operations—including all aspects of steam-turbine and generator O&M and overhaul. His deck-plates positions over the years have included steam-plant mechanic, foreman, and O&M manager. Today, he is responsible for the mechanical, welding, electrical, I&C, and planning departments at the utility's Santan and Kyrene Generating Stations.

Hughes is a dedicated leader, always ready to share his knowledge and experience on safe, reliable O&M of generating assets. He has been involved with SRP's plant apprenticeship training program since its inception in the early 1980s—serving as a classroom instructor, apprentice supervisor/manager, and member of the oversight committee charged with subject-matter development to assure proper training of the future workforce.

Harold Parker

Director of Engineering, *HPC Technical Services*

Hal Parker got his start in power generation like so many others in the business: As a GE field engineer and startup engineer. He migrated from road assignments to the company's Field Engineering Development Center in Schenectady where he authored many of GE's advanced training programs.

Since leaving GE in 1983, Parker has focused on providing training services to power generators, although he has taken field assignments in plant startups, outage technical direction, and controls-related troubleshooting. Parker owned and operated Schenectady Learning Systems from 1983 to 1989 and served as turbine/generator manager for General Physics from 1989 to 1992 before forming HPC Technical Services.

Parker's company helps power generators maximize the effectiveness of their personnel and equipment with its training, operations, maintenance, and engineering services.

Tim Parsons

Manager of Turbine Assets, *Tampa Electric Co*

Tim Parsons has been actively involved in turbine O&M for more than 20 years at Tampa Electric, where he is responsible for gas- and steam-turbine technical and long-term-agreement commercial aspects. Parsons' knowledge and respect for rotating equipment is said to be on par with the best in the industry. His passion is technical improvements with sustained superior O&M. Parsons unselfishly shares his knowledge with all those who can benefit from the guidance.

If you know a person deserving of the STUG's 2018 Individual Achievement Award, please complete the nomination form (access by scanning the QR code with your smartphone or tablet) and forward it to the steering committee for consideration.

Total Support – Total Reliability

Engineering expertise and years of experience in the field make us a valuable part of your day to day operations.

Multistage pumps are manufactured by a number of companies for high pressure medium flow applications and are critical to combined cycle plant operations.

These machines are critical to operations but have presented great challenges related to overall reliability. They are often incorrectly installed and the plants may not have the specialist resources available to diagnose problems that stem from multiple areas. Engineering, manufacturing, installation and operation are all critical to proper performance.

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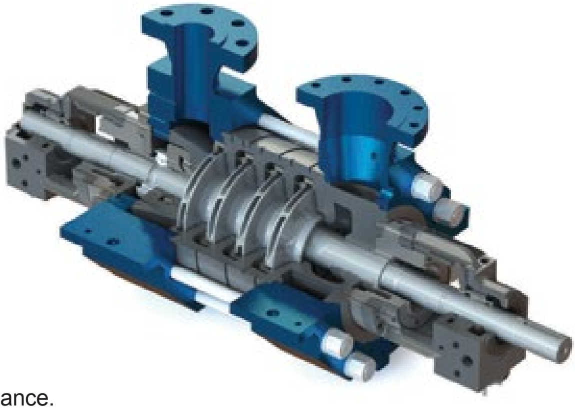

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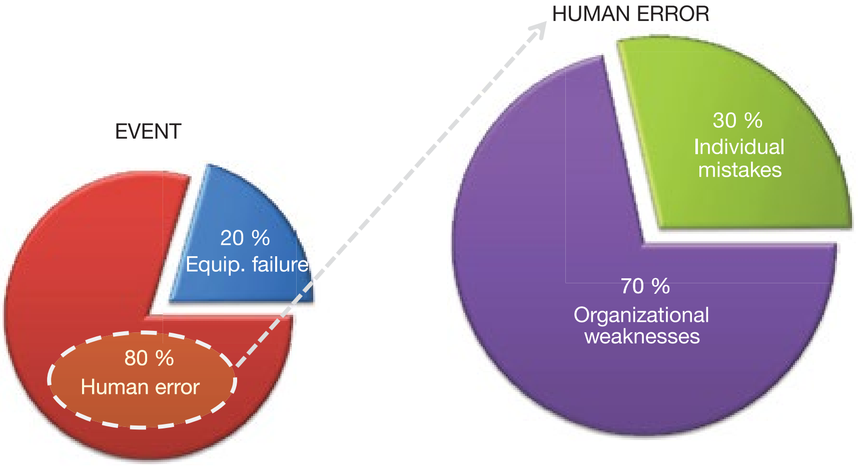
Human performance events become opportunities at NV Energy

As an integral part of its operational-excellence core principle, NV Energy recognizes that human errors or gaps in its processes can directly, sometimes significantly, impact safety as well as operational performance, reliability, and assets. Reducing and eliminating these errors and shortcomings is the essence of its ongoing Human Performance Improvement (HPI) initiative.

The goal is to transform operational groups into *learning organizations* where discovery, investigation, and problem-solving become collaborative at every level. Widespread involvement and a culture of trust are necessary to truly expose the organizational weaknesses that lead to human errors. This requires firm leadership alignment from top to bottom so that when mistakes happen they are used as learning opportunities.

Perspective. The first distinction is to separate human activity from equipment operation and stress. Equipment malfunction or failure reportedly accounts for only 20% of a plant's reliability loss, human involvement (human error) the remainder (Fig 1).



1. NV Energy reminds employees and contractors of the base perspective on events

But the latter goes far beyond errors by individuals. The human-factor category includes collective weaknesses, norms and traditions, management styles and systems, almost anything non-equipment. In fact, most of the human element (seven times out of 10) can be classified as organizational weaknesses—including such strong influences as ownership or management changes.

In that context, a concentration on HPI makes a lot of company-wide sense, and should not be taken personally. It only makes the team better.

Many organizations have launched initiatives to address these factors and occurrences. NV Energy's HPI program is robust and underpinned by five fundamental platforms. They are:

1. Event tracking.
2. Reporting.
3. Root-cause analysis.
4. Communications.
5. Proactive error-prevention tools.

When something unexpected (think *unwanted*) happens, the immediate task is to trace its origin—thoroughly and objectively.

Event tracking and reporting

"Any human action which directly or indirectly causes a significant event triggers the tracking process within the HPI system," says Steve Page, project director for NV Energy's generation organization. The tracking system calls for clear identification of the immediate direct cause or causes. To help, examples within a web-based system are listed for both *behaviors* and substandard and at-risk *conditions*.

NATO/ICAO phonetic alphabet

A Alpha
B Bravo
C Charlie
D Delta
E Echo
F Foxtrot
G Golf
H Hotel
I India
J Juliet
K Kilo
L Lima
M Mike
N November
O Oscar
P Papa
Q Quebec
R Romeo
S Sierra
T Tango
U Uniform
V Victor
W Whiskey
X X-ray
Y Yankee
Z Zulu

Significant events fall into one of the three following categories:

1. Safety. Any OSHA recordable incident.
2. Environmental. Notice of violation or spill reportable to an outside agency.
3. Production. A unit forced outage or capacity de-rate greater than 20%.

The examples are further defined as either behaviors or conditions. Acts/practices/behaviors include such things as failure to warn, operating without authority, deviation from standard procedure/practice, etc. Substandard/at-risk conditions include inadequate warning system, defective protective devices (or none), substandard tools or equipment, etc.

Each incident is reviewed by local leaders along with corporate leadership and support personnel. The events are mined for learnings to be shared throughout the company.

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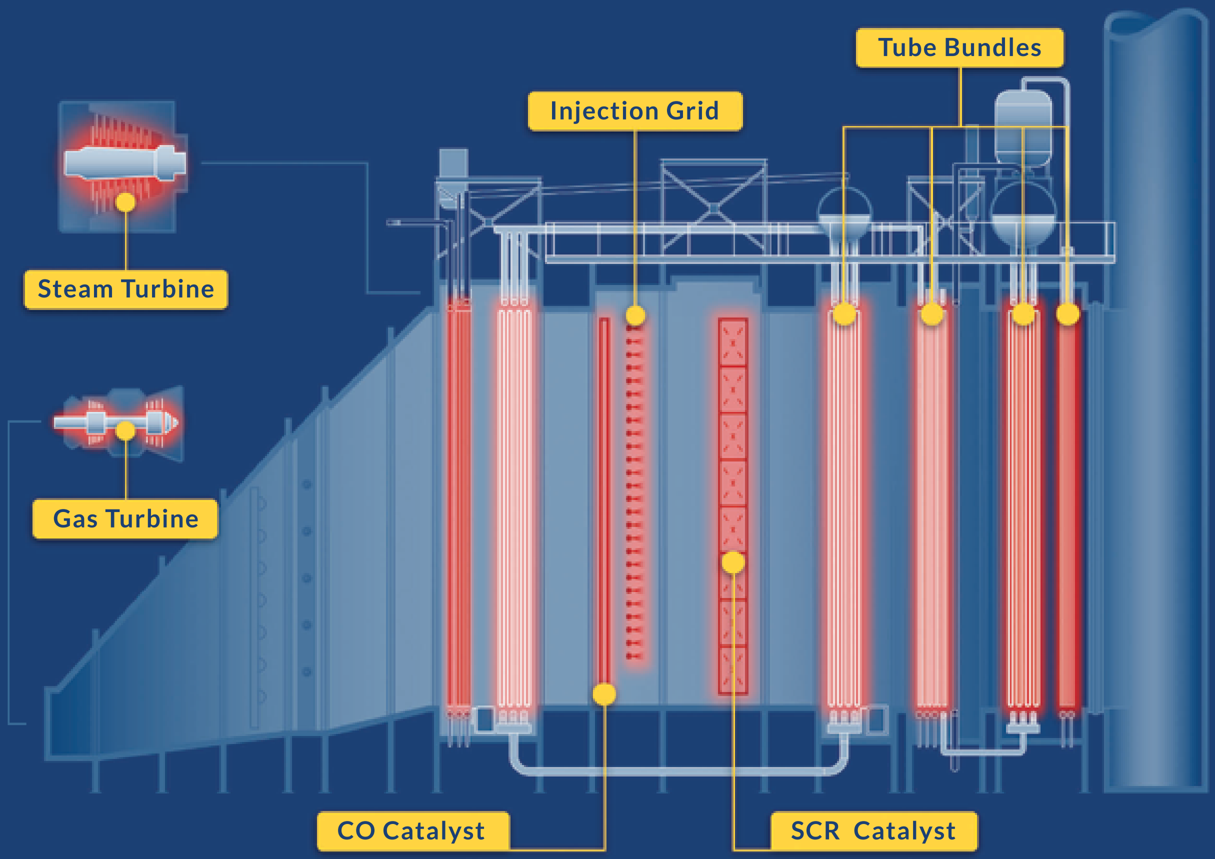

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Root-cause analysis

Root causes are more defined, more varied, and require specific identification of underlying details to draw accurate conclusions. Take, for example, physical capability, inadequate training, poor procedures, bad planning, and poor risk perception.

A clearly defined distinction between error and violation is often significant. An error is "an *unintended* deviation from expected behavior due to a multitude of reasons." A violation is "an *intentional* deviation from an expectation or expected behavior that the individual is knowledgeable and proficient in performing."

According to Page, "It is NV Energy's observation that incidents of *willful* violation are not common. Almost every mistake has a root in an organizational weakness. Therefore, candid and open discussions best occur in a *threat-free* environment. This is key. Without trust and employee engagement, a human-performance initiative will not yield much benefit."

Proactive tools

NV Energy has carefully selected and defined specific tools to reduce both errors and violations, and to ensure that the HPI program is effective and long-lasting. Specifically, NV Energy uses:

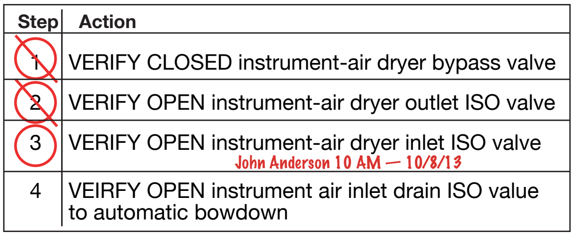
- Self-checking.
- Peer checking.
- Place keeping.
- Three-part communication.
- Phonetic alphabet.
- Two-minute drill.
- Stop!

Self-checking is an error-prevention technique specifically designed to boost the performer's attention to important or critical details before executing a task. The basic format is stop, think, act, and review (STAR).

Take, for example, the lock-out/tag-out (LOTO) process:

Step 1 (Stop) requires the person to pause before engaging in the process, ensure they are fully engrossed in the process, focus attention and minimize distractions, and, in the face of any uncertainty, stop and review the procedure.

Step 2 (Think) asks these questions: Are you on the correct equipment (and at the right unit), does the tag terminology match the equipment, are all the energy sources and work-scope details identified and understood, and do you understand your responsibilities to NV Energy and/or to the contractor?



Step	Action
①	VERIFY CLOSED instrument-air dryer bypass valve
②	VERIFY OPEN instrument-air dryer outlet ISO valve
③	VERIFY OPEN instrument-air dryer inlet ISO valve John Anderson 10 AM — 10/8/13
4	VEIRFY OPEN instrument air inlet drain ISO value to automatic bowdown

2. Place keeping is critical during all startups and shutdowns. In "Step" column, a circle indicates step was started, slash that it was completed. However, it usually is better to have more information. Use of a name or initials in the "Action" column indicates day and time the step was initiated

Step 3 (Act) means first to physically approach the equipment and confirm the tag information, then focus on the tasks of hanging the tags and locks. Next, the person must walk down the entire LOTO boundary, then communicate and correct any deviations from plant protocol.

Step 4 (Review) means to verify isolation points and tags for accuracy, ensure verification is witnessed by Operations and the first LOTO holder, verify that all signatures are recorded on the proper forms, and confirm that any deviations are reviewed, corrected, and communicated to everyone involved.

Sidebar illustrates the process involving a transfer-pump switch.

Peer-checking. To complete a critical task with even higher assurance of first-time success, NV Energy uses a peer-checking system (basically STAR with a co-worker). Communication allows verbal checking and confirmation of all steps. When the component label is read aloud, the co-worker verbally confirms. During actions, the co-worker watches closely and confirms. During review, the co-worker verifies and offers any advice for the future.

Peer-checking at NV Energy is required when:

- A task is performed for the first time.
- Potential exists for significant consequences.
- The person would feel more comfortable.
- The supervisor requires it.
- Past experience dictates it.
- Always on LOTO and confined space.

Place keeping. For written procedures, NV Energy also stresses place-keeping techniques such as circling the written step number in a procedure, both verbalizing and performing the step, then placing a slash through the number before moving to the next step (Fig 2). This also can be used to

Two-minute drill

LOOK FOR ERROR TRAPS

Task demands	Individual capabilities	Work environment	Human nature
Time pressure (in a hurry)	Unfamiliarity with task/first time	Distractions/interruptions	Stress (limits attention)
High workload (memory requirements)	Lack of knowledge (mental model)	Changes/departures from routine	Habit patterns
Simultaneous, multiple tasks	New technique not used before	Confusing displays or controls	Assumptions (inaccurate mental picture)
Repetitive actions, monotonous	Imprecise communication habits	Work-arounds/out-of-spec instruments	Complacency/overconfidence
Irrecoverable acts	Lack of proficiency/inexperience	Hidden system response	Mindset ("tuned" to see)
Interpretation requirements	Indistinct problem-solving skills	Unexpected equipment conditions	Inaccurate perception of risk (Pollyanna)
Unclear goals, roles, and responsibilities	"Unsafe" attitude for critical task	Lack of alternative indication	Mental shortcuts (biases)
Lack of, or unclear, standards	Illness/fatigue	Personality conflicts	Limited short-term memory

3. The two-minute drill is a conscious pause to gain situational awareness about task demands, individual capabilities, the work environment, and natural biases which may divert from accomplishing a task successfully


Liqui-Cel

Illustrating self- and peer-checking

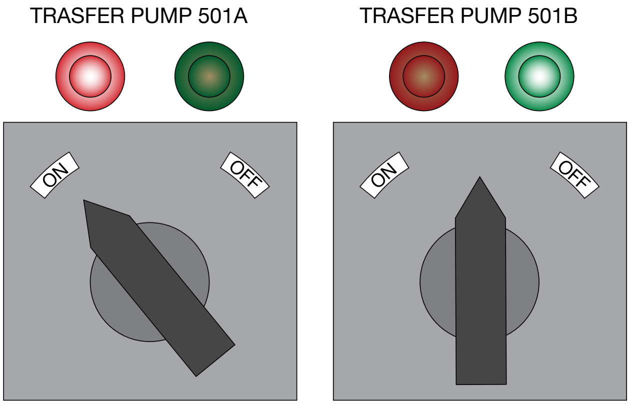
A transfer-pump switch is used here to illustrate both self- and peer-checking. The task is to operate a switch; the "act" is to move the pistol grip to the "on" position. First step is to pause and consider what needs to be done. Next, verify the correct equipment and anticipate what could go wrong.

NV Energy offers specifics:

TOUCH the pistol grip and leave your finger on it until you get to the "act" step. Then do the following:

- READ the document OUT LOUD that directs manipulation of the component.
- READ the component label OUT LOUD, checking to make sure it agrees with the document.
- VERIFY the device is in the anticipated position.
- Then, without losing eye contact and without removing your hand,
- Move the pistol grip for Transfer pump 501A to the "on" position and anticipate contingencies.

The last step is to review and confirm that the expected results did occur. Did the red light come on and the green light go out? Did the pump start? Any other indication: amps? pressure? sound?



NV Energy requires a self-check when:

- Operating a component or switch.
- Feeling rushed or distracted.
- A task is interrupted.
- A task is critical.
- Significant risk is involved.

And always (with peer-check) on LOTO and confined space.

acknowledge steps that might not be applicable. Signatures, initials, dates, and times also could be required. Place keeping is required for all written procedures, and during all unit startups and shutdowns.

Three-part communication is a technique that ensures messages are understood correctly before any action is taken. This is used every time a directive is given. First, the sender identifies the receiver by name and provides the initial message. Then, the receiver acknowledges receipt by either paraphrasing or repeating back the directive verbatim. Paraphrasing helps both parties verify full understanding. Third, the sender acknowledges that the response was correct. Actions can then take place.

Keep in mind that the third part (sender acknowledgement) is often the weakest link in this chain.

Some basic rules are important, such as avoiding the use of slang or regional words, and giving multiple instructions. At NV Energy, this technique is required when:

- Communicating operational information or directing operational tasks.
- Communicators are in high-noise areas.
- Processes or procedures are critical.
- There is a risk of miscommunication.
- There is use of radios, telephones, or other communications devices.

The phonetic alphabet is a common tool to ensure communications are clear, concise, and accurate. This eliminates confusion when dealing with letters that sound alike (b,t,p,v,d), when an acronym could be confused with another acronym, or when dealing with components with similar names. The NATO/ICAO (International Civil Aviation Organization) phonetic alphabet is the most common (table). An important point: This is used during verbal, not written, communication. Written letters are visually distinct.

The two-minute drill simply means taking the time to evaluate a job site for safety and error concerns. Typical questions to consider are permission requirements, hazards in the area (above, below, and ambient), and protective equipment requirements—among others. NV Energy emphasizes use of the two-minute drill on first entry at a location, as well as after an interruption of any type or length.

Procedure and work-package writers often do not have direct access to witness all site conditions, and are not generally present on the day the work is implemented. Thus, the two-minute drill gains critical importance. Work conditions can vary from those in the procedures, and even from the daily pre-job briefing.

And if a person is experiencing a *gut feel* about something, this is the time to raise it. "Never think that a job is easy, simple, or routine," states Page. This is the time to look for what NV Energy identifies as common error traps—such as distractions, inaccurate assumptions, time pressure, unfamiliarity, interruptions, or personal stress (Fig 3).

Stop is perhaps the most critical tool, allowing pause in task performance to verify that all key details of the task have been addressed and understood. The pause in action can be initiated by anyone. The cornerstone rule is to *fail conservatively,* meaning if the task or environment is not playing out as intended, it is imperative to stop and re-stabilize the situation. "Never proceed in the face of uncertainty," says Page. CCJ

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AGTSI Teams with Eaton on Global Product Distribution for Aeroderivative Market.
In a new agreement with power management company Eaton, Aeroderivative Gas Turbine Support, Inc. (AGTSI) of Boca Raton, Florida, has been selected as Eaton's official global distributor for aeroderivative, industrial and commercial marine engine components and services.
Eaton's products include dynamic and static seals, hoses and fittings, as well as specialty lube system sensors and components. Eaton's product reliability is proven across all gas turbine applications including aerospace, ground based industrial, power-generation and marine propulsion.
"AGTSI is well positioned to serve this highly specialized market and maintains a vast inventory of complex products and components manufactured by Eaton. AGTSI also provides operators and repair facilities that specialize in Eaton's marine gas turbines."

Aeroderivative Gas Turbine Support, Inc. (AGTSI) was established in 2004 and is a global stocking distributor of parts and assemblies for industrial and commercial marine gas turbines.
The company maintains an extensive inventory at its headquarters in Boca Raton, Florida in order to fulfill customers' "just in time" requirements.
AGTSI also facilitates component overhauls and maintains rotable exchanges for many of the parts.
For more information, please direct any request for quotes or information to quotes@agtsi.com (or sales@agtsi.com) or visit www.agtsi.com

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New challenges arise as equipment ages

Annual meetings of the 7EA Users Group typically attract just north of 100 owner/operators of GE 7B-EA engines from half a dozen countries and about the same number of exhibitors in the vendor fair. Important, too, is that about 40% of the user attendees are first-timers, year after year. The reason, of course, is that user-group meetings are invaluable training forums.

An online forum helps users stay in touch and get answers to their questions between meetings. This service, provided by Gregory Carvalho, Simplified Technology Co, and the steering committee (box), was implemented in summer 2003. Over the ensuing 14 years there have been more than 17,300 postings and registered users can access all in the archive section at http://ge7ea.users-groups.com. Presentations from the last 10 meetings also are accessible via the website.

The all-volunteer organization's scorecard identifies nearly 1200 units in the GE 7E fleet at more than 200 plants worldwide.

This report was developed from material presented at the 25th annual meeting in November 2016, virtually all of which is as current today as when the information was disseminated.

Stay connected with colleagues via the user forum at http://ge7ea.users-groups.com.

Steering committee

Syed Mehdi Ali, GM operations, Karachi Electric Supply Co
Dale Anderson, CT technician foreman, East Kentucky Power Co-op Inc
Tracy Dreymala, facility manager, San Jacinto Peakers, EthosEnergy Group
Ronald Eldred, plant manager, Rosemary Power Station, Dominion
Bob Grave, lead O&M technician, DTE Energy
Mirza Hossain, plant engineer, TransAlta Corp
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Guy LeBlanc, supervisor, Consolidated CT Plants, First Energy Corp
Tony Ostlund, combustion turbine technician, Puget Sound Energy
Doug Reves, outage coordinator, Arkansas Electric Co-op Corp
Randall Rieder, mechanical engineer, ATCO Power
Mike Vonallmen, maintenance supervisor, Clarksdale Public Utilities
Lane Watson, account engineer, FM Global

TILs critical to 7EA inspection success

The editors corralled Mike Hoogsteden, director of field services for Advanced Turbine Support LLC, which inspects scores of 7FAs annually, to learn how users can make their outages more productive and minimize the possibility of missing something that could contribute to a forced outage. He and his colleagues have opened every 7EA User Group meeting for the last several years with their presentation (updated annually), "What We Are Seeing in the 7EA Fleet During Our Inspections."

A good place to start, he said, is to review the OEM's Technical Information Letters (TILs) pertaining to the 7EA, take notes, and bring your questions to the next user-group meeting. Your colleagues and participating suppliers are the best source of advice on what's important and what's not, Hoogsteden added. The knowledge gained will help you plan the optimal outage for your gas turbines.

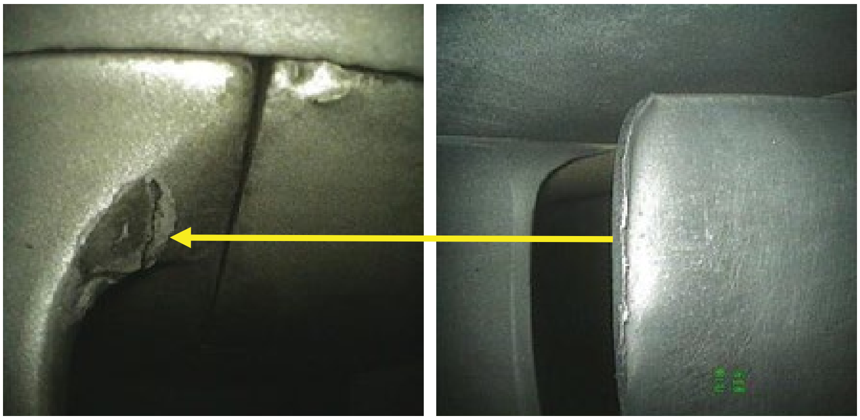
Five TILs he suggested users become intimately familiar with are these:

- 1884, "7EA R1/S1 Inspection Recommendations," which addresses the need to inspect R1 and S1 airfoils for possible damage caused by clashing—the unwanted contact between S1 stator-vane tips and R1 rotor-blade roots during operation.
- 1980, "7EA S1 Suction Side Inspection Recommendations," which advises users to inspect for crack indications on S1 vanes made of type-403 stainless-steel, regardless of whether clashing damage is in evidence on S1 and R1 airfoils.
- 1854, "Compressor Rotor Stages 2 and 3 Tip Loss," which suggests blending and tipping to mitigate the impact on availability and reliability of R2 and/or R3 tip loss. This TIL supplements information provided by the OEM in the O&M manual provided with the engine.
- 1562-R1, "Heavy-Duty Gas Turbine Shim Migration and Loss," which informs users on the need to monitor the condition of compressor shims and corrective actions available to mitigate the risks of migrating shims.
- 1744, "S17, EGV1, and EGV2 Stator-Ring Rail and CDC Hook Fit Wear Inspection," provides guidance on the repair of dovetail wear and suggests hardware and software enhancements available to mitigate the potential risk caused by operating conditions that promote such wear.

There are many more TILs that demand your attention, to be sure. They include the following:

- 1090-2R1, "Compressor R17 Blade Movement."


YF



1. **Clashing** is defined as contact between the leading edges of stationary vane tips (right) and the trailing edges of rotor blades in the platform area (left)

2. **Precise measurements** enable meaningful trending of damage progression year over year. Here, the distance between the trailing edge of the rotor-blade platform and the leading edge of the stator-vane tip is measured

- 1067-R3, "Stage 2 Bucket Tip Shroud Deflection."
- 1634, "Stages 2 and 3 Bucket Low-Speed Rub Prevention."
- 1313, "Stage 3 Bucket Tip Shroud Overlap."

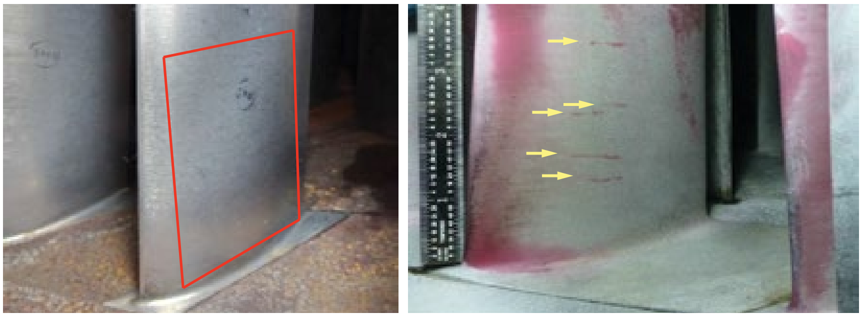
TIL 1884

It took years for the OEM to address clashing in a TIL (Fig 1). Hoogsteden believes Advanced Turbine Support was the first company to alert the industry to this phenomenon—back in 2006. TIL 1884 was issued in spring 2013. During the intervening years, Advanced Turbine Support worked closely with the users to share inspection data important to problem definition and solution.

