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CCJ
COMBINED CYCLE Journal

Reports from user-group meetings

Special interest

Feature articles

INDEPENDENT VOICE OF THE GAS-TURBINE-BASED ... R

Meetings focusing on user information needs

2020

August 23-27, CTOTF, 2020 Conference & Trade Show, Louisville, Ky, The Galt House Hotel. Chairman: Jack Borsch, john.borsch@ihipower.com. Details/registration at www.ctotf.org as they become available. Contact: Ivy Suter, ivysuter@gmail.com.

August 31-September 3, Combined Cycle Users Group (CCUG), 2020 Conference and Discussion Forum, San Antonio, Tex, San Antonio Marriott Rivercenter. Meeting is co-located with the Steam Turbine, Generator, and Power Plant Controls Users Groups; some joint functions, including meals and vendor fair. Details/registration at www.ccusers.org as they become available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

August 31-September 3, Steam Turbine Users Group (STUG), 2020 Conference and Vendor Fair, San Antonio, Tex, San Antonio Marriott Rivercenter. Meeting is co-located with the Combined Cycle, Generator, and Power Plant Controls Users Groups; some joint functions, including meals and vendor fair. Details/registration at www.stusers.org as they become available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

August 31-September 3, Generator Users Group (GUG), 2020 Conference and Vendor Fair, San Antonio, Tex, San Antonio Marriott Rivercenter. Meeting is co-located with the Combined Cycle, Steam Turbine, and Power Plant Controls Users Groups; some joint functions, including meals and vendor fair. Details/registration at www.genusers.org as they become available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

August 31-September 3, Power Plant Controls Users Group (CUG), 2020 Conference and Vendor Fair, San Antonio, Tex, San Antonio Marriott Rivercenter. Meeting is co-located with the Combined Cycle, Steam Turbine, and Generators Users Groups; some joint functions, including meals and vendor fair. Chairman: Peter So, pso@calpine.com. Details/registration at www.powerusers.org as they become available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

September 14-17, V Users Group, 2020 Conference, Niagara Falls, Ont, Canada, Hilton Niagara Falls/Fallsview Hotel & Suites. Contact: Dawn McCarter, conference coordinator, dawn.mccarter@siemens.com.

September 21-24, Frame 9FA/FB/H User Conference, Rome, Italy. Details at https://ssl.gtusers.com. Chairman: Kevin Lindley, RWEN Power, kevin.lindley@RWEnpower.com. Coordinator: Yrjo Komokallio, GTUsers.com, yrjo.komokallio@gtusers.com.

September 28-October 1, Air-Cooled Condenser Users Group, 12th Annual Conference, Danbury, Ct, Crown Plaza Danbury. Details/registration at http://acc-usersgroup.org as they become available. To present, contact Chairman Andy Howell at ahowell@epri.com; to sponsor and/or exhibit, contact Sheila Vashi at Sheila.vashi@sv-events.net.

October 12-15, V94.3A (SGT5-4000F/AE94.3A) User Conference, Prague, Czechia. Details at https://ssl.gtusers.com. Chairman: Arturo Patino, Emirates CMS Power Co, arturop@ecpc.ae. Coordinator: Yrjo Komokallio, GTUsers.com, yrjo.komokallio@gtusers.com.

October 19-22, 7EA Users Group, 2020 Conference, Houston, Tex, J W Marriott Houston at the Galleria. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

October 20-22, Frame 6FA User Conference, Budapest, Hungary. Details at https://ssl.gtusers.com. Chairman: Richard Heiden, Northland Power, richard.heiden@northlandpower.ca. Coordinator: Yrjo Komokallio, GTUsers.com, yrjo.komokallio@gtusers.com.

November 9-12, V94.2 (SGT5-2000E/AE94.2) User Conference, Prague, Czechia. Details at https://ssl.gtusers.com. Chairman: Alexey Marchenko, Fortum, alexey.marchenko@fortum.com. Coordinator: Yrjo Komokallio, GTUsers.com, yrjo.komokallio@gtusers.com.

December 2-4, Australasian Boiler and HRSG Users Group, ABHUG 2020, Brisbane, Queensland, Australia, Brisbane Conference & Exhibition Centre. Details/registration at https://www.etouches.com/ehome/abhug2020/Home. Chairman: Dr R Barry Dooley, bdooley@structint.com. Contact: Rachel Washington, rachel@meccaconcepts.com.au.

2021

February 8-12, AOG (Alstom Owners Group) Users Conference, Fourth Annual Meeting and Vendor Fair, Orlando, Fla, venue TBA. Details/registration at https://aogusers.com as they become available. Contact: Jeff Chapin, jchapin@aogusers.com.

February 21-25, 501F Users Group, Annual Meeting, Peppermill Resort, Reno, Nev. Details/registration at www.501fusers.org as they become available. Chairman: Russ Snyder, russ.snyder@cleco.com. Contact: Tammy Faust, meeting coordinator, tammy@somp.co.

March 21-24, Western Turbine Users Inc, 31st Annual Conference and Expo, Palm Springs, Calif, Renaissance Hotel/Palm Springs Convention Center. Details/registration at www.wtui.com after Nov 1, 2020. Contacts: Charlene Raaker, conference registration coordinator, craaker@wtui.com; Wayne Kawamoto, conference executive director, wkawamoto@wtui.com.

April 11-15, CTOTF 46th Spring Conference & Trade Show, Greenville, SC, Hyatt Regency Greenville. Chairman: Jack Borsch, john.borsch@ihipower.com. Details/registration at www.ctotf.org as they become available. Contact: Ivy Suter, ivysuter@gmail.com.

Week of May 17, Siemens Customer Conference for F, G & H Technology, Orlando, Fla, Rosen Centre Hotel. Meeting is co-located with the T3K Annual Conference. Contact: Dawn McCarter, dawn.mccarter@siemens.com.

May 24-28, 7F Users Group, 2021 Conference & Vendor Fair, St. Louis, Mo, Marriott St. Louis Grand. Details/registration at www.powerusers.org as they become available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

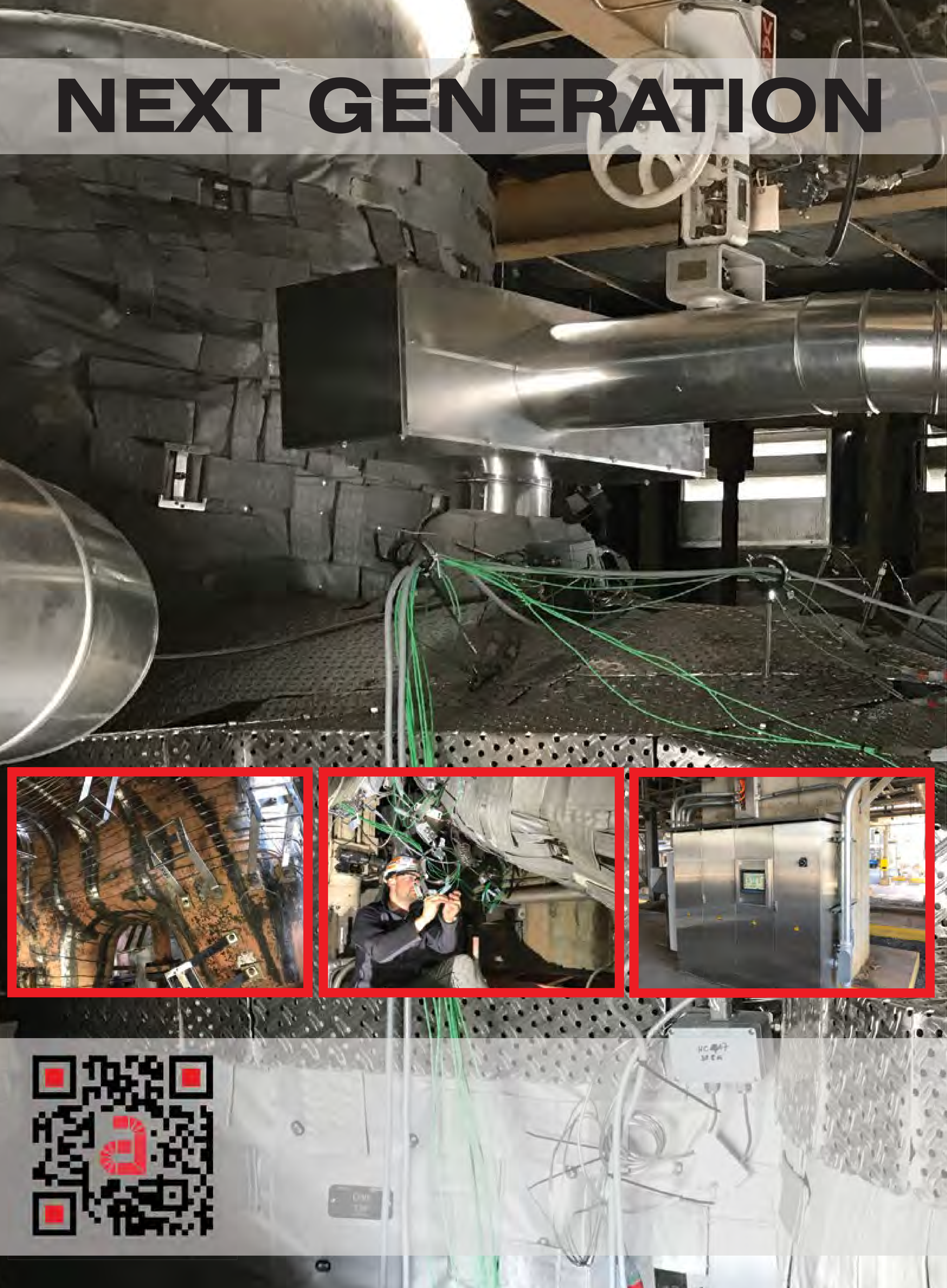
June 8-10, 501D5-D5A Users, Annual Meeting, St. Louis, Mo, Ritz-Carlton St. Louis. Details/registration at www.501d5-d5ausers.org as they become available. Chairman: Gabe Fleck, chairman@501d5-d5ausers.org.

June 14-17, Frame 6 Users Group, Annual Conference & Vendor Fair, San Antonio, Tex, La Cantera Resort & Spa. Details/registration at www.Frame6UsersGroup.org as they become available. Chair: Jeff Gillis, william.j.gillis@exxonmobil.com. Contact: Greg Boland, conference manager, greg.boland@ceidmc.com.

June 14-17, Frame 5 Users Group, 2021 Conference, San Antonio, Tex, La Cantera Resort & Spa. Meeting is co-located with the Frame 6 Users Group; some joint functions, including meals and vendor fair. Contact: Greg Boland, conference manager, greg.boland@ceidmc.com.

July 25-29, Ovation Users' Group, 34th 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.

NEXT GENERATION



2020 Conference
San Antonio
Marriott Rivercenter
August 31-September 3

COMBINED CYCLE USERS GROUP

The 2019 conference of the Combined Cycle Users Group (CCUG) was a prime example of "working together," co-located with the generator (GUG), steam turbine (STUG), and powerplant controls (PPCUG) user organizations. Attendees were invited to participate in sessions conducted by all four groups at the Marriott St. Louis Grand, St. Louis, Mo, August 26-29.

On Monday morning, CCUG offered an Environex Inc training session for all: "Strategies for improving SCR/CO catalyst performance and lifecycle." Dan Ott, president, reviewed catalyst types, reaction and oxidation chemistry, dual-function configurations, ammonia system design, low-turndown performance, lifecycle testing, and ways to improve NO_x compliance.

Owner/operators can view Ott's slides, and those of the other presenters, on the Power Users website at www.powerusers.org. Registration for access is simple and most worthwhile: More than a hundred presentations were made at the Combined User-Group Conference.

At 1 p.m., all participants came together for introductions by Jake English, conference business manager and member of the STUG steering committee. He emphasized the founding principle of sharing information and keeping the discussions technical, not commercial.

Jimmy Daghlian then presented the CCUG's 2019 Individual Achievement Award to Consultant John Peterson, formerly with BASF and a founder of the Frame 6 Users Group, and Steve Royall of PG&E. This year's Clyde Maughan Award went to James Timperley, EMSA Technical Services (formerly with American Electric Power Co and Doble), presented by Kent Smith of Duke Energy and past chairman of the Generator Users Group.

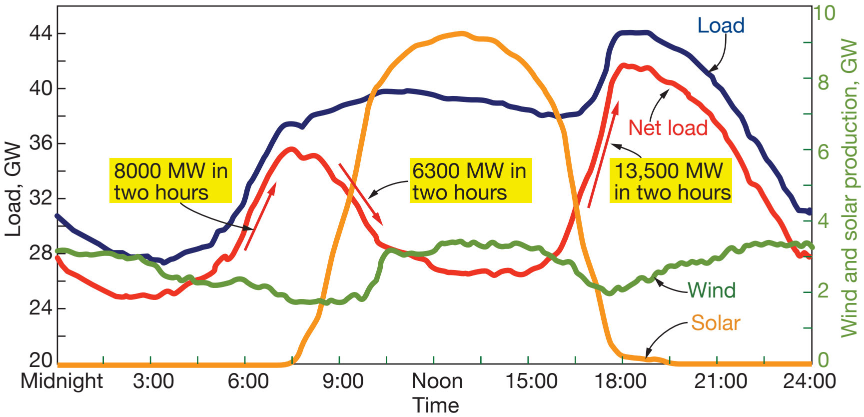
Keynotes. FBI Special Agents Kyle Storm and Jaret Depke presented the first of two keynotes: "Confronting cyber and counterintelligence threats from the FBI's perspective." Jeff Chann of GE followed with the second: "Managing your plant over the next decade." Chann addressed the common concern of survival in the changing market. His message: "If we don't react, the balancing authority will go around us and find the solution."

The tone was set for not how to thrive, but how to *survive*. The message: Contribute to the overall portfolio, be best in your zone, mix in, and realize that your plant's capabilities on Day One are not what's needed tomorrow.

More focused perhaps: "Run lean, and learn how to get the hell out of the way!"

CCUG 2019

Content from well over 100 presentations/discussions was shared at the 2019 Combined User Group Conference. What follows are highlights from a few of the CCUG presentations to give you a flavor of the meeting and to encourage your participation in the 2020 conference at the San Antonio (Tex) Marriott Rivercenter, August 31-September 2.



1. Load, wind, and solar profiles for the California ISO (high-load case, January 2020)

Critical valves and piping

Thick metal parts are having problems sooner than expected, largely because of repeat thermal transients (cycling). PG&E's Tim Wisdom characterized the challenges of cycling in Fig 1.

As Wisdom put it, "We are seeing damage to main-steam and hot-reheat valves, and cracking of the HP drum internal downcomer nozzles. The correlation between cyclical duty and increased owner/operator time and expense on high-energy piping (HEP) programs is becoming more apparent during every outage."

Major valves are failing early regardless of material, including F91 (forged P91). Components thought to be reliable for 30 years "are failing at around one-third the expected life," he cautioned.

The valves discussed suffered from delamination of hard facing materials (stellite liberation) which is generally repairable, but also from deep-body cracking which is not. Wisdom also addressed the common issues of crack-

ing in steam and bypass lines (Figs 2 and 3).

A heads-up: One site had to stop and wait for a state-authorized inspector to approve temporary repair measures for a P91 spool piece because the valve was within the code boundary of the HRSG. The ensuing discussion on the delay included a reminder of long lead times on new critical components.

So how do you prepare to cycle twice each day?

- Consider how you will manage added costs. Major maintenance expenses can double, and maintenance intervals can be reduced by half.
- Continue to leverage industry resources. (See what others are doing.)

- Know the lead times for replacements. "Look at things and have a plan."
- Anticipate!

He followed with some valuable lessons learned:

- Ensure that you have spare critical valves and stay abreast of design improvements.
- Compile risk rankings for all critical components in your HEP program.
- Ensure that *all* high-energy piping is part of the risk and inspection program. (Code only recommends 4 in. and larger.)
- Eliminate risk of dissimilar metal weld failures—for example, P91 to Type 316 stainless steel.
- Ensure your main steam and HRH strainers can capture liberated materials from degraded valves.

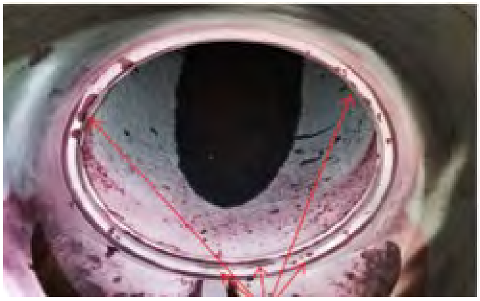
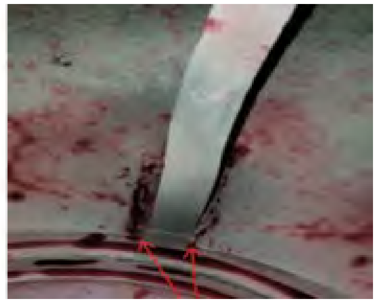
Returning to his cycling discussion, he offered a motivating mental image: "We need to be ready at all times. We have become the light switch."

GT performance

Award recipient Peterson discussed "Maintaining best gas turbine performance" with an informative historical review—including the increase in compression ratios for frame gas turbines over the years. The key today, he stated, is "the efficient compression of air."

He listed the primary factors for compressor losses:

- Mechanical damage (foreign object impact and tip-rub contact).

2. 3. Cracks in stellite valve seats (left) and on both sides of the rib at right were enhanced with penetrant and developer

- Mechanical wear of seals.
- Airfoil surface erosion, corrosion, and fouling.
- Guide-vane calibrations.
- Air and oil leaks.

Commonly used expressions for these factors are recoverable loss, unrecoverable loss, air flow loss, and compression efficiency loss.

He then reviewed various cleaning techniques including:

- Abrasive cleaning.
- Online washing with and without detergent.
- Offline washing (periodic cold crank wash).
- Hand cleaning of airfoils.

A case study on excessive Frame 6 fouling, and discoveries inside the filter house, led to a tangential discussion on the pros and cons of hydrophobic HEPA filters.

CUI

Aaron Berry, Puget Sound Energy (PSE), led the discussion on corrosion under insulation (CUI), a common threat to carbon steel, alloy, and 300 series stainless steel piping systems. The topic has become standard at most industry events, largely attributed to intermittent service.

High-risk areas, he explained, are feedwater systems, small bore fittings, dead legs, areas near HRSG penetration seals, and thin-wall interconnecting tubing. Mineral wool insulation, he stated, is the worst environment for CUI. Long periods of equipment layup increase risk.

PSE operates five combined cycles varying in age from eight to 25 years, in environments ranging from marine to arid.

Berry's key message: CUI is detectable and preventable. He covered various inspection techniques including:

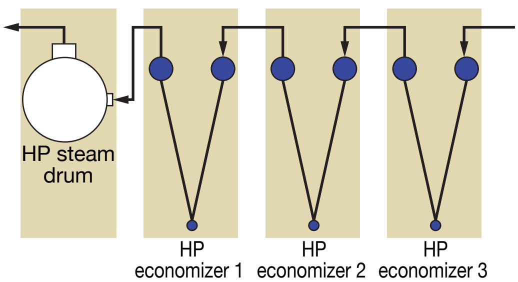
- Strip and inspect.
- Pulsed eddy current.
- Guided wave ultrasonic.
- Radiography.

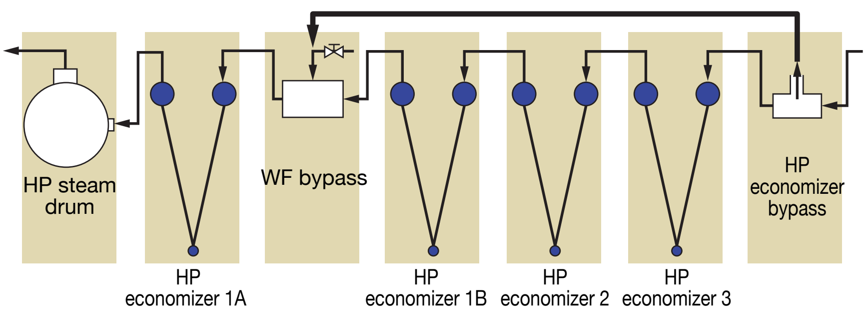
"Have a long-term program, and start inspecting," he said. "Don't wait for failures."

Chasing BTUs

HRST's Jordan Bartol next went deep on how HRSGs can influence overall plant performance. "We're chasing BTUs and trying always to improve plant heat rate."

Units built in the early 2000s are now at mid-life. Target areas for HRSG heat-rate improvements are:





4. Increasing HP economizer surface improves performance when duct firing (left), but a bypass system (below) is needed to prevent economizer steaming when not duct firing

- Economizer design and operation.
- Attemperator operation.
- Fouling (increased backpressure).
- Exhaust gas bypass.
- Casing hotspots.
- Exhaust leaks.
- Steam-turbine interaction reviews.

Economizer approach temperature is a critical parameter, discussed in detail. Bartol then turned to a typical three-pressure duct-fired HRSG with reheat, and the benefit of adding 12 tube rows to the HP economizer (Fig 4).

In his example, adding these rows increases steam-turbine output by 2.5 MW for a 1 x 1 F-class plant with duct firing. But this also requires a bypass to prevent economizer steaming during unfired operation.

The additional surface can be included in a new HRSG if heat rate while duct firing is important. Retrofits might prove difficult because of space limitations, but the SCR duct may have room available and, if so, should be considered.