Developments in inspection technology contributed to a better understanding of first-stage findings and provided information of greater value for the resolution of issues. Follow this timeline: 2008, implementation of visible dye inspections; 2009-2010, measurements added to documentation (Fig 2); 2011-2012, inspection documentation with trending data reveals an obvious increase in damage year over year. Plus, the implementation of eddy-current (EC) testing suggests an elevated level of risk to owner/operators.

TIL 1884 went beyond clashing, recommending the checking of stator vanes for cracking in the co-called "area of interest" (Fig 3). Lock-up of vanes in carbon-steel ring segments can cause higher-than-normal operating stresses, which the OEM says "reach a maximum on the suction side of the vane near the mid-chord location."

Cracking was first reported after TIL 1884 was published. In spring 2014, Advanced Turbine Support identified by way of dye penetrant two cracked S1 vanes in the same compressor. EC confirmed the findings. The



3. Area of interest is outlined on stator vane at left. Dye penetrant inspection identifies cracks in an S1 vane at right

company's inspectors found cracks in more machines over the next several months. This experience revealed that some cracks can be too fine to bleed penetrant, as recommended by the OEM; however, EC was able to find them.

Hoogsteden's suggestion to mitigate the possibility of serious damage from clashing and cracking is to perform an in-situ EC inspection to the trailing edges of all R1 rotor-blade platforms and the entire suction side of every S1 stator vane from platform to tip each peak-run season or every six months.

TIL 1980

TIL 1980, issued in January 2016, is viewed by the editors as an "addendum" to TIL 1884, addressing S1 vanes installed in legacy 7EAs (1996 and earlier) made of Type 403 stainless steel. This material is more susceptible to mid-chord cracking than the GTD™ 450 alloy used in the manufacture of vanes since 1997.

TIL1980 recommends inspection by visible means or by fluorescent dye to reveal suction-side cracks that might be present. Hoogsteden mentioned in his comments on TIL 1884 that these methods are inferior to EC for this purpose. He added that if the vanes are coated, visible or fluorescent dye penetrant inspections may not be dependable, nor have an acceptable probability of detection.

Regarding the effectiveness of ultrasonic (UT) inspection for this purpose, if coating degradation—such as disbanding—occurs, the value of UT could be compromised.

Advantages of EC Array include the following:

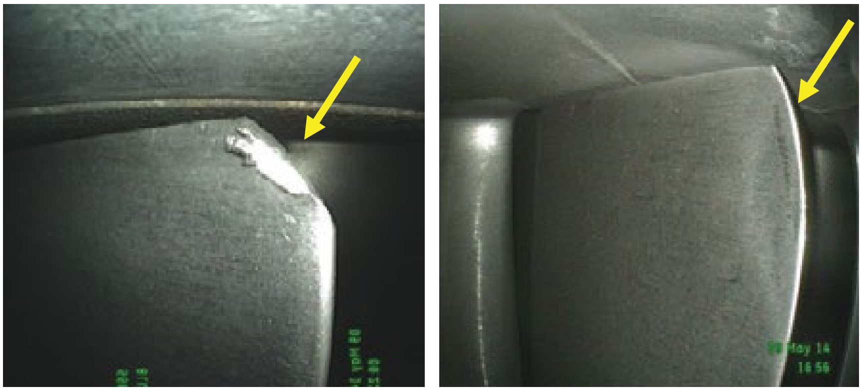
- It can detect crack initiation faster than UT.
- For coated vanes, the inspection equipment used by Advanced Turbine Support has the ability to maintain accuracy in flaw sizing (length and depth) for coating thicknesses of up to 0.125 in.
- Superior to in-situ liquid-penetrant inspection, which may miss small cracks.
- Two scans cover the entire suction face of a 7EA S1 vane.

Ultrasonic phased array can be used to supplement any suspect indications to confirm sizing of larger/deeper indications. But keep in mind that the UT probe does not cover the entire width of the stator vane—only about 0.75 in.

Hoogsteden went on to describe some of the damage found during its TIL 1884 and 1980 inspections, which go beyond what the OEM suggests. These are shown in Figs 4 through 8.

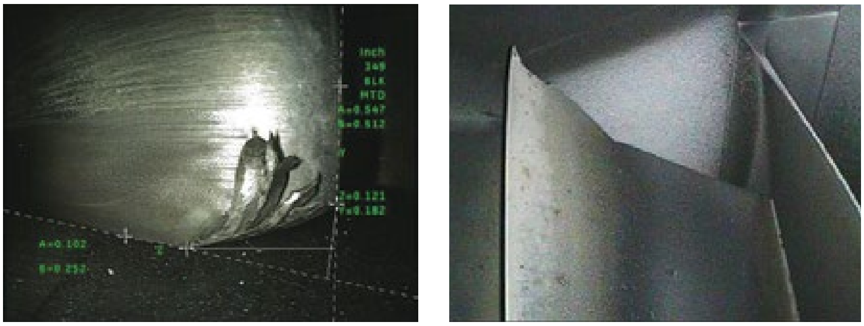
TIL 1854

TIL 1854, released in August 2012, informs owner/operators of E-class com-



4. Damaged S1 vane (left) was re-profiled with blending (right)

5. Tip was liberated from this S1 vane. Such potential damage is not addressed in either TIL 1884 or 1980



6, 7. Clashing damage experienced in the second (left) and third (right) stages remains unaddressed in a TIL

8. Downstream damage caused by liberation of metal from upstream airfoils

9. Rotor-blade tip distress is most commonly caused by rubs against the case during operation. Result may be discoloration or heat-affected zone at left or rolled metal at right

pressors about the blending and tipping of second- and third-stage rotor blades it recommends to mitigate the negative impact on availability and reliability caused by tip loss from heavy rubs (Fig 9) and/or corrosion pitting.

The OEM says fleet experience and engineering analysis have concluded that compressor rubs can be caused by casing distortion that progresses over time, and by hot restarts initiated between one and eight hours after shutdown. The latter causes critical clearances to decrease. Corrosion pitting, by contrast, can create a local stress concentration that may result in tip loss via high-cycle fatigue.

Hoogsteden pointed out that although this advisory does not address first-stage rotor blades, they too can suffer tip loss and should be included in your inspection regimen.

For R1 and R2 rotor blades showing signs of tip distress, Advanced Turbine Support recommends, at a minimum, a visible dye-penetrant inspection to determine if radial cracks have initiated (Fig 10). For R3 blades, the company recommends a minimum of a 360-deg roll with a close-up inspection of all blade tips at the same intervals.

The editors asked the field-service director why his company espouses such conservatism when the OEM doesn't. He said their recommendations are based on more than 1000 in-situ visible dye-penetrant inspections which have identified at least 64

10. Rotor-blade radial tip crack like that at left can be removed in-situ (first and second stages) in one shift as shown in the center photo. Allowing the crack to propagate can lead to a tip liberation like that at right, with consequent downstream damage

cracked rotor blades and about half as many tip liberations.

TIL 1562

TIL 1562, issued January 2007, is likely the most familiar of the advisories in this group of five because it is more than a decade old and shim liberation has been discussed frequently in user-group meetings and in CCJ. Fig 11 provides a quick review. The left-hand drawing is of a typical shim, center photo shows a shim protruding from the compressor, right-hand picture is of a shim blended flush to the case.

Hoogsteden recommends that users develop a shim map for their compressors to identify locations where shims might have been installed, then audit those locations for shims remaining. The map should be updated after every inspection. Shims protruding from the case by less than one-quarter of an inch should be monitored regularly. When the shim protrudes into the flow stream one-quarter of an inch or more it should be removed or ground off.

TIL 1744

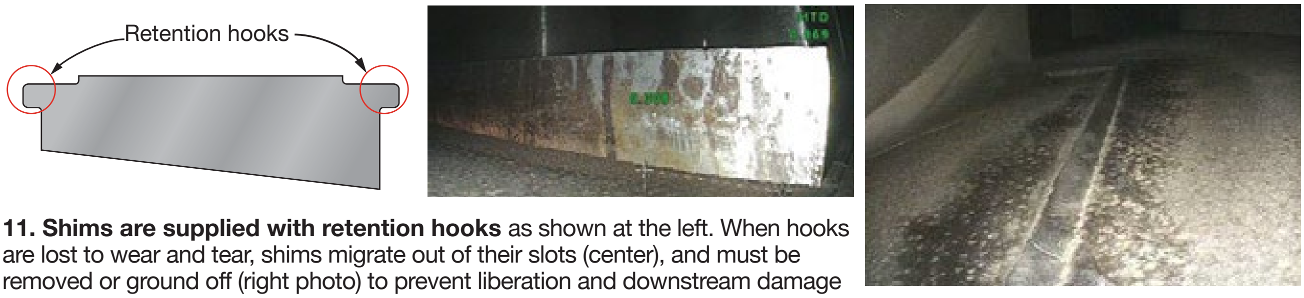
TIL 1744, issued September 2010, said 7EAs operating at part load when ambient temperature is less than 40F are at risk for major damage caused by the lifting of 17th-stage vane segments. As the segments lift up they damage the hook fits and turn into the rotating blades.

A non-OEM repair procedure described at a user group meeting attended by the editors involved milling of the damaged slot to accommodate 18-in. inserts. They were installed in the upper and lower halves of the case to retain the new vane segments. The inserts are held in place with setscrews. The user describing the procedure cautioned against considering it a permanent fix because a root cause analysis had not been completed.

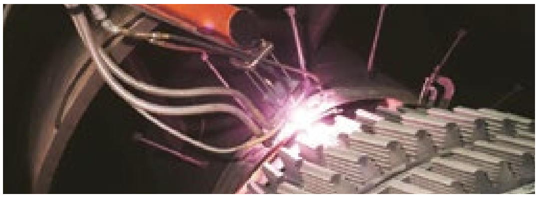
Mike Hoogsteden can be reached at mhoogsteden@advancedturbinesupport.com.

User presentations

Presentations by owner/operators are highly regarded at user-group meetings. The first-hand experience detailing how a particular job was conducted, what worked/what didn't, lessons learned, etc, can be invaluable to someone considering a similar project. Plus, there's the opportunity to ask questions and get straight-forward answers.



11. Shims are supplied with retention hooks as shown at the left. When hooks are lost to wear and tear, shims migrate out of their slots (center), and must be removed or ground off (right photo) to prevent liberation and downstream damage



Seven user presentations from the 2016 7EA Users Group conference, profiled below, are accessible to registered users on the organization's website. The titles reflect the diversity of material shared at a typical 7EA meeting—including HV electrical, generators, gas turbines, valves, etc.

- Bus replacement.
- TIL 1398 inspection of stator-end winding axial support system hardware.
- Hot-gas-path component life.
- 7EA maintenance strategies.
- Gas valve upgrade.
- 7EA compressor issues.
- Wrapper leak mitigation.

The bus-replacement presentation describes in photographic detail the retrofit of 15-kV/4000-amp circular non-segregated (non-seg) bus. More than seven-dozen images of the components and their assembly and installation, foundations, plus detail drawings, walk you through the project quickly. A companion presentation, made by Bruce Hack of Crown Electric Engineering & Manufacturing LLC, covering circular non-seg bus, switchgear and circuit breakers, also is posted on the 7EA Users' website. (Backgrounder: "High-voltage electrical emerges as a top interest area among GT users," CCJ 3Q/2016, p 70.)

TIL 1398-2, issued in March 2003, is applicable to all hydrogen-cooled, medium-size generators manufactured between July 1988 and September 2002. Its purpose is to remind users to inspect the tightness of the stator end-winding support hardware for loose, missing, and non-locking fasteners. Photos show damage done by liberated fasteners and how fasteners can be fixed in place with epoxy to mitigate the issue.

A table included in TIL 1398-2 identifies machines susceptible to loose fasteners (such as the GE 324 steam turbine/generator, 9A4, and 7A6), gives part numbers of interest, etc.

HGP component life reflects the experience of three 7EAs, each having a nominal 20 years of cogeneration service. The baseload units had operated roughly 165,000 fired hours and had fewer than 200 starts, respectively. Inspection schedule was combustion every other year, HGP every four years, and major every eight years.

Buckets:

- First stage. DS GTD-111, 12 cooling holes, GT 33 coating and TBC. Typically repair at HGP and replace at about 100,000 fired hours. Longest demonstrated run was 105,000 fired hours.
- Second stage. IN-738 and GTD-741, 10 cooling holes, scallop shroud, cutter teeth. Typically repair at HGP or major and replace at 100,000 fired hours. Longest demonstrated run on IN-738 buckets with eight cooling holes was 100,000 fired hours.
- Third stage. U-500, cutter teeth. Typically repair at HGP or major and replace at about 135,000 fired hours. Longest demonstrated run was about 140,000 fired hours.

Nozzles:

- First stage. FSX-414 with full MCrAlY and TBC coating. Repair at HGP and replace when no longer cost-effective to repair. Longest demonstrated run expected at next outage would be 140,000 fired hours. At the time of the presentation a set of nozzles with about 130,000 fired hours was at a shop for repair.
- Second stage. GTD-222 with MCrAlY coating. Repair at HGP; replace when no longer cost-effective to repair. Longest demonstrated run expected at next outage would be about 162,000 fired hours.
- Third stage. GTD-222. Repair at major; may replace at 200,000 fired hours or when no longer cost-effective to repair. Original sets of nozzles still in machines with about 165,000 fired hours of service and two repair cycles.

Shroud blocks:

- First stage. HR-120 with cloth seals.
- Second and third stages. Honeycomb.

7EA maintenance strategies. This presentation, rated "must review" by the editors, offers valuable insights based on the extensive experience of both the user and his company. The power producer has 51 7EA peaking units (no baseload) installed at six stations; 39% of the engines have Type 403cb stainless steel S1 airfoils, the remainder GTD 450. The strategies discussed had to do with S1 failure mitigation, post-outage performance loss, and rotor end-of-life.

Regarding S1, the speaker first reviewed inspection options, then discussed the company's original failure-mitigation program and why some tweaking was required. He then explained the updated plan and reviewed ongoing development of yet another mitigation plan (referred to as the "alternative" plan) based on the efforts of EPRI and its members.

TIL 1884. The speaker addressed TIL 1884 first, noting that the OEM recommends dye penetrant for NDE. The user's engineering department does not agree, believing greater accessibility is needed for a proper dye-penetrant inspection, excessive application of dye-penetrant chemicals is required, and results are inconsistent. It recommended eddy current (EC), finding it is easier to implement, results have less variability, and helps identify crack indications at a higher success rate. If an indication is found, the engineering department recommends confirmation with FPI (fluorescent penetrant inspection).

For more on TIL 1884 and what others think about the use of dye penetrant to achieve its goals, see the section above focusing on 7EA compressor inspection.

Continuing, the speaker said his company embraces 100% borescope inspection of the R1/S1 area for clashing and of recording clashing damage, if found, with photos and measurements. Mapping of clashed stators also is done.

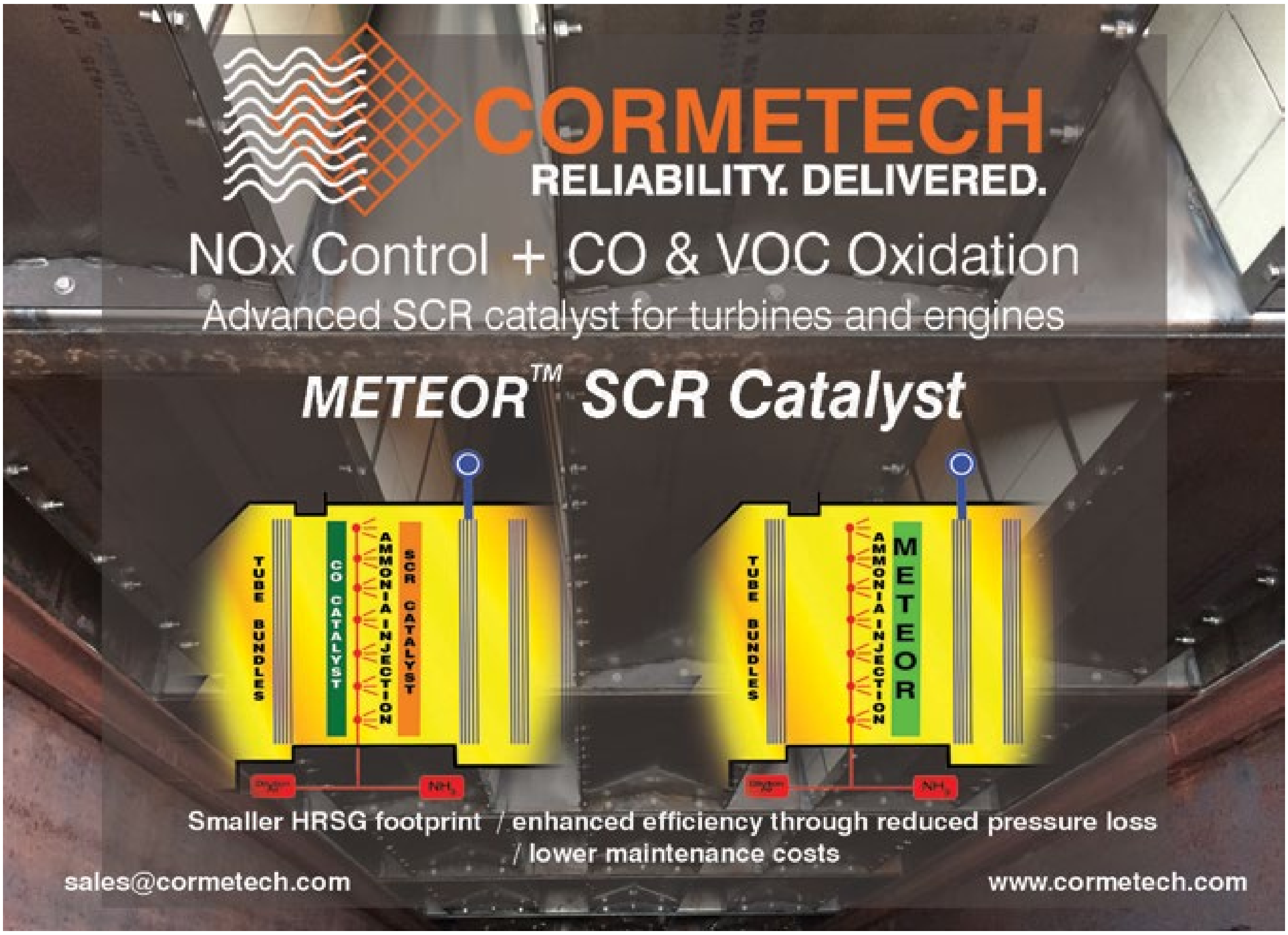
Here's how the speaker summarized the company's S1 failure mitigation observations and efforts:

- Corrosion of carbon-steel ring segments reduces vane damping and increases stator stresses if a rotating stall is experienced during startup and/or shutdown.
- At the time of the presentation, S1 failures associated with GTD 450 were airfoil tip liberations; with Type 403cb stainless steel, root liberations. The latter failures can occur with no clashing.
- TIL 1884 recommends dye-penetrant inspections only for units experiencing clashing. It does not address units with 403cb airfoils which may have crack indications without signs of clashing nor does it offer a method for determining the magnitude of indications.
- The speaker's company has qualified EC as its preferred method of S1 inspection.
- The power producer also evaluated its 7EA fleet based on S1 inspection results compared to operational profile and parameters, finding no correlation to predict S1 crack initiation and when an S1 failure would occur.

Post-outage performance loss. A relatively common complaint of owner/operators presenting on their recent major inspection experience is the deterioration of performance following restart. The editors have heard this at several user-group meetings with no particular OEM or third-party vendor singled out.

The 7EA speaker discussed performance loss after a combustion inspection (rare) and HGP. The typical finding: Pre-outage NO_x margin was different that post-outage. Engines were tuned to lower firing temperatures to assure environmental compliance. The result was a 3- to 5-MW decrease in output. The user's company, the OEM, and various third parties believe fuel/air variation explains the performance issues.

The owner has been flow-testing liners and comparing results against post-outage performance to determine



allowable flow tolerances—this to maintain firing temperature at the highest possible level and prevent loss of top-end megawatts. Another objective is improved repair processes to achieve repeatable results with vendors and reclaim lost output.

Rotor end of life (EOL). The speaker explained the following four options for rotor failure mitigation:

1. Replace the existing rotor with a new or refurbished one. This is the highest-cost/lowest-risk option but one seriously worth considering if you have majors for multiple units in the same year.
2. Refurbish to regain half a lifecycle. This is a less expensive but higher-risk alternative than the first option.
3. Replace key rotor components to achieve life extension—less expensive than the first two options with less risk than the second.
4. Inspect but do not repair may be the option of choice depending on the strategy for unit retirement. This is the lowest-cost/highest-risk option of the four presented.

The presenter closed by listing critical items to consider before formulating an EOL evaluation plan and selecting a vendor:

- Availability of rotor discs (OEM or third-party manufactured) if one or more do not pass inspection.
- Capability of the EOL contractor for replacing one or more discs—if necessary.
- Candidate contractor's rotor inspection capabilities and experience.
- Candidate contractor's EOL analytical and engineering capabilities.

The gas-valve upgrade presentation provides some project photos, data, calibration settings, operating parameters and other information of value to users considering migration from hydraulic actuation to electric. This information, combined with the experience from a recent Frame 5 fuel-valve upgrade (CCJ 2Q/2017, p 95), should help any owner/operator considering a similar project.

7EA compressor issues. A hands-on engineering manager discussed issues experienced during execution of TIL 1884 recommendations. If clashing is in evidence, removal of S1 vanes may be necessary. Options for removing them: Pull the rotor or leave the rotor in place and try to push the lower-half ring segments out of the case. The presentation illustrates how the OEM's stator removal tool handles the task with the rotor in place.

The speaker said the special tooling was successful on both machines serviced, but the task was challenging. On one unit, the hydraulic power unit developed 3100 psig to free up segments with heat and quench. The other unit required 5200 psi to break loose the ring segments.

Other discussion points: Replacement of a failed R17 blade (TIL 1346), shim pinning according to TIL 1562-R1, and turbine shell-to-exhaust frame slippage (TIL 1819-R2).

Registered users can access the presentations summarized above on the organization's website at http://ge7ea.users-groups.com.

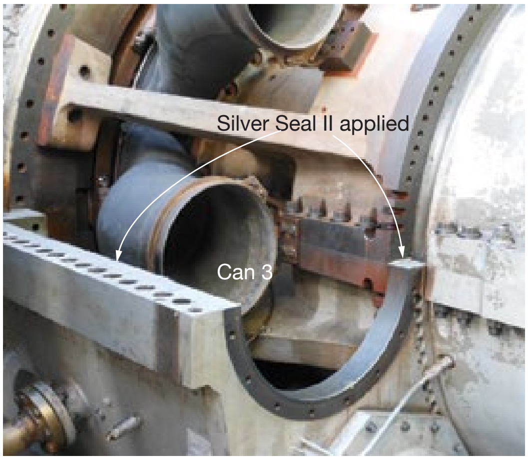
Wrapper leak mitigation

It's the rare 7EA Users Group meeting that does not have some discussion on *attempts* to mitigate leakage from combustion-wrapper joints. "Attempts" is italicized because success has been elusive. Jason Hampton, who chaired the steering committee until exiting the user side of the industry early in 2017, presented on the documented, deeply rooted frustrations experienced by owner/operators since before the millennium, to eliminate leakage at casing joints—the four-way joints in particular.

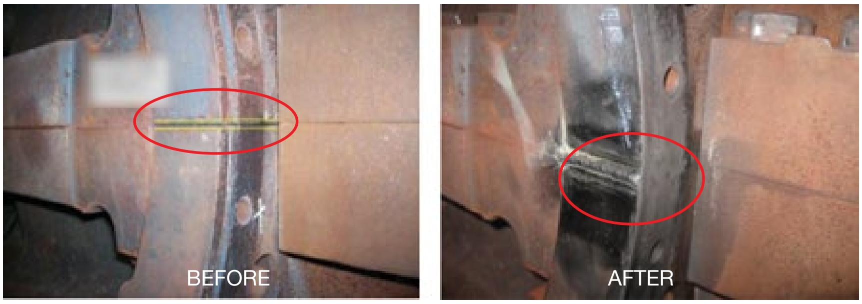
Hampton generally attributed leakage to an OEM design issue, which, in his opinion is related to insufficient clamping force in suspect areas. A contributing factor is casing distortion suffered during operating regimes not envisioned by designers.

He invested a considerable amount of personal time to peruse the 7EA User Group's discussion-forum archives hosted on its website at http://ge7ea.users-groups.com and to survey owner/operators about their experiences. Here are a few of the comments, shared in several discussion threads on the forum from 2004 through 2012; most have been edited to reduce word count:

- Split-line gaps on 7EAs are common and to my knowledge GE does not offer an effective means for eliminating wrapper leakage. Sealants have been tried with limited success.

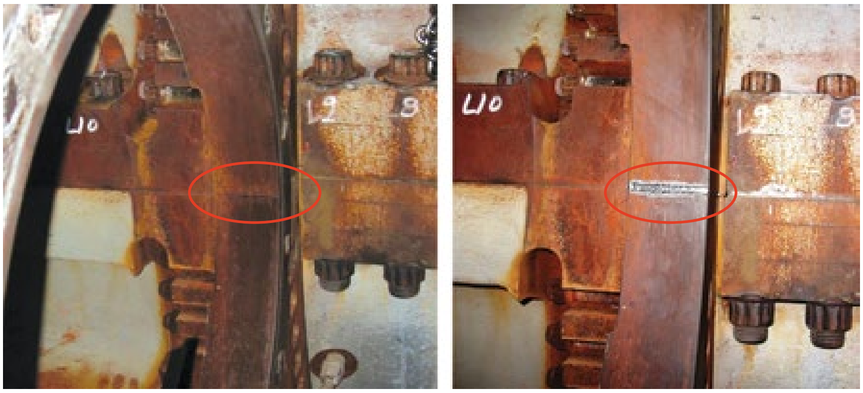


12. Use of a sealant and good bolting practices is the simplest way to mitigate wrapper leaks . . . temporarily



13. Welding of wrapper joints is an alternative leak-mitigation method. Here the inner split-line gap is in evidence (left) with Can 3 removed. After welding (right) the weld area must be machined even with the flange face

14. Some users say welding strips of plate to the outside horizontal joint is the most effective way to eliminate wrapper leaks



15. Peening is an alternative to welding for mitigating wrapper leaks

- We are experiencing split-line leaks on all six of our Frame 7s (five purchased in 1989, one in 2001).
- We ensured that the OEM torque sequence/procedure is being done correctly. Result: Leaks slowed at first. Grooved the upper casing on one unit and installed a keyway in the groove; this helped for about eight months. Tried several different sealers, but they were effective only for a short period.
- On our recent major inspection, we followed jacking instructions to the letter. Plus GE executed the work and the field TA (technical advisor) was one of the best in the business. We still have leaks.
- Leaks on the turbine/wrapper horizontal joint were mitigated by welding straps on the outer casing. Further investigation revealed internal leaks by the combustion cans.
- The original key-way mod was performed on one unit in 2006 but we still have a leak on one side at the horizontal joint. The bottom line: Money was not well spent.
- We tried peening, re-torqueing, welding, and the seal-key mod with little success. The unit where the original seal key mod was installed leaked worse after the repair than before.
- Peening over mating areas reduced the amount of air leaking by the joint but did not eliminate leakage.

Hampton then reviewed the various leak-mitigation methods attempted by the OEM, contractors, and users with marginal success. Here are the editors' notes from that portion of the presentation:

Sealants, standard bolting practice. Research suggested that a sealant and proper bolting should provide temporary leakage relief (Fig 12). However, expect fluid temperature and pressure to erode or blow out the sealant over time. Obtain appropriate torque values from GE spec 248A4158, "Bolt & Stud Torqueing."

Among the sealing products suggested: Silver Seal II, a non-hardening fibrous paste that flows into rough or irregular surfaces and expands under heat, curing to a leathery-like consistency. Manufacturer IGS Industries, Meadow Lands, Pa, claims it will not crack from thermal cycling or vibration. Two additional high-pressure/high-temperature sealing compounds suggested by users include Esco Products Inc's (Houston) Copaltite and ICS Industries' Turbo-R and Turbo-50.

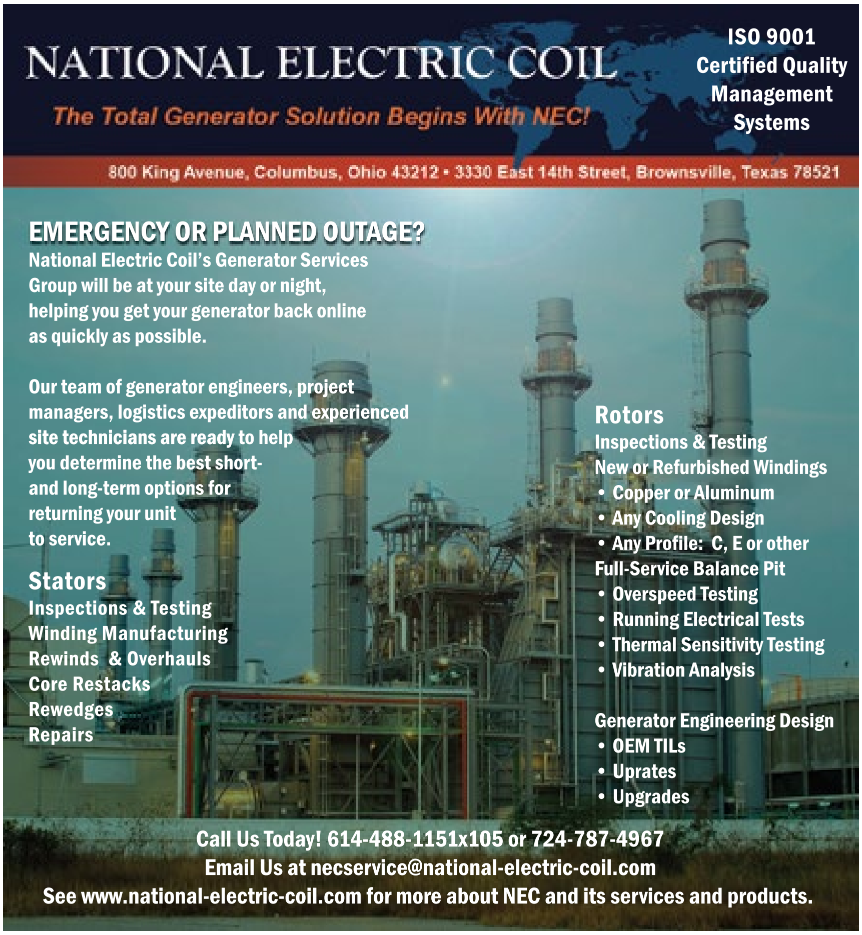
Weld wrapper horizontal joints together. This is a relatively straightforward process with split-line cans 3 and 8 removed (Fig 13).

Weld strips of plate steel on the outside of horizontal joints. This, too, is relatively straightforward as Fig 14 shows.

Peen horizontal joints after proper tensioning and removing combustion hardware.

The goal of peening is to spread metal over the joint area where leakage is occurring (Fig 15). Ways suggested for doing this:

1. Use an air hammer with a punch attachment.
2. Strike the casing along the length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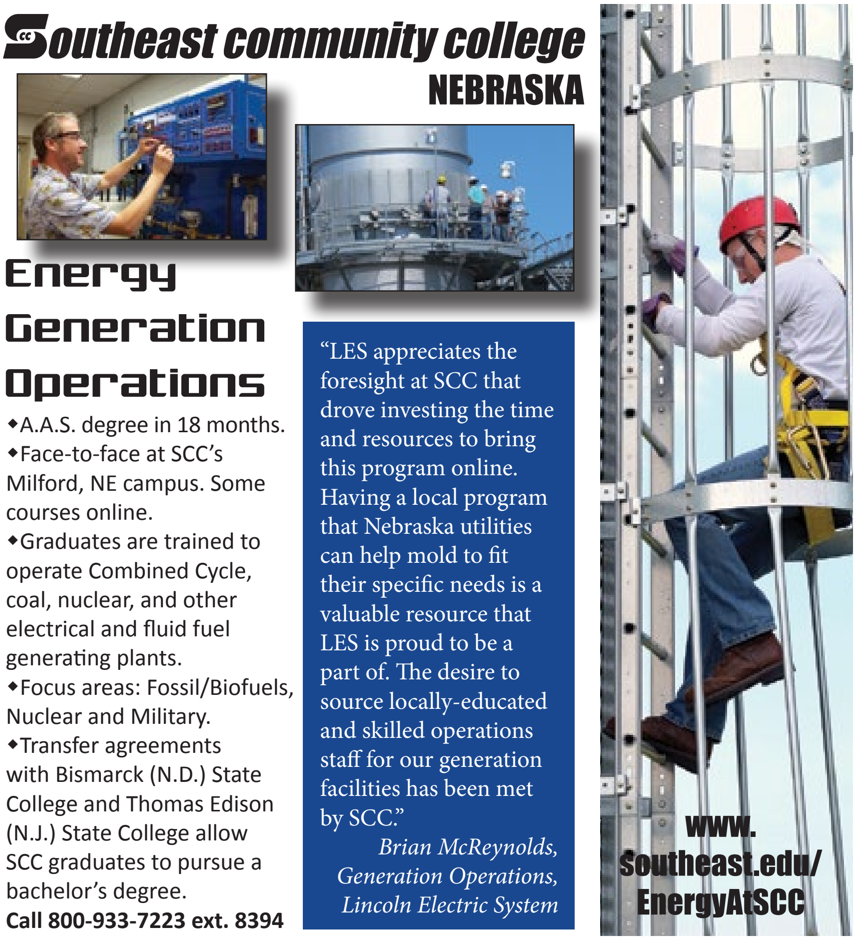
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Brian McReynolds, Generation Operations, Lincoln Electric System

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16. The OEM's "original" seal key modification was rated by users as time-consuming and costly to do and "unsuccessful"

17. Use of angle iron to seal the right side of the wrapper was the solution for the most serious leak on this unit. The angle iron was machined to fit snugly against the combustion can cover

of the joint, both above and below the joint, using the ball end of a ball peen hammer.

3. Hammer and chisel along the length of the casing both above and below the joint.

Perform "original" seal key mod. This "solution" calls for machining slots in the outer wrapper (Fig 16). Lower-half horizontal joints are machined; the upper half is flipped and supported for the machining activities. Next, install seal keys into the lower-half horizontal joints. The time-consuming and costly mod was said to offer only marginal benefit. Industry consensus is that this is not an effective method for sealing the wrapper.

Install custom shims in horizontal joints. Procedure is as follows:

- Hone horizontal joints.
- Install the upper-half wrapper and torque.
- Measure gaps along the horizontal joints.
- Remove the upper-half wrapper.

- Install shims in gap areas.
- Reinstall/torque the upper-half wrapper.

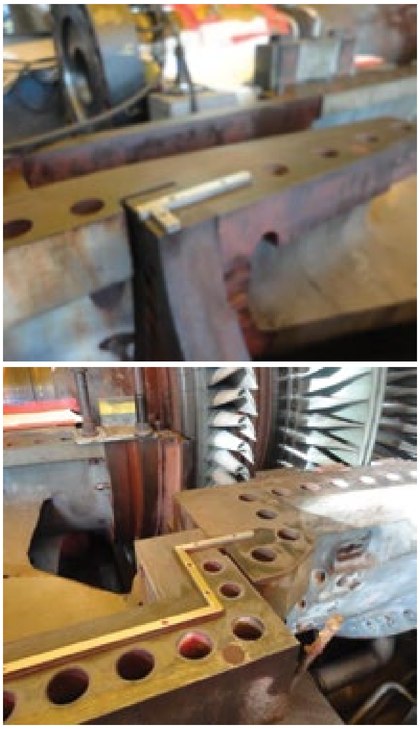
Retrofit unit with HYTORC tensioning hardware. The three-piece fastener from UNEX Corp's HYTORC Div is a direct replacement for any type of helical nut. The main reason for its introduction to the 7EA fleet was to reduce the time for bolting/unbolting during outages. The precise bolt tensioning offered by this alternative also was believed to offer more precise torqueing and better flange tightness. However, clashing experienced between the tooling and casing in some areas did not allow for HYTORC nut installation.

Install angle iron at wrapper outer joints. This method was implemented on the right side of the unit described in Fig 17 because it was the only area of significant leakage after installation of the original seal key mod. Think of this as a unique solution to a unique problem.

Perform "new" seal key mod to the compressor discharge case and wrapper.

This relatively complex mod is performed only by GE (Fig 18). It is said to be expensive—perhaps into the mid six figures. No users with first-hand experience were found by Hampton in his research.

Jason Hampton can be reached at jason.hampton@yahoo.com.



18. The user jury is still out regarding the effectiveness of the OEM's "new" seal key mod (refer to Fig 5). It is said to be pricey

Ferndale

Ferndale Generating Station

Owned by Puget Sound Energy

Operated by NAES Corp

270-MW, gas fired 2 × 1 combined cycle located in Ferndale, Wash

Plant manager: Tim Miller

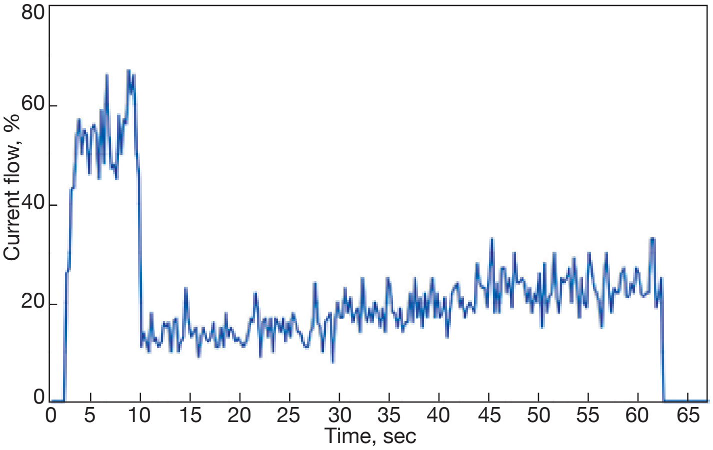
Monitor spark-plug performance to prevent failed starts

Challenge. The ignition systems for Ferndale Generating Station's 7EAs rely on spark plugs to initiate combustion. The engine model installed has two independent ignition circuits, each with its own spark plug. A unit will start as long as one circuit works properly. If both plugs fail to deliver an adequate spark, the unit won't start.

Ignition-system components are inspected and refurbished during turbine inspections as a preventive-maintenance item. If degradation between inspections results in failure of both spark plugs, the telltale means of detection is an unsuccessful start resulting from a "failure to ignite," as indicated by a control system alarm.

Although this potentially indicates a spark-plug system malfunction, it's not an absolute indicator, as other problems can trigger a "failure to ignite"—for example, issues with fuel, air flow, crossfire, or controls. The only way to determine whether an individual spark plug is functioning properly is to remove and test it.

Dissatisfied with this reactive and tedious approach, staff looked for a means of assessing spark-plug health in-situ on an ongoing basis—this to avoid costly failed starts, reliability impacts, and impromptu repairs. After researching the possibilities, Team Ferndale found no industry solution that would achieve this objective.



2. Current flow versus time during ignition sequence reflects a properly functioning spark-plug circuit

Solution. In 2013, an employee theorized that the amount of current flow in the spark-plug cable during ignition should indicate whether the spark plug is functioning properly. If current flow in the cable between the ignition transformer and plug could be measured in-situ, staff could determine if each circuit was delivering an adequate spark without having to pull and test the plug. Using this diagnostic, plant personnel could be alerted to an ignition-circuit failure regardless of whether it stemmed from a shorted, open, or dead circuit.

1. Current transformers are installed in the ignition-transformer cabinet

To prove the theory, staff began by bench-testing a properly functioning spark-plug system in Ferndale's shop to ascertain the characteristics of a healthy current level during an ignition sequence. Variants of "good" spark plugs—new, rebuilt, and used—were tested and found to produce a similar spark-intensity level. From this, personnel derived the expected current of a properly functioning plug.

Next, the O&M team examined how the current changed in various failure modes of spark plugs and cables that jeopardized adequate spark generation—for example, electrode in contact with spark plug tip, broken electrode, damaged insulators—as well as numerous ways to short or kill the circuit. Result: In all cases, the current flow was significantly reduced compared to that of a healthy circuit. In the case of a short circuit, current flow quickly decays to zero following an initial increase.

To measure spark-plug cable current flow in the installed system, the plant purchased small current transformers which provide a 4- to 20-mA current loop output proportional to current flowing in the cable. They were installed in the unit's ignition-transformer cabinet with a spark-plug cable fed through them (Fig 1). Each transformer's 4-20-mA output was wired to the respective GT's Mark V control system and the input signal scale was configured thusly: 4 mA = 0%, 20 mA = 100%.

While the level remains above 8% for Ferndale's healthy case (Fig 2), staff opted to use a low-level alarm point of 4% to allow for variations in spark intensities over time and avoid nuisance indications. The control system was configured to monitor spark-plug cable current during the ignition sequence and to generate an alarm when the current drops below the designated 4% alarm level for more than three seconds. This alarm remains uncleared until the operator performs a master reset on the respective GT's Mark V.

When a 7EA is shutdown, the plugs are positioned with their tips penetrating into the combustion can liner ID. In the initial phase of a startup, the control system performs a purge by cranking the GT without injecting fuel. This admits fresh air into the downstream spaces (GT exhaust and HRSG) in order to remove any combustible mixtures that may have accumulated.

After the purge is complete and the unit is at firing speed, the control system energizes the ignition circuits for 60 seconds while fuel is admitted to initiate combustion. When proper ignition is achieved, the control system gradually accelerates the unit to operating speed.

During acceleration, pressure builds in the combustion cans and the spark plugs auto-retract by overcoming insertion spring pressure. They remain retracted while the unit is operating. During the subsequent unit shutdown and coastdown, the pressure in the combustion can reduces to a point where spring pressure is able to reinsert the spark plug, preparing it for the next unit start.

Staff configured the system to passively monitor spark-plug performance during every start, so no operator action is required. When it identifies a potential spark-plug malfunction and generates an alarm, the operator notifies appropriate personnel so the spark plug can be removed and replaced at the next unit shutdown opportunity.

Results. During the three years the systems have been in service, they have proven extremely effective in identifying ignition-circuit issues, generating around 10 alarms collectively. In every case, when the corresponding spark plug was removed and tested, personnel confirmed that a malfunction had occurred resulting in a degraded spark or no spark at all. Without this system alerting staff to developing issues, Ferndale could presumably have incurred several failed starts along with the associated impacts.

Participants (all NAES):
Tim Miller, plant manager
Marty Stangland, I&E technician
Ferndale staff

Eagle Point

Portable CO_2 cylinder skid eliminates ergonomic hazards

Eagle Point Power Generation Facility

Owned by Rockland Capital Assets

Operated by NAES Corp

250 MW, gas-fired 2 × 2 combined cycle located in Westville, NJ

Plant manager: Frank Meade

Challenge. Reduce the potential for personal injury in the handling of CO_2 cylinders stored at each of the plant's hydrogen-cooled generators for routine and emergency purging.

When individual cylinders are emptied, new ones must be moved from a storage area located far from the point of use. Each 175-lb cylinder has to be lifted and maneuvered into position inside the storage cabinet provided for each generator (Fig 1). Between eight and 12 cylinders are used during a routine purge.

This creates several hazards—in particular, ergonomic issues associated with awkward body positioning and pinch points. Plus, with relatively few operators on shift, the existing procedure can take excessive time in an emergency situation.

Solution. The operations department's Don Stasio developed a solution by rethinking the existing cylinder handling system. He and co-workers designed a six-cylinder crate which can be moved by forklift. A 10-ft hose is used to connect cylinders in the crate to the generator for purging (Fig 2).

The crate remains outside the cylinder compartment during purging. Two cylinders are retained in the cabinet for emergency use. After a purge is completed, the empty cylinders are moved back to the storage area by forklift.

Results. The cylinder handling system is performing as intended, mitigating injury risk to plant personnel.

Project participants:
Don Stasio, plant operator
Jeff Hawksworth, maintenance planner
Frank Meade, plant manager

1. Two CO_2 cylinders are retained in the storage cabinet at the generator for emergency use (left)

2. Hose connects six-pack of CO_2 cylinders to the purge system (below)

Compelling program makes this annual meeting a top priority

It's time to decide which conferences you will attend in the first quarter of 2018, if you haven't already done so.

The first major user group meeting of the year is the 501F Users Group conference and vendor fair at the Hyatt Regency Grand Cypress, in Orlando, February 25 to March 1. CCJ editors rate this is a "must-attend" event for owner/operators of 501F engines.

The all-volunteer organization's steering committee (sidebar) has posted the agenda on the group's website (scan QR code Agnd on p 56 with your smartphone or tablet). This year's program has many of the same compelling elements as the information-rich 2017 conference, which ran four and a half days and included the following:

- User presentations on issues identified in the fleet and solutions implemented, as well as on experience with upgrades to improve unit performance.
- User-only roundtables promoting open discussions and short presentations by owner/operators on safety, combustion section, hot-gas section, inlet and exhaust, compressor, rotor, generator, and auxiliaries. The roundtables typically run an hour each.
- Special closed sessions, ranging from two to four hours each, by major products/services providers. Mitsubishi, PSM (Ansaldo Energia SpA), Siemens, and GE are on the 2018 agenda.
- Vendorama program. Last year, 38 companies made 41 technical presentations ranging from 30 to 50 minutes each to bring users up to date on products/services of interest to the 501F community. The ink was not quite dry on the 2018 lineup when CCJ went to press in mid-December.

  The 2017 program matrix—seven time slots in each of six rooms, running from 9:30 a.m. to 4:00 p.m.—allowed each attendee to participate in up to seven presentations. Note that Vendorama presentations are vetted by the steering committee to ensure a technology focus and to eliminate blatant sales messages.
- Vendor fair, following the Vendorama program on the first day of the meeting, which last year provided users the opportunity to peruse the offerings of 89 vendors. The 2018 exhibition will be similar.

USERS 501F GROUP

2018 Conference and Vendor Fair

Hyatt Regency Grand Cypress
Orlando, Fla
February 25 – March 1

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If you have never attended a 501F Users Group meeting, make the 2018 conference your first. The following report, based on information aggregated from the 2017 meeting, offers a glimpse at the knowledge you will gain by participating. Material like this, possibly vital to your plant's future success, is not available in one place anywhere else (QR Reg).

Important note for shy O&M personnel: The 501F Users Group is a collaborative organization and first timers (about half of the 125 to 150 attendees typically expected at an annual meeting) are accorded the same respect as veterans.

User presentations

Three user presentations were selected by the editors for inclusion in this report. All have elements of value to most 501F owner/operators; plus, they illustrate the value of participating in the organization's meetings.

Turbine blade-ring burn-through

Vital stats: 2 × 1 combined cycle powered by 501FD2 gas turbines commissioned in 2001 with an average of nearly 60,000 equivalent operating hours per engine and nearly 3200 equivalent starts.

Incident profile: One engine tripped on blade-path spread; a high-temperature alarm was received for disc-cavity (DC) 2 prior to the trip.

Initial findings:

- Event lasted three minutes.
- Combustion seemed stable.
- Inlet-bearing vibration increased slightly during the event.
- Blade-path thermocouples (TCs) 1 and 16 increased to 1185F and then dropped to less than 1000F, causing

the trip.

- Coast down took 23 minutes, only slightly longer than normal.
- Turning-gear amps were normal after coast-down.

Operators decided to spin-cool the unit. After the gas turbine was off turning gear, inlet guide vanes were inspected for looseness, TC2 was found melted, and debris was in evidence when the exhaust door was opened. A borescope inspection revealed significant turbine damage. A crawl-through of the combustor case confirmed burn-through of two blade rings (Fig 1); the unit was disassembled.

Damage assessment:

- Combustion hardware was fine.
- R1 vanes had minor impact damage at the trailing edge.
- Tips of R1 blades were worn off and there was evidence of trailing-edge impact damage.
- Two segments of the R1 ring segment were missing.
- The breech in the R1 blade ring was about 10 in. in diameter.
- R2 vanes revealed local melting.
- R2 blades suffered impact damage.
- There was no damage to the R2 ring segment.
- Downstream impact damage.

Root-cause analysis incorporated hardware inspection, metallurgical analysis, and review of operating data and of inspection reports. Investigations revealed the following:

- Metallurgical analysis showed nothing out of the ordinary.
- R1 vanes had been repaired previously and areas of erosion had been repaired during the last outage.
- R1 ring segments were installed new, not refurbished.
- Assembled blade-tip readings were within spec for non-VGP (Value Generation Program) components.
- Hardware had 569 equivalent starts and 12,700 equivalent operating hours at the time of failure.

1. Blade ring was destroyed by hot gas following the liberation of ring segments

- Previous borescope inspections identified a rub in the area where the ring segments were missing. The rub had removed the thermal barrier coating and smeared base metal; however, the OEM considered the damage low risk and approved a return to service.

An operational review identified the following changes in the engine over time:

- One week prior to the event, a step change occurred on the blade-path TC—7-deg-F warmer on BP TC1. The monitoring center was asked to watch for a worsening condition. No vibration change was noted.
- Baseload output dropped by 1 to 2 MW over the week prior to the event. But operators would not have detected this on a cycling unit with varying loads.
- While the temperature in DC2 remained stable, the cooling valve opened gradually throughout the week leading up to the failure.

So, what happened? No single root cause was in evidence and the findings were relatively inconclusive. A timeline of events during the week leading up to and including the trip was difficult to compile based on operating data.

Investigators believed that the combination of blade-tip rubbing on the ring segment which removed TBC and

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GE2
MH1
MH2
MH3
MH4
Presen
PSM1
PSM2
PSM3
PSM4
Reg
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SLZ2

potentially reduced cooling, and vane shroud erosion which reduced ring-segment leading-edge cooling, likely caused erosion of the ring segment and isolation segments—thereby allowing liberation of the ring segments. After the ring segments liberated there was no protection for the blade ring from hot gas.

Experience with GT uprate, exhaust cylinder fix

Following up on key topics from the 2017 meeting, the editors caught up with Adam Sensenig, who made two presentations at last February's conference in Reno, Nev. During a mid-November visit to Dynegy Inc's Ontelaunee Energy Facility in Reading, Pa, Sensenig, Ontelaunee's plant engineer, provided additional details on the recent uprate of the facility's two gas turbines and a "fix" for cracking of strut shields in the two-piece exhaust cylinder, a 501F fleet-wide issue.

As background, Ontelaunee is a 2 × 1 combined cycle which went commercial in 2002, and features 501FD2 machines. In recent years, the plant has been operating primarily at base load, with an average capacity factor of 87% for 2016. In 2014, the plant contracted with PSM for a long-term service agreement (LTSA) and the company's GTOP 6 upgrade package.

GTOP (Gas Turbine Optimization Package) is PSM's non-OEM performance-enhancement offering for the 501F market. The uprate increases mass flow to 501FD3 levels. By signing with PSM, the plant avoided the exhaust cylinder and R4 blade-ring replacements characteristic of the OEM's uprates.

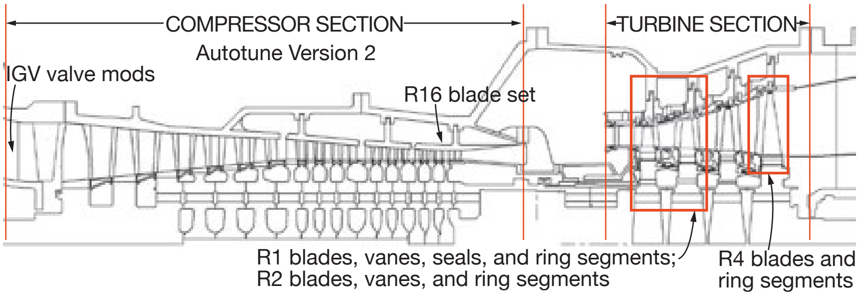
The plant was first out of the gate with GTOP for the 501F. About 18 months transpired between project kickoff and completion. Overall, Ontelaunee gained 7% in net plant output with a 1.7% improvement in net plant heat rate. It was able to maintain a large portion of the increase in output by way of an aggressive online water-wash program.

Five upgrade elements. Sensenig breaks down the uprate modifications into three areas: new blade-path components that take advantage of prevailing metallurgical, coating, and design improvements; modified inlet-guide-vane (IGV) actuators to boost air flow by extending stroke length from minus 2 to minus 6 deg; and by adding auto-tune capability (Fig 2).

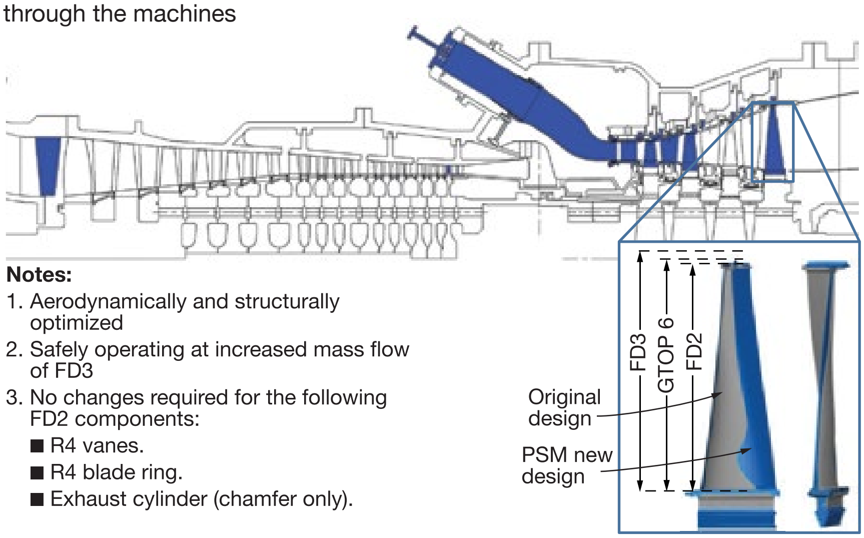
Overall goals were to increase the air/mass flow through the turbine, reduce the amount of air required for blade path cooling, and achieve a higher total exhaust temperature.