For the increasingly familiar topic of attemperation, Bartol listed some negative consequences of lowering the steam temperature set point in the control room, using, as an example, a 7FA with typical three-pressure HRSG. Such action can do more harm than good, he warned. The increased spraywater flow can damage downstream pipes and tubes, contribute impurities to steam, and decrease steam-turbine performance.

In the HRSG tube bundles, baffles reduce exhaust-gas bypass. Gaps that allow hot gas to bypass heat-transfer tubes hurt performance; even small gaps can allow significant bypass. Properly maintained gas baffles therefore become critical to good performance (Fig 5).

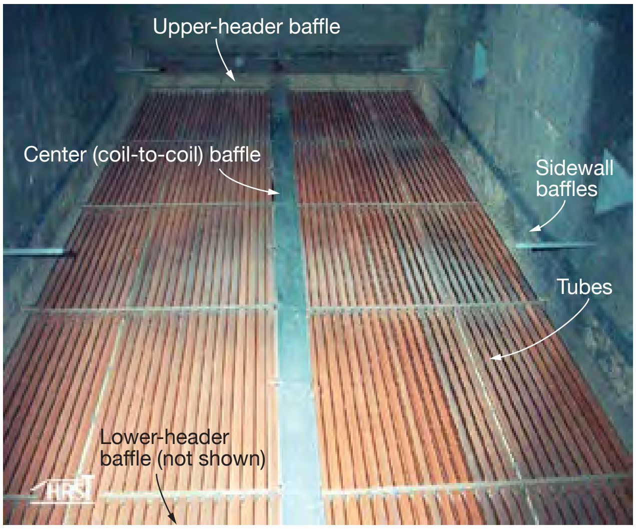
"Baffles are relatively inexpensive yet very important devices," he said. "But they must be properly designed for thermal expansion, must be sturdy, and must be part of each inspection. Fixing a small portion can result in a large performance gain."

Casing hotspots may have a smaller impact on performance, but can lead to cracks and have a negative impact on safety. Exhaust leaks also affect performance. Common leak causes are failing bellows, torn fabric seals, failed penetration seals, and failed expansion joints.

For steam-turbine interaction, "Watch pressure drop in the reheater section" (from exit of HP stage to entrance of IP stage). A 10-psi increase can reduce steam turbine output by 0.2 MW in the F-class example (Fig 6).

Piping damage, drain control

HRST's Guy Thompson followed with the negative impacts of superheater, reheater, and piping drain problems and the formation of condensate, an increasingly encountered topic.



5. Baffles force gas-turbine exhaust gas to flow through HRSG tube bundles, maximizing heat transfer

6. Performance impact (in megawatts) of the following on a 250-MW, 1 × 1 F-class combined cycle:

Optimize economizer for duct firing, add 12 rows of finned tubes	2.5 MW
Attemperator set point low by 20 deg F	0.7
Turbine-exhaust-gas backpressure high by 5 in. H_2O	1.2
Gas bypass attributed to coil baffle gaps*	1.2
Hot spot, 100 ft² at 600F	0.04
Large exhaust leak, hot end	0.5
Pressure-drop increase of 10 psi in reheat steam system	0.2

*Based on gaps between two modules of a 360-MW, 1 × 1 F-class combined cycle

His focus was on low-point in the high-temperature reheaters and superheaters. During the past 15 years, emphasis has been on drain size, drain valves and automation, and operating practices to ensure condensate removal.

He then offered some rules of thumb to reduce resultant tube and header damage, generally recommending 2-in. drains for the range of pressures encountered by F-class HRSGs.

Condensers

Intek (Tim Harpster and Tony Bonina) offered case studies on distinctive instruments for monitoring steam-turbine surface condensers. Specifics focused on both early detection of performance issues and long-term monitoring for:

- Cooling-water flow rate.
- Vacuum equipment capacity.
- Air in-leakage detection.
- Data systems validation.

Discussions also covered:

- Steam pressure and temperature.
- Cooling-water inlet and outlet temperatures.
- Differential pressures across waterbox orifices.

Case studies showed specific results of RheoVac® condenser monitors, Rheotherm® flow and fouling sensors, and integration with other temperature and pressure instrumentation. Benefits included improved circulation and reduced backpressure.

SCR, AIG tuning

Jeff Bause, CEO of Groome Industrial, addressed SCR catalyst replacement and tuning of the ammonia injection grid. He first noted ongoing improvements in catalyst technology.

Case studies focused on the importance of AIG cleaning for efficiency, conversion rate, and system capacity.

One suggestion: Use a permanent sampling grid specifically designed to continually test AIG effectiveness, take samples throughout the grid (no probing), and make AIG tuning easier and more precise using detailed probe maps.

Catalyst-replacement case studies covered specific NO_x conversion data, ammonia slip, and ammonia consumption comparisons before work, after work, and after tuning.

Forward-looking discussions included the increasing presence of sulfur from shale gas, the smaller size of some replacement catalysts, and use of dual-function catalysts to reduce both space and backpressure.

NERC CIP

The North American Electric Reliability Corporation (NERC) Critical Infrastructure Protection (CIP) plan is a set

7. Water beading in condenser attributed to use of a film-forming amine

of alerts and requirements designed to secure the assets needed for operating North America's bulk electric system.

Frank Lyter (Talen Energy) presented a CIP update with discussion points for:

- Reducing risk to the bulk electric system.
- Standardizing industry processes.
- Enhancing feedback to NERC.
- Issuing timely NERC alerts.

Upcoming CIP Standards (CIP-003-7 and 8) will take effect in early 2020 to address:

1. Physical security.
2. Electronic access security.
3. CIP exceptional circumstances—for example, supply quality concerns.
4. Transient cyber assets.

Laptops and removable media included in No. 4 above are among the greatest new security challenges, he said. They are in wide use throughout each site, particularly during outages, and involve many individuals, groups, and companies. Checklists and processes initiated by Talen Energy were shown and discussed in detail.

NERC alerts also were reviewed—including concerns over Chinese supply and drones used for both security and surveillance. Alerts and bulletins provide guidance on such timely issues. In 2019, an alert was issued on drones offering this specific guidance:

- Purchase drone devices and components from reputable vendors.
- Understand how and where drone data are being stored.
- Determine how the drone will interact with infrastructure and networks.
- Perform detailed risk assessments.
- Implement multiple internal reviews and controls.

Multiple controls could include monthly checklists, contractor report reviews, and analysis tracking documents. Also, standardizing forms across an owner/operator fleet can streamline the review processes.

Lyter's message: "We now need to consider vulnerabilities not normally considered."

Amines

Calpine's Stan Avalone and Craig Cannon discussed the fast-growing topic of film-forming substances (FFS, including amines), focusing on recent company experience. Calpine's HRSG reliability issues have been severely impacted by unscheduled layups and both single- and two-phase flow-accelerated corrosion (influenced, in part, by unit age).

The presenters' experience, water beading in a condenser, has shown the benefit of a polyamine protective film. Once formed, in their example, the protective film remained intact even after dosage fell below the required level or was interrupted for a short period of time (Fig 7).

Nitrogen blanketing remains the industry standard for long-term layup, but layups with amines can help reduce corrosion and the potential for underdeposit corrosion in evaporator tubing. Unlike other protection methods, the presenters explained, "the FFS technique is implemented in advance of the unit outage while the equipment is still operating."

Application methods and recommendations were outlined, along with the caution of over-feeding.

Calpine's future plans include studying the differences in available and emerging FFS products, expansion of this chemistry to more units, and combining the feed of neutralizing and filming amines to make initiation and long-term optimization easier at each site.

Outage planning and management

Phyllis Gassert, director of asset management at Talen Energy and the CCUG 2019 chair, began by asking three fundamental yet critical questions:

1. When is the right time to start planning a major outage?
2. Who should be involved with the planning process?
3. When do you start including the contractors?

"Any outage of three weeks or more needs at least two years of planning," stressed Gassert. "Bring your managers into the entire planning process, and put your plans in each contractor bid."

Gassert's presentation covered all important areas including maintenance, defining the roles of not only contractor staff but also your own, and physical site management. Beyond the many traditional items, Gassert added some interesting thoughtworthy items:

- When planning parking, don't forget shift overlap (more cars).
- For parts, plan space for both incoming and outgoing (more parts).
- Prepare purchase orders and change orders in advance (to avoid interruptions, stress, and possible careless errors).
- Watch carefully for contractors' incoming assumptions or undisclosed expectations—cranes, elevators, facilities, etc.

Go for the realistic, not the best, schedule. And remember: "Under budget and on schedule means nothing if someone gets hurt."

Gassert was asked, "When do you implement scope freeze?" The answer: at three months out. Any deviation requires at least two authorized signatures.

Workforce and community

Dr Robert Mayfield, a former submarine commander and today plant manager of Tenaska Westmoreland Generating Station (Fig 8), shared some insights on life in his combined-cycle environment.

"Knowledge must be created and captured, shared, and transferred, and organized and integrated. Our biggest problem today is skill sets."

Westmoreland is a nominal 1000-MW combined cycle with only 24

8. Tenaska Westmoreland Generating Station is a 940-MW, 2 × 1 combined cycle powered by M501J gas turbines. Commercial operation was declared at the end of 2018 employees. Perhaps more significant, 80% of the staff has moved from a union coal-plant position to this non-union combined-cycle environment.

His comments touched on numerous aspects of daily management and life at the facility, including interpersonal relationships of staff and regard for the community, while focusing on the common issues of today's environment. Items such as:

- Increasing merchant operations (PPAs fading away).
- Long-term agreements being modified or expiring.
- Ageing equipment and personnel.
- The need for more predictive maintenance.
- Competition for employees.
- OEM lack of experience.
- The need to do more with less.

His closing comments offered some hope, while touching on labor and skills shortages:

- Stay away from management fads.
- Welcome briefings on bad news.
- Seek employee opinions.
- Train operators to take action.
- Offer tours, tours, and more tours. Get employees noticed and involved.
- Promote community volunteerism.
- Be aware of changes in the energy market.
- Be ready for an unannounced audit or inspection at any time.
- Praise employees and calibrate when necessary.

In discussing training, he repeated Henry Ford: "The only thing worse than training your employees and having them leave is *not* training them and having them stay."

He ended with a thought-provoking quote by Dale Carnegie: "Employees don't leave companies, they leave people."

Wednesday

Wednesday was reserved for presentations by the 2019 diamond sponsors, General Electric and Siemens, and platinum-plus sponsor Mechanical Dynamics & Analysis. Participation was limited to users and personnel from the three sponsors.

Siemens personnel offered details on the following:

- Review of NERC critical infrastructure protection and cybersecurity data.
- Maximizing market participation through grid support and ancillary services.
- Increasing combined-cycle flexibility through exhaust purge credits, attemperator operation, and integrated Flex-Power Services™.
- Gas-turbine upgrades for higher capacity, increased efficiency, and longer inspection intervals.
- Brownfield engine exchange programs.

Experts from MD&A addressed specifics of balancing to reduce vibrations, not only on the turbine, but on other balance-of-plant (BOP) rotating equipment as well. Cautions were issued on common mistakes made while balancing. Details were then given for low- and high-speed balancing on location and at MD&A facilities, along with specific criteria for gas-turbine, steam-turbine, and generator rotors.

Alignment discussions and graphics focused on couplings and internals, specifications, and the impact of foundation settlement. Coupling example details covered both 16-point and laser methods and equipment.

General Electric spearheaded the afternoon discussions with a range of topics.

Available Siemens, MD&A, and GE discussions in other user group sessions provided unique opportunities for CCUG participants to expand into specifics for generators, steam turbines, and powerplant controls.

The following day, MD&A offered tours of its gas and steam turbine/generator repair facility in St. Louis. CCJ

Macroetching aids in removing heat-affected zones of rubs

By Craig Spencer, Calpine Corp, and **Neil Kilpatrick**, GenMet LLC

With a little luck, you'll never experience significant rub damage to your rotors. By design, OEMs usually provide generous clearance between the rotor and non-rotating parts except where it's unavoidable: bearings and seals. OEMs mitigate the rubbing risks associated for those close clearance components with smart material selection—such as Babbitt, brass, and nylon. Those features work well enough when everything operates according to design, but that doesn't always happen.

When significant rub damage does occur, repair options can be limited based on location and severity, but ideally the remedy requires only removal of the heat-affected material, which can be tricky if not done with the proper process.

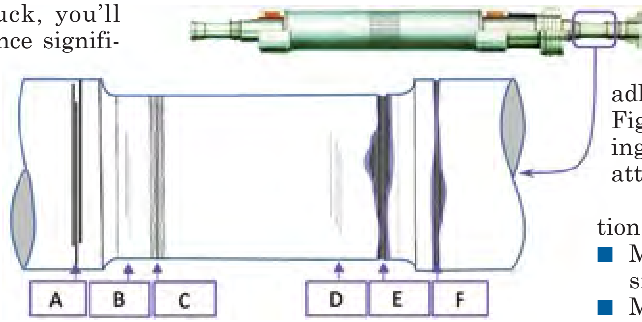
Shaft rub basics. When your rotor is turning, any solid material that comes into contact with the rotor surfaces has the ability to cause rub damage. The severity of that damage depends on the total amount of energy and rate of energy transfer which occurs during the rub.

The most common rub occurs when some hard substance (grit) gets caught between the rotor and the bearing or the seals and that grit exceeds the given clearance, causing the grit to machine the surface of the rotor, making a groove with no evidence of heat, metal adhesion, or bulging.

Normally, a few small grooves pose no appreciable risk, and can simply be polished out (Fig 1; A, B, D).

If there are more than a few grooves, and/or if they are relatively deep grooves—such as from a hydrogen seal (Fig 1; C), bearing oil seal (E), or labyrinth seal (F), you may need to perform a step machining of the shaft surface, and replace the seals, and possibly the bearing, to fit to the new diameter.

Another common rub occurs when seal strips are set to an inadequate clearance during a maintenance outage. Generally speaking, these seal strips will wear in the necessary clearance in time, sometimes yielding deposits from the seal strips adhered to the shaft. Usually there's no appreciable damage to the shaft substrate, and only shaft polishing is needed to remove the deposits. However, severe cases should be metallically evaluated after polishing, as noted with friction rubbing described below.



1. Some grooves caused by rubs are small enough to be polished out (A, B, D); others are relatively deep (C, E, F) and require machining to eliminate

2. Shaft bluing shown, from heat and metal adhesion, was attributed to a friction rub

Less common, but potentially much more severe, is a friction rub created by contact between the turning rotor and a non-rotating member of the unit assembly as a result of an abnormal operating condition—such as a loss of lubrication or an abrupt lateral event like an L-0 blade liberation. Because of the relatively high energy transmission in a relatively short amount of time, these friction rubs often do show evidence of heat, metal adhesion, or bulging at the rub site. Fig 2 shows an example of shaft bluing from heat and metal adhesion attributed a friction rub.

Possible remedial options for friction rubs include, in order of severity:

- Machining out the damage to a smooth bottom groove.
- Machining the damaged zone smooth and locally heat treating to temper back the heat-affected material.
- Machining out the damage and replacing the removed material using TIG welding.
- Replacing the shaft in whole or in part.

To better understand the need for these repairs, we should better define the physics of this type of damage.

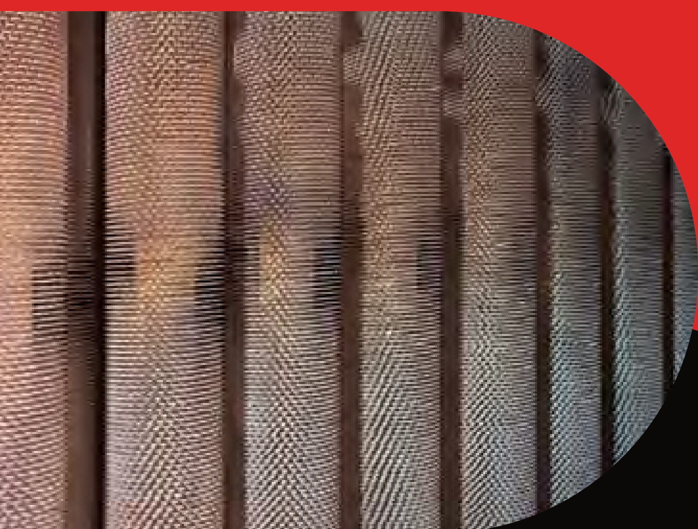
Friction rub physics. The profile of a friction rub is depicted in Fig 3, where the rotor (in gray) rotates against a stationary object.

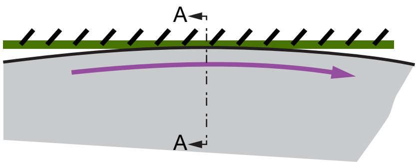
Because of the great momentum in the rotating shaft, it usually will continue to rotate no matter how hard it makes contact with the stationary object, at least for some time. High-energy friction contact can result in highly localized extreme temperatures within the shaft in proximity to the rub, often exceeding 1300F. Given that shafts normally are made of high-strength, low-alloy steel, this heating is often enough to locally transform the structure to soft austenite.

While the rub is active, heat flows into the rotor as depicted in Figs 4 and 5. As temperature builds in the hot zone (B-B), the hot metal tries to expand, but the cold surrounding metal is much stronger and more stable and compressional yielding occurs. As temperature increases, compressional yielding increases and locally reduces the strength.

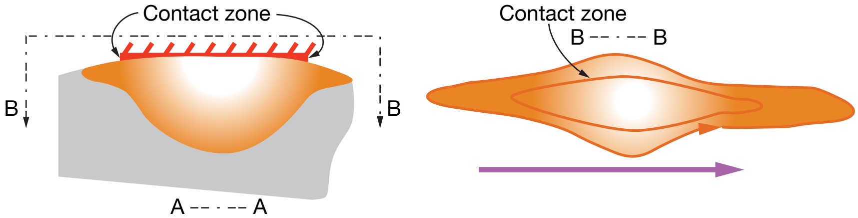
During this intense rubbing, it's common to form adhesive metal-smearing deposits on the surface.

When rubbing stops, the hot zone effectively is quenched down to the

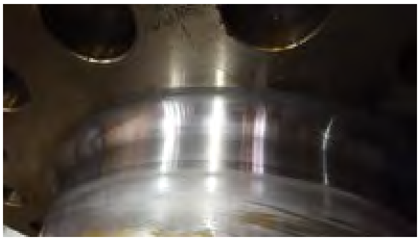




3. Profile of a friction rub shows shaft rotating against a stationary object



4, 5. Heat-affected zone is profiled at left. When the rub is active, temperature increases in the hot zone (B – B) shown at the right



6. HAZ is difficult, virtually possible, to identify visually after a skim cut

7. Center whitish island of material is significantly harder than the balance of the rotor surface

8. Microetching immediately after a second skim cut shows there's still a HAZ in the rotor

temperature of the surrounding metal. In typical rotor magnetic-steel components, this means that a local hardening transformation to martensite can occur. At the same time, a significant contraction of the former hot zone occurs, and the stress state of transformed metal zone will change to what can be a very high tensile stress.

Martensite is very hard and brittle, and so it is not uncommon for cracks to develop at this point because of the residual tensile stress. Rub severity is somewhat proportional to the likelihood for cracking to occur.

With this type of damage, crack initiation and propagation from normal operating stresses cannot be predicted, but, clearly, the probability of cracking is likely significant. This condition also means that the part (rotor forging, blower hub, blower blade, etc) is now capable of erratic and unpredictable behavior. This makes it imperative to treat or otherwise remove the damaged material, collectively known as the heat-affected zone (HAZ) from the shaft if it is to remain in service.

HAZ removal. As noted above, there are several repair options, depending on the location and severity of a shaft rub.

Usually, the most cost-effective and expedient manner to deal with a HAZ on a shaft involves machining it off. Because you want to preserve as much of the shaft substrate as possible to endure operational stresses, this machining is an iterative process, where usually skim cuts of the surface on the order of a radial depth of 5 to 25 mils are taken, and the remaining surface is evaluated for a need for additional skim cuts.

Depending on method of evaluation, there are challenges to accurately determining the remaining HAZ after a skim cut. If you look at Fig 2 of the as-found rotor, the damaged area is obvious. However, as you can see in Fig 6, the HAZ is much more difficult, if not impossible, to identify visually after a skim cut. The entire surface looks the same.

Within the HAZ, changes have occurred in the microstructure of the rotor steel. As a result, the steel in the HAZ is harder. Given that it's not practical to cut up the shaft to examine the microstructure under a microscope to check for HAZ, it is common practice to check the hardness of the shaft as a proxy for determining if HAZ remains.

Typical hardness testers use a pen-like device to shoot a diamond-tipped projectile into the shaft surface and measure its response. It tests one location at a time with each impact. The reading is a highly localized average of the hardness at the test location.

And there's the figurative rub: How can you be certain that you're testing the correct location with this highly localized test on a rotor surface which looks like Fig 6? After a skim cut, it's too easy to lose your references for locating the potential remaining HAZ, meaning you may get a false negative report showing no remaining HAZ simply because it was tested in the wrong location. This opens the door to possible crack initiation in service due to the remaining hard material.

A better alternative to evaluating remaining HAZ is a process called macroetching. It involves first polishing the surface with about a 600 grit or finer sander, and then applying an acid solution to the surface (10% Nital in this case). The changes in the steel microstructure cause variations in the grain structure and precipitates around the grain boundaries. The macroetching solution helps to accentuate these grain boundaries in a way which can be visually discerned with the naked eye in localized regions on the shaft.

In Fig 7, you can see the results of macroetching after the first skim cut, as well as measurements of Brinell hardness (HB). The hardness in the primary macroetching indication measured 457 HB, while measurements outside of the HAZ measure a nominal 271 HB. If you've got really sharp eyes, you may be able to discern in Fig 7 how there is a center whitish island of material surrounded by a material which is darker than the balance of the rotor surface. Such an appearance is typical of significantly hardened material.

Unfortunately, the rotor surface in Fig 7 is somewhat mottled by contact after the etch was performed. For a better perspective of what a rotor surface looks like shortly after macroetching, refer to Fig 8, which was captured after the second skim cut. There's no need to do a hardness check because it's obvious that there's still a HAZ in the rotor.

Conclusion. Rather than hardness testing, you should insist on macroetching to evaluate remaining HAZ when dealing with magnetic steel. Don't assume that the shop uses macroetching as a standard practice. Even if the shop isn't familiar with macroetching, they should have a metallurgist/NDE contact who is. But in every case, the work must be done by qualified personnel.

Stainless steels are more difficult to examine with macroetching, so if your rub involves a stainless component, like a generator rotor endwinding retaining ring, it is even more important to consult with an expert metallurgist for options. CCJ

CCJ launches global coverage of GT user groups

The first gas-turbine user group known to the editors got its start in the US in the mid-1970s. It provided valuable experience on the operation and maintenance of these relatively new prime movers, which were ordered by electric utilities in large numbers following the Northeast Blackout of 1965. Back then the dominant engines for power production were Pratt & Whitney's FT4 and General Electric's Frame 5.

With world leaders in the development of industrial GTs—GE and Westinghouse Electric Corp—headquartered here, where natural-gas transmission lines moved fuel over long distances relatively inexpensively and additional capacity always was needed, larger and more efficient engines debuted regularly, promoting a need for user groups to facilitate technical communication among the owner/operators. Meetings of these organizations attracted 60-Hz users from around the world.

But what about 50-Hz users? Until recently, there was no efficient way for CCJ to follow the frame-specific experience of these owner/operators, most meetings being small and geographically dispersed. However, over the last several years, the organization known as GTUsers.com has built a loyal following among European, Asian, and Middle Eastern owner/operators who regularly participate in its online and face-to-face conferences. CCJ and GTUsers.com have agreed to work collaboratively to help users share experiences globally.

Here are some facts about the V fleet to keep in mind as you read through this report:

- There are about 1000 V engines operating worldwide. This total includes both E- and F-class models operating at 50 and 60 Hz, providing plenty of experiences to share across national borders.
- Two OEMs manufacture V engines, Siemens and Ansaldo Energia. The engine designations for Siemens machines are SGT5-4000F (V94.3A, 50 Hz), SGT5-2000E (V94.2, 50 Hz), SGT6-4000F (V84.3A, 60 Hz), and SGT6-2000E (V84.2, 60 Hz). For Ansaldo engines, the designations are AE94.3A and AE94.2—50 Hz only. Roughly 80% of all V machines in service were made by Siemens, the balance by Ansaldo under a Siemens license.
- In round numbers, there are about five-dozen V84.2s operating in the US, three-dozen V84.3As. CCJ has covered the 60-Hz fleet since the mid-2000s. Siemens has hosted annual face-to-face meetings over the last decade and invited the editors to participate. The 2020 conference will run from September 14 to 17 at the Hilton Niagara Falls/Fallsview Hotel & Suites in Niagara Falls, Ont, Canada.
- GTUsers.com has hosted web meetings for V users since 2009, face-to-face meetings since 2014. The 2020 conference of the V94.3A users takes place in Prague, Czechia, October 12-15; the V94.2 meeting, Prague, Czechia, November 9-12.

What follows are summary notes from the 2019 V user conferences in the US and Europe, plant best practices, and technology updates from Siemens and several third-party service providers—including ARNOLD Group, Sulzer, and APG.

GTUsers.com

GTUsers.com, a web portal designed and maintained by Gasre Oy (www.gasre.com) to facilitate communication among owner/operators of gas turbines, transitioned from a "hobby" to a professional service in 2014. Coincidentally, the independent Finnish firm, launched in that year the development of its TMMonitor™ product for gas-turbine maintenance management and parts tracking. This software is represented in the US by Lodestar™ and Turbine Technology Services Corp.

The activities of GTUsers.com are coordinated by Yrjo Komokallio, a turbine specialist, who is CEO of Gasre. The web portal is segmented by engine type (currently 11 machines are represented), and access to the discussions, databases, etc, associated with each is restricted to the members of that group. You can be a member of a group only if you own and operate such a unit. The individual groups are controlled by their own end-user steering committees. In sum, more than 5000 users, representing over 1500 gas turbines participate in GTUsers.com,

Pertinent to this report, GTUsers.com has hosted web meetings for owner/operators of V94.3A (SGT5-4000F, AE94.3A) engines since 2009 and for V94.2 (SGT5-2000E, AE94.2) machines since 2012. Annual conferences were added in 2014 and 2015, respectively. Last year (2019), the 94.3A group met in Istanbul in October, the 94.2 users in Berlin in November.

Sponsors of GTUsers.com activities familiar to CCJ readers include ARNOLD Group, Sulzer, APG, MD&A, Freudenberg, Liburdi, Dekomte, Trinity Turbine Technology, and Gas Turbine Controls.

V94.3A, highlights from Istanbul

There were eight V94.3A user presentations at last year's meeting, half based on experience in Europe, half in Asia. The European speakers focused on the following: gas-turbine O&M history covering nearly 10 years, generator

major, expansion-joint failure analysis and repair/replacement, and combustion tuning to allow an increase in fuel temperature. Presenters from Dubai Electricity & Water Authority discussed GT inspection findings, what is believed to be the world's fastest major for this frame (11 days), and the underlying cause of fuel-oil flex-hose damage.

Here are thumbnail sketches of the assets upon which the presentations were based:

- Two single-shaft combined cycles with a total full-load output of 870 MW, designed for a nominal 300 starts annually, hot starts (less than 8-hr shutdown) in 15 minutes, warm starts in 50 minutes.
- Two single-shaft combined cycles built in the mid-2000s with a total full-load output of 850 MW.
- Early 2000s repowered oil-fired steam station (2 × 125 MW) burning gas with heavy-oil backup. Current configuration is two 363-MW 1 × 1 × 1 combined cycles.
- Standard 2 × 1 combined cycle rated 850 MW.
- Plant built in stages with 400-MW single-shaft combined cycles installed nearly a decade apart.
- A 590-MW 2 × 0 addition to power and desalination plant.
- Two 375-MW 2 × 1 combined cycles with flash distillers.

Perhaps there's no better way to learn about plant operations than to listen to a user colleague give an objective review of his plant's history and be able to ask questions. This speaker's review covered eight years from commercial start to an extended HGP more than 34,000 EOH and nearly 400 starts later.

He talked about the plant's experience with hexavalent chrome—sampling and measurement, and dealing with contaminated insulation mattresses. Conclusion: Further investigation is required to assure a safe working environment on the steam turbine.

Another safety topic discussed was working at height, including the use of davits to tie off worker harnesses when climbing on the turbine.

Moving to the compressor, the speaker discussed IGV actuator ring axial wear and repair, plus replacement of rollers, bushings, and pins. A diaphragm exchange made necessary because of wear at vane hooks was another talking point. Exchange of the compressor bearing shell because of damage, the need for new shaft coupling bolts, repair of the coating on the leading edges of airfoils, and other compressor topics kept attendees in their seats.

Mention of a trip caused by the unexpected closing of IGVs during baseload operation was a surprise highlight of the presentation. Analysis revealed the cause was servomotor internal leakage, considered an isolated incident.

In the combustion chamber, minor repairs were required. In the turbine, all vanes were disassembled and reassembled; a few were replaced. Plus, blades in Rows 1, 2, and 3 were renewed.

Recommissioning revealed engine work during the outage enabled a power boost of more than 2%; heat rate also was better.

The original metal-bellows expansion joint installed between the gas turbine and exhaust duct had 125,000 EOH and more than 1200 starts at the time of failure. Material was described as heat-resistant austenitic stainless steel. The expansion joint was designed for 12,000 cold starts, 620C operating temperature, ±50 mm elongation, and ±1 mm movement in the vertical direction.

Plant personnel knew they had a problem because both the temperature and the concentration of carbon monoxide inside the package had increased significantly. Plant operations were modified to avoid unit trips. Inspection revealed the joint had failed in two locations—at the 12 and 6 o'clock positions—and insulation was damaged. Temporary metal shields mitigated damage to affected components.

Temporary repairs were made about six months after the failure was identified, but the protective pillows and belting holding the pillows became ineffective over time and the replacement of the expansion joint became necessary. The new joint was installed during a steam-turbine outage.

There were difficulties with the installation, which should not be surprising. Examples: misalignment between the exhaust section and the gas turbine as well as cracking and deformation of the transition cone. Leak testing was the final step in the replacement project.

A finding during the root-cause analysis (RCA) investigation was that sliding feet on the exhaust cone were not performing as intended and hang-ups impeded expansion of the joint during turbine starts, causing stresses that contributed to cracking. At user meeting after user meeting the editors hear of problems with sliding feet on heat-recovery steam generators, rotor air coolers, shell-and-tube heat exchangers, etc. They should be inspected and lubricated annually.

The failure of flexible hoses for fuel oil can be avoided in many cases. The speaker describing her experience said that before the unit's minor inspection, the operator received a fire-detector alarm, and personnel found the flex hose between one burner and the manifold ring completely torn apart. It was replaced. Flex-hose damage also was found on at least one other machine.

Like the condition of sliding feet in the previous experience, the condition of flexible hoses must be monitored. Subject matter expert Brian Hulse, a frequent contributor to CCJ, acknowledges that hoses are expensive and that users always try to extract maximum value from them before they're replaced. Replace decisions are not easy because the hoses used on most gas turbines are manufactured with no published shelf-life or working-life limitation.

Hulse says plant O&M personnel should be aware that the following conditions impact hose life and to be on the lookout for them during inspections: chaffing, kinking, prolonged exposure to UV, mechanical abrasion, lying in fluids (water, fuel, oil, etc).

A simple database can help you avoid surprises. Include any recommendations on the care of hoses offered by the gas-turbine manufacturer in the O&M instructions for your machine, note the type of service for each hose cataloged, enter findings of routine inspections, inspection interval, inspection procedure, etc.

Also, bear in mind that some hoses are equipped with an exterior protective sleeve—usually called a "Firebraid" in the US after the trademarked product. This sleeve is designed to protect hoses from the hazards of high heat and occasional flame. If the Firebraid is torn, chaffed, or oil-soaked, the hose should be removed from service—especially if it too shows signs of distress.

A generator major was scheduled early based on the OEM's recommendation to replace all hydrogen seals after about 64k EOH and 1700 starts. Wedge tightness was an initial concern when the unit was removed from service, but the inspection team ruled it "acceptable" based on results of a test method provided by Siemens USA.

Several small cracks were found on the generator's PPS (hydrogen Performance Plus Seal™) segments. The bumper ring also was damaged. No obvious root cause was identified. The speaker advised that segments can be replaced onsite, but bumper-ring replacement requires a factory visit. Important: Damaged segments cannot be replaced individually; the entire ring must be replaced. Attendees also were made aware of the OEM's devel-

opment of a special tool for installing new PPS segments.

Several wrinkles were found in stator top bars. "Advanced" wrinkles could be seen by the naked eye; several other bars sounded hollow on one side when tapped in the same area. Insulation was cracked in areas revealing advanced wrinkles and it was repaired. Engineers determined that wrinkles and delamination were caused by thermal expansion/contraction of the bars during starts and shutdowns, which had increased in recent years. The repairs contributed to a significant reduction in partial discharge, which had been increasing over time.

Generator bushings were changed to ones with cast rather than welded supports to mitigate damage caused by vibration. However, the new design also showed signs of vibration damage on all three phases, as indicated by green dust. Engineers could not determine the cause of vibration. The three bushings had capacitance deviations, likely caused by bad connections between clamp and the inner electrical-field control layer. One bushing was replaced. The other two were relocated to new positions at "star" points, where there is no voltage stress.

An upgraded bearing (MKD11) was installed on the gas-turbine side of the generator because of tilting and problems during turning-gear start. The new bearing has improved lift-oil grooves and coated bearing saddles, but its normal temperature runs about 6 deg C higher. Monitoring of the new bearing is ongoing.

Combustion tuning was discussed by an engineer associated with a practical research project for a large generation company. The goal of the program was to minimize cost of power production while maximizing efficiency and output. Results enable the company to tune its engines at less cost than would be charged by the OEM.

The sticking point described was that while the gas turbine met performance guarantees, it was not possible to operate at the maximum fuel temperature (200C) at low ambient temperatures. The power generator wanted 200C fuel at all times to increase efficiency.

A solution was found whereby fuel temperature was raised and efficiency increased. The annual saving in fuel and carbon costs amounted to more than $US100,000. Plus, NO_x emissions were reduced. Work on the project continues with the goal of fine-tuning combustion and saving still more fuel.

Outage time reduction is the goal of virtually all power producers when they are "in the money." Speaker described how his company was able to reduce the time for major inspections on two gas turbines from 51 days in 2013 to 11 days in 2018 and 2019. Likely you find this hard to believe. Learn what's truly possible by attending user-group meetings for your engine.

For this case history, be aware that plant personnel were motivated to set a world record for the major inspection of a SGT5-4000F. And they were empowered to do so. There was plenty of relevant in-company experience to draw upon: It owned and operated two-dozen V94.3As.

The first engine to complete its 11-day major (2018) required more than 12,000 man-hours of effort from a field staff of 115 working 11-hr shifts; the second engine's 11-day major in 2019 took just north of 9400 hours with 95 field staff working 10-hr shifts.

Critical to the achievement were the following:

- Detailed planning and prioritization of work permits to minimize the time needed to isolate various systems.
- Created a fast-track entry process for staff and logistics at the security gate.
- Maximized onsite logistics—such as meals, laundry, transportation, etc—to minimize lost time.
- Conducted a kickoff meeting of all field staff prior to the outage to build a sense of ownership in the project.
- Shifted critical risky activities to outside the overhaul period. The thinking: The shorter the outage the lower the technical risk and the fewer the number of human errors.

Project planning was especially critical to success, the speaker said. Here were some of the key steps taken:

- Activities thoroughly planned in advance with resources mapped to overcome foreseen challenges.
- Staff qualifications were scrutinized and the best team selected.
- Optimized the work-shift model to permit round-the-clock activity.
- Organized and managed spare parts and tools to minimize time constraints.
- Conducted daily project review meetings to identify and eliminate schedule sticking points and to measure progress.

The speaker closed by identifying some considerations to shave days from the outage schedule, including these:

- Consider a rotor swap rather than a shop visit.
- Provide onsite capability for coating compressor blades.
- Review lessons learned and implement optimized findings into your plans.
- Swap out burners, valves, etc.
- Focus on enhanced project management techniques.

Inspection findings were reviewed by an engineer from a major generator. A summary follows:

- Minor inspection revealed TBC loss and some oxidation of the protective layer on the pressure side of two first-stage turbine blades, which were replaced.
- Linear crack indication on the platform of one second-stage blade, also replaced.
- Bearing balls found missing on one side of the turning-gear pinion. It was replaced.
- Lift-oil pump failure was characterized by black-colored oil, metallic chips in the filter, and coupling damage. After failed parts were replaced, oil was run through the filter until clean.

Extended HGP inspections on the gas turbines for one 2 × 1 combined-cycle block (nearly 68k EOH/314 starts) at a two-block plant revealed the following:

- Compressor bearing reverse thrust pads were found scored to a depth of 0.4 mm; coking was in evidence.
- All vanes were removed for NDE, two were replaced because of excessive caulking clearances, IGVs and first- and second-stage vanes were recoated, compressor blades in Rows 1-4 were recoated on the leading edges of the airfoils, some new tiles were required.

During recommissioning, new KV curve settings were required for gas control valves, newly implemented logic called for in product bulletins presented problems, compressor bearing temperature came in higher than expected, the baseload power output was lower than expected, a unit trip was experienced during a switch-over from diffusion oil mode to fuel gas.

The second combined cycle at the plant went through its extended HGP inspection the following year with some of the same findings identified with the first block—such as replacement of a few blades and vanes in the compressor, coating fix on compressor blades. Recommissioning of Block 2 also was similar to that of Block 1.

V94.2, highlights from Berlin

There were six V94.2 user presentations at the 2019 meeting, half based on experience in Europe, half in the Middle East. Speakers focused on the

following: results of an extended HGP, follow-up on repairs to a compressor's axial bearing after two years of operation, outage findings, damage to turbine blades attributed to domestic object damage, damage found in the solenoids of natural-gas vent valves, and finding the location of a generator ground fault.

Here are thumbnail sketches of the assets upon which the presentations were based:

- A two-decades-old, 486-MW, 2 × 1 combined cycle in CHP service having an overall thermal efficiency of 92%.
- A 216-MW 1 × 1 combined cycle that began commercial operation 10 years ago.
- A 480-MW 2 × 1 combined cycle (COD 1998) that went into service a few years earlier as two simple-cycle V94.2(3) units.
- A 10-yr-old, 380-MW, 2 × 1 gas-fired combined cycle with oil back-up.
- A two-decades-old, 450-MW, 2 × 1 combined cycle designed for resid/distillate and converted about 15 years ago to gas/distillate.

EHGPI. The speaker began with an overview of the unit's operating history: about 29k EOH/400+ starts to the first major; second major at nearly 63k EOH and 500 starts; third major and lifetime extension at approximately 100k EOH/700 starts; and the extended HGP inspection, the subject of the presentation, at 42k EOH/230 starts following the third major.

About 10% of owner/operators were said to perform the Siemens HGPI, which has a workscope similar to a major, with rotor removal—but no rotor de-stack. Such an overhaul runs about 29 working days, each with two 10-hr shifts. The speaker recommended having some time in the schedule to rectify "as-founds." Another recommendation: Plan for a six-day recommissioning of a dual-fuel machine that includes low part-load testing.

Here's a list of what was done during this EHGPI:

- All upper-half casings removed.
- Rotor pulled along with compressor and turbine bearings. De-bladed rotor on roller rotor support stand but didn't de-stack.
- Compressor stator vanes and first six rows of rotating blades removed.
- Full disassembly of the combustion system.
- Exhaust casing removed.
- Recoated compressor rotor blades and IGVs offsite (first time since COD). Stator vanes were new at LTE and recoating was not necessary.
- Grit blasted all components removed from the rotor.
- Overhauled all auxiliaries.
- Installed upgraded fourth-stage divided seal rings for non Si3D vanes.

The as-founds included the following:

- Damage to the trailing-edge tips of two Row 8 and one Row 9 compressor blades.
- Fretting wear on tile support ring.
- Excessive T hook wear.
- Wear on mixing-chamber castellations.
- Wear on some sharks' teeth on the inner casing.
- Wear and tear on exhaust-casing housing and on the exhaust expansion joint just before the diverter damper.

The as-founds were repaired by caulking, welding, etc, or parts were replaced—such as vanes, burner inserts, and divided seal-ring segments. Most of this work was captured in quality photographs and of significant value to attendees.

Of interest to attendees wanting to extract maximum value from their machines, compressor rotating blades here now have more than 140,000 EOH, while third-stage turbine blades and vanes have run north of 80k EOH, with about one-third of the run hours at partial load.

Outage was taken in 2019 for an engine that had accumulated 162k EOH since COD two decades ago with a "to do" list that included mods to reduce NO_x emissions, combustion-chamber repairs, and implementation of a program to reduce low-frequency combustion dynamics.

The plant's NO_x reduction campaign began in fall 2017 in cooperation with Siemens. Key actions: Mods to pilot-gas control on a sister unit of the engine involved in the 2019 outage; plus, optimization of part-load pilot-gas flow. The trial project achieved the established goals and the changes were duplicated on the second engine.

Combustion-chamber repairs focused on the flame tube and mixing-casing castellation areas as well as on the HR3 burners. Burner rings were replaced and work was necessary on the bottom plates of the flame tube.

Improvements to the combustion monitoring system, a joint research project with the OEM, called for the addition of six dynamic pressure sensors and seven acceleration sensors on the combustion chambers (total for both). Low-frequency dynamics were thought to contribute to the wear of relevant parts. Metallurgical examination of the burner inset ring and an evaluation of dynamic pressure and acceleration pointed to "hammering" wear as the predominant damage mechanism.

The pilot-gas setting was adjusted to reduce pressure amplitudes while maintaining NO_x emissions within prescribed limits.

Next step was to investigate the impact of ambient temperature on hammering using remote combustion monitoring tools. This was to have been done during winter 2019/2020 but no update on the project has yet been made available. Wear progress will be confirmed visually during the engine's next minor inspection.

There was an unexpected finding to deal with as well during this outage: Loose and unattached burner-ring down holders. In round numbers, two-dozen down holders were loose on each combustion chamber, and a few others were either found out of position or tight but in the wrong position. Incorrect installation was the root cause; the work order provided was not followed.