Regarding the blades, the R16 compressor blades feature a different airfoil shape, and were a "drop-in" replacement. The R1 blades, vanes, and seals were modified to decrease cooling-air flow, as were the R2 blades and vanes. The last-stage R4 GT blades are about a ¼-in. taller to accommodate the higher mass flow and additionally reduce exhaust swirl (Fig 3). R3 blades and R3 and R4 vanes remain the same. Of these, Sensenig credits opening up of the IGVs and the taller R4 blades as having the biggest impact on the results.

The IGV actuator mods could be accomplished by replacing the actuator or modifying existing ones. Onte-



2. Increasing stroke on the IGV actuators, and modifying the R4 turbine blades, proved to be the more significant of the modifications with respect to improved performance. Basic objective was to increase air and mass flow through the machines

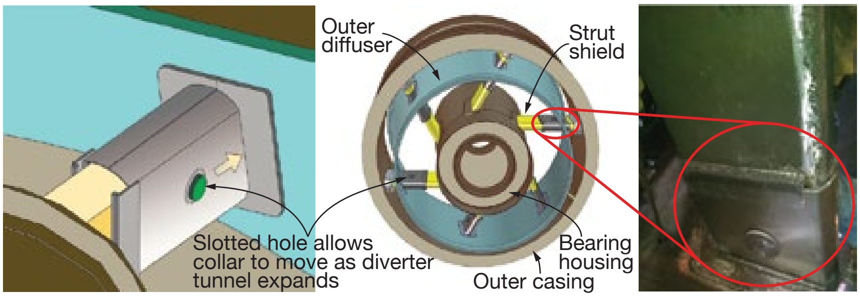


Notes:

1. Aerodynamically and structurally optimized
2. Safely operating at increased mass flow of FD3
3. No changes required for the following FD2 components:
    - R4 vanes.
    - R4 blade ring.
    - Exhaust cylinder (chamfer only).

3. New R4 blades safely handle the same higher mass flow as would be expected from an FD3 upgrade, while avoiding costly additional component replacements


FORUM



4. Collar overlay on the original strut shields for the two-piece 501F exhaust-cylinder housing addresses the thermal-expansion issue at the root of many mechanical issues with this component

launee had one spare actuator which was modified for one unit and the plant purchased a new actuator for the other GT.

Auto-tuning, through the combustion dynamics monitoring system (CDMS) and PSM's Autotune Version 2, assures flame stability—and emissions stability—under all operating conditions. One consequential saving with the auto-tune, says Sensenig, is that the plant no longer has to call someone out to adjust the controls for seasonal ambient conditions.

Attention to BOP. The upgrade did require the plant's (and its third-party engineers) careful attention to balance-of-plant (BOP) impacts. PSM conducted the plant assessment up to through generator output but only guaranteed simple-cycle GT performance. Some BOP impact examples:

- The four-way joint where the turbine casing and the combustor shell meet has significant fleet-level issues. The uprate leads to higher shell pressure, and the impacts, such as greater potential for leakage, has to be monitored.
- More air flow through the turbine, of course, means more air flow through the HRSG; plant personnel need to keep up with HRSG maintenance, and be cognizant of the higher HRSG backpressure.
- The HRSG high-pressure steam drum safety valve had to be resized and replaced.
- The SCR's ammonia vaporizer is running at near capacity at maximum output; while ammonia consumption per megawatt dropped, the absolute level of ammonia feed increased because unit throughput increased.
- Water-treatment chemical consumption increased because of higher demineralizer demand and cooling-tower load.

In general, Sensenig notes, "We're anxious to see what the parts will look like after 24 months of operation."

Because Ontelaunee was Rev 0 for the PSM GTOP, a substantial effort was required to qualify the R4 blade design, which added three to four days to the outage. Blade monitoring had to be conducted under a variety of operating modes, including startups, shutdowns, speed sweeps, IGV sweeps, and inlet fogging and steam power augmentation.

Other issues Sensenig describes as run-of-the-mill for outages and significant equipment modifications. The plant experienced a trip during overspeed/under-speed testing because of the trip-limit settings. Capability to modify the controls within the TXP DCS "was limited" and the plant had to "clean up" unused counters and other items to free up processing space, but Sensenig notes this should not be an issue with the newer control systems.

Exhaust-cylinder fix solves "most" problems. Ontelaunee was not first for the exhaust-cylinder fix, performed by Texas-based Braunflex LLC. Important to note is that this fix doesn't solve all the problems experienced fleet-wide with the support struts (Fig 4), but for a fraction of the cost of a new exhaust cylinder, it solves the most important ones.

At the 501F Users Group meeting, Sensenig reported that, upon inspecting one modified unit after 5000 operating hours and 10 starts, only minor stress-relief type cracking on the inner load plates had been observed. At the time of the CCJ visit, both GTs had been modified. With 25 starts and 11,000 hours on the first modified unit, they both are "looking good." No additional severe cracking has been observed.

The two-piece cylinder design issues stem from differential thermal expansion between the inner diffuser piece and the outer case. The issues range from common strut shield cracking to complete liberation of the load plates. Other repair options offered included new flanged load collars and replacing load plates with a new material, but neither adequately addresses the fundamental thermal expansion issue.

The modification at Ontelaunee is essentially a Hastelloy X collar *overlay* onto the original strut shield. The collar allows for controlled growth while still supporting the outer diffuser. Said another way, the outer diffuser can expand *independently* of the inner diffuser and outer casing.

User readers interested in knowing more are urged to access the PowerPoints on the 501F Users Group website (shortcut: scan QR Presen). The slides include diagrams with rich detail of blade comparisons, 3-D graphics of the modified components, before and after performance graphs and tables, and much more.

Special closed sessions

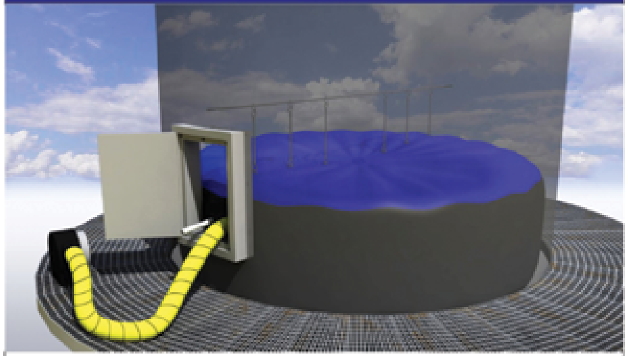
There were five special closed sessions of from two to four hours each at the 2017 meeting featuring detailed technical presentations on 501F performance-improvement solutions offered by industry heavyweights Ansaldo Energia Group's PSM, GE, Mitsubishi-Hitachi Power Systems (MHPS), Siemens Energy Inc, and Sulzer Turbo Services.

They were conducted among user presentations and discussion sessions on Tuesday (Feburary 21), Wednesday, and Thursday to maximize participation. The special sessions all were well attended by owner/operators who asked insightful questions and actively participated in discussion opportunities. Presentations can be accessed by registered users on the group's website (QR Presen).

Ansaldo/PSM

PSM's four-hour session incorporated presentations on the vendor's product line, combustion solutions, airfoils and upgrades, rotors and cases, and service capabilities (QR PSM1). Primary participants were Jeff Benoit, Brian Micklos, Hany Rizkalla, Lonnie Houck, Kevin Powell, and Luis Rodriguez.

Benoit opened with a simple message: PSM is fully aligned and integrated with Ansaldo Energia (AEN) and the company's path forward is clear. Only a year earlier, at the time of the 2016 501F User Group meeting, PSM was not officially part of AEN. Today, its wide-ranging capabilities in shaft-line and rotor work are supported by facilities in North America (USA), Europe (Italy, Switzerland, Russia, Netherlands, and UK), Asia (China), and Middle East (Abu Dhabi). The company's inspection and repair capabilities are considerable, Benoit said, with offerings spanning four engine classes (13 OEM frames), steam turbines, electric generators, and heat-recovery steam generators.

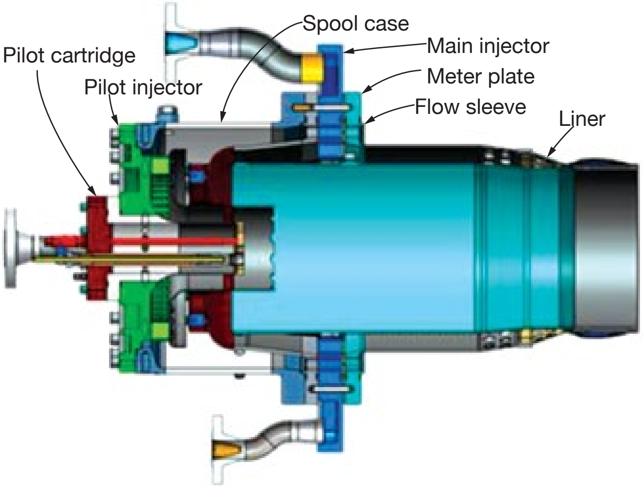


Micklos, who has global responsibility for PSM products used in Siemens/Westinghouse and MHPSA gas turbines, followed Benoit, opening his presentation with two statements that surprised the editors and likely others in the room:

- In January 2017, the 501st set of PSM-designed turbine hardware for the 501F shipped from the company's Jupiter (Fla) headquarters/shop.
- That same month, the 501st set of PSM-repaired hardware for the 501F was processed through the company's Jupiter facility.

He then reviewed the key elements of PSM's full scope of support for 501F gas turbines covered by the company's LTAs (long-term agreements) and engines owned by transactional customers, discussing its capabilities in the following areas: part design and procurement, field service and available kits, repairs for equipment made by different OEMs, project management, service engineering, and fleet management.

Micklos noted that PSM has about two dozen 501Fs covered by LTAs, stressing its objective to use/reuse components the owner has on hand before supplying PSM parts. After summarizing PSM's lineup of hardware, which is set-wise compatible for applicable frames, the product manager concluded with a review of company 501F firsts in "banner year 2016": first exhaust cylinder installation, first rotor swap, and first performance upgrade. The last item, the Gas Turbine Optimization Program (GTOP), was said to be roughly the equivalent of a Siemens FD3 upgrade for performance, but executed in a smaller scope (QR PSM2).



5. FlameSheet™ offers owner/operators with access to shale gas the benefit of extended fuel flexibility. Example: It can accommodate a 30% variation in the Modified Wobbe Index

Rizkalla opened his presentation on the combustion system with a review of PSM component experience. About 70 sets of pilot nozzles had been sold as of February 2017, he said, with fleet leaders above 60k fired hours and 1250 fired starts; transition pieces, about 95 sets sold, leaders at more than 50k FH and 1070 FS; extended turndown combustion baskets, about 24 sets sold, leaders above 29k FH and 460 FS; and support housings, about 20 sets sold, leaders at more than 26k FH and 220 FS.

Component durability is confirmed by fallout rates of 0% for all of the above except Gen 2 and 3 baskets which are about 10%. Gen 4 baskets are expected to have a fallout rate of 0%. Fleet leaders for transition pieces and pilot nozzles are now third interval of 25k equivalent baseload hours.

Rizkalla then discussed the benefits of PSM's FlameSheet™ combustion system—extended turndown capability, improved durability, and greater fuel flexibility compared to traditional OEM offerings (QR PSM3). Plus, the exact same combustor fuel-injection system parts can be used in the 7FA machine and 501F.

Commercial experience, available

only on 7FAs today, was described as a "remarkable technical success" by an owner/operator presenting at the 2016 meeting of the 7FA Users Group. The 501F FlameSheet™ (Fig 5) has passed all rig tests.

Benefits of the dual-fuel combustion system, the speaker said, includes its ability to meet expectations when the gas supply's Modified Wobbe Index varies by up to 30%. Plus, gas with a hydrogen content of up to 40% is easily accepted, and turndown to 30% load while maintaining emissions compliance is possible.

Houck covered compressor products, GTOP upgrade experience, and turbine hardware fallout in his 45-min presentation. You can get access the company's catalog of compressor components on the website at www.psm.com; no need to explain more here. Also, the latest GTOP experience is described in the "User presentations" section of this report by an owner/operator (QR PSM4).

The long life of turbine hardware is evidenced by the shop repair results during overhauls. Today, the expected fallout rates for Gen 3 R1 vanes, Gen 3 R2 blades, and Gen 4 R2 vanes are zero; for Gen 3 R1 blades, less than 10%. Note that all of these components reflect improvements in cooling design and material selection over the original OEM offerings.

Powell's presentation covered the rotor from A to Z—including, overhaul experience, evaluation, repair, and lifetime extension. He also explained PSM's exhaust replacement solutions; but they are not reviewed here. The latest industry experience on 501F exhaust cylinder and manifold replacement will be described in future article, "Repairs never-ending? Replace problematic exhaust systems."

The speaker quickly reviewed PSM's rotor capabilities (removal, inspection, shipping, parts replacement with upgraded components, repair, balancing, re-assembly, etc), noting that the company had overhauled two rotors by the time of the 2017 meeting, with another in the shop.

A description of PSM's compressor-tie-bolt inspection capability, in partnership with Advanced Turbine Support LLC, came next, along with the recommendation that owner/operators get baseline data at or around 900 equivalent starts to mitigate the possibility of an in-service failure. In-situ phased-array ultrasonic testing is the preferred method. PSM's redesigned bolt was said to be an improvement over the OEM's original design.

In the last segment of his presentation, Powell explained PSM's rotor overhaul process using a comprehensive flow diagram and then reviewed the company's component analysis capabilities, which he considers among the industry's best. This material, plus repair and lifetime extension examples, are too detailed to cover here but you can access the presentation on the 501F User Group website.

Rodriguez closed out the four-hour program with a description of the company's engineering support services, partnerships, processes for evaluation of findings and disposition, issue resolution methodology, and case studies on R1 turbine disc cracking, torque-tube housing, air separator, R2 turbine ring segment, and exhaust cylinder.

If you have no history with PSM, a review of the slides Rodriguez presented is a good way to get to know the company and its people quickly. Think of it as a first step in the due diligence process for a future project.

General Electric

GE was a new entry on the agenda of the 501F Users Group annual meeting in 2017, conducting a two-hour closed session for users on its aftermarket solutions for Siemens and Mitsubishi engines. Recall that GE acquired 501F technology as part of its purchase of Alstom in late 2015. The company will update owner/operators on its 501F initiatives at the 2018 meeting in Orlando.

GE's cross-fleet solutions business focuses on development and implementation of services for non-GE plant assets (QR GE1). As part of the cross-fleet services portfolio for the 501F, the company provides turbine maintenance support and upgrade products that enhance performance to meet plant operating needs (QR GE2). Using the Fleet360* services concept, solutions are available to address all major gas-plant components through a system-wide approach to plant optimization. GE reported that it has the following capabilities for the 501F:

- Maintenance and repair services using dedicated cross-fleet field resources and an extensive network of repair facilities.
- Upgrades that infuse patented GE technology to reduce maintenance costs and improve operational flexibility.
- Tailored digital solutions—including monitoring, diagnostic, and analysis capabilities at the turbine and plant levels.
- Flexible multi-year agreements structured to address changing operational and business needs.

Technology updates. As part of ongoing development efforts, GE reported completion of validation testing of its 501F combustion technology. This involved the use of both low- and high-pressure test rigs, combining protocols from GE and Alstom for a more robust test approach that allowed the design team to minimize iterations and improve accuracy and efficacy of testing.

LP test results revealed better-than-expected turndown and combustor stability across the full load range while validating expectations around NO_x at baseload, pressure drop, and fuel flexibility.

The test results also showed that the GE configuration is compatible with the existing OEM topology, eliminating the need to make casing alterations during an upgrade.

Test-methodology and summary information was presented to 501F users as part of the GE Connect Webinar series in October 2017. It's likely this material will be reviewed at the 2018 meeting—another reason for those unable to participate in the webinar to attend the conference in Orlando.

While development for future offerings has been progressing, so has the execution side of the business. GE reported completing two outages on schedule and having performed multiple combustion and HGP repairs on 501FD2, FD3, and F3 (Mitsubishi) machines as part of its cross-fleet multi-year agreement portfolio.

Outage scope included inspection, plus implementation of high-fogging systems, on six machines at two 501F powerplants—with corresponding controls modifications. In general, GE said, it has seen significant opportunity in helping 501F users manage through turbine controls obsolescence, specifically around Human Machine Interface (HMI) server hardware, as well as modernization of combustion dynamics systems and combustion tuning with its AutoMapping solution.

In Spring 2018, GE will complete the installation of two 501F upgrade packages, providing the users with improved performance potential while increasing the interval capability up to 32k and eliminating the need for subsequent standalone combustion inspections. While the first upgrades are being installed on F3 and FD3 machines, the offerings are compatible across multiple frames.

MHPS

Background. Mitsubishi Heavy Industries Ltd established its US headquarters in Orlando in 2001. Led by former President and CEO Dave Walsh, the company was new to the US power-generation market and looking to expand its global footprint. Industry veterans may recall that MHI and Westinghouse Electric Corp had shared a technology agreement and partnered in the development of the original 501F gas turbine. That partnership was terminated shortly after Siemens' acquisition of Westinghouse in November 1997.

Nose to the grindstone, Walsh followed the business plan that was developed and built world-class manufacturing facilities. He hired top-notch leadership and staff, and quickly demonstrated the ability to stand toe-to-toe against companies that had been serving the US market for more than a century.

At first, Mitsubishi focused on new-unit sales and parts and services for its equipment. In addition to the new M501F and M501G gas turbines that were sold, the company offered aftermarket solutions to owner/operators of Siemens Westinghouse W501F engines, having intimate knowledge of those machines—in particular, models up to the FD3.

Early in 2014, Mitsubishi and Hitachi agreed to a joint-venture of their power-generation business units, and Mitsubishi Hitachi Power Systems (MHPS) was created (QR MH1). Along with this JV came Mechanical Dynamics & Analysis, a three-decades-old company specializing in "other-OEM" services, parts, and repairs of gas and steam turbines and generators (QR MH2).

MD&A, launched by a former GE employee, had built a reputation as a trusted OEM-alternative services provider with a skilled workforce and world-class facilities—such as its high-speed balance center in St. Louis.

The JV essentially provided MHPS full access to the generation aftermarket business in the Western Hemisphere overnight. Today the company typically services Mitsubishi and Siemens equipment in its shops while MD&A focuses on "other-OEM" equipment. Both rely on each other's facilities as necessary to meet customer commitments.

After 15 years at the helm, Walsh retired in March 2016. Major initiatives completed during his tenure included construction of the high-tech Savannah Machinery Works manufacturing center, the merger of Mitsubishi's and Hitachi's thermal-power-generation systems businesses with the new name of Mitsubishi Hitachi Power Systems, and expansion of the organization to more than 2000 employees.

Paul F Browning, an experienced senior executive with roots in the power-generation and oil-and-gas industries, was appointed Walsh's successor. Like Walsh, Browning embraces a robust presence at user-group meetings. In fact, the four-hour MHPS program at the 2017 meeting of the 501F Users Group, Browning's first, may have been the company's best ever—at least in the editors' eyes.

Mark Bissonnette, VP service sales and marketing, opened the session with the welcome message that MHPS had improved the competitiveness of its offerings and was responding to RFQs faster than in the past. He stressed the importance of quality in company activities, illustrating its success with a 97% first-pass yield on its turbine blades and vanes. Compressed outage schedules were another positive mentioned.

Two more takeaways: (1) MHPS is receptive to developing solutions with users and has the flexibility to support these initiatives. (2) It has digital solutions ready for implementation that benefit both reliability and customer's bottom line.

Travis Pigon, a gas-turbine design engineer began by offering visual evidence to validate a 32k service interval for hot parts. He showed photos of M501F turbine blades and vanes with up to 40k equivalent fired hours (EFH) and more than 1000 equivalent starts (ES) with no visible platform cracking or erosion; coatings were intact, too. The parts were fit for service with light repairs or none at all. Registered users can access this and the other MHPS presentations at http://501f.users-groups.com (QR Presen).

The benefits of upgrading a W501FD2 engine with MHPS F3 parts was the subject of a case history presented by Pigon. He said F3 parts enabled a threefold increase in EFH between inspections, from 8k to more than 25k (approximately 115 ES); gas-turbine output increased by approximately 4% and heat rate improved by greater than 1.5%. Once again, photos of parts proved his findings.

Five more units covered by the LTSA also were upgraded with F3 parts. In all cases, the speaker said, tuning was accomplished without unexpected issues. Output improvement across the five engines ranged from approximately 3% to 7%, heat rate by 1.5% to 5.5%. Expect improvement to vary among engines because of the level of compressor cleanliness, wear and tear on parts, condition of seals, etc.

For MHPS users, Pigon covered the highlights of an M501F3 upgrade to F4 during a standard major inspection outage to improve engine performance and durability. He said the F4 upgrade is applicable to the W501F fleet as well. Inspection after the first interval revealed intact coating, no base-metal degradation, and the capability to meet 32k intervals.

The speaker closed with a positive view of MHPS' exhaust cylinder solution for the W501F based on improved material, floating diffuser system, cooled robust aft static seal, and passive strut cooling system. Improvements to the original W501F exhaust manifold: improved material, reduced upstream flange thickness, partitioned teardrop, vertically bolted two-piece manifold, elimination of circumferential ribs.

The MHPS offering is a drop-in replacement with no aux piping or foundation changes necessary. Design is based on the company's M501F3- and G-frame designs, which have no history of fatigue cracking in more than 10-million hours of operation. A feature stressed: Ability to remove the exhaust bearing through the teardrop rather than removing the tail cone or the upper half of the exhaust cylinder.

Scott Cloyd, GM gas turbine service engineering, focused on the company's experience gained during more than 200 comprehensive rotor inspections (CRI)—including about a dozen at its Houston and Savannah facilities. One of his primary objectives was to raise user awareness regarding corrosion and torque tube cracking, cautioning that these could be the newest fleet issues.

He addressed corrosion first, saying some units may go 12 or more years before their first HGP. Corrosion occurs primarily because of condensation in a cold rotor cycling in and out of service while subjected to ambient-temperature and humidity changes. The condition is exacerbated when wear from blade rock reduces the contact area between the blade and disk fir-tree serrations. This concentrates stress at the top-most serrations; defects in the serrations below can amplify stress in the already highly stressed locations.

This was a vintage Cloyd engineering lesson of value to users (QR MH3). Consider reviewing his presentation in detail (QR Presen).

The first of the four case histories Cloyd reviewed, and the only one profiled here (another reason to access Cloyd's presentation), involved a hot-gas-path inspection on a W501FD2 machine that had operated for 12 years in peaking service. It took four shifts just to remove R1 blades. Corrosion was severe, rendering magnetic-particle examination ineffective. Replicas quantified pitting in critical stress areas.

Dental molds were taken of the turbine-disc root serrations. Blue-light scans were performed on the molds. Areas of corrosion buildup were identified in high-stress regions and could not be removed safely. Bear in mind that such buildup can conceal more severe pitting, adding to the risk factor. Plus, buildup impedes blade installation, thereby increasing outage duration, cost, and risk of assembly damage. Compressor discs also revealed corrosion pitting.

The customer's decision was to remove the rotor because of the unknowns and potential safety and financial risks. MHPS supplied an exchange rotor to reduce downtime and return the unit to service quickly (QR MH4).

Torque tube cracking was next on Cloyd's agenda. Recall that the torque tube on W501F engines joins the compressor and turbine sections of the rotor. Two machines in the fleet had reported forced outages caused by vibration events traced to through cracks in their torque tubes, which were concealed by the air separator.

The through crack was found on one unit, after only 10k operating hours (but 90k turning-gear hours), and it continued for about 45 deg around the circumference of the torque tube. High vibration forced the unit out of service.

At this time, visual inspection for torque-tube cracking is not possible while the rotor is assembled. However, Cloyd said a method is under development. This would benefit users because after initiation, crack propagation is slow. It is followed by rapidly progressing high-cycle fatigue and failure. Thus early crack detection would allow for outage planning and parts acquisition before a vibration event.

A few technical solutions mentioned by Cloyd were rotor replacement (exchanging with a new or refurbished rotor), in-kind torque-tube replacement, and an upgrade option. The last includes a replacement torque tube with additional thickness where cracks have occurred and with a bolted air separator (elimination of the spring-loaded goose-neck design).

Cloyd is a fountain of information. There were several other parts to his presentation of considerable value to users—including a CRI planning checklist, a list of recommended pre-CRI inspections, photos of historical rotor findings, turning-gear wear and corrosion-prevention options, etc. This presentation is too good not to have a copy of.

Jim Kelleher, director of turbine and generator repairs, presented on the company's new turbine and generator repair group, with facilities in Savannah, St. Louis, and Houston. He quickly reviewed the company's onsite and shop capabilities and then focused on generator inspection, testing, and aftermarket solutions. The new organization combines the talents of both MHPS and MD&A to repair and provide parts for generators supplied by MELCO (Mitsubishi), Hitachi, GE, Alstom, Westinghouse (read Aeropac), Toshiba, and Brush.

He spoke to the "technical differentiators" in both generator inspection and repair services that Kelleher said put the greater MHPS organization ahead of the competition. An example was the company's new High Heat Transmission (HHT) insulation system on stator bars, which provides enhanced heat-transfer properties that lower stator-bar operating temperatures by 7% to 10%. Kelleher recalled the "Rule of 10": Life of electrical insulation is reduced by half for each rise of 10 deg C in insulation average temperature.

The technical solutions presented were aimed at helping users better plan for outages and extend service intervals.

Matt McGough, product line manager, took attendees on a tour of the company's Orlando Repair Center (where it performs gas-turbine component repairs), covering capabilities, manufacturing and repair processes, specialized tooling, design improvements, etc. You can see the highlight reel at your desk by accessing

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McGough's presentation in the conference archives at http://501f.users-groups.com.

He said the following are key "differentiators" that favor MHPS in the contractor selection process:

- Extensive operating history and validated repair techniques—including heat treatments, tooling, inspection, and coatings.
- OEM design authority onsite to respond to fleet issues with developed proven repair criteria.
- One-stop overhaul shop offering OEM quality at competitive pricing.

Paul Richmond, strategic parts manager. "Parts Strategy to Reduce Lifecycle Costs" is a presentation you should access if adding MHPS to your bidder's list for aftermarket services. Richmond reviewed the company's process for bid evaluation and proposal creation, offered current trends in repair classification and fallout, and presented MHPS' strategy for reducing lifecycle maintenance cost.

Siemens

Frame Owner Shantanu Natu did the heavy lifting for Siemens with a crisp, informative presentation on the SGT6-5000F (a/k/a 501F) product line hitting the following core interest areas of attendees:

- Interval extension.
- Performance upgrades.
- Rotor upgrades.
- Exhaust options.
- Turndown technologies.

Natu's presentation filled about half of the two-hour Siemens session. He was followed by Andy Media who spoke on repair technology developments, Adi Srinivasan on digital products, Jeff Williams on field-service developments, and Galen George on controls and digitalization (QR Sie1).

Readers are encouraged to access the presentations, Natu's in particular, on the user group's website at http://501f.users-groups.com. There is a tremendous amount of material of value to owner/operators in the well-organized slides. Natu's focus on the upgrade options available for each model in the fleet—especially the F (introduced in 1993), FC+ (1996), FD1 (2000), FD2 (2001), and FD3 (2005)—can make these machines more competitive in the increasingly challenged fuel-fired segment of the industry.