At user meeting after user meeting there are examples of poor attitude, supervision, and training causing or contributing to issues that should not have occurred. Most senior plant personnel are aware of both this and the corrective actions necessary; however, schedule and budget constraints often dictated by others unfamiliar with plant operations militate against success.

During an engine inspection the leading edges of 26 first-stage turbine blades were found with varying degrees of distress; plus, the trailing edge of one was missing a 1-in. piece of material. Two blades in the second stage also were found damaged. In the fourth stage, dents were found on the leading edges of two blades, with a crack found emanating from one of the dents. There was no evidence of any loose material in the combustion chambers or exhaust diffuser to support the OEM's belief that FOD was the cause.

A special inspection of the combustion chamber and mixing casing revealed a portion of the baffle plate was missing at the transition from the flame tube to the mixing chamber. That DOD caused the blade damage.

With the unit under an LTSA, Siemens pulled the affected combustion chamber and welded in a new baffle plate. On the other combustion chamber, the OEM trimmed four constellations in the transition area to prevent contact with the baffle plate during operation and avoid a repeat of the incident.

HGP inspection at 33k EOH: highlights. This case history begins two years ago at 16k EOH when the axial bearing for the compressor of this unit was found damaged. Bulletin PB3-13-5015-GT-EN-01 had been implemented in 2015. At 33k EOH bearing condition was determined "acceptable." However, single pads that had suffered scratches were replaced as were pins and spring elements because of minor wear.

- A crack was found in the inner casing in the region of the holder. No cause was identified. Local weld repair was the solution; no heat treatment was required.

- Both transition rings were found with heavy wear. Replacement was preferred over weld repair because it was faster and less expensive. The mixing chamber outlet was modified as necessary to align with the new transition rings. Heat treatment was recommended and done.
- Inspection of the F-ring upgrade implemented in 2015 found no issues.
- Condition of the inner liner for the exhaust casing suggested installation of both a thicker end cover (9 mm instead of 5) and side compensators.
- Upgrade of vanes and seal segments for the turbine's third and fourth stages brought to light fretting wear not found previously.

Generator trip alarm was received on startup with turbine speed 260 rpm, rotor voltage at 270 V and current at 375 amps. Plant personnel reviewed the excitation drawing to identify test points. Next, all brush holders on the generator were removed and the alarm reset. The excitation side was tested and found acceptable.

An insulation resistance (IR) measurement on the generator rotor revealed less than 2k ohms. However, the resistance between one rotor terminal and ground was found low. Winding resistance for the rotor, measured after using external heaters to reduce humidity, was fine at 154.6 milliohms.

OEM Ansaldo Energia recommended repeating the IR measurement with a megger at 500V dc for 1 minute. Expecting the IR measurement would still be low, the manufacturer provided instructions for locating the portion of the winding affected by the ground and then cleaning it with acetone.

The ground gremlin was found in the area of the "B" slip ring and radial bolts. The speaker described the process of disassembling the slip-ring housing and the IR measurements taken to pinpoint the problem. Removal of the generator shields allowed a borescope inspection that identified the presence of lube oil on both shields and the rotor and evidence of foreign parts hitting the fan—as well as a piece of metal. An IR measurement after repairs confirmed the problem was solved.

Vent valves installed in the natural-gas supply line to the combustion chambers, an integral part of the generating unit's safety system, are arranged to fail open. This means if the valves don't operate properly, like the solenoids at this plant, the valves will open and the turbine will trip. In one year, the speaker said, four out of nine solenoids failed, negatively impacting plant reliability and availability.

The valves are located in different areas of the plant—some warmer than others. Personnel determined that heat was a primary factor in the failures. Changing out solenoid valves to the 240V dc coil type and cooling with air from the service-air system in locations of high heat seems to be a reliable solution. Operational observations continue.

Siemens

The Siemens SGT5/6-2000E (V94.2/84.2) and SGT5/6-4000F (V94.3A/84.3A) fleets are among the world's most successful gas turbines, having been continually upgraded over their respective lifetimes (39 years for the E-class engines, 26 for the F-class) to improve performance and help owner/operators remain competitive as power generators. Worldwide, about 1000 machines (50- plus 60-Hz) produced by the OEM and its licensees, are operating today.

The V Users Group serving the North American market is relatively small, the number of Dot 2 and Dot 3A units here accounting only for about 10% of the global fleet. Siemens Energy Inc organizes the annual meeting with help from users—including Scott Wright of PowerSouth Energy Co-op, J R McKinney of Arkansas Electric Co-op Corp, and Preston Walsh of Great River Energy.

The 2020 conference is scheduled for September 14-17 in Niagara Falls, Ont, Canada, at the Hilton Niagara Falls/Fallsview Hotel & Suites. V users interested in attending should contact Dawn McCarter, conference coordinator (dawn.mccarter@siemens.com). Participation in the exhibition accompanying the meeting is restricted to Siemens alliance partners.

There were about a dozen presentations by Siemens at the 2019 meeting last September in Pittsburgh. The editors summarize here the content of the comprehensive engineering and modernization/upgrade presentations for each frame. The remainder, listed below, can be accessed through the Customer Extranet Portal (CEP):

- Asset performance management.
- Expanded scope solutions for total plant optimization.
- Fuel specific solutions.
- Advanced technology update.
- Brownfield engine exchange.
- Generator update.
- Controls and electrical update.

SGT6-2000E

The 40+ slide engineering presentation on the V84.2 engine at the 2019 conference began with a review of key facts for the combined V94/84.2 fleet: Well over 400 units operating worldwide, 35% of owner/operators under an OEM long-term service agreement, more than 30-million equivalent operating hours (EOH), and 99.6% overall fleet reliability.

The takeaways from this chart: There's a wealth of experience to benefit from when problems arise at your plant, provided you attend the annual user conference and build a network of colleagues to contact when help is needed; the aftermarket services business is competitive; and the fleet's impressive reliability encourages upgrading engines, or purchasing new the latest model for plant expansion, when opportunities arise.

The next slide reinforced the long-term value of the SGT5/6-2000E to owners. It showed that the fleet continues to grow, nearly 40 years after its introduction in Waldheim, Germany, in 1981, and more than 30 years after the first units in the US began commercial operation in 1989 at the Hay Road Power Complex, Wilmington, Del. Fact: In the 2017-2019 period there were 28 new units and BEX (brownfield engine exchange) replacements—one-third in the 60-Hz market.

A BEX replacement enabled PowerSouth Energy Co-op's McWilliams Power Plant in Covington County, Ala, to boost the output of its mid-1990s vintage SGT6-2000E(2) from 102 to 114 MW by swapping it out with a new late-model SGT6-2000E(8). Improvements in the engine's gross simple-cycle efficiency from about 31% to 35% over the years made replacement more economically attractive than continuing to change parts and do regular maintenance upgrades. Plus, NO_x emissions were reduced to 10 ppm from 13-16 ppm.

Major work on the BEX project, the first-of-its-kind in the US for the OEM, included the design/manufacture/installation of a new intermediate shaft between the turbine and generator, and modifications to the air-inlet house and exhaust diffuser—in addition to replacing the gas turbine, of course. The original generator remained as it was.

Siemens reported that it has done more than two dozen BEX projects worldwide and has several more in the works. Bear in mind that the concept is not unique to the V94/84.2 fleet. Projects completed and under development involve such engines as the V94.3A, V64.3, 501D5A, W701, 501FC, and 501FD3.

If you're new to this fleet or haven't kept up on the mods and upgrades to improve performance you might want to access this information on the CEP—especially if your plant is more than 10 years old. Over the last decade your plant's requirements likely have changed with regard to dispatch schedule, emissions, power output (perhaps you can sell more electricity today than previously), etc, and new investment might strengthen your market position.

Si3D. One consideration might be re-blading the turbine with the OEM's Si3D (Siemens innovative 3D) blades and vanes, which became available for 60-Hz service as the first decade of the millennium came to a close. These airfoils enable significant improvement in output and efficiency.

Initially, owners re-bladed the first two stages of the turbine to achieve a nominal increase in output of 5 MW, and an efficiency improvement approaching 1%. Given the excellent results, many owners re-bladed Rows 3 and 4 when those airfoils were made available, gaining another 2.5 MW and 0.5% efficiency. Today, about half of the V94.2 fleet (and 40% of the V84.2 fleet) is equipped with Si3D blading. All new SGT5/6-2000E turbines have Si3D blades and vanes.

RCIE. Knowledge gained in the conduct of more than a hundred Rotor and Casing Inspections and Evaluations on SGT5/6-2000E machines over the last 10 years was the next topic. The good news: Typically no significant findings were reported fleet-wide for most rotor and casing components between 100k and 150k EOH. Siemens' recommendations: NDE rotor components at 3000 starts; consult with the OEM's engineers two years prior to the major inspection in the 123k-133k EOH timeframe regarding the optimal maintenance schedule for future operation.

A couple of case histories were presented on actions taken to address inspection findings; an insightful bar chart showed very few key compressor and turbine components (discs, tie rods, etc) have been replaced across the baseload fleet because of indications revealed during RCIEs, which began in 2009. In addition, cutaway color-coded drawings allowed attendees to see which baseload-engine parts typically can run up to 200k EOH, and beyond, with proper inspection and maintenance, those recommended for replacement, and those requiring a unit specific assessment.

For RCIEs performed on peaking units at 3000 starts, the goal is to make the necessary improvements to enable operation for up to 6000 starts. Replacement of compressor vane carriers 1 and 2 with GG25 material, and turbine discs 3 and 4 with X12 material, are recommended for about two-dozen North American engines. But final go/no go decisions depend on unit-specific assessments. Replacement of all rotating compressor blades also is recommended by the OEM at 3000 starts.

Tile holders for all engines in this frame should be replaced at between 100k and150k operating hours.

Wet compression is a proven technology for boosting gas-turbine output on hot days and Siemens has more than 70 systems installed worldwide on its large 50- and 60-Hz frames. A review of wet-compression experience on SGT5/6-2000E engines since 2003, with the fleet leader at more than 14k OH, provided the following two observations, among others:

- No pitting corrosion has been identified on any V94/84.2 unit, and no tendency to pitting corrosion is expected.
- Coating loss has been observed on the leading edge and pressure side of some units but corrosion has not.

Modernization and upgrade products scheduled for release in 2020 will continue to boost the capabilities of this frame and its performance. Many of these enhancements were discussed at the Pittsburgh meeting with respect to the 50-Hz machine which will host the first commercial deployments; 60-Hz applications to follow. Some of the products discussed include the following:

- Si3D+™ next-generation turbine blades and vanes for greater power and efficiency, and companion compressor bearing to accommodate the higher thrust load with the new airfoils. Think of the new bearing as availability/reliability insurance.
- New hot-ambient compressor design to extract maximum performance for engines located in warm climes—such as Africa, Middle East, and Bangladesh.
- Reduction of cooling air required in the combustion chamber brings NO_x emissions below 10 ppm.
- Ultra-fast starting.
- Enhanced fuel flexibility, including hydrogen.

41k EOH. The value of Siemens' 41k EOH Maintenance Concept received air time. Owner/operators that have not yet implemented 41MAC (shorthand lingo) might want to review its benefits. In brief, it involves the replacement or modification of key turbine components to extend their lifetimes and reduce life-cycle costs. What's involved includes new coatings for turbine blades, advanced inner casing and mixing chamber design, plus the HR3 burner and flame-tube modification.

41MAC can be combined with other modernizations—such as firing-temperature increase and Si3D blades and vanes—to boost overall performance.

SGT6-4000F

The V84.3A session began much like the E-class segment of the program, with a review of key facts about the frame: more than 370 engines of Siemens manufacture operating worldwide, 22-million EOH of fleet experience, and more than 99.3% overall fleet reliability. One big difference between the sister frames is that 80% of the F-class units operate under a long-term service agreement with the OEM, compared to about 35% for the E-class machines.

The theme of this session was "Future-proofing your plant: Ensuring commercial success through mods and upgrades." Confirmation of the OEM's commitment to continual performance improvement is that the fleet service factor (operating hours divided by period hours) increased from 57% to 62% in the last three years even as competition in the power generation sector of the industry intensified and renewables gained market share.

Reviewing the OEM's development plan for future enhancements—some already in commercial service or beta testing—one comes away with the belief that this frame is destined to remain competitive for many more years. If any of the following products/services are new to you, access the 4000F Engineering Session slides on the CEP for more information, or contact the Siemens representative for your plant.

Maintenance:

- Optimized maintenance intervals.
- Increased outage flexibility.
- Wider range of service concepts available—including the fast outage incorporating innovative field service solutions.

Performance:

- Performance boost with Siemens' Advanced Turbine Efficiency Package.
- Upgrade with Service Packages 7 and 8—including cooling-air reduction, HGP improvements, compressor mass-flow increase.
- GT Auto Tuner:
- Low-NO_x emission solutions.

Flexible operation:

- Increased load gradients.
- Fast start, turn up, extended turndown.

- Optimized part-load capabilities.
- Expanded Wobbe range and hydrogen capability.

Improved airfoils. One of the speakers explained why compressor blade and vane enhancements have contributed in a major way to gains in output and efficiency: Improved manufacturing processes and materials. For example, five-axis precision milling has replaced conventional manual finishing methods, improving the accuracy of the airfoil profile and leading and trailing edges. Working surfaces also are smoother, and improved materials mitigate corrosion and erosion.

33MAC. The 33,000 EOH interval, introduced in 2009, is the standard maintenance concept for the SGT5/6-4000F. The leap from 25MAC, when the engine was introduced in 1996, to 33MAC (some machines have had positive experience to 38,000 hours), was enabled primarily by improvements in coatings and airfoil geometry and cooling. Looking ahead, advanced turbine hardware, scheduled for 2022 commercial availability, with a new base material and geometry improvements to increase low-cycle-fatigue life, will allow up to 2000 starts—double that of today's blades and vanes.

FODS Smart. The benefits of Siemens' Foreign Object Detection System, installed on well over a hundred turbines worldwide, were examined. FODS provides continuous monitoring for potential loss of combustion-chamber parts by way of acceleration sensors and a data acquisition and evaluation unit. System warns if a minor issue is detected (one that might lead to a system fault in the future) and alarms on a fault.

Other topics addressed included improvements to inlet guide vanes for faster response and the RCIE process, similar to that described above for the E-class engines.

The mods and upgrades presentation for the V84.3A was introduced with a chart that said enhancements to assure rapid frequency response, fast starting, part-load optimization, combustion of synthetic liquid fuels, and lower emissions by use of a premix pilot burner were ready for validation on this engine. Operational experience was offered on the following products:

- Service Package 6 (SP6). Implement during a major outage to increase efficiency and boost power output. SP6 includes the HR3 burner with reduced swirl (HR3 RS), combustion chamber requiring less cooling air (CAR), and improved turbine blades and vanes. Upgrade benefits depending on conditions are a gas-turbine power boost of up to 16 MW and an efficiency increase of up to 0.7% (for a 1 × 1 combined cycle, 21 MW and 0.4%).
- Compressor Mass Flow Increase (CMF++). Implement during a major outage to increase power output by up to 13 MW from the gas turbine and up to 22 MW from a 1 × 1 combined cycle.
- Part load optimization. Implement during an HGP inspection to reduce minimum load while maintaining CO within regulatory limits and to improve frequency response. Hardware mods include new seals in the compressor and modifications to the inlet guide vanes. Quantification of financial benefits requires a site evaluation.
- NO_x reduction. Reduce NO_x emissions while increasing power output. Calculation of benefits depends on fuel, site conditions, and other considerations.
- GT Auto Tuner (GTAT). Implement during a minor inspection to maximize efficiency and minimize emissions during normal operational changes. First use revealed a NO_x emissions reduction of up to 10% by activating the GTAT and virtually no degradation in power output over time between major outages.

V84.2/V84.3A users

Perhaps the best way to begin this section on experiences shared by V84.2/ V84.3A owner/operators during the annual conference of V users at the Pittsburgh Marriott City Center, September 2019, is to share the following passage from an announcement on the meeting from Scott Wright of PowerSouth Energy Co-op:

"Many of you know Olaf Barth, who has been the key contact for the users to Siemens for the last few years, is leaving the group. Dominion no longer owns Manchester Street, so Olaf is working on other topics. Many thanks to Olaf for his expertise and all his efforts." The CCJ editors extend their thanks to Olaf as well. He continues to be a valuable resource for us when gas-turbine O&M questions arise on these and other frames.

Interaction among owner/operators at the annual V conference is robust, similar to that at other user group meetings. These are ideal venues for tapping into the industry's knowledge on how to operate your plant more economically, reliably, and with less environmental impact.

Perhaps the best way to characterize the availability of OEM representatives, third-party suppliers, and plant personnel to address your concerns and answer your questions is *free* consulting—provided by experts. And this meeting is truly free, the OEM picking up all but your transportation and hotel room costs. It's the optimal way for anyone with a V machine in his or her plant to learn.

Given today's CV19 challenges, keep in touch with Siemens' Dawn McCarter (dawn.mccarter@siemens.com) regarding the 2020 meeting, scheduled for Sept 14-17 at the Hilton Niagara Falls/Fallsview Hotel & Suites in Niagara Falls, Ont, Canada.

Safety is a first-day topic sure to create discussion and get attendees engaged. At last year's V meeting hexavalent chrome—a byproduct of welding chrome-containing alloys—was a topic of great interest, as expected. Siemens employees had expended great effort in the last year to mitigate the issue—finding the contaminant on combustion basket flanges, bolting, exhaust diffuser, exterior case of the IP turbine, etc.

The yellow residue identified with the problem, calcium chromate, is formed by the oxidation of a chrome-containing base metal in the presence of a calcium source—such as anti-seize compounds and high-temperature insulation pads. Anti-seize test results reported at the meeting indicated Molykote, Loctite, and Nominal Blue Grease tested positive for hex chrome, while Kluber, Tiodize, and Lube-O-Ring were negative. Kluber Paste HEL46-450 and Tiodize T8F-H were recommended.

Additionally, bolts that had tested positive and were bathed in a 10% citric-acid solution for 5 to 10 minutes, then rinsed with clean water, reduced chrome 6 to harmless chrome 3. However, no such easy cure for contaminated insulation; it must be disposed of in an environmentally responsible manner.

Doing business online. There are questions from the floor at virtually every user meeting concerning the OEM's processes and procedures, and last year's V meeting had its share—including snags in the ordering of parts (such as functionality issues encountered when using the online quoting/ ordering system), delivery delays, response time on technical issues, etc.

Siemens representatives listened carefully and provided immediate assistance where possible. More thorough guidance was reserved for a web meeting in early March. The good news from that event: Enhanced e-commerce capabilities would be released this fall.

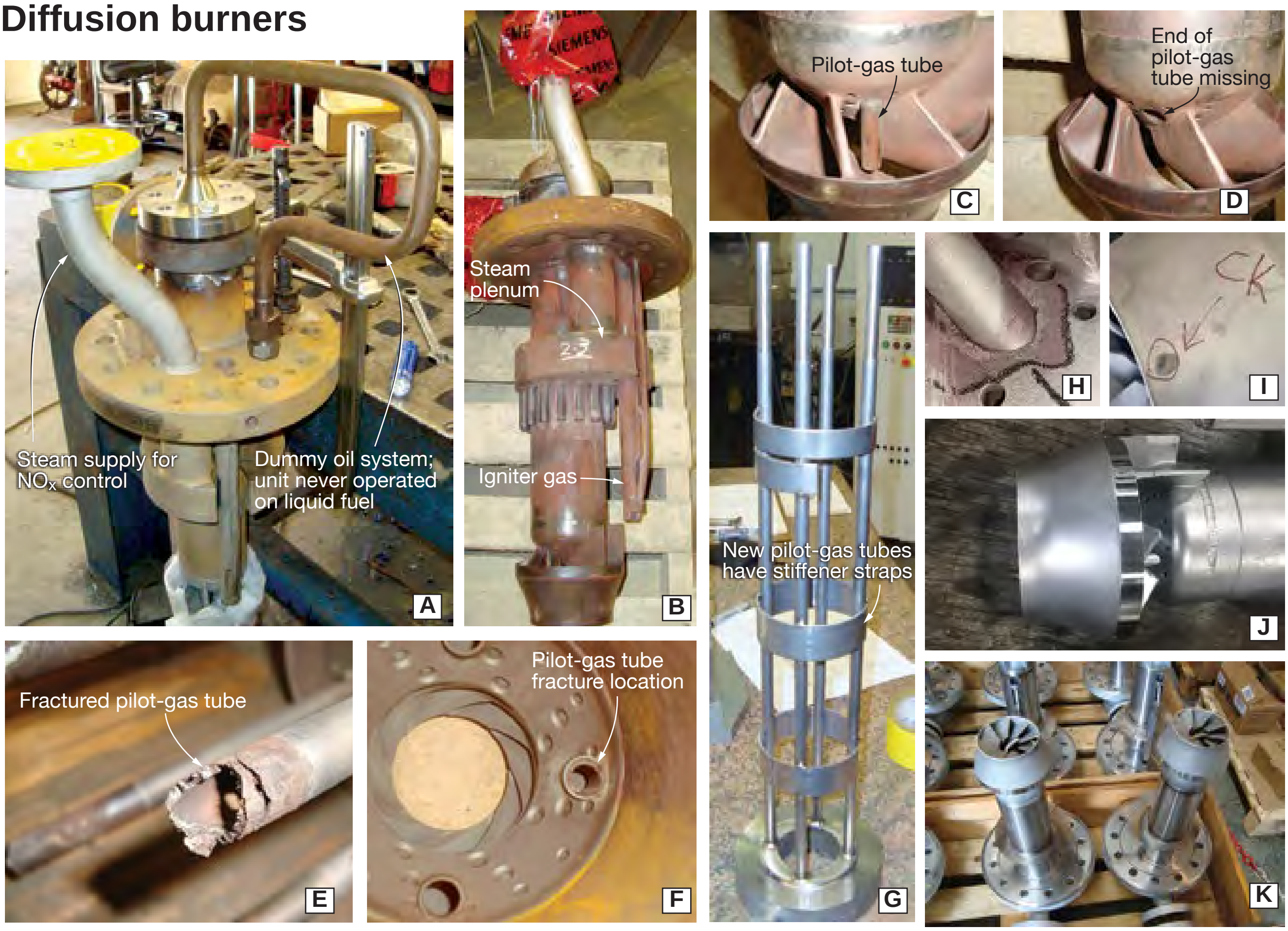
Plant specific questions and observations included the following:

- The SPPA-E3000 Electrical Solutions Excitation and Startup Frequency Converter System was regarded problematic by several users who thought more specifics should be made available to owner/operators. One attendee suggested that the excitation system was a "black hole."
- A participant said his steam turbine experienced vibrations close to the trip limit when a restart was attempted less than two hours after shutdown.
- Failure reported in a blowoff bypass line: Butterfly valve was installed backwards but never noticed until the third major.
- Support for Teleperm and TXP parts, training, and service was called into question by one user with a legacy unit.
- Gas-turbine output reported dropping a few months after a CMF (compressor mass flow) upgrade, and hadn't recovered. No other user in attendance had experienced this and the OEM questioned whether the performance loss was a problem unrelated to CMF. Evaluation continues.
- Exhaust transition liner with low EOH was said to have experienced excessive cracking. More information and analysis were required for a proper evaluation.
- A user expressed interest in operating at a lower gas supply pressure and wanted to know if pressures lower than those stated in the O&M manual be allowed. Question was referred to the OEM.
- Problems were reported with combustor thermocouples of a new design released to the fleet.
- Some discussion revolved around the compressor casing and when it was likely to need replacement.
- Performance degradation over time was another topic of interest. Can the degradation be correlated to starts and EOH? What are the ranges for loss and recovery? What can users do to minimize losses?
- Issues igniting in high humidity received mention. One specific question: Should there be any change to tuning or procedure to accommodate high humidity?
- Wet compression versus power augmentation was discussed. With Caldwell Energy in the exhibition hall, attendees could get answers to their questions direct from the experts.
- Actuators for inlet guide vanes were reported by one user as being upgraded to REXA Electraulic™ actuators which combine the simplicity of electric operation, the power of hydraulics, and flexibility. There was no manufacturer support available for the legacy actuators being replaced.
- Paint specs for the filter housing were discussed with Taylors Industrial Coatings Inc recommended by one attendee (see "Air inlet system maintenance critical to assure top gas-turbine performance" elsewhere in this issue).
- Vane-carrier cracking was identified as a problem in the V84.3A fleet.
- One user was upgrading his gas turbine's evap-cooler framework from PVC to stainless steel to combat premature degradation. Schock Manufacturing was mentioned for its filter-house work, in addition to silencers and exhaust systems.

APG

Eta Technologies LLC, believed by many to be the nation's leading inde-

Diffusion burners



Pre-mix gas distributors

pendent provider of new and aftermarket parts and maintenance solutions for Siemens V series industrial gas turbines, was purchased by APG in mid-2018. Principals Rich Curtis and John Kearney, who launched Eta Tech in 2004 and were well known to V users, joined APG as part of the acquisition.

Eta Tech's expertise fit seamlessly with APG's strategy of providing full-service solutions to the power industry—including turbine component repair, rotor repair, new-parts manufacturing, and field service—thereby creating a highly capable aftermarket resource for owner/operators of V engines worldwide. To date, APG has focused its attention on the E-class V84.2 engine.

With few opportunities in the US for showcasing its products and services to the V user community, APG's Curtis and Kearney caught up with the editors to review both the issues they are finding during visits to US plants powered by V84.2 engines and the successful corrective steps they have used to restore engine health. The many explanatory photos included here double as a valuable training aid for new hires and as a reminder for veterans who have not been involved in an overhaul recently.

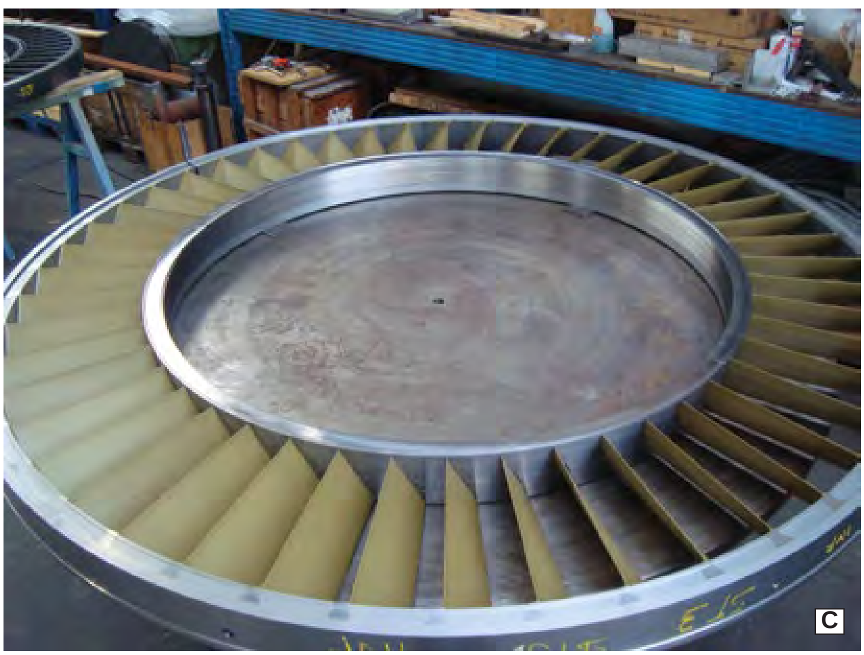
1. Diffusion burners

Broken pilot tubes found during burner inspections must be repaired quickly to maintain outage schedule. Recall that four pilot tubes are installed in each burner (Figs A and B) to deliver pilot gas to the swirler (C) for stabilizing combustion while in premix operation. For the case illustrated, not all pilot-gas tubes were in evidence (D), some having fractured (E) just above the hole through the swirler casting (F).

Metallurgists, including Curtis, suspected stress corrosion cracking of the 300-series stainless steel tubes was the underlying cause of the pilot-tube failures and selected Inconel-600 as the replacement material (G).

The burners at this plant exhibited other damage as well—such as severe oxidation of carbon-steel oil-burner flanges, which were weld-repaired and finish-machined as part of the

Compressor diaphragms



Fuel-oil burners

project. Also of note, the thermocouples provided by the OEM were not replaceable without disassembly. Eta Tech developed a replaceable T/C mod, now included among APG's solutions.

Perhaps the biggest challenge on this project, Curtis said, was completing the repairs, installation, and final inspection within a 12-day window to avoid an outage extension. The plant had no spare burners so replacement of the pilot-tubes was the only viable option.

At other plants, swirler casting defects—including cracks and porosity (H and I)—have been found. No problem, generally speaking, according to Curtis, APG can now manufacture new and replace swirlers, as well as diffusion-burner assemblies (J and K).

2. Pre-mix gas distributors

Curtis next discussed repairs to the legacy H-style gas distributor. He seemed particularly proud of the procedure Eta developed to replace corroded "S" bends (Fig A), originally fabricated from 16Mo carbon steel, with P11 material of increased wall thickness.

The company's fixture enables the making of precision repairs (B) as an alternative to purchasing a new distributor assembly from the OEM for significantly more money. A corrosion-resistant coating adds a measure of protection (C).

Note the notches in the six distributors to accommodate the igniter tube visible in Fig B in Section 1 on diffusion burners.

Curtis mentioned seeing "S" tubes lose up to 40% of their wall thickness, much like HRSG tubes subjected to FAC. The weld process used, he continued, has been qualified with sample cut-ups and hardness traverses as-welded and after stress relief. Welds made in refurbishing gas distributors are stress-relieved, x-rayed, and liquid-penetrant inspected.

Over the last several years, most V84.2 units in the US fleet have upgraded to the so-named HR3 style of distributor, where pre-mix gas is delivered to each of the six "heads," a/k/a diagonal swirlers. Fuel gas enters the air stream through holes in the airfoils in each head. Damage mechanisms associated with this design include fretting wear of the flange on each head (D) and corrosion of the airfoils (E).

Should airfoil corrosion or other damage get too severe for repair, APG offers a new HR3 (F).

Kearney, a former plant manager, interjected that an additional "hot button" on this component today is the cleaning of internal passages. He said

Combustor flame tubes

Exhaust diffuser cladding

the OEM brings an ultrasonic cleaning bath to the plant for this purpose, but users have told him this method is ineffective and expensive. Plus, disposal of spent cleaning solution can be problematic in some locations. APG offers an offsite thermal cleaning alternative (takes about a week from removal to reinstallation).

3. Compressor diaphragms

Kearney said many V84.2s he's familiar with have never had compressor diaphragms removed for inspection or repair. Simple erosion and corrosion over time is to be expected and not much of a concern beyond reducing compressor efficiency.

However, diaphragms are prone to developing airfoil cracks emanating from the inner tenon, where the vane attaches to the assembly's inner ring (Figs A and B). Curtis concurred with what he believes is a general feeling among users that the OEM has overly conservative repairability criteria on the number/sequence of cracked vanes that allow or disallow full diaphragm repair.

Eta Tech, and now APG, routinely extend these criteria if analysis confirms the decision.

In the event repairs are not practicable, APG has the engineering/manufacturing know-how to make all diaphragm stages (C). In fact, Curtis said, new coated diaphragms were delivered to customers last year.

4. Fuel-oil burners

According to Kearney, Siemens manufactures two different styles of fuel-oil burner lances: oil only and oil/water, the water circuit for NO_x abatement and/or power augmentation. The OEM design relies on shrink fits to separate and seal the water and oil flow channels, Curtis added, connections that can fail in service and cause coking (Fig A), bellows damage (B, oil/water design only), unusual spray patterns, and flame-tube damage.

Burners that are repairable are completely disassembled by APG, cleaned, parts replaced as necessary, reassembled, and flow-tested. When repairs are not cost-effective APG offers new. It manufactures both styles of burners (C and D). Excellent performance in service is claimed.

5. Combustor flame tubes

The OEM's design of combustor flame tubes has evolved over the years to address service-related material distress. The upper F-ring (Fig A) and the lower tile support ring (B) are made from carbon steel and are exposed to combustor temperature—thereby making them prone to severe oxidation damage.

Curtis recalled mechanical design changes made by the OEM to protect the F-ring—changes requiring the purchase of new-style combustor dome plates and relocation of combustor-brick "removable" rows. He said Eta Tech took a different approach: Make F-rings and tile support rings from an oxidation-resistant alloy that did not require flame-tube or dome-plate configuration changes, and add TBC to mounting hardware for combustor-brick "removable" rows. APG can supply all of the hardware used in the combustors, including the ceramic bricks.

Recently, APG has manufactured and delivered new flame tubes with rings of upgraded nickel-based alloy. Plus, it has repaired and upgraded used flame tubes with the upgraded rings (C).

6. Exhaust diffuser cladding

The exhaust diffuser, or frame, for the V84.2 has inner and outer cylindrical and conical sections and airfoil-shaped struts that support the turbine end-bearing compartment (Fig A). Replacement of the stainless-steel liner for the diffuser is necessary when embrittlement occurs and cracks occur, and poor weldability makes repair difficult. For users opting to replace damaged components, APG offers individual sections of cladding (B) or full-replacement cladding "kits."

7. Rotor disks

Looking ahead, Curtis said that as V84.2s approach 200,000 equivalent operating hours, compressor (photo) and turbine rotor discs, and hollow shafts, become candidates for retirement.

Anticipating coming demand, APG has completed all necessary engineering work and supplier qualification for the supply of new rotor components. The company is expecting orders for delivery in late 2020 and beyond.

Rotor discs

ARNOLD Group

A1. The first 3D single-layer insulation system was installed on a V engine in Germany by ARNOLD Group in 1996

ARNOLD Group is well known worldwide for its gas- and steam-turbine insulation solutions; in Europe and Asia also for its powerplant rotating-equipment and valve field-services capabilities (www.arnoldgroup.com). The company's history in gas-turbine insulation, the focus of this report, goes back nearly a quarter of a century to the installation of the first Arnold 3D single-layer system on a SGT-1000F (V64.3A) machine at EnBW Energie Baden-Wuerttemberg AG's 1200-MW Altbach/Deizisau combined heat and power plant (Fig A1).

Since then, more than 300 V-type engines—most V94/84.2s and .3As—in Europe, Asia, Africa, the Middle East, and the Americas have been insulated by Arnold. These units were manufactured by Siemens or its licensees—including Ansaldo Energia (Europe and Asia), Shanghai Turbine (China), and LMZ (Russia). Many other models of gas turbines also wear Arnold.

Revisiting Altbach, in more than two decades of service only 14 blankets have required replacement on that unit. Having an Arnold technical field advisor onsite during outages is said to have contributed significantly to this excellent service history: The TFAs made certain that the hundreds of *numbered* insulation blankets required for a typical E- or F-class gas turbine to assure easy access to critical instrumentation, borescope holes, etc, were removed, handled, stored (temporarily), and replaced correctly.

To date, Arnold has replaced the insulation on seven SGT6-2000E gas turbines in the US (Fig A2), with a few more projects in the pipeline for 2021. No SGT6-4000F machines have been refurbished in North America yet, but several SGT5/6-4000Fs in South America have been.

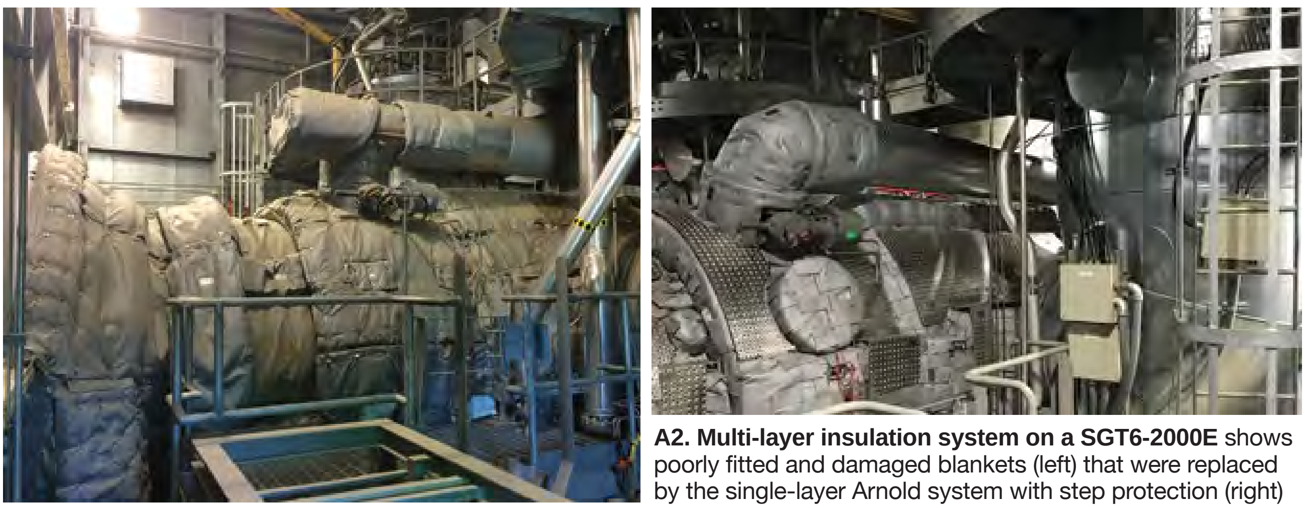
Why replace insulation. Pierre Ansmann, global head of marketing for ARNOLD, says it's only a matter of time before the economics of electric power generation suggests US owner/operators consider seriously replacement of the original insulation on their SGT6-4000Fs and other SGT6-2000Es.

Loss of earnings results from poor design/installation of turbine insulation and/or premature wear and tear of blankets. A plant's balance sheet can be impacted negatively by reduced power production, contractual penalties, damage to mechanical and electrical equipment and instrumentation, and shorter outage intervals.

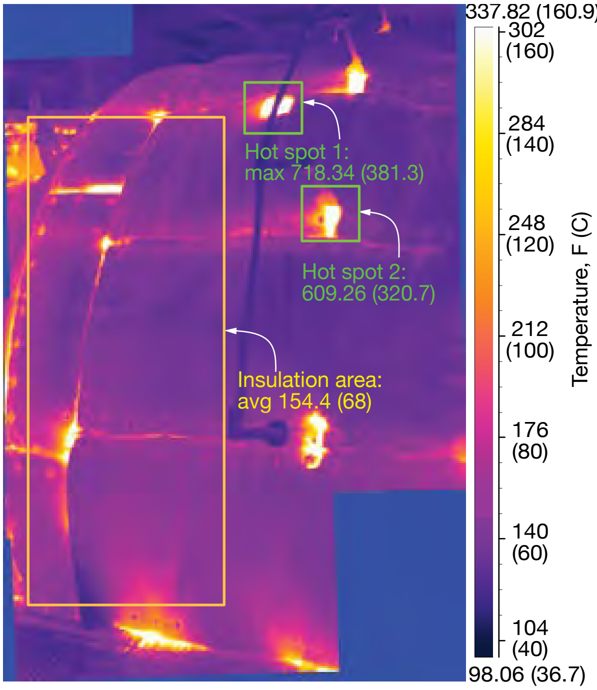
Insulation can wear out faster than you think, he says, particularly that installed on gas turbines with issues dictating frequent removal of their upper casings. If your unit was purchased during the "bubble" of 1999 to 2004 and still has its original insulation, Ansmann recommends conducting a thermal survey (Fig A3) to evaluate its effectiveness, keeping personnel safety in mind.

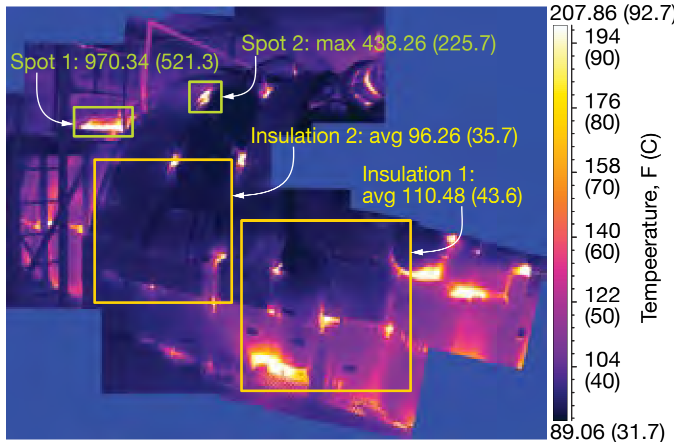
Benefits of replacement typically include less heat loss, less noise in the enclosure, a reduction in insulation removal/replacement time during outages, greater flexibility in maintenance scheduling, and longer lifetimes for in-package equipment—especially heat-sensitive motors, wiring, and instrumentation sometimes associated with unit trips.

Note that all the V engines in the US that have upgraded their machines with Arnold insulation began commercial operation during the bubble. They reported having done extensive repairs to the original blankets, or replacing them, during every outage. As-built performance remained elusive, however. In these cases, marginal materials of construction, and the use of blankets



A2. Multi-layer insulation system on a SGT6-2000E shows poorly fitted and damaged blankets (left) that were replaced by the single-layer Arnold system with step protection (right)





A3. Thermal scan of gas turbine with the original insulation shows an average temperature between about 153F and 189F at full load (left) while a sister unit with new Arnold insulation averaged between about 95F and 110F (right). The thermal scans were "stitched together" because of camera-lens constraints. While the emissivity of the diamond plating over the new insulation and the angle of the pictures for both units impacted accuracy of the temperature measurements, the surface of the reinsulated machine clearly is much cooler than that of its sister

well beyond their design durability limits, made the decision to replace a relatively easy one.

As a rule of thumb, Ansmann figures standard insulation systems typically perform as-designed for three to five off/on cycles, not close to Arnold's guarantee of 15 cycles when removal and reinstallation are done correctly. After about five outages, he says, users with insulation made by others often find blankets difficult to reinstall properly—especially where they overlap.

This is particularly true when

Key steps in insulation replacement

The success of any engineering project depends on rigorous planning. Pierre Annsman, a member of ARNOLD Group's management team, told the editors at a recent user conference that a good first step in an insulation replacement project is a photo session with the candidate turbine.

A laser scan allows the company's design and manufacturing personnel to adjust existing shop patterns for a particular engine model to the unit being reinsulated. Bear in mind that in-package piping and equipment arrangements vary.

Adjustments to the manufactured blankets may be required in the field to accommodate such things as flange positions, thermocouples, borescope inspection ports, etc. This work is done by experienced technicians—think of them as tailors—equipped with the proper sewing hardware.