Natu also covered the F4, F5, and F5ee engines and their experiences with the technology advancements introduced between 2009 and 2017 and now offered to the earlier models where applicable. Your participation in the 2018 meeting of the 501F Users Group meeting Feb 25 to Mar 1 at the Hyatt Regency Grand Cypress will be more productive if you can make time to review this material beforehand and write down questions to ask both the OEM's engineering team and user colleagues with first-hand experience.

For the record, there are 275 501F-FD3 machines in the worldwide fleet (nearly two-thirds of those FD2s) and well over a hundred 5000F(4)-5000F(5ee) engines. Some of the upgrades covered by Natu also are applicable to the Mitsubishi 501F fleet, which is about one-fifth the size of the Siemens fleet globally.

Key takeaways from the presentation include the following:

Interval extension products for hot-gas-path (HGP) components in engines with advanced ULN (ultra low NO_x), advanced DLN (dry low NO_x), and DLN 1.1 combustion systems are available and expected to run 33k equivalent baseload hours (EBH) or 1200 equivalent starts (ES) between overhauls—for example, from installation to the first HGP inspection and from it to the first major. Combustion inspections have been eliminated.

Slides dedicated to each combustion system describe features of major components—baskets, pilot nozzle, support housing, transitions, transition seals, and R1 vanes—that enable the interval extension and performance improvement. To illustrate: For the advanced ULN system, baskets have two rows of resonators, offer resonator-ring durability, and feature an improved spring-clip coating.

If you take the time to retrieve and review Natu's slides you'll also see how many engines are operating with the various improvements. For example, there were 54 machines in the F, G, and H fleets operating with the advanced ULN combustion system when he presented in February; another 19 were in the queue at that time. Personnel from some of these plants will be at the 2018 meeting, giving you the opportunity to get details on installation and performance direct from colleagues.

The advanced ULN combustion system can restrict NO_x emissions to less than 9 ppm at the exhaust manifold without water injection and do that 90 deg F above the standard FD2 firing temperature to improve performance. The DLN 1.1 is capable of restricting NO_x emissions to 25 ppm while operating at a firing temperature 20 deg F above that of a standard 501FD2; the advanced DLN also holds NO_x to 25 ppm, but while firing 70 deg F higher than the FD2.

Natu went on to discuss many thermal-performance upgrade options for F-class frames. For example, with an advanced DLN or ULN combustion system, improvements in blades, vanes, exhaust system, and rotor can maximize your return by extracting another 31 MW from the base FD2 engine while reducing heat rate by more than 600 Btu/kWh. Significant improvements also can be realized for FD3 machines—as much as 16 MW more output with a heat-rate benefit of nearly 240 Btu/kWh.

Technology advancements offered by the FD6 rotor as a replacement for FD2 and FD3 rotors were said to include materials changes to improve yield, creep, and fracture properties. New compressor tie bolts and nuts and elimination of the air separator contribute to higher reliability and performance.

Exhaust system. It seems no 501F discussion is complete without coverage of improvements to correct shortcomings in the design of the original Westinghouse exhaust cylinder and exhaust manifold. Three participants, including Siemens, spent meaningful podium time to extoll the virtues of their designs, especially service durability (QR Sie2).

Natu presented two options to attendees—a single-piece exhaust (SPEX) for models FD3 and above, and an advanced two-piece exhaust for FD2 and earlier models. The former was cited for its thermal performance improvements; the latter is a drop-in replacement to maintain the existing turbine cylinder and manifold interface.

Turndown to low load while still maintaining less than 10 ppm CO emissions is an important consideration for owner/operators today. The first Siemens product—low-load turn down (LLTD), Version 1—has been validated to 50% rated output the group was told. About 30 units are so equipped. Version 2, installed on eight units at the time of the meeting, has advanced logic to accommodate turndown to 30% to 35% load. Natu put up a slide to illustrate piping arrangements for both versions, the system for V2 obviously more complex.

An engineering and financial analysis of both versions as they pertain to your plant and its operating profile is recommended. While both offer a part-load heat-rate benefit, being able to operate down to about one-third rated output, rather than one-half, may extend the life of hardware by allowing the plant to continue in operation at low load rather than debit the fatigue bank account by shutting down and cycling.

Also, V2 requires an inlet heating system which would benefit the engine by reducing the potential for ice formation and possible downstream damage.

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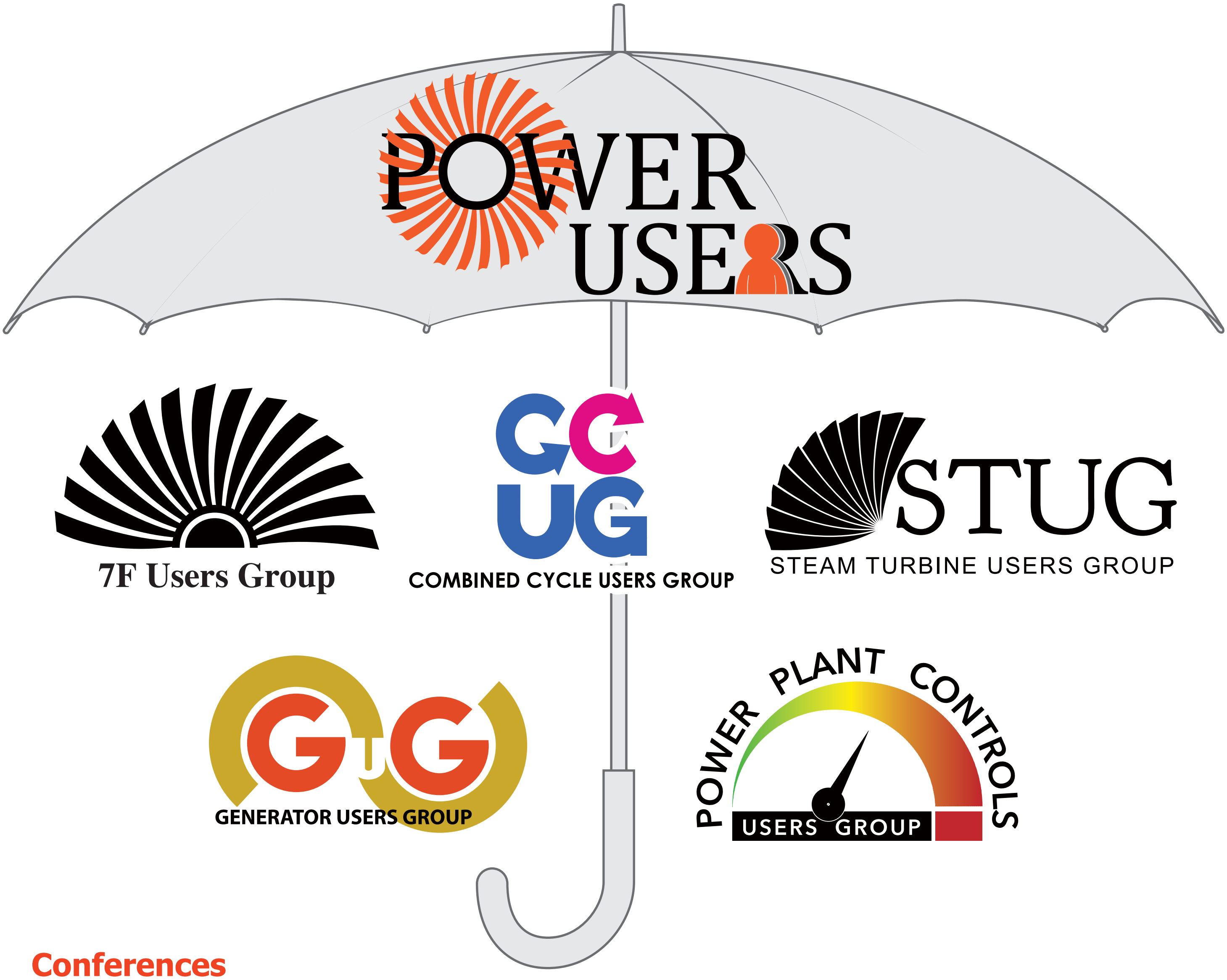

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Sulzer

Given the high level of interest in the condition of rotors in ageing fleets like the 501F (engine models up through the FD3), Billy Bottera, manager of gas-turbine rotors for Sulzer Turbo Services Houston Inc, was invited to participate in a closed user session and update owner/operators on the company's capabilities and experience. More than half of the presentation focused on the rotor—some slides having details on dimensions, materials, numbers of components, etc, that owner/operators often scurry to find when they don't have access to O&M manuals.

Bottera began with foundational information: He called it "Anatomy of the 501F rotor." Did you know a 501F rotor weighed 54 tons with its 1193 compressor blades and 334 turbine blades installed? Learn more by accessing the presentation by simply scanning the Presen QR code or reviewing CCJ's article on the subject using QR SLZ1.

Next, the speaker walked attendees through the company's rotor-shop capabilities—his area of expertise—describing as-received inspection, de-stacking procedures (QR SLZ2), NDE, balancing, weld repair options, machine tools, special inspections to check air-baffle condition and curvic contact, etc.

Judging by facial expressions, the section of Bottera's presentation on rotor issues, causes, and solutions held the attention of virtually all participants. Here are the problems he discussed:

- Broken interference, alignment fit on the forward stub, which is conducive to high rotor runouts and severe vibration. In the example the speaker gave, the unit shut down on high vibration; inspection revealed runouts up to 18 mils. The register fit on the forward stub was found broken off—completely. A repair was engineered and the damaged fit was machined out to accept an insert. The bushing was installed with interference and then machined to final size to accommodate correct interference to the adjacent wheel.
- Fretted/worn air baffles between turbine wheels. Cause: Anti-rotation tabs/pins wear and/or break off, allowing the air baffles to rotate and wear; in extreme cases, they can liberate and damage the turbine. The standard Sulzer fix, which requires disassembly: Manufacture air baffles and modify anti-rotation slots to accommodate more robust anti-rotation tabs. A field modification also is possible using a different approach. Pictures are available in the presentation.
- Compressor locking-key wear and fatigue. This condition must be addressed before key liberation causes blade liberation and severe damage to the compressor. Periodic inspection of the locking keys is recommended. Bottera said that Sulzer has improved the design of the locking keys, allowing for a more robust tab.
- Insufficient air-separator crush to the R1 turbine wheel. This is conducive to fretting of the air separator against the wheel; failure in extreme cases. Bottera spoke about inspections and repair options to mitigate this issue.
- Compressor through-bolt failure. This was a hot topic a few years ago; you can research the history at www.ccj-online.com by using the search function on the home page. Sulzer and several others providing aftermarket services for the 501F have redesigned the forward compressor nuts, and through bolts, to mitigate the risk of fastener liberation.

Bottera mentioned a Sulzer best practice with regard to field work. He noted that 501F compressor and turbine blades frequently are replaced in the field. Sulzer typically coats the compressor section to mitigate pitting and facilitate blade replacement. Once the rotor is coated, weighed and sequenced, blade sets are installed in progressive fashion. When fully bladed, balance is trimmed and a six-point residual unbalance check is performed.

The best practice comes in when blades are supplied by others. Bottera recommended that these airfoils be moment-weighed by Sulzer so there's no possibility of having to remove blades again to balance the machine. The added cautionary step can save outage time and money.

Vendorama

A valuable component of the upcoming 501F Users Group conference is the Vendorama program, scheduled for the first day of the meeting ahead of the vendor fair. It gives attendees access to live presentations by dozens of products/services providers offering O&M solutions.

At the 2017 conference, 37 companies made 41 technical presentations ranging from 30 to 50 minutes each to bring users up-to-date on proven technologies of interest to the 501F community. The program matrix—seven time slots in each of six rooms, running from 9:30 a.m. to 4:00 p.m.—allowed each attendee to participate in up to seven presentations vetted for technical content by the organization's all-volunteer steering committee.

The accompanying sidebar illustrates the diversity of subject matter provided in the Vendorama program. Several presentations summarized below provide perspective on the quality of the information disseminated. Discussion on some of these topics is unique to the 501F Users Group annual conference and another good reason to sign up for the 2018 meeting today (QR Reg).

Owner/operators of 501F gas turbines can access presentations identified in the sidebar by dialing up the organization's website (QR Presen) and clicking on "Conference Materials." Since you must be a registered user to get this information, there may be an additional registration step if you're not an active member. There is no registration fee.

Improving back-up liquid-fuel-system reliability, JASC (QR Ven1).

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," (QR Ven2) 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 point to success both in protecting against coking and eliminating the need for "verification" firing of oil monthly to confirm liquid-fuel system reliability.

With the company's 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, JASC now offers 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, a 7F gas turbine operated on liquid fuel during commissioning of its fuel-system upgrade in April 2016. The unit operated exclusively on natural gas over the next nine months, burning oil only during the second week of January 2017. The turbine started and operated on liquid fuel without incident.

A typical F-class unit needing to confirm oil firing capability would have paid approximately $30,000 each month the test was conducted. Thus,

not having to run tests for nine months after the upgrade was completed saved about a quarter of a million dollars.

Next generation turbine insulation, ARNOLD Group USA LLC (QR Ven3).

ARNOLD Group's single-layer insulation system was said to be state-of-the-art technology capable of solving all known insulation-related problems associated with the operation and maintenance gas and steam turbines.

During operation, it enables users to decrease compartment temperatures significantly—by more than 50% in some cases—while decreasing fuel consumption and increasing power production. During maintenance activities it reduces outage time and related cost because there are fewer blankets to remove, repair, and replace. Plus, less local insulation labor and less scaffolding are required for outages.

ARNOLD's Pierre Ansmann said the company guarantees reuse of its insulation system for 15 outages without a decrease in efficiency.

Advanced repair processes for 501F vanes, Sulzer Turbo Services Houston Inc (QR Ven4).

First half of the presentation was dedicated to the primary failure modes of 501F vanes (oxidation, thermal distortion, and thermomechanical fatigue), focusing on oxidation. Recall that the degree of oxidation depends on temperature and time, the former controlled by the cooling scheme, explained with a series of excellent drawings.

Laredo Womack, operations manager for the company's Component Div, said the weakest links in the cooling chain described were the leading-edge air dam and the inner pressure pan/bathtub.

Failures generally are caused by a loss of cooling air to the showerhead on the leading edge and/or to the pin fin cooling on the trailing edge. Photos illustrated typical damage.

After passing mention of conventional repair processes (solution, blend, jacking, welding, stress relief, machining), Womack dug into advanced repairs—coupon replacement, core-plug guide replacement, and brazing (wide gap, narrow gap, and preform, or slump, if you prefer). Unfamiliar with slump brazing? It is a method for repairing highly contoured areas on airfoils that have become too thin. It's benefit: Extend vane life at optimal time and cost.

Drawings detailed how vanes are sectioned for coupon repairs, photos illustrated the repair process—coupon fitting, bracing, throat check, plating, welding, NDT, and re-establishment of cooling holes.

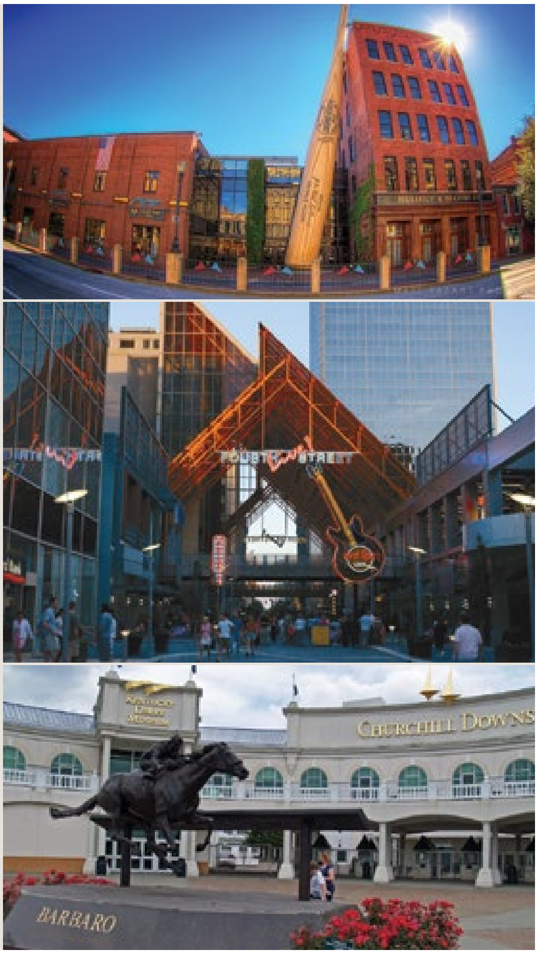
Guidelines for inlet filter selection, CLARCOR Industrial Air Inc (QR Ven5).

An important takeaway from the presentation's first dozen slides was that poor air filtration accounts for approximately 60% to 80% of overall GT losses. That statement alone was incentive to listen to Dan Burch, who reinforced his presence by way of example: An F-class gas turbine operating 8000 hours annually and selling power at $50/MWh pays a penalty of about a quarter of a million dollars for every 1 in. H_2O increase in pressure drop across the inlet air system. The obvious message: Dirty filters can cost you big time.

Following an overview of filter ratings and typical industry tests, he suggested several other tests you should ask prospective vendors to conduct on their products to enable an informed buying decision, including these:

- Dust and salt removal efficiency.
- Humidity, mist, and fog testing.
- Burst tests, both wet and dry.
- Dust holding capability.
- Rough handling testing.
- Hydrophobic performance with loading.
- Temperature-extreme suitability.
- Gasket testing.
- Overall performance (beta site trials and mobile test rigs).

Burch then conducted a side-by-side comparison of HEPA filters made of



microfiber glass media and ones made with a layer of d-PTFE membrane. He concluded the former as better able to handle the moisture than the latter.

Online transformer oil conditioning, C C Jensen Inc (QR Ven6).

Transformer oil conditioning was only part of Axel Wegner's presentation, which also covered in overview fashion the conditioning of steam- and gas-turbine lube oil, (QR Ven7) control fluids, cooling-tower fan gear oil, (QR Ven8) and diesel fuel in storage.

The last was a new entry in the conditioning playbook for powerplant oils. Most users are familiar with treatments for lube and control oils, but the conditioning of diesel oil at a dual-fuel plant was unknown to many. At the plant Wegner described, one equipped with a nominal 1-million-gal storage tank, the gas-supply failure plan called for running gas turbines for three to five days three times annually.

The oil was not up to the quality required for GT use and the plant had no choice but to remove water, microbial contamination, and particulates from the fuel before burning it. Using a filtration system similar to that used by C C Jensen for turbine oil was a viable solution. In only one pass through the filter, water content was reduced from 702 to 71 ppm (1500 liters of water removed from the oil), 2-micron particle contamination was reduced from 28,860 to 17,041, and sodium and potassium levels were reduced below recommended levels.

Oil sampling: Particle counting, Hy-Pro Filtration (QR Ven9).

Selecting a sample port for trending particle count was the focus of this presentation, which is recommended viewing (by the editors) for anyone responsible for oil sampling, because of its practical approach and level of detail.

The main point is that you can acquire an oil sample to check fluid health and chemistry (acid number, viscosity, additive package condition, dissolved metals, water, oxidation) from virtually any location in the system. However, locations for trending particle count are limited. The two recommended were at the lube-oil pump outlet upstream first filter assembly and from the reservoir cooling a polishing loop upstream filter assembly.

Location of the sample port is important, too, with the middle 50% of the pipe the optimum. Several slides describing placement are a "how to" for those who have not performed this task previously. A couple of case studies with charts of sample data were provided.

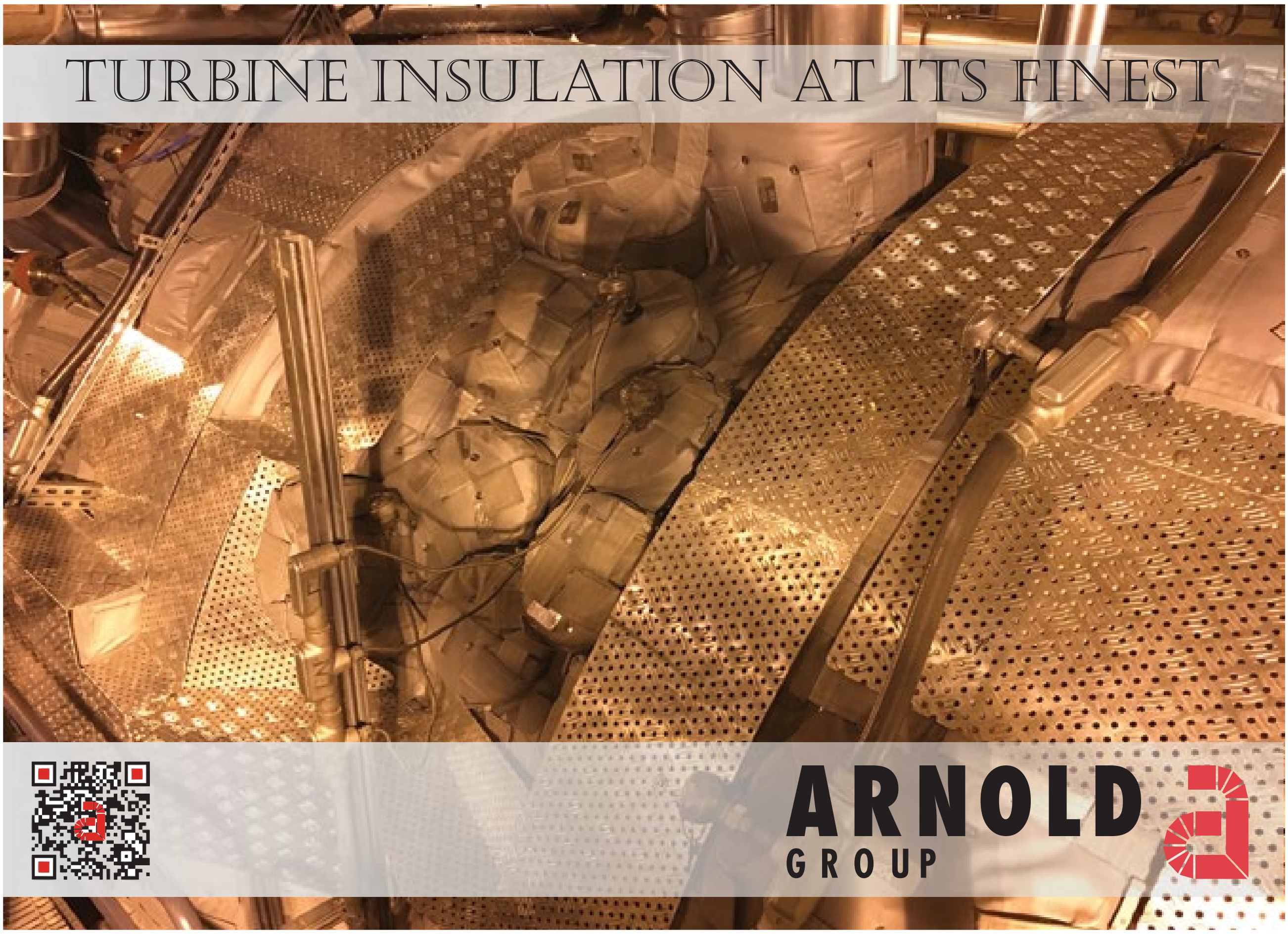
Benefits of maximum access for borescope inspections, Advanced Turbine Support LLC (QR Ven10).

This is a must-view presentation because the story is told in pictures illustrating the level of detail possible for accurate damage assessment when adequate access is provided for borescope inspections. A few of the many components shown include the following: inlet-strut cracking, compressor impact damage, locking-key wear, aft movement of compressor blades, diaphragm wear buttons, hook-fit wear measurement, missing tie wire in the combustion section, cracks in rocket swirler supports, turbine-blade platform cracks, etc.

Separate sections of the presentation covered the following:

- Exhaust-strut inspections—visual damage assessment, dimensional checks, liquid-penetrant and phased-array inspections of welds—made possible by access gained through the exhaust duct.
- Compressor spindle bolt in-situ inspection using advanced phased array. Sectoral image and waveform scans illustrate the power of the technique.

Lifecycle cost considerations for GT inlet filtration systems, Camfil Power Systems (QR Ven11).



The lifecycle cost analysis provided for a high-efficiency, medium-velocity air filtration system incorporating weather hood, turning vanes, pre-filter (F6, F7), and final filter (F9, E10) illustrates how you might perform an in-house analysis to aid management decisions.

Inputs to the equations provided include gas-turbine capacity, revenue from power produced, cost of fuel, cost of downtime, frequency and cost of compressor washes, and filtration costs—including disposal fees.

The case study profiled considered lifetime costs (replacement filters, etc) and identified key cost drivers. The summary chart of results in this instance showed a financial benefit for using a pre-filter and E10 final filter over an H14.

501F turbine update, Emerson Automation Solutions (QR Ven12).

Tom Zuvlis spent his time at the front of the room discussing strategies to optimize the performance of 501F-powered combined cycles equipped with Ovation control systems. He focused on a suite of advanced applications (QR Ven13) that individually, or in various combinations, can achieve the following:

- Reduce fuel use on cold starts and on warm and hot transitions.
- Improve startup consistency and ensure on-time breaker closure.
- Reduce plant chemical consumption.
- Improve shutdown procedures to bottle-up the unit for fast, efficient restart.
- Reduce metal fatigue.
- Improve overall plant reliability.

Aeropak I and II stator rewind preparedness, AGTServices Inc (QR Ven14).

When you think your generator rewind project is well-planned, that's when to access Jamie Clark's presentation and go through his 40-plus slides to identify what you've forgotten. This presentation is a checklist which may be worth its weight in gold to anyone lacking rewind experience. Even if you sat in on Clark's presentation you likely couldn't take notes fast enough take down all the best practices and lessons learned.

The first slide confirms why you're considering a stator rewind: the effects of age, increase output, design deficiency, or winding damage, etc. Several photos serve as a wake-up call, illustrating insulation breakdown experienced by others. Next slide: A list of general outage considerations—including plant configuration, other shaft-line work planned, stator design, laydown space, crane availability, etc.

Then comes the nitty-gritty, slide after slide. A couple of examples to encourage viewing of the presentation:

- Sure, you have lots of space, but it's outdoors. Where do you store your field? Significant planning/logistics are required to provide sufficient environmental/ambient protection, FME, etc.
- Most combined cycles require "working at height." This can present logistical challenges for field removal. Are there axial impediments to crane access to the field? Many units have buss work running axially out of the collector end, adding to disassembly work, etc.
- The field removal "platform" may become your "dance floor" for the rewind. But some additional costs (such as equipment rental charges) may offset the perceived benefits and saving from less scaffolding, etc.

Outage preparation and conduct, TOPS LLC (QR Ven15).

Toby Wooster began his presentation positing that the natural flow of an outage can be disrupted, enhanced, degraded, empowered, or destroyed by a number of factors. History and systematic study, he said, can identify

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The 37 companies listed below made the presentations specified at the 2017 conference of the 501F Users Group. Those identified in color are CCJ business partners; you can learn more about the products and services they offer by connecting to their listings in the periodical's Buyers Guide. Simply scan the QR code BG Co with your smartphone or tablet. Users can access all the presentations via QR code Presen.