The most economic scheduling for insulation replacement is about 20 single-shift weekdays with two TFAs and six local insulators. Calendar time can be reduced, of course, by working weekends, increasing the number of TFAs, and running double shifts. Turbines typically are reinsulated during major or hot-gas-path inspections in parallel with mechanical work. Insulation is not on the outage critical path.

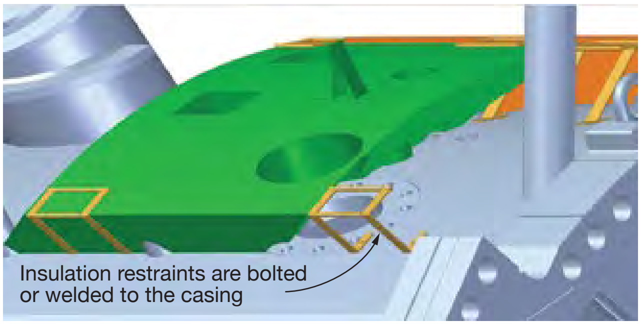
Work begins when the turbine is cold and proper scaffolding is installed, if necessary. Insulation is removed by a local contractor, typically in a day and a half, and plant I&E technicians remove all instrumentation. About another two days is required to cut off all pins installed to accommodate the original insulation system, grind the pin stubs smooth with the casing, and brush/vacuum the unit and package clean.

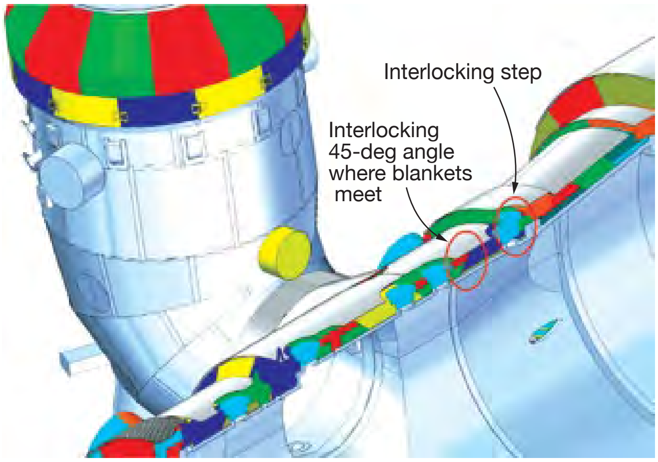
Respiratory protection is highly recommended during this work. It's also a good idea to have a health and safety engineer to measure the concentration of dust in the package to assure safe working conditions.

Installing the retention brackets and studs (photo) required to position and attach the new insulation is the next step. If the casing is forged steel, these components can be welded to the casing; if cast, drilling and tapping are required. Both procedures are done in accordance with the OEM's recommendations. At this point, may be a good idea to laser scan the unit again to pin-point the location of all attachments, just in case.

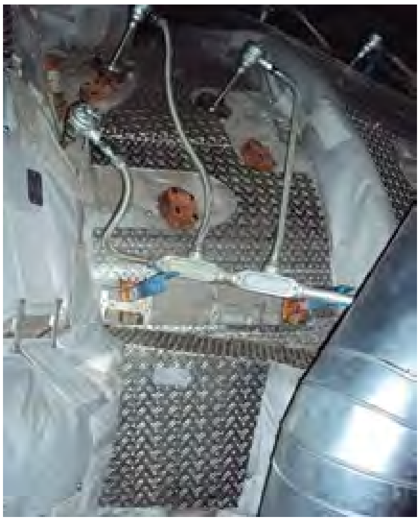
Final steps: Install the new insulation system, have I&E techs replace the instrumentation removed previously, and dismantle temporary scaffolding.

Insulation support studs are either drilled/tapped, or welded, to the gas-turbine casing. Supports are fixed with nuts to the studs





A4. 3D shaped blankets that characterize the Arnold insulation system offer a snug fit with the gas-turbine casing (left). They are designed with interlocking 45-deg angles and steps where the blankets meet to prevent gaps caused by thermal expansion of the casing. Note that insulation thickness varies along the shaft line to maintain approximately the same surface temperature (maximum of about 113F) whether you are standing on the compressor section or exhaust diffuser



A5. Arnold insulation is instrumentation friendly. Access by IE&C techs is relatively easy

A6. Step protection allows longer life for insulation

blankets must be held in place by pins welded to the casing. Pins are not used in the Arnold insulation system: Rather, interlocking high-temperature-resistant blankets, cut to conform to the turbine surface (Fig A4), are held in place by industrial Velcro® and a unique support system that is secured by studs welded to the casing. You may recall that pins sometimes are removed during maintenance for safety concerns, or otherwise; if not replaced, there's little chance of getting blankets tight.

Other concerns of plant personnel regarding marginally designed and ageing insulation systems, in Ansmann's experience, include these:

- Insufficient protection for thermocouples, borescope inspection ports, and instrumentation (Fig A5).
- Activities that require walking on insulation can move blankets out of position and/or release fibers—a possible health threat. Arnold's aluminum deck-plates-style step protection system reduces the possibility of insulation damage during maintenance (Fig A6).
- Sagging of insulation can cause uneven thermal expansion of the casing.

Sulzer

Sulzer's Rotating Equipment Services unit—formerly Sulzer Turbo Services—offers a wide range of inspection, shop, repair, and manufacturing services for gas and steam turbines, generators, pumps, compressors, and other power and process equipment. The company actively supports the V94/84.2 and V94/84.3A fleets through its participation in user meetings here and internationally. It has major shop facilities worldwide to serve powerplant owner/operators.

Not familiar with Sulzer? Tour the company's website at www.sulzer.com for an overview of shop capabilities pertinent to your equipment—including physical and metallurgical inspections, welding, heat treatment, machining, turbine and compressor coatings, rotor disassembly/reassembly, etc. Sulzer offers field-service (Fig S1) and new-parts manufacturing to complement its repair offerings.

Most of Sulzer's efforts with regard to V engines focus on the Siemens SGT5/6-2000E and Ansaldo AE94.2 machines. Aftermarket services for about two-thirds of this market segment are "competitive"—that is, not influenced by an OEM's long-term services agreement. By contrast, Siemens says 80% of the SGT5/6-4000F engines it has supplied are governed by an LTSA.

While Sulzer, like ARNOLD Group and APG, does perform repairs and field services for some 94/84.3A owner/operators, the manufacture of *major* new parts is not included among its current offerings.

New parts. The company makes the following parts for *legacy* 94/84.2 engines: compressors; inner casings, mixing chambers, and flame tubes for the combustion section (Fig S2); and Row 3 turbine blades. Plus, for the 94.2 only: combustion-section heat shields and fuel nozzles, as well as turbine blades for Rows 1 and 2 and vanes for Rows 1, 2, and 3.

For 94/84.2 models through Version 7: Combustion-section inner casings, mixing chambers, and flame tubes; turbine vanes for Rows 1 and 2. Additionally, new fuel nozzles are available for 94.2 models through Version 7.

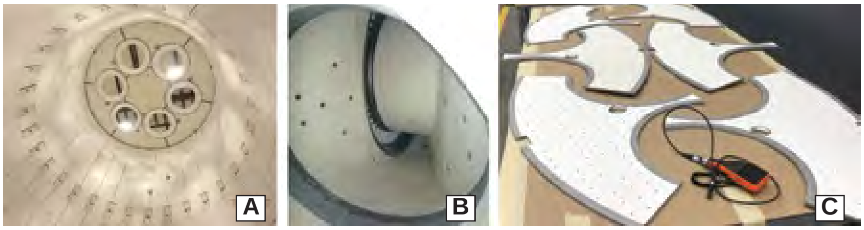
New parts are said to be "ready to drop in," having the same form, fit, and function as those supplied by the OEMs.

Mods and upgrades for critical 94/84.2 parts are a significant part of Sulzer's value-add offerings. Some examples follow:

- Relocation of the F-ring to mitigate burnout of tile clips by moving the

S1. Sulzer operates worldwide with extensive field-services capabilities complementing its new-parts manufacturing and repair offerings

S2. New-parts manufacturing offerings include a fully assembled inner case, drop-in ready (left), and mixing chamber (right)



S3. Coating upgrades are included among Sulzer's many aftermarket solutions for the V94/84.2 fleet. Components typically coated with TBC include flame tube (A), inner case (B), and burner plates (C)

holders to a region of lower temperature, in addition providing easier access to tiles for replacement.

- Coating upgrades for flame tubes (Fig S3). This includes adding thermal barrier coating (TBC) to burner plates, bezel rings, and F-row tile clips; plus, depositing chrome carbide (CrC) on bezel rings and burner plates.
- Flame-tube upgrades include an Inconel overlay for F-rings and Hastelloy-X tile support rings.
- Improved cooling-hole pattern for flame-tube burner plates. Also available are larger plates and a material upgrade to Haynes 230.
- Inner-case upgrades include TBC coating of the hot-gas-path surface and CrC coating of inlet collars.

Burners, etc. Sulzer recommends swapping out legacy H burners with the HR3 low-emission design (Fig S4), which is said to offer the following benefits:

- More stable combustion, primarily because of better mixing of the fuel gas with combustion air.
- Increased resistance to flame flashback. One reason: The higher velocity of the fuel/air mixture through the HR3's optimized flow channel reduces the probability of the flame traveling upstream.
- Corrosion-resistant gas supply piping minimizes leakage risk and reduces maintenance.
- Reduced NO_x emissions. The better mixing of fuel and air inherent in the HR3 design eliminates flame hot spots (emissions spikes) associated with the H burner.

Sulzer also actively promotes its E-UP program for the 94/84.2 fleet, which promises users a 5-MW increase in power output and a 0.8% efficiency improvement for retrofitting turbine Rows 1 and 2 blades and vanes with airfoils of its design.

S4. Sulzer recommends swapping out legacy H burners installed on early V94/84.2 engines with the HR3 low-emission upgrade

All incorporate what the company believes is an improved nickel-base superalloy (Rene 80), TBC coating system, and more efficient airfoil design.

The specific coating system selected depends on an engine's operating conditions. Generally speaking, MCrAlY is used on the external surfaces of Row 1 and 2 airfoils because of its superior oxidation and corrosion resistance in both base- and peak-load applications. Use of TBC is optional where necessary to reduce metal temperatures and thermal gradients for improved protection against creep and fatigue. Internal surfaces have an aluminum diffusion coating to help prevent intergranular attack.

In addition, R1 vanes feature internal impingement cooling, re-staggered and optimized airfoil design, integrated cover plate with impingement cooling, and cut-back trailing edge. Highlights of the R2 vane design include tilted and optimized airfoil design, serpentine internal cooling geometry, and throttle sleeve to control the mass flow of cooling air.

For R1 turbine blades, enhancements include: cut-back trailing-edge design adopted from the 94/84.3A blade, serpentine internal cooling geometry, and squeeler tip.

The enhancements cited above are said to allow Sulzer's Row 1 and 2 turbine blades and vanes to operate reliably in engines with turbine inlet temperatures of up to 1080C (1976F).

Riverton

Comprehensive training transforms coal-plant personnel into multi-skilled CCGT operators

Challenge. Powerplant technical training has evolved from learning on the job to VHS tapes to DVDs to eLearning with hands-on laboratory modules. As the power-generation business strategy changed to include the Riverton Power Station's conversion from coal to combined cycle, steps were put in place to re-tool operations personnel. Led by Plant Manager Ed Easson, efforts to research and establish an operator training process got underway. Initially, what was to be an application for one plant site was expanded to include additional sites.

Plant management looked for resources that would take operations training to a new level and provide a more systematic, comprehensive approach to building a multi-skilled workforce. But, what do you do when you don't find what you're looking for? You build your own. That's exactly what Liberty Utilities' plant managers did.

Solution. In 2016, the Energy Supply Operator Training System was launched. Comprised of three key learning and development strategies, the system reflects a focus on plant performance indicators, operator competencies, and continuous improvement.

The learning and development strategies are the following:

- eLearning courses including electrical, mechanical, I&C, power generation, industrial math, leadership, and communications. The 24/7 access provides plant operators the flexibility needed to complete courses in shift-work environments. The curriculum currently includes 126 courses over multiple development levels with annual reviews and enhancements.
- Performance laboratories that build on the associated eLearning courses are designed and delivered by in-house subject matter experts. Labs for each development level provide hands-on, experiential learning. Currently, there are 21 labs in the training system with annual reviews and enhancements.
- On-the-job training (OJT) always has been a mainstay of learning and typically very informal. The training system recognizes OJT as a critical component deserving of acknowledgement and documentation of operators' progress. A more formal process that defines the scope of OJT is in practice with refinements in development.

The company's Learning Management System provides eLearning course access, and training system records tracking and reporting.

Riverton Power Station

Liberty Utilities

285-MW, gas-fired, 1 × 1 combined cycle powered by a V84.3A(2) gas turbine, located in Riverton, Kan

Plant manager: Ed Easson

Results. 2019 marked the fourth year of implementation. Four operators had completed training system requirements with six more working through their programs. Operators continue to expand knowledge and skills to build on their multi-skill capabilities.

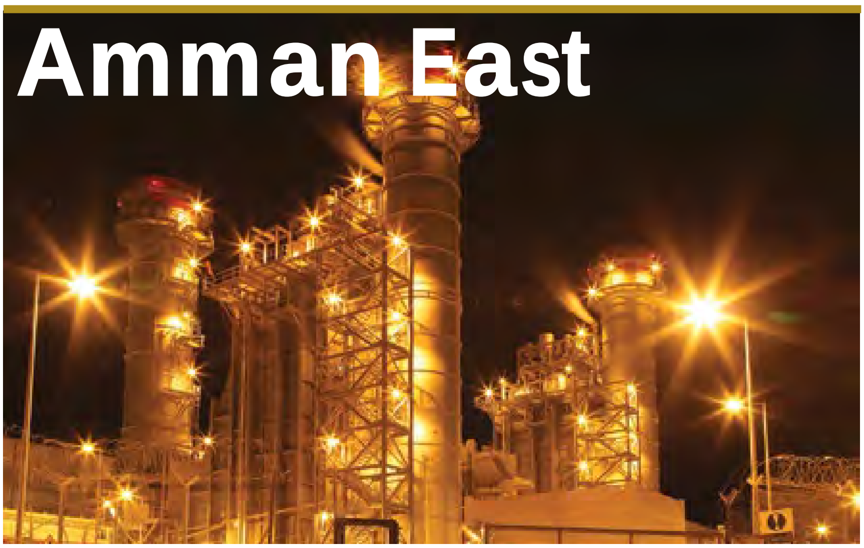
As with any new process, training or otherwise, experiences along the way point to new possibilities for continuous improvement of the system. Content and process reviews/updates are natural steps within the training system and continued visionary leadership will ensure an effective and successful operator training system for years to come.

Project participants: In addition to the following management and super-

visory personnel who designed and expanded the training system, and in-house subject matter experts (SMEs) who provide laboratory instruction, several operators have assisted in building props and training skids for the labs.

Plant managers: Ed Easson (Riverton), Brian Berkstresser (State Line), Randy Richardson (Energy Center), Fred Prutch (Asbury)
Local projects managers: Cody Dennis, Garth Ince, Blair Johnson, Michele Jordan,
Maintenance managers: David Eaton, Curt Kennedy, Justin Moll
Operations managers: Cory Larson, Bryce Robertson, Kenny Stratton
Generation operations, director, central region: John Woods
Generation operations, project managers: Jason Osiek, Shaen Rooney
Results managers: Robert Morris, John Shipley
Energy supply training manager: Heidi Nonnenmacher
Foremen: Andy Massey (maintenance), Paul Tuter (electrical)
Senior operator/technician: Alvin Mitchell

Amman East



Amman East Power Plant

AES Jordan PSC

420-MW, dual-fuel, 2 × 1 combined cycle powered by V94.2 gas turbines, located in Al Manakher, Jordan

Plant manager: Peter Kuijs

Customized ear plugs protect hearing

Challenge. Hearing protection is one of the main health challenges at the AES Jordan site. Personnel (especially O&M teams) are exposed to high noise areas daily. The hearing protection devices used were disposable ear plugs or ear muffs. Their main deficiencies: Discomfort, incorrect use, infection, and lifecycle cost. The main objective of the project was to provide more effective noise protection with a device suitable for use by all AES Jordan employees.

Solution. Meet with a qualified vendor to explain plant requirements and to take noise measurements in high noise areas at the site. Based on that information, one custom set of ear plugs was fabricated for an experienced craft person and performance tests were conducted in the vendor's lab and onsite to assure satisfaction. Next steps: Ear profile measurements, training, and supply of the approved product to staff.

Results:
- Reduces exposed noise level by 5 to 7 dB below that possible with normal hearing protection.
- Perfect fit for maximum comfort to avoid misuse.
- Protection against ear infection. Special material used in manufacture is washable and helps prevent bacteria from forming.
- Affordable; payback within a year. Durable product has an average life span of four years.
- Replicable for all AES businesses.

Project participants:
Anas Diab and Laith Jaraabeh

AES Levant

Editor's note: AES Levant's 16 tri-fuel (gas and light and heavy oils) engines are located in close proximity to AES's Amman East combined cycle (above). Both plants, managed by Peter Kuijs, share best practices.

AES Levant Power Plant

AES Levant Holdings BV Jordan

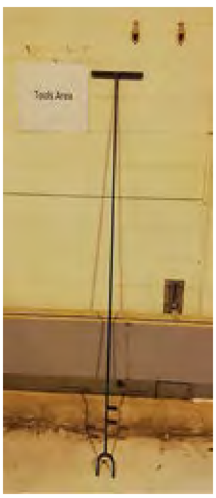
250-MW, tri-fuel (gas and light and heavy oils) peaking facility consisting of 16 diesel engines located in Al Manakher, Jordan

Plant manager: Peter Kuijs

Custom valve tool facilitates fuel transfers

Challenge. During a fuel changeover, the position of the light-fuel-oil (LFO) cooler bypass valve must be changed. It is located in a very congested area and difficult to reach. Plant staff looked for ways to increase availability, reduce LFO consumption, and create a safer work environment. Plant staff evaluated three possible solutions: valve relocation, valve automation, and developing a special tool.

Solution. Personnel evaluated the three options and decided on developing a custom tool. Relocation and automation had much higher costs and required greater effort to implement while achieving a similar goal. The special tool (photo) was designed by plant personnel and made to operate the valve safety.



Results. A fuel changeover before tool development took two hours, now it takes only 20 minutes. This reduction in time amounts to over $25,000 in fuel savings annually; the project paid for itself in a month.

Project participants: Anas Diab, Laith Jaraabeh, Abdelsalam Rashed, Mohammad Awni, Yousef Hassan, Yousef Khammash, Shaker Bala'awi

Custom oil-mist separator tool eliminates issues

Challenge. Plant was plagued by difficulties associated with its oil-mist-separator repair kit. Staff brainstormed ideas for improvements to reduce maintenance cost, minimize staff effort, and improve plant availability.

Solution. Weighing options between a complete changeout of the kit and design of a tool to more easily disassemble and reassemble the kit, plant staff decided on the latter.

Results. Design, manufacture, and implementation of the customized tool has reduced operator efforts, improved oil-mist-separator reliability, and reduced maintenance cost. This saves over $63,000 annually; the project paid for itself in less than one month.

Project participants: Anas Diab, Laith Jaraabeh, Ashraf Qasim,

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Tues, June 16. 1:00, Welcome; 1:15, Safety session; 2:30, Combustion session; 3:00, Vendor fair. *Note: All times US eastern daylight saving (UTC/GMT -4 hours)*

Wed, June 17. 1:00, Combustion continued; 2:00, Compressor session; 3:00, Vendor fair.

Thurs, June 18. 1:00, GE technical sessions; 3:15, GE virtual rooms.

Tues, June 23. 1:00, Auxiliaries session; 1:30, How generator minors turn into majors, AGT Services; 2:30, Generator rotor removal/installation systems, Enerpac; 3:30, Vendor fair.

Wed, June 24. 1:00, Auxiliaries continued; 1:45, MD&A technical sessions; 3:30, MD&A vendor fair.

Tues, June 30. 1:00, Auxiliaries continued; 1:30, PSM technical session; 2:30, American Chemical Technologies/Shell Lubricants technical session; 3:30, PSM and ACT/Shell vendor fair.

Wed, July 1. 1:00, Rotor session; 1:45, Doosan Turbomachinery Services technical session; 3:30, Doosan vendor fair.

Thurs, July 2. 1:00, FieldCore technical session; 3:15, GE virtual rooms.

Tues, July 7. 1:00, Exhaust session; 1:30, APG technical session; 2:30, Hytorc technical session; 3:30, APG and Hytorc vendor fair.

Wed, July 8. 1:00, Top Ten 7F topics; 1:15, EPT Clean Oil technical session; 2:15, TC&E technical session; 3:30, EPT and TC&E vendor fair.

Tues, July 14. 1:00, GE University I: Compressor, turbine, rotor, and combustion; 3:15, GE virtual rooms.

Wed, July 15. 1:00, GE University II: Controls, accessories, and operability: 3:15, GE virtual rooms.

Thurs, July 16. 1:00, GE University III: Flexibility and asset management; 2:30, Repairs; 3:15, GE virtual rooms.