AAF International, HEPA filtration and the issue of corrosion

Advanced Turbine Support LLC, Benefits of maximum access for borescope inspections

AGTServices Inc, Aeropak I and II stator rewind preparedness

Allied Power Group, 501FD2/3 Row 4 turbine-blade repair quality

Alta Solutions Inc, Next generation vibration protection systems

American Chemical Technologies Inc, Eliminating varnish in GT systems

Arnold Group USA LLC, Next generation turbine insulation

Brace Integrated Services Inc, Best practices: Freeze protection and winterization programs

Camfil Power Systems, Lifecycle cost considerations for GT inlet filtration systems

C C Jensen Inc, Online transformer oil conditioning

CLARCOR Industrial Air Inc, Guidelines of inlet filter selection

Coverflex Manufacturing Inc, Coverflex exhaust wall seal

Crown Electric Engineering & Manufacturing LLC, Circular non-seg bus duct

EagleBurgmann Expansion Joint Solutions, New expansion-joint design for 501F turbine exhaust

Emerson Automation Solutions, 501F turbine update

Frenzelit North America Inc, CT exhaust expansion joints and penetration seals

GE, Innovative 501F repair capability; Pressure wave technology for HRSG cleaning

Hy-Pro Filtration, Oil sampling: Particle counting

Industrial Air Flow Dynamics Inc, Expansion-joint failures and cracking RCA review

Intertek Group plc, Asset performance management tool for combined cycles

JASC, Improving back-up liquid-fuel-system reliability

Lectrodryer LLC, Generator auxiliary upgrades with emphasis on hydrogen safety

Mee Industries Inc, Maintaining/upgrading inlet-air fogging systems

Mitsubishi Hitachi Power Systems, Parts strategy to reduce lifecycle cost; Turbine section component repair

National Breaker Services, Switchgear life extension

National Electric Coil, What maintenance matters?

Nederman Pneumafil, Dealing with moisture for air-inlet filtration technology

Parker Hannifin Corp, Simplifying GT piping and tubing connections

Peerless Manufacturing Co, Advancements in SCR technology

Pioneer Motor Bearing Co, Fluid-film bearings

PowerPHASE LLC, 8000-hr parts life extension on a 501F using dry-air injection

PSM, Ansaldo Energia Group, PSM controls capabilities for 501F

SETPOINT™, Intelligent sampling and storage of vibration waveforms

Sulzer Turbo Services Houston Inc, Advanced repair processes for 501F vanes

SVI Dynamics, Common problems with CT exhaust liner and silencer systems

Tetra Engineering Group Inc, Impact of creep-fatigue cracking in Grade 91 pressure parts

TOPS LLC, Outage preparation

elements that can change an outage in both duration and quality.

Safety is intertwined in the culture an outage takes on and can be controlled when proper steps are taken. The flow of safety, as in quality, can be affected by constructive and proactive practices. To control outage flow by cultural improvements, you must first identify the key elements of cultural change.

Wooster identified some positive ways to improve outage flow that are both simple and direct. He said that the nature of man stays the same; therefore, by identifying and targeting positive change in outage culture you can implement practices that save time and money, and prevent accidents.

Owner/operators typically want the same thing, he noted: A safe outage that restores the unit to like-new condition while saving as much money and time as possible. Some simple actions taken can accomplish these goals. A couple of positive cultural changes the speaker suggested are these:

- Safety pause. Take a couple of moments to think about what you're going to do before you do it. Sounds simple, but by weighing the consequences of every action you can eliminate accidents.
- Attitude—honor up, honor down, honor all around. Every person involved in an outage is a stakeholder in the outage outcome. By honoring others, outage culture will change for the better and healthy input will occur while positive feelings drive the outage to an early completion. CCJ

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Paul White's legacy

Paul White shows the 2015 Individual Achievement Award presented by the Combined Cycle Users Group

When Paul White crossed over to the spiritual world from the physical Nov 16, 2017, he was well prepared for the journey and certainly was welcomed by those who had preceded him. White was a deeply religious man who taught Sunday school and gave church activities his full support—all while excelling in his engineering day job, and contributing to gas-turbine user-group initiatives with his deep technical knowledge and considerable people skills.

The challenge in writing an obituary for an exemplary human being and professional is that it never really meets your expectations, and likely those of the many readers who knew White well—there's so much to say. Perhaps the best way to honor such an individual is to keep him in your conscious mind to help guide your thinking. You might ask yourself when dealing with a knotty problem: What might Paul have done in this situation?

The editors knew White best from his involvement in gas-turbine user groups. His highlight reel includes leadership roles in the following organizations:

- 7F User Group steering committee member from just prior to the millennium until retirement as a full-time Dominion Resources Inc employee in the first quarter of 2013. He was a past chairman of that august organization.
- Combustion Turbine Operations Technical Forum (CTOTF™), leadership committee member for many years—including several as chairman of the GE Roundtable and the Siemens Roundtable.
- Combustion Turbine & Combined Cycle User's Organization (CTC^2), past chairman of the steering committee.

White was among the industry's best discussion leaders and a great asset in any Q&A session having to do with gas turbines. He was successful in getting his point of view across without raising his voice or denigrating anyone's opinion. His approach was debate, yes; argue, no. White's technical knowledge and calm demeanor earned him industry-wide respect. One example: He was recognized by the Combined Cycle Users Group in 2015 with its Individual Achievement Award.

White took great pride in his ability to recognize talent from afar, recruit those individuals, and mentor them to the point where they could advance on their own and expand the capabilities of the gas-turbine technical support organization he led. White made it a point to bring new members of his team to user-group meetings and introduce them to as many participants as he could. He knew well that building a proper network to aid in decision-making was vital to success for both the employee and employer.

The registered professional engineer (North Carolina) also knew that he could not properly motivate and lead without keeping up with generation technology. White participated in many technical symposia over the years, several focusing on new materials and cooling schemes for gas turbines.

Consider that from the time he graduated from North Carolina State University in 1974 with a BS in Mechanical Engineering—two years after the nominal 52-MW GE Frame 7B was introduced—until he retired from Dominion as a part-time employee in December 2016—shortly after the 384-MW GE 7HA.02 became available—turbine inlet temperatures increased from about 1800F to 2900F.

Career profile

1974—Bechtel Power Corp, nuclear focus, design and field engineer.
1978—Duke Power Co, senior engi-

Road warrior. White loved riding his bike, sharing stories and adventures with family and friends. Riding the Blue Ridge Parkway was annual event, complete with hiking and camping

The Family White. Paul White's son John, wife Christine, Paul, grandson Jacob, daughter Emily (l to r) neer, gas turbine (and steam turbine) technical support.

1997—Duke Energy North America, director of engineering, responsible for strategic turbine expertise in both current and developing technologies.

2000—Dominion Resources Inc, manager of O&M, provide technical support and strategic management for a fleet of about 75 gas turbines, spanning legacy to advanced technologies.

2016—GT & ST Consulting Corp, shop build surveillance on complete component and unit assembly tasks for Dominion's first J machine.

Remembrances from. . .

Bob Kirn. Amidst the early 7F Users Group meetings that were more of a fruitless slugfest between the OEM and a handful of owners suffering from bucket munching turbines, there emerged an individual who, while already known as a steady hand and cool head, would become one of the stalwarts of the gas-turbine industry.

Paul White, with his steadfast, oft-repeated belief that problem resolution could be best accomplished through cooperative efforts punctuated by full disclosure and free discussion, was quickly recognized by the user community as one who could be trusted to not only "find the solution" but to—and of such greater importance—"share the solution."

His successful method of cooperative effort was so widely recognized that even GE invited him to speak to their services group in the company's efforts to foster a more cooperative approach to customer service. Paul had made a lifetime of sharing his talent and he agreed to participate, and with the same level of honestly and enthusiasm that he approached everything. No doubt the subsequent and on-going success of the 7F Users Group is a legacy to the open-forum structure he promoted and to the personal qualities that he so strongly displayed.

For more than two decades, Paul and I exchanged information, sought and offered advice for never-ending calamities and frequently crossed paths on the user-group circuit. His commitment to finding solutions and providing the best information possible to anyone who asked never wavered; nor did my personal pleasure in seeing him at meetings and being able to swap stories, bounce new ideas, or just share a genuine handshake.

Christa Warren. Paul was the best manager and mentor I ever had, and will always remember what I learned from him. Thanks to Paul, I had the opportunity to join the gas-turbine industry and work with him. He created a legacy that will live on through all of his mentees.

Wherever and whenever his name comes up it always results in a positive comment; no matter whom you talk to. Even I catch myself thinking, "What would have Paul done?"

He presented himself and his team with such class, humility, and respect he made everyone around him feel valued and respected. I will never forget how he would refer to all colleagues as his friends, and how when he described your role on our team he made you feel like a million dollars.

It is sentiments like this that make people remember Paul for who he was. Although he will be deeply missed, the impact he made on those around him will continue to resonate through the years.

Sam Graham. Of all the good things I can say about Paul White, the one that stands out the most is his wonderful character. Paul was a true gentleman in every sense of the word, which was obvious to everyone around him; he was a genuine pleasure to be with.

Paul worked constantly to mentor younger engineers and to make a positive impact on the 7F Users Group. He was a great contributor to the user community and a long-serving member of our steering committee.

You could always rely on Paul to provide a composed and thoughtful voice to any situation. His wisdom and self-control were vital during the hard conversations required with the OEM when these machines were in their infancy. Paul could be counted on when times were rough, always with a warm heart and a smile.

This industry, and this world, could certainly use more people like Paul. He will be greatly missed.

John Gundy. We remember Paul White as a loving and devoted family man, mentor, and friend. Not only was he caring and compassionate, Paul was humble, adventurous, and enjoyed life, sharing his faith with those around him—which was something special. His contributions to the industry and willingness to teach others from his life's lessons were priceless.

I was blessed to be hired by Paul, and he mentored me before I took on the role of engineering manager for Dominion Energy's Combustion Turbine Operations. Paul will be missed at Dominion Energy and by the many friends he made throughout his career.

Case study reveals hidden value in old iron

Marty Magby was at the 7EA Users Group's annual conference in St. Augustine the week of October 23, as the editors expected; he's been a meaningful contributor to discussion sessions at this forum for years. However, he came to the 2017 meeting wearing Allied Power Group (APG) gear after attending the last 11 years in shirts with an owner/operator's logo. Nothing should surprise anyone in the electric power industry these days given the ongoing structural changes.

Magby's forte is large rotating machinery. His gas-turbine inspection and overhaul experience is a good fit for APG given its "bundled solutions" initiative and expansion plans. The recently appointed director of the company's field services group, Magby is responsible for planning and managing work for both union and non-union customers and for growing the firm's service offerings.

The opportunity to speak with Magby for about an hour in a quiet spot was rewarding: He shared his experiences on a Frame 7B major inspection completed shortly before joining Allied. The project scope and notes below provide a checklist others overhauling 7B-EA engines may find helpful.

But before digging into the details, he urged his colleagues to begin their projects with a business case to justify the proposed work scope. Of course most users in plant management know this, he said, but they sometimes jump-start outage planning—their comfort zone—based on previous experience. In his view, this may not produce the desired outcome.

Magby's recommendation: Take a clean sheet of paper and write down how the asset scheduled for an overhaul makes money for the owner and how it is dispatched. Sounds elementary, but the exercise can be revealing.

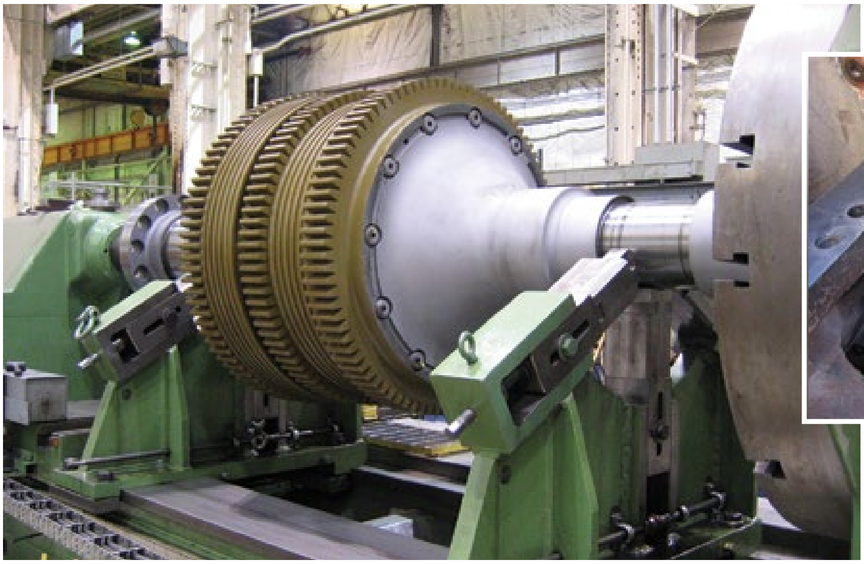
Next, check the unit's permits to be sure it is offered to the market in the most favorable way for the owner. That's obvious, most might say. But given today's rapidly changing market dynamics, it might not be so. "Opportunities" can change virtually overnight.

Case in point: The dual-fuel 7B Magby was lining up for a major inspection was in its fifth decade of service and approaching 2500 starts and 15,000 hours of operation. Firing temperature for this "standard" engine was about 1850F. The unit was capable of 55 MW on a favorable summer day.

Interestingly, about three years ago the owner had decided to retire this machine, and two sister units, in the first couple of years of the coming decade while continuing to operate a conventional steam plant for the next two decades. "This was the plan when I went on vacation," Magby said, "but by the time I returned, the old plan had been scrapped and I was told to do what was necessary to keep the 7Bs running for 20 more years; the steam unit would be retired instead."

Clearly, the gas turbines were better suited than a steam unit to accommodate the start/stop operation required to fill in around rapidly increasing renewables generation in the area. The 7Bs could go from cold iron to rated load in 10 minutes. They also required less O&M manpower. Management had determined upgrades performed during the major would enable a site staff reduction from 19 to three with no personnel onsite for some hours.

A review of the "grandfathered" air permit revealed the true value of the old iron. The gas turbines only have an annual limit on NO_x emissions. Thus they can be offered into the market at any at virtually any output—even as



1, 2. Runout check (left) and replacement of first-stage buckets (above) typically are included in the refurbishment plan for a high-hours/high-starts 7B turbine rotor low as 1 MW, if that makes financial sense—and be available to fast-ramp to meet market demand. Magby's challenge in planning the outage was to be sure no modification would trigger a New Source Review.

Orders in hand, it's important for the project manager to do his or her homework before proceeding. Magby recommends reviewing operating records and previous outage reports and then conducting in-depth discussions with the following groups:

- Plant personnel, to identify issues requiring correction.
- Users with relevant experience in engine overhauls, to take advantage of industry best practices and lessons learned.
- Vendors, to conduct a preliminary evaluation of the alternatives considering experience, cost, lead times, special installation requirements, etc.

While conducting the foregoing discussions, he said, it's important to keep in mind the critical project drivers—in this case, 20 more years of reliable service, reduced staffing, and periods of unstaffed operation.

3. The exhaust section of a high-starts engine takes a beating over the years and typically is upgraded or replaced after about three decades of service

Project scope

- Remove the engine rotor. De-stack, clean, and coat the compressor section to protect against corrosion; correct blade migration. De-stack turbine rotor, clean, and coat fir trees to eliminate bucket rock (Figs 1, 2); remove bore fan as suggested by the OEM in one of its Technical Information Letters.
- Replace exhaust cylinder and diffuser (Fig 3).
- Conduct wheel-space thermocouple mod to allow t/c access without lifting the casing.
- Conduct bearing-metal thermocouple mod to monitor bearing temperature.
- Bently mod to upgrade vibration monitoring capability.
- Replace turbine and load-compartment enclosures; expand turbine compartment enclosure.
- Upgrade flame scanner and eliminate water cooling.
- Rewind the air-cooled generator with existing copper; correct shorted turn.
- Replace magnetic retaining rings on the generator rotor with ones of 18-18 stainless steel.
- I&C and valve refurbishment (conducted by plant staff).
- Re-wedge the generator stator.
- Switch from hydraulically actuated gas valve to one with electric actuation.
- Replace original lube-oil pump with two motors with separate ac and dc pumps.
- Modify SSS clutch for today's service.
- Upgrade purge bleed valves.
- Recharge accumulator.
- Replace radiator and clean the coolant system.
- Inspect and clean lube-oil cooler. Install a booster cooler to address high-oil-temp issue.
- Upgrade mist eliminator.
- Replace starting motor.
- Upgrade voltage regulator.
- Modify the generator protective relay to satisfy new NERC rules.
- Rewire unit to eliminate cannon plugs and degraded wiring. Circuits were rewired externally to eliminate to the degree possible all connections inside the enclosure.
- Install an isolation switch between the generator and generator step-up transformer.
- Replace switches (on/off) with transmitters in control circuits to eliminate failures with the former.
- Paint visible exterior surfaces with an environmentally acceptable coating system.
- Documentation upgrade. Big effort to update drawings and instruction books and convert them for electronic access.
- Controls. The gas turbine's Bailey Infi 90 system was retained. Staff did not want to replace it; had plenty of spares and the internal talent to maintain it.

Marty Magby can be reached at mmagby@alliedpg.com. CCJ

LM6000-powered combined cycle with OTSG proves fast, flexible, resilient

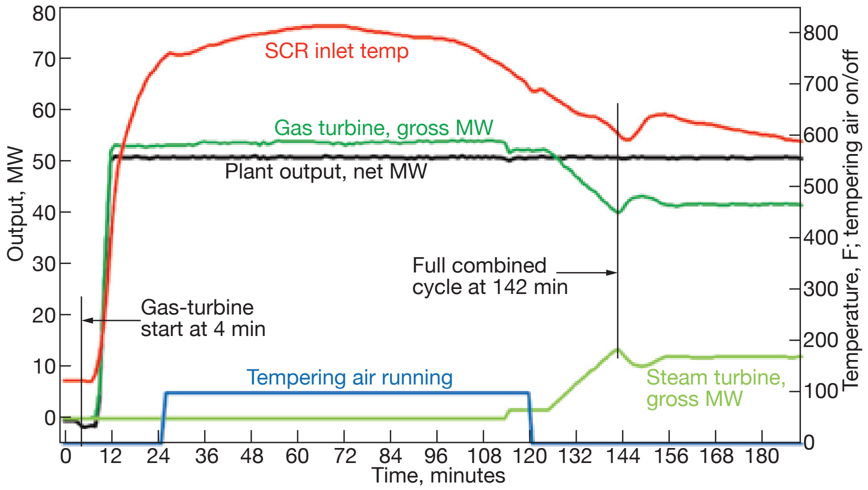
By Dave Tateosian, PE, Clean Power Consulting Partners

In a power world that typically views bigger as better, aero engines often are not considered when it comes to planning new generation. However, given the growing demand for flexible fuel-based generation to fill in around intermittent renewables, they may fit in your future plans.

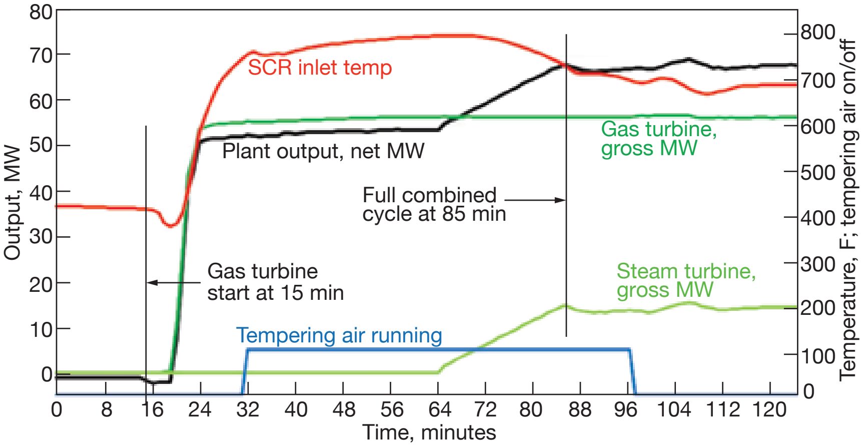
The goal of this article is to assist you in decision-making by examining the beneficial operating characteristics of a recently completed 1 × 1 combined cycle equipped with a 10-minute-start aero gas turbine (GT), a once-through steam generator (OTSG), a single-pressure steam turbine (ST), and conventional balance-of-plant equipment (sidebar).

This equipment configuration was selected to meet the owner's need for a reliable, efficient, and dispatchable thermal resource capable of starting quickly and providing the operational flexibility to address the variability of renewable resources. The combined cycle has the following characteristics:

- **Fast,** offering the 10-min starting capability typically associated with a peaking unit. Full combined-cycle output and efficiency generally can be achieved from a cold start in less than two and a half hours (absent any water-chemistry restrictions).
- **Flexible,** offering the simplicity of a peaking unit, the efficiency and emissions performance of a combined cycle, a wide operating range, and the ability to respond quickly to requested load changes.
- **Resilient,** offering full gas-turbine output even after a steam-turbine or boiler trip. Plus, restart of the steam plant while the gas turbine continues to operate over its full operating range.



1. Cold start to 51 MW



2. Warm start to 68 MW

Air-permit impacts on plant design

The combined cycle was a replacement for an existing steam boiler plant with a gross output of 71 MW. Air permit considerations drove a decision that the new unit have a maximum gross output of 71 MW, limiting plant output and heat rate somewhat. Example: The single-pressure OTSG's stack temperature was higher than what might normally be used (about 315F at full load) to restrict output to 71 MW; the unit's full-load heat rate of 7800 Btu/kWh would be reduced with a lower stack temperature. Duct firing was not included in the plant design because of the output ceiling.

For this unit, air emissions had to meet combined-cycle standards whether the unit was operating in the simple- or combined-cycle mode. This posed additional design challenges for these reasons:

- The variation in exhaust-gas temperature entering the SCR, depending on whether heat was being extracted for steam production

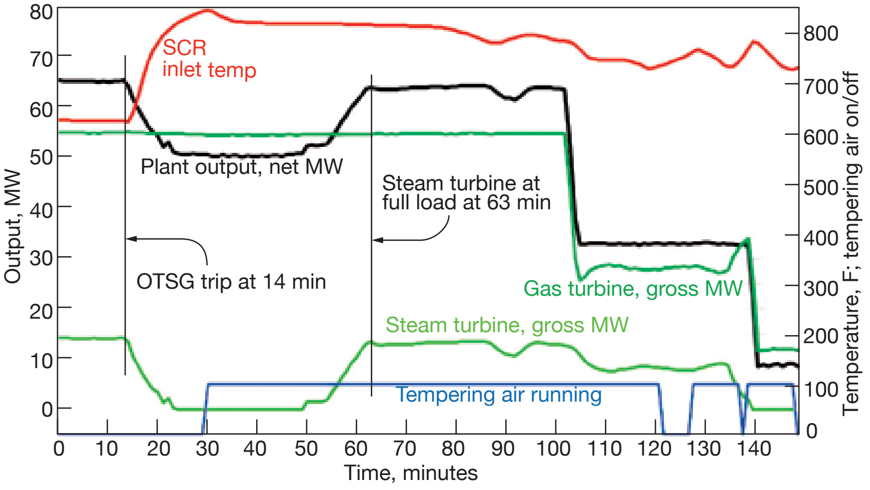
Principal plant equipment

The combined cycle profiled in the main text consists of the following equipment:

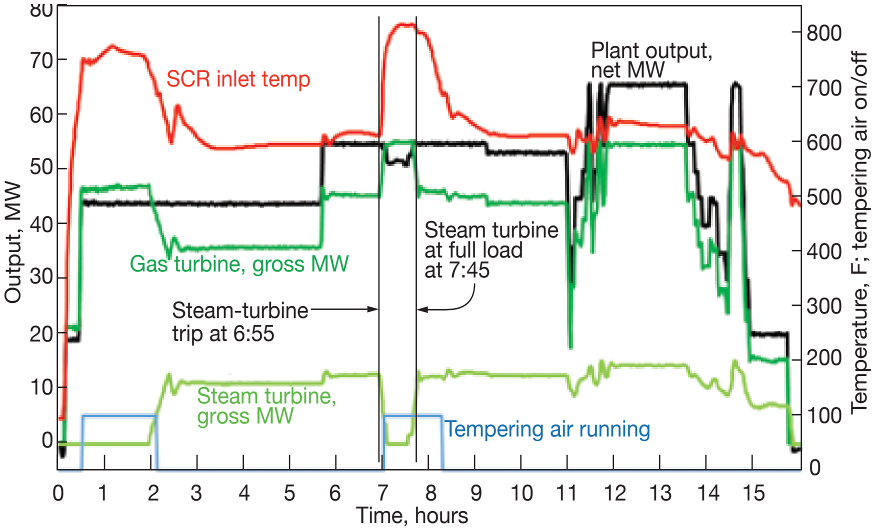
- LM6000PG gas turbine with water injection for NO_x control, a SPRINT power augmentation system, and a mechanical chiller for inlet-air cooling. Supplier: GE.
- Single-pressure once-through steam generator equipped with CO and SCR catalysts and an ammonia injection system for NO_x emissions control. Also, a continuous emissions monitoring system. Supplier: Innovative Steam Technologies Inc.
- Condensing steam turbine. Supplier: Shin Nippon Machinery Co (Japan).
- Deaerating condenser, titanium-tubed, with full steam bypass capability. Supplier: Maarky Thermal Systems Inc.
- Wet cooling tower uses recycled water to reject heat from the steam cycle and auxiliary equipment. Supplier: Cooling Tower Depot Inc.
- Fuel gas compressors, two 100%-capacity units. Supplier: Kobelco/Kobe Steel Ltd.
- Circulating-water, condensate, and feedwater pumps, two each, 100%-capacity. Supplier: ITT Inc, Goulds Pumps.
- Condensate polisher, pre-coat type, full flow. Supplier: Graver Technologies.
- Open cooling-water system uses circulating water to reject heat from the closed cooling-water system and inlet-air chiller, three 50%-capacity pumps. Because the chiller represents about 50% of the thermal load and is not always required, three half-size pumps are optimal, providing sufficient redundancy and flexibility.
- Closed cooling-water system provides cooling for the GT and ST oil and generator coolers.
- Electric auxiliary boiler.
- Additional balance-of-plant equipment includes air compressors, water sampling system, fire protection systems, and chemical feed system for water chemistry control.

during combined-cycle operation or the exhaust gas was being cooled by use of tempering air during simple-cycle operation.

- The variation of exhaust-gas mass flow through the SCR, depending on whether tempering air was being added during simple-cycle operation or not being added during combined-cycle operation.



3. OTSG trip and restart



4. Cold start with steam-turbine trip

Were this a greenfield project, consideration might have been given to a two-pressure design with benefits of slightly greater output and reduced heat rate. However, capital cost would have increased given the need for low-pressure (LP) feedwater and steam circuits and associated equipment.

Given that the benefit of increased electrical output and efficiency occurs primarily at high loads, an evaluation of the expected operating profile would be warranted to assess the cost benefit of adding an LP system in a unit of this size.

OTSG versus HRSG

The table compares operational capabilities of a combined cycle equipped with an OTSG to one with a conventional drum-type heat-recovery steam generator. Note: In this table, "combined cycle" denotes operation when gas-turbine exhaust heat is used to produce steam—irrespective of whether that steam is used for power generation or not. For example, the steam turbine may be offline with steam bypassed to the condenser.

Operational experience

To illustrate the unit's "fast, flexible, and resilient" capabilities, plant-performance trends are provided for the following evolutions:

- Cold start (Fig 1).
- Warm start (Fig 2).
- OTSG trip and restart (Fig 3).
- Cold start with steam-turbine trip and load changes (Fig 4).