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Unconventional stator design, construction complicate rewinds

By Jamie Clark, AGT Services Inc

1. First step in rewinding a stator is to remove the end arms of the bars

A relatively common major repair encountered by generator owner/operators is replacement of the stator winding. There are two general methods for designing/constructing stator windings. They are:

- Conventional: It uses stator bars that are fully impregnated with resin and the resin is fully cured. The assembly materials—for example, fillers and wedges—are dry, thus there is no bonding between the slot contents and the stator iron.
- GVPI (global vacuum pressure impregnation): It uses stator bars on which the groundwall is "dry"—that is, essentially mica tape with no resin material applied. The wound stator is then placed in a large tank where a vacuum is applied to remove all moisture and air from the groundwall. Next, the tank is filled with resin and pressurized to force saturation of the groundwall with resin. Finally, the stator is removed from the tank and placed in an oven to cure the resin. With this system there is strong bond between the slot contents and the core iron.

There is a third type of winding sometimes used that is "almost" conventional versus GVPI. It is intended to reduce material and labor costs in the factory, but it does not consider repair complexity in the powerplant. In this system, the bars are installed fully cured, but there is a saturated "wet" filler in the bottom of the slot and between the bottom and top bars.

Additionally, during the stator wedging process, another layer of saturated felt is installed under the wedges. After baking, the excess resin in the wet fillers fully bonds the slot content to the core iron and the winding behaves as if it were GVPI'd. Adding wet filler beneath the stator wedges makes routine stator rewedging more complex and actually increases the risk of top-bar insulation damage. But that's a topic for another time.

The replacement procedures for a conventional winding are well understood and straight forward—and stator rewinds have been routine for about a hundred years. GVPI windings became common on large generators recently, and because removal of a bonded winding tends to be very difficult, standard

2. In a conventional winding bars are lifted by a sling

3. High-pressure water jet safely removes insulation on the top and sides of the bar removal procedures have not yet been developed.

However, AGT has successfully rewound several stators with GVPI windings, and described its procedure for winding removal at the 501F Users Group's 2020 Conference and Vendor Fair, last February, at the Hilton in West Palm Beach, Fla. A summary of that presentation follows:

The first step is removal of the end arms of the bars (Fig 1). In a conventional winding, bars are lifted by a sling (Fig 2). But with a GVPI winding this succeeds simply in kinking the bar near the core end. However, it has been found that the insulation on the top and side of the bar can be safely removed using a high-pressure water jet (Fig 3).

Alternatively, but a bit more time consuming, the bar's top layer of insulation can be destructively removed and the stator-winding strands can be "peeled out," either in groups or one-by-one. Certain bar configurations may have single, wide strands simply layered on top of each other, much like a generator field winding. But generators with high ratings may have configurations of multiple-strands wide by many strands high—for example, six strands wide × 20 strands tall. Peeling is relatively easy in the first case, the second not so much.

4. Stator-bar removal from a GVPI winding can be difficult (left). Procedure for removing bottom bars is illustrated at the right

5. Slot cleaning of a GVPI winding often is done using dry ice

It may be questioned that the core lamination insulation will be damaged by the high-pressure water jet, and it is certain that the insulation on the edges of the laminations will be impacted. However, the voltage is very low and industry experience with multiple methods of stator-core slot cleaning and repairs, followed by "suitability for service" testing to industry-acceptance criteria for core iron/insulation, confirms that interlaminar insulation remains unaffected.

The water jetting process is restricted to the slot sides and bottom, and both the water jet tip and pressures are specifically chosen to effect only removal of the epoxy. Since some slots are very narrow, this can complicate removal methods and, in some instances, use of a precisely selected rotating tool (specific wheel material, size, depth control, etc) may be required.

As with all stator rewinds, conventional or GVPI, once the process is completed, the entire stator undergoes standard acceptability testing—including high-flux and EL CID testing.

With the bar insulation removed, the bars can be extracted with some difficulty using procedures similar to those used on a conventional winding (Fig 4). Once the bars are out, the core can be cleaned with dry ice, vacuum, and/or brushing (Fig 5). Dry out will be needed and full flux core test advisable (Fig 6).

After the core is clean and dry, and has satisfactory flux test results, winding installation can proceed as with a normal winding. CCJ

Acknowledgement: Clyde V Maughan contributed to this article.

6. Important to dry the stator after cleaning (left) and advisable to conduct a full-flux core test (right)

Advanced CDM detects impending combustor failure, prevents forced outage

By **Benjamin Emerson, Jared Kee,** and **Tim Lieuwen,** Turbine Logic;
Bobby Noble and **Leonard Angello,** Electric Power Research Institute;
Dallas West, ENMAX Energy

Editor's note: *This article introduces a novel combustion-dynamics monitoring (CDM) algorithm and a case study to demonstrate its successful detection of a gas-turbine combustor fault which otherwise might have done extensive damage to both the combustor and hot-section components. Failures of this type often develop from small, insipient faults which produce subtle signatures in the dynamics data.*

Fault signatures can be detected by advanced monitoring algorithms to identify them before parts fail and force the unit out of service. The CDM algorithm described here blends data analytics and combustion domain expertise with existing combustion monitoring data. It currently is fielded on a fleet of frame units and has successfully caught several faults at sufficiently early stages to plan repairs without a forced outage.

Some of the most-costly forced outages are those that stem from failures in the gas-turbine hot section. These failures are particularly catastrophic when they compromise the turbomachinery. While the power turbine is subject to its own failure mechanisms, it is also vulnerable to debris from combustion-system failures.

Typical lean premixed frame-engine combustion systems have several parts that tend to degrade and fail—including the transition piece, combustor liner, TBC coatings, cross-fire/cross-flame tubes, and fuel injection/premix hardware. The last includes dual-fuel nozzles, center bodies, swirlers, and numerous other components depending on the engine make and model. All of these parts have limited lifetimes because of the harsh operating environment, and unwanted phenomena such as flashback, autoignition, and combustion dynamics.

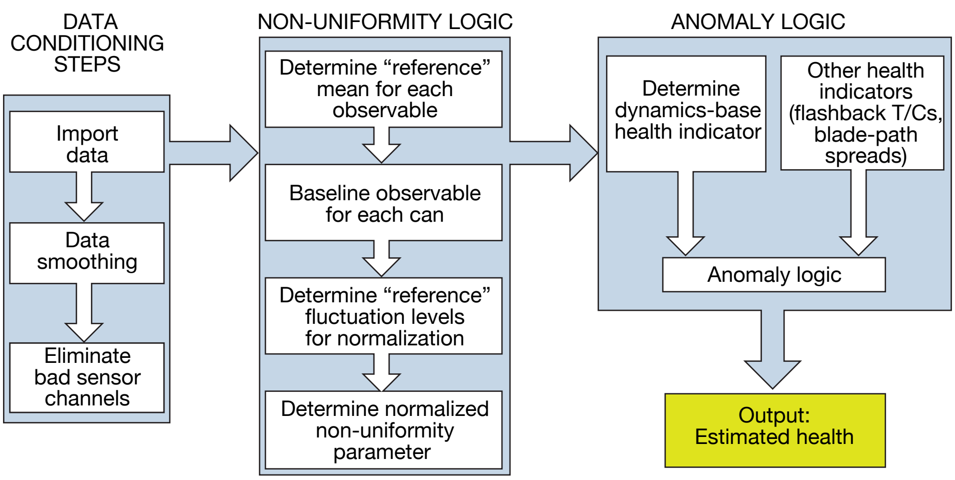
Failures produce fault symptoms—such as issues with operability and emissions, tuning challenges, elevated temperature spreads, and "drifting" combustion dynamics in one or more combustors. When these symptoms are not recognized, the part eventually fails catastrophically and the unit trips because of the loss of one or more combustors, or of the power turbine. Combustion dynamics often provide the earliest symptoms of such issues.

Permanent CDM systems on can-annular frame engines typically include a sensor for every combustor can to measure acoustic pressure. The OEM or third-party monitoring software reads the time-dependent pressure signals and periodically implements a fast Fourier transform (FFT) to convert them into frequency-dependent spectra. These spectra are partitioned into several bands, or bins, within which the software monitors for the peak pressure amplitude and its corresponding frequency. The "bin data" are stored in the historian.

Combustion-dynamics bin data are used for tuning by both manual tuners and automated tuning systems. In addition, the data provide these two opportunities:

- Detect and prevent dynamics levels that would threaten the hardware—that is, the dynamics are monitored to ensure they don't become too loud and cause damage.
- Monitor dynamics data for symptoms of existing faults.

Combustion dynamics are very sensitive to faults such as (1) cracks that change flow paths, and (2) premixer damage that affects flame shape. Thus, CD can be monitored for small changes (amplitude increases or decreases) or frequency drifts that might indicate the early stages of a component failure. Some operators use trending or advanced pattern recognition software to monitor for these symptoms.



1. Output of the algorithm illustrated is an estimated health indicator

2. Crack developed and grew, eventually causing the transition piece to fail

The EPRI and Turbine Logic team has developed and patented a CDM algorithm that detects these symptoms and runs continuously and autonomously without any model-building or retraining: The algorithm continuously trains and retrains itself. In addition, the algorithm can distinguish among instrumentation faults, hardware faults, and tuning issues.

Health-algorithm basics

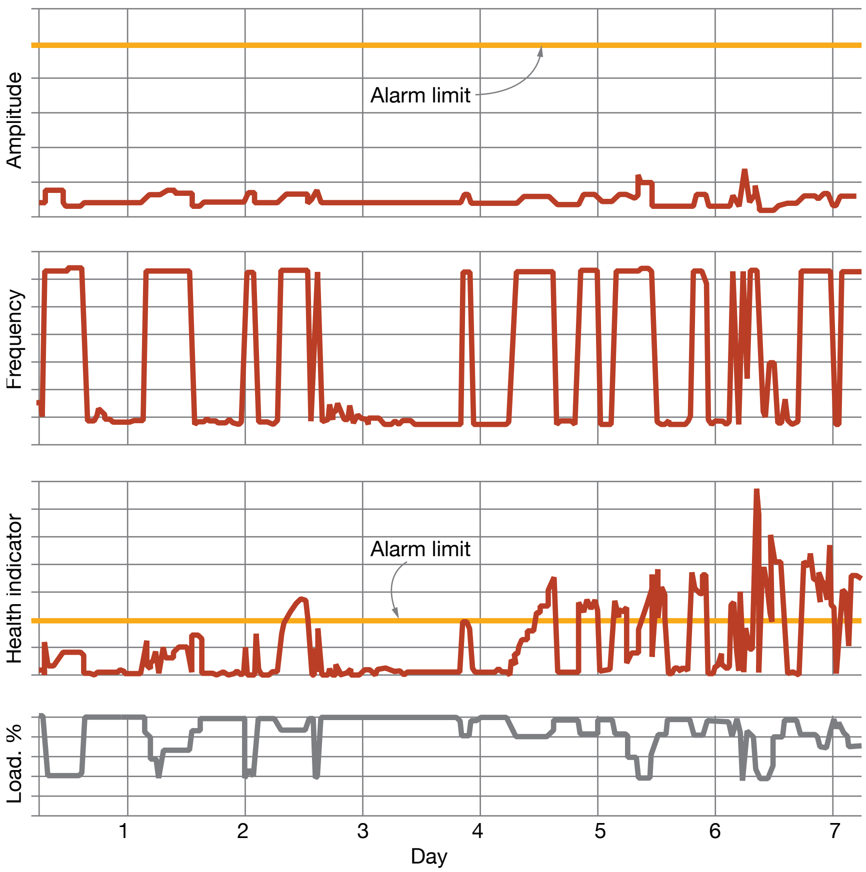
The health algorithm consists of a data conditioning step, a non-uniformity check, and an anomaly check (Fig 1). The first identifies and handles instrumentation faults and other issues with the data stream. The non-uniformity step finds the combustion-dynamics signature of the unit during recent times that matched the current operating conditions. Finally, the anomaly logic analyzes the past and present CD signatures of each combustor to identify anomalous behaviors.

Dynamics signatures come from the bin data (peak amplitudes and their frequencies). Anomalous behaviors are defined as a deviation of one combustor's dynamics signatures compared to its peers and its past. The peers are the other combustors on the engine. An anomalous behavior may include situations where a combustor becomes louder, becomes quieter, or exhibits a frequency drift compared to the other combustors and compared to its past behavior. Note that a quieter combustor does not necessarily indicate a healthier system!

The output of the algorithm is an estimated health indicator, which is a statistical representation of the severity of the outlier. When a combustor has outlier dynamics behaviors relative to its past and its peers, this can be explained by either an instrumentation fault or a hardware fault. The former may include condensation in standoff tubes, cable connector wear, or probe failure.

Hardware faults include any alteration to the combustor hardware—including cracks, leaks, and melting. For a given unit, dynamics signatures often can be paired with a particular probable hardware fault based on experience collected across the fleet. This experience is collected into a fault matrix, which is currently available for 7FA and 501F units.

The net result of this algorithm is an indication that a combustor is "changing," which can be indicative of an instrumentation fault or an early symptom of a hardware fault. Instrumentation faults can be distinguished from hardware faults, and the hardware fault can often be pinpointed using a fault matrix.



3. Screenshot of the combustion-dynamics algorithm at work shows data for No. 14 combustor captured during crack propagation in the transition piece. Top row presents raw amplitudes at levels well below the OEM alarm limit. Second row shows frequency data, indicating a 1660-Hz tone. Third row presents health indicators generated by the algorithm, with some values exceeding the alarm limit. Last row shows the load profile, indicating that the issue is apparent during turndown

Common catches

The monitoring algorithm described is designed for any can-annular gas turbine with a CDM system. However, the monitoring teams at EPRI and Turbine Logic historically have applied it most often to 501F and 7FA units and have gained experience with the combustion-system faults that the algorithm most commonly catches in these units.

Some of these catches have been predictive during live monitoring, while others have been "postdictive" catches in historical data to develop and demonstrate the algorithm, as well as to identify the time where the fault began to noticeably manifest itself. The most common catches for 501F units have been cracks in transition pieces and combustor liners; in 7FAs, fuel injection/premixing hardware damage.

Case study: ENMAX Energy

An ENMAX Energy plant had experienced a significant force outage attributed to a gas-turbine component fail-

4. Borescope inspection confirmed a cracked combustor resonator

ure. What happened was that a crack developed in a combustor transition piece that grew until the component failed completely. In 2017, EPRI began providing monitoring services to the plant in an attempt to prevent future combustion-dynamics-related gas-turbine failures.

During the first year of the program, the algorithm detected abnormalities in the combustion dynamics data from one of a 501F engine's combustors (Fig 3). The team reviewed the data in collaboration with the plant to rule out the possibility of an instrumentation fault, and subsequently concluded, with a high degree of certainty, that the combustion-system hardware had suffered damage.

Because the CDM algorithm is sensitive to hardware faults at very early failure stages, the plant had time to manage the issue. A borescope inspection during the next planned outage confirmed the suspected combustor damage, validating the algorithm (Fig 4).

Plant personnel approached the OEM with the borescope images and were assured that the machine could continue to operate until a scheduled outage. Rather than discover this issue in a forced outage from part failure, the monitoring algorithm enabled the plant to catch the issue early and operate the asset confidently without impacting the dispatch schedule.

Summing up, CDM offers more than just damage prevention by monitoring and limiting combustion-dynamics levels. It is a valuable health diagnostic tool. Combustion-system faults commonly manifest in the combustion-dynamics data, even at early stages of the fault. Advanced monitoring algorithms can detect these abnormalities, distinguish them from instrumentation faults or basic tuning issues, and alert the plant of an impending problem. Successful implementation of these algorithms prevents forced outages and buys time to plan and schedule inspection and repair. CCJ

Just released: TGDs on generator cooling-water chemistry, FFS, air in-leakage

The Power Cycle Chemistry (PCC) working group of the International Association for the Properties of Water and Steam participated in the 2019 IAPWS annual meeting in Banff, Alta, Canada, Sept 29 – Oct 4, where it announced the availability of several new Technical Guidance Documents (TGDs) and provided updates on the development of others.

The annual meeting of the IAPWS (pronounced eye-apps) Executive Committee and working groups attracted 92 scientists, engineers, and guests representing 16 countries. Purpose of the conference is to connect scientists with the engineers who use their information. Both groups of professionals benefit: The researchers/scientists learn about problems seeking resolution while the engineers gain access to the latest research results.

IAPWS Executive Secretary Dr R Barry Dooley of Structural Integrity Associates Inc, well known to the global power-generation community, said the meeting was extremely productive for the PPC working group. He reported that four new TGDs had been released in the last year, urging those responsible for maintaining top performance from their electric generating plants to download the documents at no cost from the organization's website at www.iapws.org and benefit from content compiled by the global thought leaders in powerplant chemistry.

The latest TGDs published by IAPWS are the following:

- "Application of film-forming substances in industrial steam generators" offers guidelines and processes for the proper use of FFS.
- "Chemistry management in generator cooling water during operation and shutdown" is of particular importance to combined-cycle owners.
- "Application of FFS in fossil, combined cycle, and biomass powerplants." This updated document provides guidelines and processes for the application of both FF amines and FF amine products.
- "Air in-leakage in steam/water cycles" addresses the detection and measurement of air in-leakage as it relates to optimum cycle chemistry and maximum thermal-cycle efficiency for a wide range of generating plants.

Eight additional TGDs, introduced between 2008 and 2016, also are available free-of-charge on the IAPWS website. They offer a wealth of practical information on topics such as steam purity for turbine operation, phosphate and sodium hydroxide treatments for steam/water circuits of drum-type boilers, instrumentation for monitoring cycle chemistry, how to measure carryover of boiler water into steam, etc.

Dooley said several whitepapers and new TGDs are in progress—including FFS for nuclear plants, corrosion-product monitoring for cycling plants, demineralizer-system integrity and reliability, geothermal steam chemistry, and flue-gas condensation. Plus, work has been started on a document targeting electric boilers.

He added that the number of TGDs continues to increase, providing robust, practical, and technically correct water and steam guidance to industry. Note that existing TGDs are reviewed and updated periodically to ensure they are maintained current and relevant.

A status report on the PCC-related International Collaboration (IC) between Canada and New Zealand on corrosion of boiler steels in the presence of mixed contaminants was included in the Banff PCC discussions. A new IC was approved related to corrosion product sampling analysis and assessment to provide more data for the ongoing PCC initiative in that area.

The next IAPWS meeting will be held in Turin, Italy, Sept 6 – 11, 2020.

Finally, users wanting to learn more about specific aspects of the TGDs, and the experience of the industry's owner/operators with them, can post questions to the HRSG discussion forum chaired by Bob Anderson on the Power Users website at www.powerusers.org. An alternative is to attend the annual meeting of the *HRSG Forum with Bob Anderson* where significant discussion time is allocated to these topics. CCJ

Tailoring global experience to meet the needs of local user communities

1. Combined Cycle Conference specific to the needs of Saudi Arabian users was hosted by the Ali A Tamimi Co and coordinated by Keck Group International LLC

Reliable electric supply in the Kingdom of Saudi Arabia depends to a large degree on the proper operation of gas turbines, which dominate the country's generation infrastructure. At the end of 2018, Saudi Electric Co (SEC), the leading producer of electricity with a nominal 70% market share, had 53,500 MW of capacity installed at its 40 powerplants. Simple-cycle gas turbines comprised about one-third of that total, combined cycles a quarter, and oil- and gas-fired steam turbines most of the remainder.

Worth noting is that Saudi Arabia is the world's largest producer of desalinated water, relying on 17 facilities to provide that product. Several desal facilities have been sited together with power stations.

Many types of gas turbines are installed in Saudi Arabia for electricity production and mechanical-drive applications. They include the GT11, 501D5, 501D5A, V84.2, M501F, Frame 5, and 6B; most are scattered among the various IPPs and industrial self-generators. By contrast, SEC relies heavily on GE Frame 7s and has more than 150 EAs and FAs in its fleet.

SEC plant personnel often participate in 7F Users Group (www.7Fusers.org) meetings in the US, but it's impractical financially for more than a few of the company's many engineers to attend. A solution was to hold a Combined Cycle Conference (Apr 3, 2019) and a Power Generation Technical Workshop (Dec 11, 2019) in Saudi Arabia.

The first meeting, sponsored by SEC, was hosted by the Ali A Tamimi Co and coordinated by Keck Group International LLC (Fig 1). Tamimi is a respected provider of engineering and onsite O&M services—including turnkey upgrade projects—to SEC and others in the power, petrochemical, and oil and gas industries. KGI, headed by two former GE executives—Richard Keck (richard.keck@keckgroupint.com) and Bob Johnston (bobjohnston99@comcast.net)—provides consulting services in support of combined-cycle operations and performance improvements.

The second conference was sponsored by Saudi Aramco, a/k/a Saudi Arabian Oil Co, at its facilities in Dhahran (Fig 2). Saudi Aramco, which owns 7% of SEC, is both the utility's main fuel supplier and an important customer.

Combined-cycle conference

Adel Al Shuraim, CEO, Tamimi Energy, opened the Combined Cycle Conference. His welcome was followed by that of Khalid Al Tuaimi, EVP, SEC Operations. The morning's technical presentations followed, beginning with recommendations for improving combined-cycle performance by CoreTech Industrial Corp's Joel Holt, engineering manager (jholt@cticus.com) and Bruce Martindale, consulting engineer (bruce.martindale@gmail.com).

Holt (Fig 3) and Martindale did double duty, following up their opening presentation with a primer on how to reduce plant startup time. Johnston was next with a review of uprates for non-capital parts—with no changes to existing gas-turbine capital parts.