Comparing the operational characteristics of OTSG- and HRSG-equipped combined cycles

	OTSG-equipped combined cycle			HRSG-equipped combined cycle		
	Gas turbine	**OTSG**	**Steam turbine**	**Gas turbine**	**HRSG**	**Steam turbine**
Gas-turbine startup	Operates in simple cycle and can reach full load in less than 10 minutes	Shutdown	On turning gear or shutdown	Operates in combined cycle. Load may be limited by HRSG heat-up limits. Time to reach full load varies based on HRSG design limits, but can be much more than 10 minutes	Produces steam which is then bypassed to the condenser	On turning gear
Simple-cycle operation	Operates in simple cycle over the full load range	Shutdown	On turning gear or shutdown	Cannot operate in simple cycle (unless there is a bypass stack) because the HRSG can be damaged if operated without producing steam	Cannot operate in simple cycle	On turning gear or shutdown
Boiler warmup	Operates in simple cycle to warm the OTSG so it can receive feedwater	Shutdown	On turning gear or shutdown	Operates in combined cycle; warmup time varies based on HRSG design limits	Produces steam which is then bypassed to the condenser	On turning gear while the HRSG, steam lines, and condenser are warmed
Boiler startup	Operates in combined cycle with feedwater flow gradually increased	Produces steam which is then bypassed to the condenser	On turning gear while the steam lines are warmed	Operates in combined cycle	Produces steam which is then bypassed to the condenser	On turning gear while the steam lines are warmed
Steam-turbine startup	Operates in combined cycle	Produces steam which is then bypassed to the condenser	Brought to synchronous speed and then loaded; steam bypass to the condenser gradually is reduced	Operates in combined cycle	Produces steam which is then bypassed to the condenser	Brought to synchronous speed and then loaded; steam bypass to the condenser gradually is reduced
Combined-cycle operation	Operates in combined cycle	Produces steam	Operates in combined cycle	Operates in combined cycle	Produces steam	Operates in combined cycle
Boiler shutdown	Operates in combined cycle with feedwater flow to OTSG reduced gradually, or all at once, depending on operational needs. Operation is unaffected by OTSG shutdown	Following feedwater isolation, steam production continues until the OTSG boils dry	Continues to operate while the OTSG produces steam and then is shut down or trips. After the ST trips, steam is bypassed to the condenser	Operates in combined cycle, with the GT and HRSG shutting down in concert	Continues to produce steam which is bypassed to the condenser	Typically is shut down prior to the boiler
Gas-turbine shutdown	Operates in combined- or simple-cycle mode	Following feedwater isolation, steam production continues until the OTSG boils dry	Continues to operate while the OTSG produces steam and then is shut down or trips. After the ST trips, steam is bypassed to the condenser	Operates in combined cycle, with the gas turbine and HRSG shutting down in concert	Continues to produce steam which is bypassed to the condenser	Typically is shut down prior to the boiler
Unplanned ST trip	Operates in simple cycle unaffected by steam-cycle upset	Continues to produce steam, which is bypassed to the condenser (subject to condenser limitations)	Tripped and steam is bypassed to the condenser	Operates in combined cycle with the HRSG steam bypassed to the condenser—unless the steam-turbine trip cascades to an HRSG trip, in which case the gas turbine is tripped	Continues to produce steam, which is bypassed to the condenser (subject to condenser limitations)	Tripped and steam bypassed to the condenser
Unplanned HRSG trip	Operates in simple cycle unaffected by steam-cycle upset	Following feedwater isolation, steam production continues as the OTSG boils dry	Continues to operate while the OTSG produces steam and then is shut down or trips. After the ST trips, steam is bypassed to the condenser	Shuts down because the boiler cannot accept more heat	Following feedwater isolation, limited steam production continues to protect water levels in steam drums	Operation may continue while the HRSG is producing steam, but the steam turbine may be tripped to protect water levels in steam drums. After the ST trips, steam is bypassed to the condenser

The terms used in the illustrations are defined this way:

Plant output, net MW is the combined output of the gas and steam turbine/generators less the unit auxiliary load.

Gas-turbine, gross MW is the GT generator output.

Steam-turbine, gross MW is the ST generator output.

SCR inlet temp is the temperature of the exhaust gas upstream of the SCR inlet.

Tempering air running gives fan on/off status.

Cold start

When the unit starts up cold, the gas turbine ramps to achieve the desired plant load setpoint—51 MW for this particular start. The closed and open cooling-water systems are started at the same time to support GT operation; hence, plant net output is lower than GT output because of the auxiliary load.

Once there is sufficient exhaust heat to vaporize the 19% aqueous ammonia, the reagent is injected into the OTG to react with the SCR catalyst and reduce stack emissions to permitted levels. A tempering-air fan starts to prevent overheating of the SCR catalyst.

The circulating-water and condenser-vacuum pumps, and the auxiliary boiler, are placed in service to pull vacuum, sparge the condenser, and begin reducing dissolved-oxygen levels in the condensate. Additionally, the condensate pumps are used to recirculate condensate through the polisher to meet water-chemistry requirements.

Once the recirculating condensate chemistry is acceptable, and the OTSG has warmed up to the minimum required startup temperature, the feedwater flow control valve is opened. Feedwater flow gradually ramps up and steam production begins.

When the steam lines are warmed up and the steam-turbine inlet steam conditions are met, the turbine is started, paralleled, and loaded. Typically, it is operated VWO (valves wide open). The ST follows the GT and the plant control system adjusts gas-turbine output so unit net load matches the target.

Warm start

A warm start proceeds more quickly than a cold start because water chemistry typically is closer to being in-spec. The primary constraint is the time to warm the OTSG (and the significant catalyst mass within). Steam-turbine metal temperature is another consideration. Typically, full load can be achieved within about 70 minutes—or about half the time needed to reach full load on a cold start.

OTSG trip, restart

As part of unit testing, the OTSG was tripped manually with the unit at full load. Steam-turbine load decayed over the next 10 minutes and the generator breaker opened. Steam was bypassed to the condenser to reduce steam pressure to the point where the steam drains could be opened and the OTSG prepared for restart.

Absent heat removal through the steam system, SCR inlet temperature increased and the tempering-air fan started automatically to control catalyst temperature.

The OTSG was restarted; subsequently, the steam turbine. The ST was back to full load within 50 minutes of the OTSG trip. During this time, the GT continued to operate unaffected by the steam-plant upset, delivering approximately 85% of the total plant capacity.

Cold start with ST trip, load changes

The combined cycle entered commercial operation in late 2016. A typical day's operation in response to system dispatch is illustrated by the timeline below. On this day, the unit also experienced an ST trip, and its recovery.

0632 hours. Cold start, dispatch to 19 MW.
0655. Load increased to 44 MW (simple cycle); steam plant readied for startup.
0827. The ST was paralleled and its load increased. Gas-turbine load decreased to maintain a steady combined-cycle output of 44 MW.
1208. Unit load increased to 55 MW.
1325. Steamer tripped, GT went to full load and the unit operated at 52 MW.
1401. ST was paralleled.
1408. Unit load returned to 55 MW.
1541. Unit load reduced to 53 MW.
1727 to 2130. Several load changes between 20 and 66 MW to accommo-

date system dispatch requirements.
2213. GT shutdown initiated.
2218. GT offline.
2219. OTSG trips.
2220. ST offline.

Wrap-up

Experience with this unit confirms its relative ease of operation. Startups and shutdowns are straightforward, akin to a simple-cycle unit. The ability to make rapid and frequent load changes without having to manage drum water levels eases the burden on the operator.

Further, the ability to effectively separate the steam plant from the gas turbine provides both operational flexibility and the capability to keep a significant part of the plant's generating capacity in service where other combined cycles might have lost all their generating capacity because of a steam-plant trip cascading into a unit trip.

Although the plant performance metrics presented above are for a specific site and equipment arrangement, the overall conclusions hold true—in general. Today many aero and some frame gas turbines offer 10-min-start capability—some even faster starting. While the 10-min start is critical in offering some services—such as peaking and non-spin reserve—the flexible and resilient attributes of this type of unit remain when using a gas turbine with a longer start time.

The bottom line: Combining the capabilities of a 10-min-start GT with an OTSG results in a unit that can start quickly, operate in the simple- or combined-cycle mode, and accommodate steam-plant upsets by allowing the GT to produce power while the steam turbine is restored to operation. This is an optimal mix of capabilities to address today's dynamic electricity demands. CCJ

About the author

Dave Tateosian, PE, principal, Clean Power Consulting Partners, was the owner's project manager, as well as construction and commissioning manager during the latter stages of the project. He acknowledges the assistance of the Pasadena Water & Power plant staff—in particular, Robert Picou—in the preparation of this article. GE, ARB, POWER Engineers, and Stantec are recognized for their contributions to the project's success.

Consider the impact of new operating regimes on your SCR's performance

It's easy to forget about the "big box" selective catalytic reduction (SCR) unit sandwiched in your HRSG modules, even though it stands between you and compliance with your air permit, and your ability to operate.

At the 2017 Combined Cycle Users Group Conference, held in Phoenix the last week of August, Andy Toback, Environex Inc, did his best to remind users that SCR process parameters have to be re-evaluated when gas turbines are upgraded, plant operating tempos change, duct-burner operation is more prevalent or variable, and/or the latest G and H technology machines are being deployed. Otherwise, you may be leaving money on the table or setting yourself up for unexpected costs and performance issues down the road.

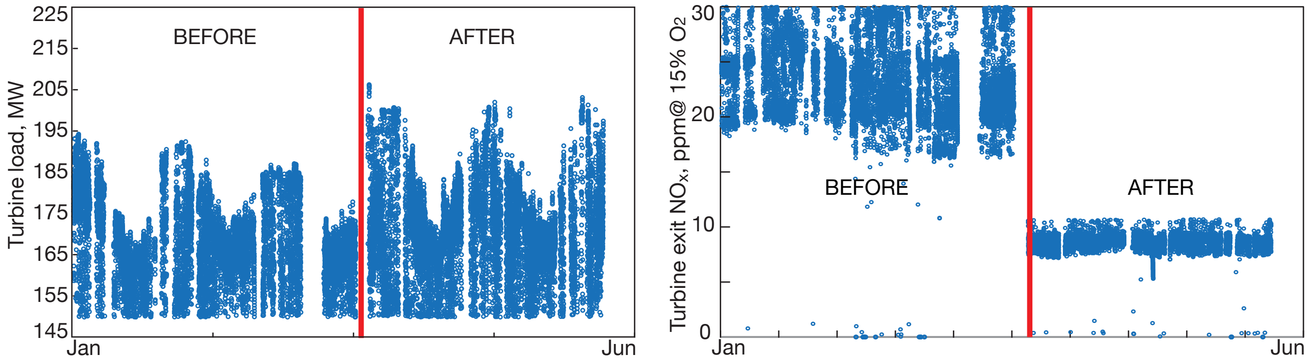
Toback's main message is that you need to adjust the original design expectations for the SCR based on real-world operating data, the key to optimizing the process for new conditions.

For an actual 7FB.01 to 7FB.04 upgrade, for example, the new combustors added 7 MW of output and lowered turbine NO$_x$ levels entering the SCR (Fig 1). Because the catalyst going forward typically will convert 9 ppm NO$_x$ levels from the turbine, compared to the original design of 25 ppm, the relative catalyst activity level, representing the expected end of life, can now be projected out beyond 10 years (Fig 2), compared to 5.5 years with the original combustors.

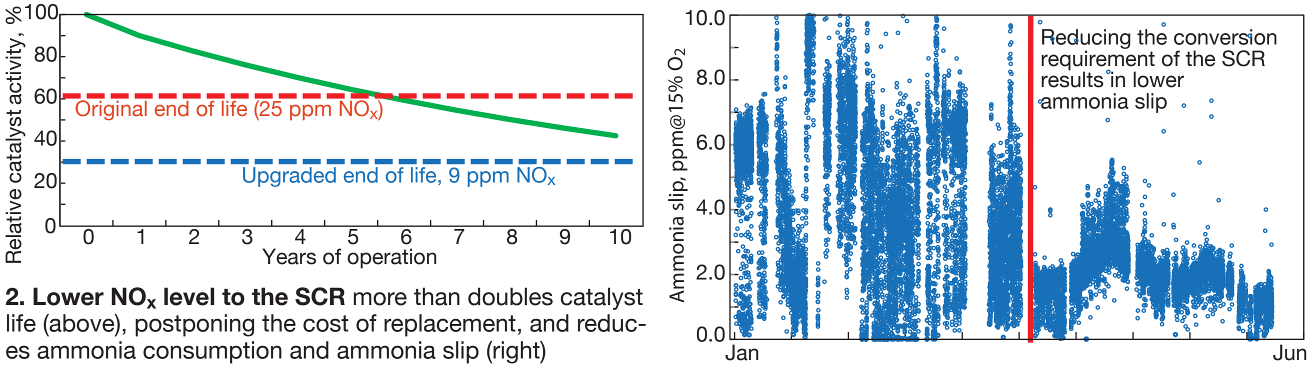
Ammonia consumption and ammonia slip at the stack also are reduced significantly because of the lower NO$_x$ conversion requirement for the SCR system. Due to the improved combustor dynamics, gas-turbine CO levels are not expected to change even though the NO$_x$ levels have decreased.

Toback's second example is a 7FA.03 to 7FA.04 + DLN 2.6+ upgrade (Fig 3). The good news is that the megawatt output gain was higher than expected, another reason why actual measurements are important. However, peak-load fuel and exhaust flows increased accordingly, the turbine exit NO$_x$ levels did not change appreciably, but the SCR temperature increased by about 20 deg F after the upgrade.

The original Dot 03-machine catalyst design life projection was about 21 years. The upgrade design *expectation* reduced it to around 13 years. Based on the actual operating data, however, the catalyst life should be more like 18 years (Fig 4). Both an expected

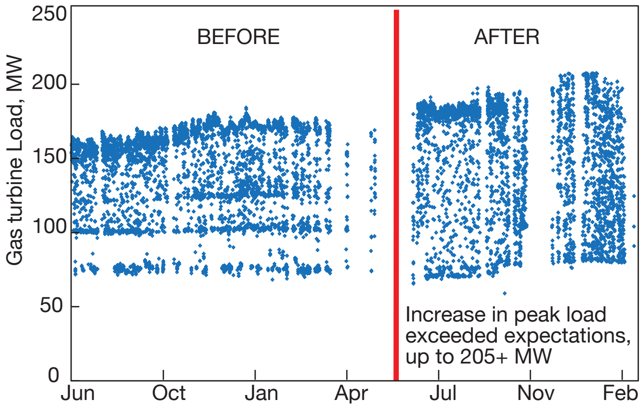


1. Gas-turbine combustor upgrade resulted in a desired gain in megawatt output (left), but also reduced significantly the NO$_x$ levels entering the SCR (right)



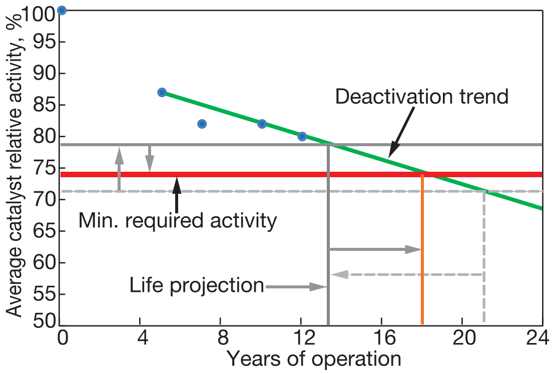
2. Lower NO$_x$ level to the SCR more than doubles catalyst life (above), postponing the cost of replacement, and reduces ammonia consumption and ammonia slip (right)

Operating parameter	7FA.03 actual operation	7FA.04 w/DLN 2.6+ design expectation
Maximum GT load, MW	178	195
Maximum fuel flow, 1000 lb/hr	75.6	84.2
Exhaust temperature, F	1038	1115
SCR inlet NO_x, ppmvdc	9.0	10.4
Stack NO_x requirement, ppmvdc	2.0	2.0
NO_x conversion requirement, %	78	81

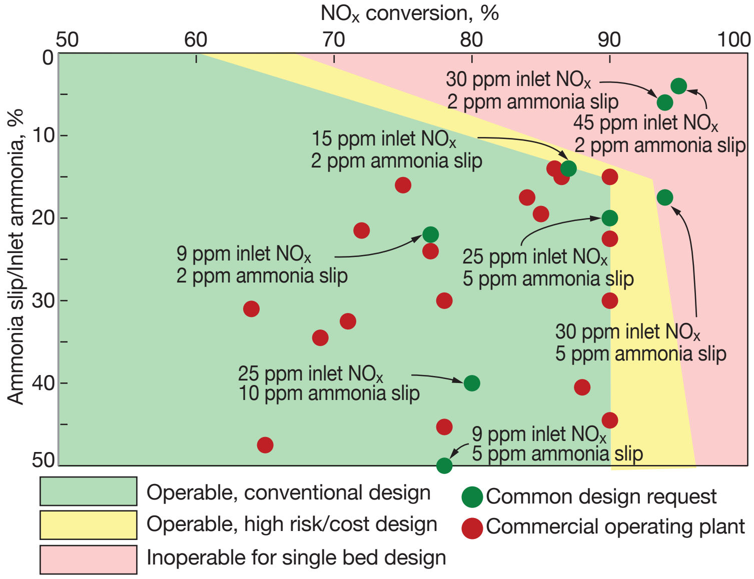


Increase in peak load exceeded expectations, up to 205+ MW

3. Conversion of a 7FA.03 to a .04 with dry low-NO_x 2.6+ design changed the SCR operating parameters (left) and raised output appreciably (right). Data reflect peak-load operation, no duct firing



4. Expected design life of the catalyst is around 13 years with the upgrade; however, actual measurements showed no change to the SCR inlet NO_x levels, which should extend catalyst life to about 17.5 years



5. Advanced G and H machines result in NO_x levels to the SCR as much as five times that of earlier models; single-bed designs don't provide the catalyst volumes necessary to achieve similar stack outlet NO_x levels at reasonable slip levels

increase in engine NO_x from 9 to 10.4 ppm and higher exhaust flows impair catalyst life, but because the actual operating data showed no change in gas-turbine NO_x levels, the minimum catalyst-activity requirement did not increase as much as anticipated.

For advanced G and H machines, the news isn't so good. Toback stated, "We're being asked to achieve the same 2 ppm NO_x and ammonia-slip levels (typical of the toughest permits) even though these machines have five times the turbine-exit NO_x levels." Plus, they likely will be required to cycle and operate at less than design output for significant operating hours over their lifetimes.

Fig 5 indicates that for these performance specifications, you'll either have to accept high operating and compliance risk at the ragged edge of the capabilities of traditional single-bed SCRs or resort to a more complicated and more expensive SCR design.

When you operate advanced-technology machines at low loads, you tap out the capabilities of the design (Fig 6). "The ammonia injection grid can't handle both the NO_x levels at the maximum design output and what would be typical at 30-50% load, because of the corresponding changes in mass flow, temperature, and mixing."

Environex specialists believe owner/operators of G- and H-class machines will have problems because vendors are supplying SCRs with inadequate catalyst volumes. It's also important to consider adding a permanent grid made of stainless-steel tubing within the HRSG housing which allows you to periodically take 2-D distribution-grid measurements for NO_x and NH_3 and more accurately tune the AIG distribution valves.

Such capability nominally adds about $50,000 to the budget, a sum that looks paltry compared to the

Load level	% of rated load	100	75	50	25	15
Ambient temperature	F	73	73	73	73	73
Power output	MW	168	125	83	41	24
Exhaust flow	million lb/hr	3.6	3.2	2.6	2.6	2.6
Exhaust temperature	F	1100	1000	1000	776	684
Turbine exit NO_X	ppm@15% O_2	25	25	45	45	45
Turbine exit CO	ppm@15% O_2	10	10	400	3500	3000
Stack NO_X (90% conversion)	ppm@15% O_2	2.5	2.5	4.5	4.5	4.5
Stack CO (90% conversion)	ppm@15% O_2	1	1	40	350	300

6. Low-load operation, such as between 30% and 50% MCR, impairs SCR and CO catalyst operation (data presented are for a 501F); this impact likely will be more pronounced for the advanced G and H machines penalties of non-compliance. The high NO_x conversion requirements for these systems coupled with low ammonia-slip limits decrease the tolerance for non-ideal ammonia-to-NO_x distribution. You should expect this to increase the required frequency for ammonia-grid tuning.

Duct burners, of course, are another source of NO_x and CO which must be accounted for through real operating data. SCR inlet NO_x can more than double at design GT output and full duct firing and the SCR operating temperature can climb by 50 to 100 deg F. Inlet CO, meanwhile can decrease. During interim periods as duct burners come up to full capacity, or remain at part load, NO_x and CO emissions can be quite variable. These impacts can be quite striking if your unit was designed for baseload operation.

Generally, Toback concludes, increases in exhaust flow to the SCR impairs catalyst life, while decreases in SCR inlet NO_x and CO emissions and increasing SCR operating temperature extend it. If your machines are no longer operating the way the SCR was designed, it's time to consider a program to acquire the operating data needed for optimizing the SCR process for new conditions. CCJ

How natural-gas fuel variability impacts GT operation

By **Scott Sheppard, Ben Emerson,** and **Tim Lieuwen,** Turbine Logic

Natural-gas fuel composition has considerable influence on gas-turbine emissions and operability. This might not have been a concern to you previously, but the possible impacts on your engines of increasing reliance on non-traditional pipeline gas—in particular, shale gas, but also LNG, and byproduct fuels from industrial processes—suggests you might want to read on.

Even if you have "good gas," be aware that the negative impacts of gas-constituent variability can be magnified by the high firing temperatures of today's most advanced gas turbines. Reason is that these machines must "work harder" to achieve low-NO_x emissions and thus have fewer "knobs" to mitigate fuel-composition impacts.

The Wobbe and Modified Wobbe indices are two standard properties used in practice to determine the effects of fuel variability. But they only indicate the changes in heating value and usually cannot describe how changing fuel composition will affect emissions and some potentially damaging operability issues.

Aside from NO_x and CO emissions, there are four operability issues of importance to plant personnel. They are:

- Blowout, or when the flame physically exits the combustor; also referred to as blowoff.
- Flashback, or when the flame moves upstream into premixing sections not designed to withstand high temperatures.
- Combustion dynamics, or the damaging pressure oscillations associated with oscillations in the combustion heat release.
- Autoignition, or the spontaneous ignition of a reactive mixture of fuel and air in the premixing section of the combustion chamber. The effects of autoignition and flashback are the same, but the underlying reasons and fuel sensitivities are completely different.

These four issues, which Turbine Logic routinely observes when performing root cause analyses, pose risks to gas turbines and are closely tied to operating conditions and fuel composition.

Before discussing the impacts of fuel variability on gas turbines, it is important to understand the composition of natural gas, which in North America typically contains 85% or more of methane. The next most common constituent is ethane at about 7% or less, followed by propane at about 1.5% or less. Other components include other higher hydrocarbons, nitrogen, carbon dioxide, and hydrogen. From an operability point of view, it is convenient to divide the fuel constituents into three buckets: higher hydrocarbons, hydrogen, and diluents.

As previously mentioned, the Wobbe Index and Modified Wobbe Index both describe the effect of fuel composition on fuel heating value, with the Modified Wobbe Index also accounting for fuel temperature. In addition to Wobbe Index recommendations, OEMs typically include a fuel specification for their gas turbines on levels of higher hydrocarbons and hydrogen. By operating within these recommendations, operators generally can avoid some of the operational issues mentioned earlier. However, the combustion-dynamics issue is particularly sensitive and difficult and is an issue that must be actively monitored and managed by operators.

There is a relationship between some of these operability issues and Wobbe Index—for example, higher ethane and propane contents in fuel leads to a higher fuel heating value, which also increases autoignition risks. Nonetheless, two fuels with the same Wobbe can have substantially different blowout, flashback, combustion-dynamics, and autoignition tendencies. Thus, Wobbe Index alone cannot be used to ensure safe, reliable operation.

Effects of fuel composition on operability

The operability concerns described below apply mostly to dry-low-NO_x/dry-low-emissions/ultra-low-emissions (DLN/DLE/ULN) systems. They are much more prone to these issues than diffusion systems—most notably combustion dynamics, which are a product of combustor design and the effort to keep NO_x emissions as low as possible. Diffusion systems do experience some dynamics issues near blowout, but they can be avoided by operating with a sufficient blowout margin.

Blowout. One of the biggest factors impacting flame blowout—also known as blowoff or lean blowout (LBO)—is the flame speed of the different fuel mixtures. Flame speed is the speed at which the flame moves through the reactants during combustion. Hydrogen addition has particularly significant impacts on increasing blowout margin because of its much higher flame speed than methane.

Propane and ethane also have higher flame speeds, but the effect is much less significant than hydrogen. By contrast, diluents (particularly CO_2) reduce blowout margins as they act to reduce the fuel's flame speed.

Takeaway 1: Increases in diluents pose the greatest blowout risk.

Flashback. As previously mentioned, the presence of hydrogen and higher hydrocarbons can move a flame upstream into premixing passages. Swirlers, fuel lances, and premixing passages are not designed to withstand the high temperatures that would occur with a flame in the premixing section and can quickly sustain damage.

In some events, this hardware may liberate and travel downstream through the power turbine, causing catastrophic damage. Loosely speaking, flashback can be thought of as the "opposite" of blowout; for this reason,

the H_2 level limits in DLN system fuel specs are set by flashback margin.

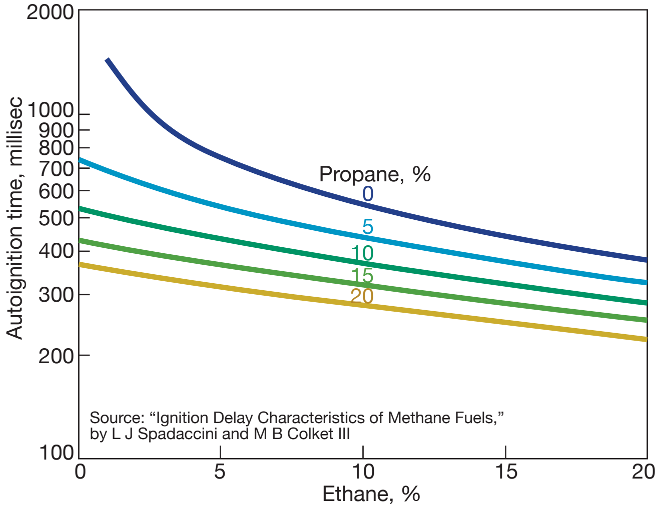
Takeaway 2: Increases in hydrogen content pose greatest flashback risk.

Combustion dynamics. Fuel composition directly affects combustion dynamics. However, in contrast to other operability concerns, the effect is non-monotonic with operational parameters which make it particularly difficult to predict. For example, while increasing H_2 levels always will decrease flashback margin, combustion-dynamics amplitude can either increase or decrease, depending upon other operating conditions.

Takeaway 3: Changes in fuel composition may decrease combustion dynamics, increase combustion dynamics, or have no effect at all.

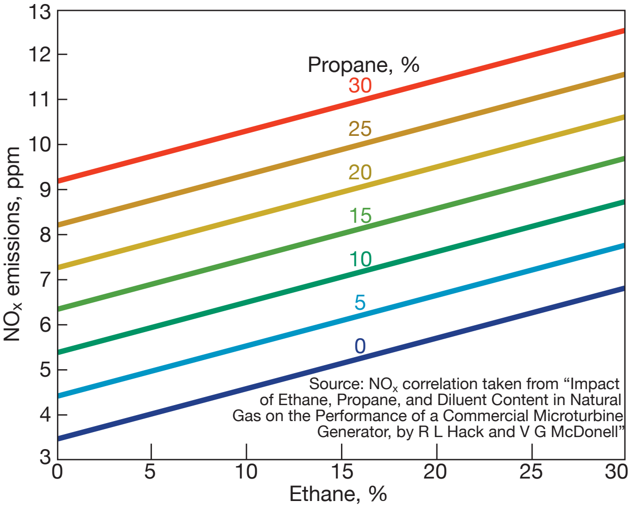
Combustion dynamics pose a direct threat to combustion liners, transition pieces, and cross-fire tubes. If the combustion-dynamics amplitudes are severe, liberation of these parts may occur, with hardware travelling downstream through the power turbine. Combustion instabilities can also lead to blowout and flashback.

Because of the sensitivity of combus-



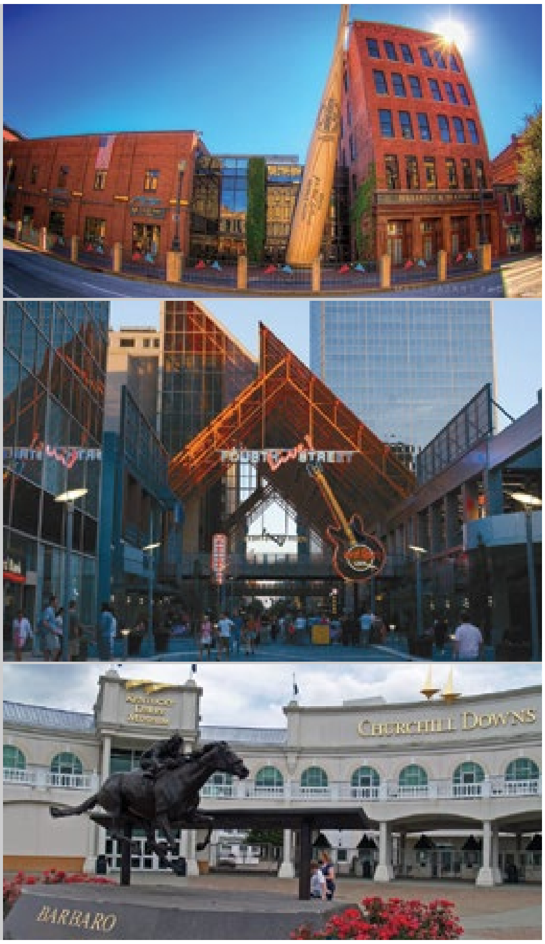
Source: "Ignition Delay Characteristics of Methane Fuels," by L J Spadaccini and M B Colket III

1. Autoignition time varies with the amount of methane, ethane, and propane in natural gas. Operating conditions that underpin the data presented here are pressure, 30 atm; gas temperature, 800K; equivalence ratio, 0.5



Source: NO_x correlation taken from "Impact of Ethane, Propane, and Diluent Content in Natural Gas on the Performance of a Commercial Microturbine Generator, by R L Hack and V G McDonell"

2. How NO_x emissions are impacted by the amount of ethane and propane in natural-gas fuel. Tests of four different fuel blends were conducted using a Capstone C-60 MTG gas turbine operating at a pressure of about 4 atm and a turbine exhaust temperature of 1175F



tion dynamics to the details of the flame configuration inside the combustor, dynamics are sensitive to *all* changes in fuel composition—that is, changes in higher-hydrocarbon, hydrogen, or diluent content. Note: In this case, the risk is *changes* rather than *increase*. The Turbine Logic combustion dynamics monitoring group has observed increased challenges with dynamics, and the need for more frequent tuning because of gas composition issues.

Autoignition. Hydrogen and higher hydrocarbons also significantly decrease autoignition temperature and times, leading to increased autoignition risks. While symptomatically similar to flashback, the physics of autoignition is different. In this case, if the autoignition time of the fuel mixture falls below its residence time in the premixing tubes, the fuel mixture may spontaneously ignite in the premixing zone.

Similar to flashback, autoignition can damage premixing passages, swirlers, and fuel lances. As with any of these other operability issues, liberation of any of these parts poses a threat to the power turbine. Fig 1 shows the how quickly autoignition times decrease with increasing amounts of ethane and propane in natural-gas fuel.

Takeaway 4: Higher hydrocarbons (especially when coupled with the higher compressor discharge temperatures of aeroderivatives) pose the greatest autoignition risk.

Nitrogen oxides. There are two main NO$_x$ formation pathways:

- NO$_x$ produced in the flame, which generally is a few ppm and heavily influenced by fuel composition.
- NO$_x$ produced post-flame, which really only depends on flame temperature.

Thus fuel composition influences on NO$_x$ emissions are somewhat dependent on the nominal NO$_x$ emissions of the gas turbine. Assuming the firing temperature stays fixed as fuel composition varies, for units with relatively high NO$_x$ emissions (nominally 15 ppm and higher), NO$_x$ production is dictated mostly by the firing temperature and is largely insensitive to fuel composition.

On the other hand, units that have fairly low NO$_x$ emissions (less than 5 ppm) will see a significant effect from changes in fuel composition. Data suggest that NO$_x$ concentrations may even double with changes in fuel composition for such low-NO$_x$ systems. Fig 2 shows how much NO$_x$ production can increase, in the low-NO$_x$ case, with increasing amounts of ethane and propane in natural gas.

Takeaway 5: The lower a gas turbine's NO$_x$ emissions, the greater the impact of fuel composition on those emissions.

Carbon monoxide. The effects of fuel composition on CO production are largely controlled by whether it moves the system closer to, or farther from, lean blowout. If the unit is near LBO, CO emissions typically already are high, but can still be raised significantly by the presence of higher hydrocarbons and hydrogen in the fuel. Away from LBO, CO emissions may still rise with the addition of higher hydrocarbons and hydrogen, but the effect is quite small.

Takeaway 6: Similar to blowout, increased diluent content poses the greatest CO risk.

Recommendations

A fuel treatment system will mitigate the fuel-variability effects on each of the operability issues discussed above. These systems are equipped for removing solid particulates and higher hydrocarbons. The latter is accomplished by condensation and liquid removal.

Most OEMs also recommend some degree of fuel superheating before use in a gas turbine to ensure that no fuel

condenses before reaching the fuel nozzles. Condensed fuel can cause significant autoignition issues. Even with a good fuel treatment system, small concentrations of liquid hydrocarbons from the fuel gas remain a risk when liquids are entrained from the liquid knockouts. This may occur with higher hydrocarbons, because the knockouts fill more quickly and require more frequent draining than experience might dictate.

Along with Wobbe Index recommendations, OEMs issue fuel specifications for their units. They are designed to accommodate blowout and flashback margins, and those phenomena should not occur when operating within the specs. However, even when operating within the recommended specs, combustion dynamics and emissions may be impacted by changes in fuel composition.

The greatest operational risk that cannot be managed by staying with OEM fuel guidelines is combustion dynamics. Turbine Logic's experts strongly recommend users have a combustion dynamics monitoring system (CDMS) to warn of impending issues, and also have protocols in place for ensuring sensors are healthy; plus, appropriate notifications if levels exceed alarms.

In the authors' experience, every engine monitored by Turbine Logic has had multiple dynamics excursions exceeding thresholds as the ambient temperature and load varied. The need for shorter tuning intervals only can be confirmed by CDMS.

Several options are available to control loud combustion instabilities, and all are used by manual- or auto-tuning systems. These include varying the fuel temperature within the OEM spec, altering the fuel staging, increasing the non-premix pilot fuel, varying the amount of inlet air chilling, and varying the amount of steam/water injection. De-rating is the last resort.

To complicate things, because of the non-monotonic nature of combustion dynamics, a change in fuel composition can alter the unit's response to each of these operational changes. Since combustion dynamics don't have a one-to-one relationship for different operating conditions, installation of a CDMS can provide great insight into how your units respond to different operational changes. CDM systems provide nearly instantaneous feedback and will facilitate the building of a knowledge base around how your units behave regarding combustion dynamics.

If you continue to have combustion-dynamics issues while keeping NO_x concentrations within regulatory limits, consider installing an auto-tuning system. It monitors dynamics and emissions and has control logic to minimize emissions while keeping combustion dynamics within acceptable limits to prevent hardware damage.

Auto-tuning systems typically have the ability to regulate several operational parameters— including firing temperature, fuel splits, and even fuel-split schedules. When either dynamics or an emissions excursion occurs, auto-tuning systems step in and nudge these parameters to return the gas turbine to safe and compliant operation. While seasonal tunes remain a good idea, and sometimes a necessity, the auto-tuning system will handle the day-to-day changes that gas composition variability may introduce. **CCJ**

HRSG best practices: Plan now for old age

It happens to all of us. One day we wake up and realize, we're not young anymore. You can, in the same breath, decide you need to do some things differently. Or, you can ignore it, and pay a larger price later.

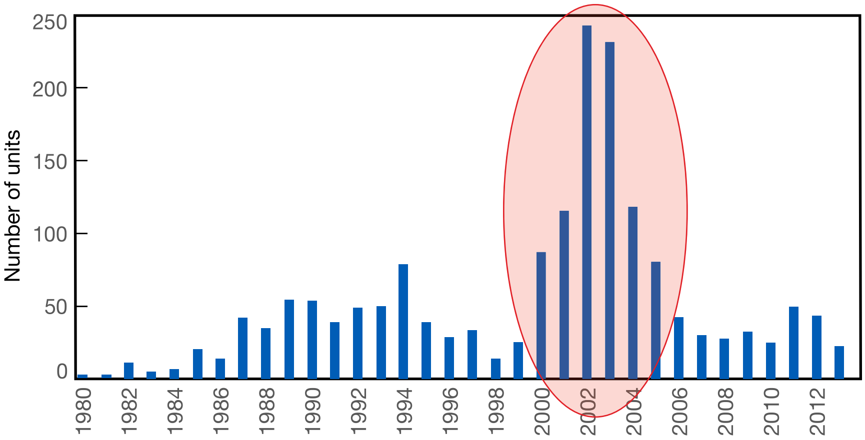
The same thing is true with heat-recovery steam generators (HRSGs). Combined-cycle plants experienced the equivalent of the post WWII "baby boom" between 2000 and 2005 (Fig 1). These units are now in or approaching the second half of their 25-30-year design life.

The need to acknowledge this reality and plan accordingly was considered important enough that the Combined Cycle Users Group (CCUG), at its 2017 conference in Phoenix at the end of August, devoted the better part of a morning to the subject so that the experts at HRST Inc could identify some the problems users could experience and possible solutions.

At an industry level, Bryan Craig noted that the general goal is to plan for and avoid similar ageing problems experienced with the fleet of fossil-fired boilers installed a generation earlier. The range of issues presented, and the photographic evidence from operating units, in the HRST slides is so extensive that users are strongly encouraged to access the original presentations at www.powerusers.org. This article gives some highlights.

Like many fossil units, combined cycles often operate in ways not designed for—that is, less baseload and more cycling and dispatch. Some of the original design materials and methods may be questionable as well.

Creep and overheat damage in superheater and reheater tubes is the first problem Craig tackled. Most tube overheat incidences occur downstream of the duct burner and are caused by flame impingement. Flames should never make contact with tube metal yet they often do. Rules-of-thumb for flames are that they should be 6-10 ft long, they should be independent and separated, and reach one-half to two-thirds down the firing duct.



1. HRSGs in the large fleet of units installed in the US between 2000 and 2005 are now approaching "middle age" and need different maintenance regimes

2. Cameras installed in the duct-burner area can wirelessly relay images back to the control room to check in real time for flame impingement on tubes, which will help prevent creep and overheat damage

While users should view flames at least once daily, and preferably once per shift, through the unit's viewports, a better idea is to install cameras in the firing duct (Fig 2) on the walls, floor, and/or ceiling and wirelessly transmit the images to screens in the control room. Damage is often worse in areas difficult to view through the casing ports.

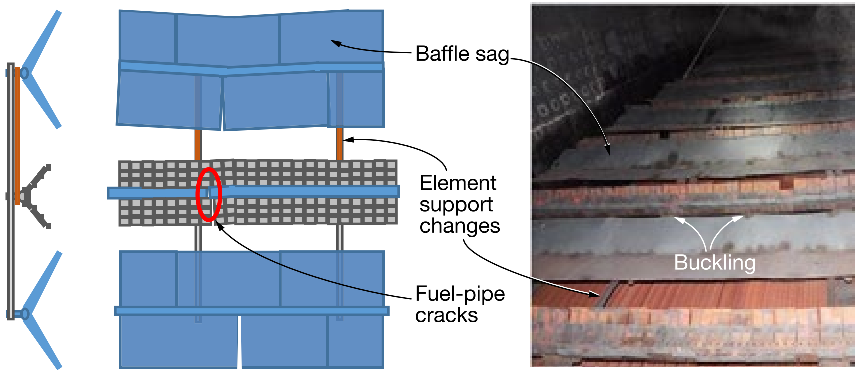
Up next were duct-burner problems, notably baffle sagging, cracking, and fluttering; flame-holder failures; coking; burner-nozzle cracking; and flow-distribution equipment failure. In the case of baffles, for example, they often sag under their own weight as the radiant heat weakens the metal. Because they also provide horizontal and vertical support to the burner elements, weakness in the baffles causes problems in the burners, such as fatigue cracks. Fig 3 illustrates the some of the issues with one type of burner and vintage, and the fix HRST has implemented.

Casings experience cracking and corrosion problems at the roof because of numerous piping penetrations, and on the sides where temperatures generally above 800F may exist. Unrepaired casing cracks can lead to graphitization and more extensive repair work. Of course, any cracks, especially in the roof, lead to rainwater ingress and insulation failures, which only compound problems with internal surface corrosion.

In the duct-firing area, there's more insulation to protect against higher temperatures. However, when the burners are not running, this becomes the coldest area of the casing. If the temperature dips below the exhaust gas dewpoint, acidic condensation may occur, leading to rare cases of stress-corrosion cracking. High NO_x environments, units with no SCR for example, are especially prone to SCC.

Ageing problems in economizers. Craig focused on the return-bend style of economizer design (different from panelized economizers). Much of the economizer's weight is supported by the return bends, making them prone to corrosion fatigue. Startup thermal shock aggravates the situation. To address this, HRST has developed a retrofit support system that avoids any new pressure parts (Fig 4).

Craig offered suggestions and more robust inspection, testing, and assessments for addressing high-pressure evaporator waterside deposits and high-temperature piping. The API 579/ASME FFS-1 specification to assess "fitness for service" and remaining life should be considered for high-temperature piping. He noted that a "high percentage of welds being tested are problems." For areas prone to corrosion under insulation, Craig suggested retrofitting vents and drains (Fig 5).



3. Burner baffles often support the burner elements. Baffles prone to sagging and buckling (above), typical for one manufacturer's offering in the 1999 to 2004 period, can be replaced with a stronger and more durable design (below)

4. Shoring up economizer tube return bends with supports shown can help prevent cracks from corrosion fatigue (above)

5. Corrosion under insulation can be addressed by adding venting and draining capability to remove moisture/water ingress (right)

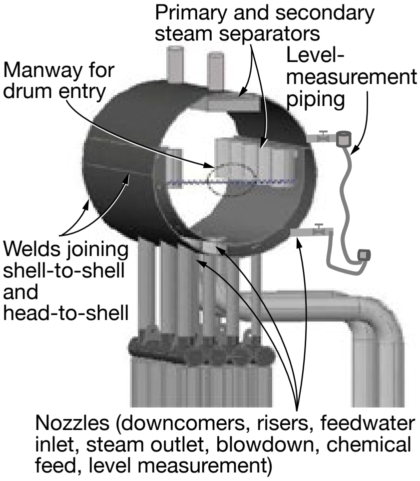
Steam drums

Part deux of the HRST trio of presentations at CCUG was handled by Lester Stanley and focused on HRSG steam drums. Stanley led off with a quick primer on steam drums, their function, and refresher illustrations, and a list of five important steam-drum components (Fig 6). Then he identified the five issues he would address:

- Steam-purity degradation.
- Drum-level-measurement piping condition.
- Nozzle weld cracking.
- Shell weld cracking.
- Manway sealing reliability.

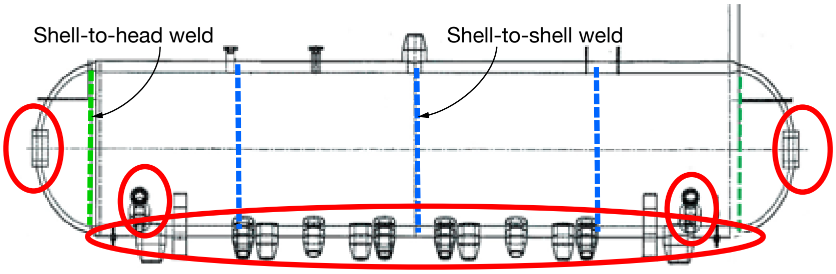
"Steam-drum performance and steam purity were probably carefully tested at commissioning," Stanley said. But in the second half of life, "age is affecting the mechanical condition of the drum internals." This can result in excessive water carryover. Specifically:

- Primary and secondary separators get fouled with rust.
- Fouling occurs in the final separators, increasing velocity and impairing moisture separation.
- Gaps appear in the final separators, allowing wet steam to pass through.
- Separator housing and supports

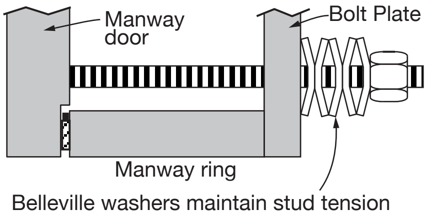


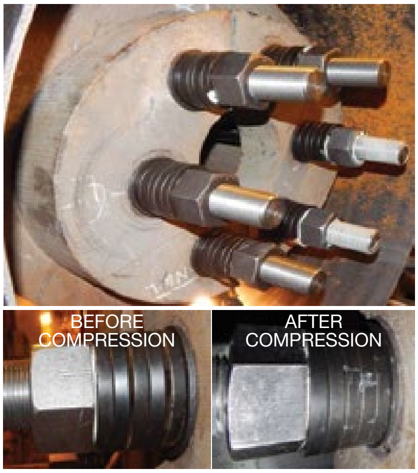
6. Steam-drum components indicated are most prone to ageing risks, according to HRST engineers

7. Removable insulation that protects better against rainwater (left), compared to what you see at the right, will help guard against corrosion of small-diameter piping characteristic of level-measurement piping



8. Nozzle and shell welds for piping protruding from the steam drum are numerous and subject to ageing risks, especially when the unit is cycled heavily. Robust formal inspection programs are recommended





9. Steam-drum manway door with Belleville washers (above) may be the optimal choice if replacement is necessary. It seals better than standard fasteners and offers more protection for personnel because by avoiding the hot retorqueing required by some HRSG suppliers

fail from stress and also allow wet-steam bypass.

- Errors occur in drum-level sensing, leading to higher water levels and less volumetric space for moisture to drop out; this is usually caused by level-transmitter calibration/compensation.

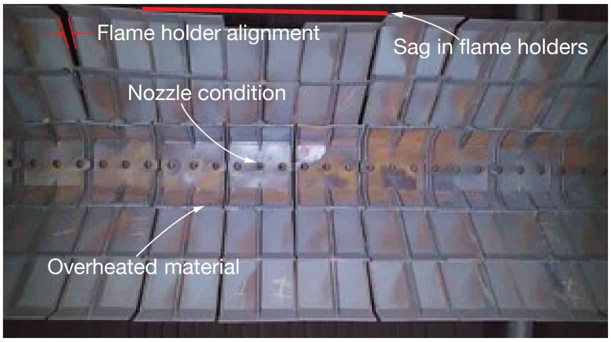
Detecting these problems is best done through more frequent saturated steam sampling, and even continuous on-line monitoring.

The condition of drum-level piping is critical for accurate level sensing. Age-related risks include plugging of sensing lines with debris and corrosion of small-diameter external piping. The latter risk grows with increased downtime. Removable insulation blankets exacerbate rainwater ingress. Solutions are to inspect under insulation more frequently and consider use of removable insulation with better protection against rainwater (Fig 7).

The focus for nozzle and shell weld cracking is the high-pressure (HP) drum but all steam drums should be inspected, Stanley urges. Although the intermediate-pressure (IP) drum is the least susceptible to weld cracks, it's easy to include it in the inspection program for the HP and LP so you "sleep better at night."

On/off cycling drives weld cracks in the HP drum. This causes temperature differentials between the shell and its nozzles because the drum pressure cycles across a wide range, such as from 0 to 400 psig. Problem is, there are numerous thick nozzles and shell welds in an HP drum (Fig 8). In the LP drum, internal diameter (ID) pitting, leading to cracks, is the notable threat.

Stanley then spent considerable time reviewing several relevant inspection techniques and offered suggestions for how to prepare for and set



10, 11. Drone photographs allow close-ups in areas difficult to see from normal viewing points. Photo left indicates sag in flame-holder components, overheated areas; other close-ups even help assess burner nozzle condition. Close-up of finned tubes at the top of a panel (above) help assess their condition up an inspection program. Perhaps the overriding message was, don't try this at home; in other words, retain an experienced, qualified crew.

Manway reliability was Stanley's final topic. The ageing risk is the deterioration of the gasket sealing surface over time from cleaning and removing old gasket material, impurities in water residue, gouging from steam cutting or closing damage, and corrosion during downtime. The gasket sealing surface has to be smooth but not "polished" smooth, and there's more precision necessary in the serrations (like an album surface) than you might think.

There are a few specialists with the proper tools to re-machine the sealing surface, but sometimes replacing the door may be the best option. This allows you to ease the problems associated with achieving the minimum sealing stress for various types of gaskets. The proper seal stress is difficult to achieve with studs and a torque wrench because drum pressure in operation provides the last increment of stress necessary. Many HRSG OEM manuals require hot retorquing procedures, which are dangerous and should be avoided.

Stanley thinks a manway door with Belleville washers is a better design (Fig 9). Eliminating hot retorquing allows you to install a steam shield for additional personnel protection. Stanley noted that the Belleville washer design has gone through several years of demonstration in the field.

Drones

Your plant cred may be lacking these days if you don't have a presentation on drones at your user group meeting. Natalie Teuchert, completing the HRST triumvirate, filled that bill at the CCUG. The first of Teuchert's slides reviewed the basics of using drones at the plant—FAA regulations, training and certification, and some things to think about regarding drone construction.

The second part was replete with rather dramatic comparisons of what you "see" with a drone inside your unit versus what you can detect visually looking up from the floor, including photos of burner condition (Fig 10), close ups of burner nozzles, hairline cracks in flame holder castings, bent igniter tubes, close ups of finned tubes at the top of a tube panel (Fig 11), and many others.

Teuchert's main conclusion is that drones allow you to inexpensively inspect areas prone to ageing issues more frequently, and thus avoid costly problems down the road. **CCJ**

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- Instrumentation for monitoring and control of cycle chemistry.
- Volatile treatments for the steam-water circuits of power plants.
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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.

M & M Engineering

Provides failure analyses and related services to industrial and insurance-company clients. M&M's expertise includes corrosion in boilers, steam turbines, generators, combustion turbines, deaerators, feedwater heaters, and water and steam piping.

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 Breaker Services

Industry leader in switchgear life optimization, life extension, and system upgrades. Manufactures new, highly customized low- and medium-voltage switchgear and provides on-site troubleshooting, maintenance, and testing of existing systems.

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

Pign, eliminating the need for service contractsrovides 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 des 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

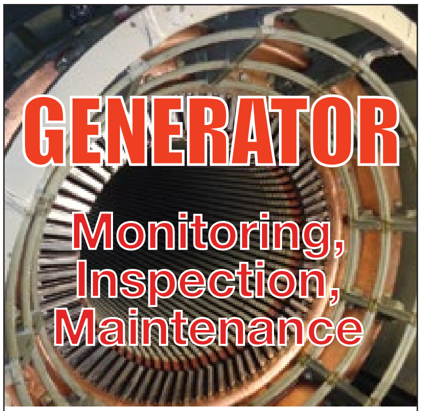
Clutches enable operators to disconnect generators from simple-cycle turbines for synchronous-condenser service. Clutches also find application in CHP plants and in single-shaft combined-cycle facilities where operating flexibility is beneficial.

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.

ValvTechnologies

Global leader in the design and manufacturing of zero-leakage metal-seated ball valve solutions for severe service applications. Committed, dependable partner providing the best isolation solutions to ensure customer satisfaction, safety and reliability, and improved process and performance.

World of Controls

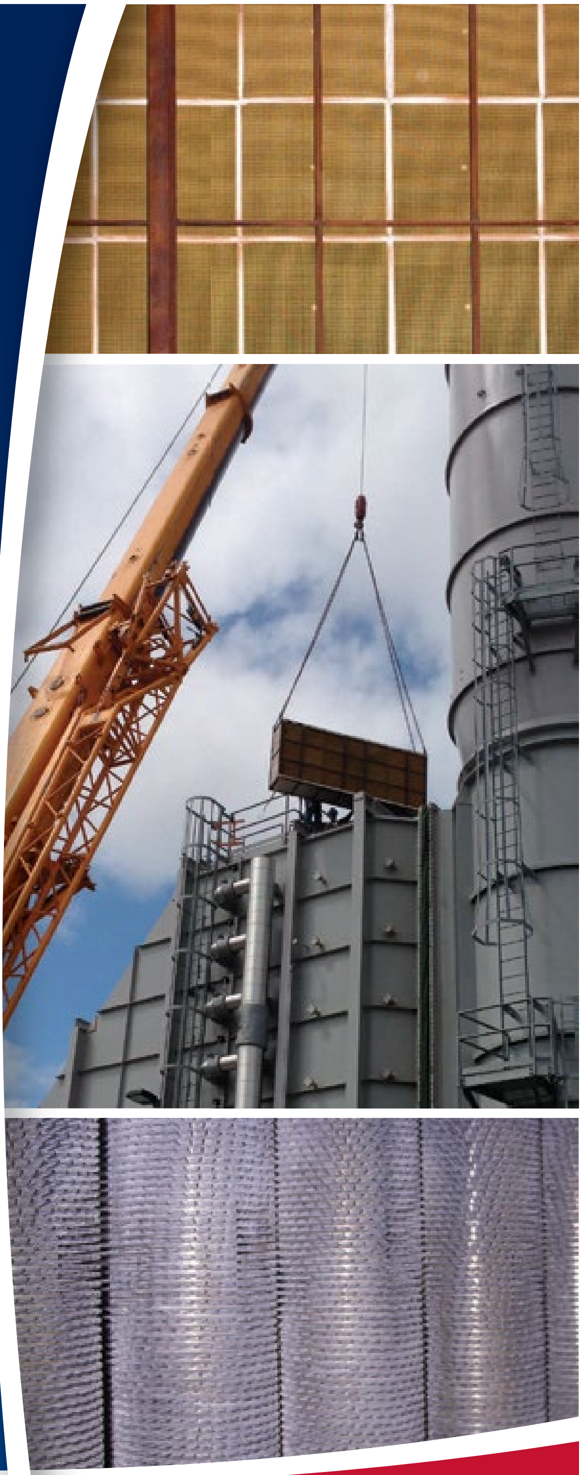
Worldwide, low-cost provider of DCS circuit boards offering an array of ancillary services which include testing/repair of circuit boards, parts, DCS troubleshooting, Dos support, HMI upgrades/backup and field-based mechanical and controls training.

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.




Together for a
cleaner, quieter and
safer world