HRSG improvements were addressed by CMI Energy's technical manager, Raphael Stevens (raphael.stevens@cmigroupe.com) and VP Habib Grini (habib.grini@cmigroupe.com).

Presentations on steam-turbine upgrades and training programs for gas-turbine, steam-turbine, and generators, were developed by MD&A's Eamonn Rogers (erogers@mdaturbines.com) and Dave Hagenbuch (dhagenbuch@mdaturbines.com).

Exhaust-system upgrades and repairs, by Innova Braden Europe's Ed Chan (ed.chan@innova-gl.com) and Moustafa Al-Shami (moustafa.al-shami@innova-gl.com), closed out the morning program.

The afternoon was reserved for Q&A and open discussion.

The presentations focused on specific issues that each vendor had addressed at combined-cycle plants and showed how that experience could benefit generating facilities in Saudi Arabia. The vendors participating in the conference had agreed to work collaboratively to provide owner/operators of the kingdom's 15 operating combined cycles complete solutions. Representa-

tives from all those powerplants were among the 100 or so attendees.

Saudi Arabia's combined-cycle infrastructure includes the following, based on CCJ's research:

- Ten 7EA-powered 4 × 1 plants designed for crude oil only. Gas turbines, rated 56 MW each, installed from 2010 to 2012; 130-MW GE steam turbine/generators added to each block between 2014 and 2016 along along with unfired NEM HRSGs.
- A 7001FA-powered 3 × 1 designed for gas only installed in 2012, equipped with Hyundai HRSGs and a GE D11 steamer.
- A 7000FA-powered 4 × 1 designed for gas only installed in 2013, equipped with Hyundai HRSGs and a GE D-11 steamer.
- Two 7F.05-powered 4 × 1 facilities designed for gas with oil backup. Gas turbines, rated 172 MW each, installed in 2014-2015; Alstom HRSGs and 341-MW steam turbine/generators added to each block in 2017.
- Four 7F.05-powered 3 × 1 facilities designed for gas only are scheduled for 2021 operation. Gas turbines, rated 215 MW each, will be integrated with Alstom HRSGs and 342-MW Alstom steam turbine/generators.

Holt and Martindale breezed through a review of the principal systems and components in a combined-cycle plant, explaining the functions of each in relatively few words. Then they summarized plant startup (hot, warm, cold) and shutdown procedures, identifying issues sometimes experienced with each step and how to avoid them.

Technical warmup complete, the speakers were ready to tackle one of the meeting's primary objectives: Encourage attendees to pursue procedural and equipment changes to enable faster starts of their combined cycles without compromising reliability and service life.

The significant penetration of renewables into the power generation market has caused many combined cycles to switch from baseload operation to cycling duty—including the ability to start quickly when non-fuel resources suddenly disappear.

The speakers noted that combined cycles installed in the last five years or so typically were designed and equipped for the new demanding service. But some older plants are not able to accomplish warm starts in less than four hours, which makes profitable dispatch difficult, if not impossible, in today's competitive power markets. However, new procedures, software, and some equipment upgrades, the group was told, could drive down plant warm restart times to 90 minutes with a generally acceptable investment.

Performance improvement was another topic of major interest given older combined cycles have suffered efficiency reductions over the years. To fully assess areas that should be addressed to improve thermal performance, the speakers recommended doing a current heat balance and comparing it to the original. The main areas requiring improvement will stand out, it was said.

Focused uprates within the capability of existing equipment are a proven path to performance improvement. Keep in mind that most older gas turbines receive upgraded parts when they purchase replacements or spares because OEMs are continually improving the capability of their offerings.

But manufacturers rarely assess the overall capability of the GT when only selling parts. Owner/operators, sometimes assisted by an independent consultant, frequently find a thorough review can guide the selection of parts capable of increasing GT output by as much as 3%, possibly more. This, plus the accompanying increase in exhaust energy boosts overall combined-cycle power and efficiency.

A comprehensive audit of the physical plant, and of the procedures that guide operations, often point to affordable improvements with big returns. The HRSG can be an efficiency hog when wear and tear allows flue-gas bypass of heat-transfer surfaces and catalyst by way of failed baffles and seals, and when gas- and/or water-side deposits retard heat transfer. Steam-turbine upgrades and repair/replacement of key exhaust-system components—ductwork, dampers, etc—can

2. Saudi Aramco sponsored a Power Generation Technology Workshop, developed by Keck Group International LLC, at its facilities in Dhahran. Hosts and presenters are in the photo

3. Joel Holt of CoreTech Industrial Corp, both a former user and engineering leader for an OEM, explains to users how to reduce plant startup time

provide significant benefits as well.

Bob Johnston's "Non-Capital Parts Uprate Program" was an ideal sequel to Holt and Martindale's presentations, which focused on equipment. Johnston's "program" focused on applying non-hardware related controls changes to match the capability of hot-gas-path (HGP) parts, thereby increasing gas-turbine output and efficiency. The speaker told the group that all the parts of his "program," which have been applied successfully to scores of GE engines, also can be used to improve the performance of machines made by other OEMs.

He should know. Johnston, a four-decades GE veteran, retired in 2008 as manager of the company's Gas Turbine Services Engineering Group, which supplied upgrade/uprate packages for a fleet of more than 7000 frame engines. Industry veterans likely have seen his name on documents in their files.

Johnston began with a review of items that could result from a non-capital-parts uprate study—including the following:

- Higher firing temperature possible with improved HGP parts.
- Change in the angle setting for inlet guide vanes (IGV).
- Increase in power at higher ambient temperatures by changing the isotherm setting.
- Exhaust-thermocouple corrections.
- Degradation correction to the control curve.
- Use of a tilted control curve to improve hot-day performance.

The speaker put up on the screen a valuable table of key data for all Frame 7 models from the introduction of the PG7651A in 1970 to the PG7241FA in 1999. It includes rated output, firing temperature, air flow, heat rate, and exhaust temperature—information needed for comparison purposes in performance studies.

Johnston's "carrot" was that for any "older" unit, it is likely that sufficient parts have been upgraded through normal supersedure procedures such that they would enable your gas turbine to produce more power. A thorough HGP review can confirm this. He added that most Frame 7 spare parts introduced after your engine was built are directly interchangeable with those in your machine. To illustrate: The later-vintage spare parts for the MS7001B/C/E/EA machines are directly interchangeable with all prior vintages of MS7001 units.

Attendee interest was piqued when Johnston said that degradation correction, along with use of the tilted control curve, had increased the output of some units operating in high-ambient-temperature environments by as much as 1.6%. Only controls changes were required, same hardware. For an MS7001EA this translates to about 1.2 MW of additional power.

The driver for using a tilted control curve is simply that most owner/operators value output on hot days more so than on cold days. Recall that standard GE control curves maintain a constant firing temperature at all ambient temperatures. Tilted control curves overfire on hot days by 16 deg F and under-fire by 25 deg F on cold days. Extensive analysis by the OEM in the mid-1990s was said to confirm that this approach had no net impact on parts life or maintenance intervals. Hundreds of successful applications were reported.

Non-recoverable performance degradation attributed to increased clearances, blade finish, and casing distortion, among other impacts, reduces output. Plus, it also adversely affects the compressor discharge pressure/turbine exhaust temperature relationship, resulting in under-firing of the unit.

The speaker said that extensive performance testing can be done to quantify the degree of under-firing, but that a 5-deg-F reduction in exhaust temperature and a 9-deg-F drop in firing temperature are typical. The simple approach, he said, was to apply an exhaust temperature correction to the control curve and regain the power lost (about 0.8% for a mid-1990s vintage 7EA).

HRSG improvements. The CMI presentation included case histories on HRSG modifications to match a gas-turbine upgrade, dry-ice blasting for tube cleaning, and retubing—topics typically covered in depth at meetings such as the *HRSG Forum with Bob Anderson* (www.hrsgforum.com) the European HRSG Forum, and the Australasian Boiler and HRSG Users Group.

HRSG mods to match a GT upgrade described work done at the UK's King's Lynn power station (COD 1997) in 2017-2018. The ambitious project included replacing the gas turbine, refurbishment of the HP and LP sections of the steam turbine, and its generator, and addition of a street to the air-cooled condenser.

Goal was to make the plant more flexible (300 or more starts annually), enabling its profitable operation in an increasingly competitive market. This required maximum use of existing infrastructure, improved output and efficiency, high reliability and availability, etc.

CMI's effort focused on recovering heat from flue gas at higher temperature than could be handled by the 1990s HRSG. Redesign/replacement of the HP superheater and reheater was required.

The presentation essentially was a collection of photographs "narrated" by the speakers to explain how the old pressure parts were removed and the new pressure parts installed—a confidence builder for those who may have thought such a retrofit project might not have been possible.

Case studies for energy savings—including tube cleaning and retubing of damaged heat-transfer surface—closed out the CMI segment of the program. Most of the material presented can be found in CCJ's archives. Access by typing your request into the search function box at www.ccj-online.com.

MD&A's program included a presentation on D11 HP/IP replacement, which might also have been of interest to many users in the US given the large number of D11 steamers in this country. Dave Hagenbuch focused on D11 issues reported by owner/operators and the features and benefits of MD&A's solution—and that of parent company Mitsubishi Hitachi Power Systems.

Dished diaphragm repair options, "hot swap" and spare sub-assembly offerings for stop valves and control/intercept valves, and packing rings and seals also were covered in the steam-turbine segment of the agenda.

Training wrapped up the MD&A effort. Seminars offered on steam-turbine fundamentals, alignment, advanced repairs, and performance evaluation and improvement were described in addition to workshops on gas-turbine fundamentals and the Mark VI control system.

Innova Braden Europe presented its air-inlet and exhaust-system retrofit solutions for 7EA and 7FA gas turbines as the morning drew to a close. The speakers began with exhaust systems, covering typical problem areas in older-style plenums—such as hot flanges and outer skin, overheated turbine and load compartments, liner damage, etc. Solutions discussed were well illustrated to facilitate the transfer of knowledge. Much of this material has been covered in CCJ over the years and is readily available with a couple of mouse clicks. Just access www.ccj-online.com and use the keyword search box on the home page.

Bypass diverter dampers were the next topic. Once again, photos illustrated the problems encountered and the solutions available. Cracks on the diverter-damper frame, blade cover, and toggle arms all were discussed, as was damage at the seal-air frame of the diverter-damper blade and wear and tear at the connection to the diverter-damper blade hinge. This material does not get much air time at user-group meetings in the US because regulations here typically do not support the use of diverter dampers.

Diagnostic tools, such as acoustic cameras and drones, and project case histories from major plants worldwide completed the presentation.

Technical workshop

The Power Generation Technical Workshop hosted more than a hundred participants from Saudi Aramco's engineering office and facilities. The agenda was similar—some presentations basically the same—to that of the earlier Combined Cycle Conference. Holt presented again on combined-cycle efficiency improvements and faster starts, Johnston on uprates of non-capital parts, and Stevens and Grini on HRSG improvements. MD&A covered its training offerings again and replaced some of the SEC steamer presentations with ones on gas-turbine rotor life extension and HGP repairs.

Several topics were in addition to those addressed at the SEC meetings, the prepared presentations running until mid afternoon when a panel was convened to address topics of interest not covered earlier in the day. Presentations added included these:

- Upgrades for air-cooled condensers, Frederic Anthone, manager of aftermarket support, SPG (frederic.anthone@spgdrycooling.com).

- GT inlet chilling systems, Tom Tillman, principal engineer, Turbine Air Systems Inc (ttillman@tas.com) and Bob Johnston.
- Fuel additives for NO_x emissions reduction, Mutasim Al Khayri, technical development manager, Clariant Al Tamimi (https://clarianttamimi.com) and Bob Johnston.
- Regenerative-cycle conversions for all types and models of gas turbines, Ty Moore, VP operations, PalCon (www.palconltd.com).

MD&A's Hesham Awwad opened his company's session with a presentation on GT rotor lifetime assessment (RLA). He noted that MD&A does not refer to this activity as an "end of life" evaluation, urging attendees not to "pull the plug" too quickly because an RLA can help owner/operators decide on the best options for ageing assets. He stressed that MD&A's goal is to help users achieve their planned operating strategies for remaining life through validation, repair/coatings, and/or replacement of limiting components.

Awwad explained his company's inspection process flow path, inspection scope and equipment, and testing and analytical tools used to develop a rotor-health assessment for planning refurbishment activities, or replacement through MD&A's rotor exchange program. 7FA compressor upgrades, DLN2.6 combustion parts/repairs, and 7EA/7FA compressor and turbine replacement disks were included in this portion of the program.

Greg Alexander then moved to the podium to discuss new-parts manufacturing and component repairs. Repairs are performed on 6B, 6FA, 7EA, 7FA, 9E, 9FA, V94.3, and V84.3 buckets, nozzles, shroud blocks, and fuel nozzles. Company offers new HGP parts for 7EA, 7FA.03, and V94.3 machines, the group was told.

Inspection and repair of 7FA.03 and 9FA combustion and turbine parts is a focus of MD&A's aftermarket business with a goal of reducing scrap.

Anthone began with the requisite company history and product portfolios for both wet and dry cooling systems, moving quickly through that boiler plate to focus on the inspections, technical advice, maintenance services, and spare parts available to improve performance as operating conditions change. To learn more about air-cooled condensers, access www.acc-usersgroup.org where you will find presentations on a wide range of chemistry and O&M topics archived from the time the ACC Users Group was founded 12 years ago.

It's no secret, turbine inlet cooling increases the power gas turbines can produce on hot days. Tillman's presentation focused on water-cooled chiller systems with heat rejection via an evaporative cooling tower and these refrigerant options: R-1233zd (HFO) and R-134a. For plants located on the coast, seawater heat exchangers can replace the standard cooling towers. Typical filter-house modification kits were covered as well.

Users wanting background information on alternative inlet cooling technologies should visit www.turbineinletcooling.org and CCJ's editorial archives at www.ccj-online.com.

Fuel additives for emissions control is an important topic for a Saudi audience given the large number of gas turbines burning crude oil. In these units, the speakers said, additive is injected upstream of the liquid-fuel stop valve. Focus of the presentation was experience with FuelSpec R114-05 (0.05% Mg/0.4% Fe by weight) in reducing carbon soot emissions.

Smoke and particulate measurements taken by an independent Saudi-based certified test lab, and performance data captured and analyzed by Saudi Aramco and US-based Efficient Fuel Solutions, revealed a reduction in smoke and particulate emissions of 30% when using R114-05, compared to operation on untreated crude oil. The additive injection rate was 1 liter per 130-million Btu. Test was conducted over two days. CCJ

TURBINE TIPS, No. 6 in a series

Troubleshooting Speedtronic Mark I and II control systems

By Dave Lucier, PAL Turbine Services LLC
www.pondlucier.com

Overfiring during startup

General Electric Speedtronic™ Mark I control systems were installed on gas turbines in the early 1970s, primarily on MS5001N and MS7001B engines. Fig 1 shows a typical Mark I panel being tested using a device known as the Speedtronic Calibrator. Note that the Calibrator has two ribbon connectors patched into designated locations and that the engineer is using digital voltmeters.

1. Speedtronic Mark I panel is at left, engineer uses Calibrator at right

Case history. The owner/operator of a Frame 5N near Houston called PAL Turbine Services on a hot summer day and reported that its engine would "hang up" during startup when the speed reached about 1800 to 2000 rpm, well below the operating speed of 5100 rpm. Troubleshooting actions taken for the symptoms described on the phone had been unsuccessful. The situation was dire, the user said; power from this unit was needed urgently.

Plant personnel were unfamiliar with "manual" gas-turbine operation to bypass the automated start and get the unit in service. This was explained in Turbine Tip No. 2, published in CCJ No. 59, p 48. (If you can't find your copy of that issue, go to the search function at www.ccj-online.com and punch in "Turbine Tip No. 2.")

2. Thermocouple averaging cabinet (left), with cover removed (right)

PAL General Manager Dave Lucier told the editors, "As good luck would have it, I had a set of Mark I turbine elementaries and control specifications with me. I accessed the Internet from my car, parked outside a hardware store, booted up my computer, called the plant operator, and then walked him through some troubleshooting techniques.

3. Failed reference oven for average exhaust temperature

The turbine was shut down at the time. "I asked the technician, who had a millivolt source, to connect it to a particular amplifier associated with an analog output from the 12 control thermocouples (Fig 2). He found the gremlin, a blown 240F oven (Fig 3).

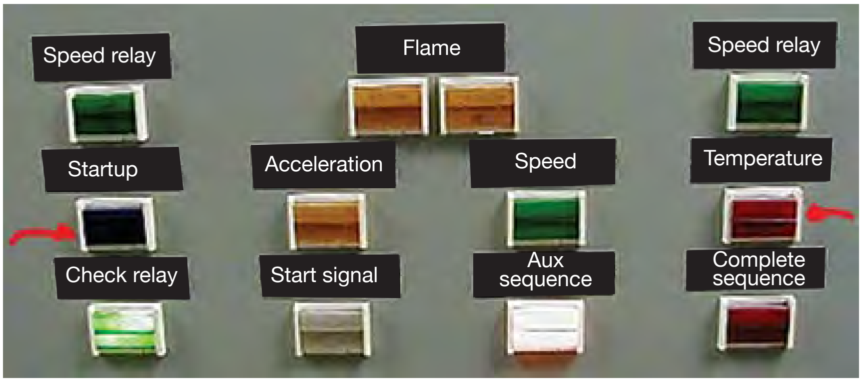
"With no spare on hand, I suggested that the technician borrow one from either **OTA** or **OTB** until we could supply one. Recall that the control card has three similar ovens. Inside the black box in Fig 2, there are these three so-called reference ovens:

- Average temperature control (TC-1 through TC-12); it creates signal **TXA**, a/k/a average exhaust temperature.
- Over-temperature control A (T1, T3, and T5); it creates signal **OTA**.
- Over-temperature control B (T2, T4, and T6); it creates signal **OTB.**

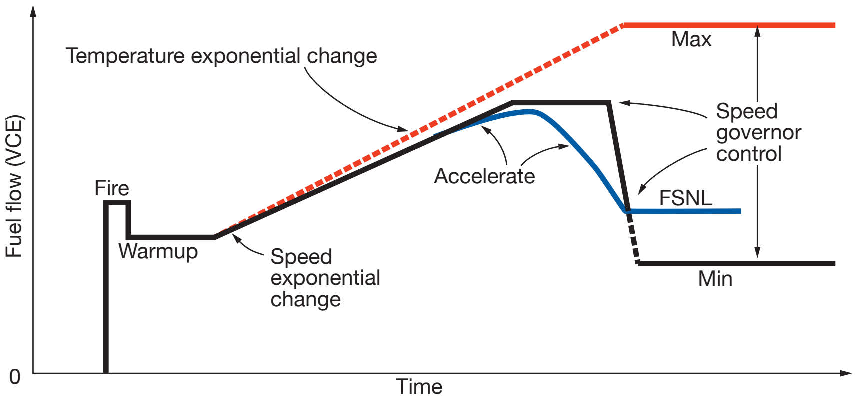
Other points to remember: GE temperature control and protection systems are *not* referenced to 0F. The output signal must exceed 240F before the analog output signal goes "positive." Also, **TXA, OTA,** and **OTB** are "compared" for over-temperature protection. A disparity of about 50 deg F among the three temperatures triggers an alarm. Additionally, if **OTA** or **OTB** exceeds 970F an alarm occurs; at 1000F, the turbine will trip and shutdown.

TXA is one of the functions that can "control" the voltage signal, hence fuel flow to the combustors. During turbine

4. Startup control and over-temperature alarm and trip systems



5. Light "On" in Minimum Value Gate display identifies system in control



6. Startup graph plots the command signal **VCE** versus Time. The middle of the diagram offers a simplified representation of how the Minimum Value Gate **MVG** control concept is used on all GE gas turbines, as the various signals "vie for control" of **VCE** (and, therefore, fuel flow to the combustors) when the GT is operating. Simulation of a fired startup can be done to turn on/off panel lights shown in Fig 7 to confirm the turbine will operate properly when called upon to start

startup, there are three "competing" controls that can take charge of the command voltage signal called **VCE,** a/k/a variable control electronic (Fig 4, right).

This is known as the minimum value gate **MVG** (Fig 5). Lights in the middle row of the photo identified by red arrows are the controls that can limit and lower the **VCE** voltage to control fuel flow. A light is "On" when in control.

During turbine startup, the following control variables can limit (or reduce) **VCE** and, therefore, limit fuel flow to the combustors:

1. **ACCEL VCE** limit. Default. High limit at 8.5 V when no other takes control. *Blue light.*
2. Accelerate exponential (**VCE** rate of change—0.2 V/sec. Adjustable on card.
3. Acceleration control—approximately 50 rpm/sec. Not adjustable on card. *Yellow light.*
4. Temperature exponential change (**TXA** rate of increase)—5 deg F/sec. *Red light.*

Returning to the starting problem in Texas, it was determined that the 240F oven for the **TXA** reference failed because it overheated. Lucier continued, "To get plant personnel through the crisis, I asked the technician to unsolder the failed oven and install the **OTA** oven until we could provide the plant with a spare (used) card. In the meantime, operators would have to live with a continuous exhaust-temperature-differential alarm.

Lesson: It helps tremendously to understand the "normal operation" of GE gas turbines with Speedtronic Mark I control and protection systems. If you don't know how the system is supposed to work, how can you recognize "abnormal" conditions?

Startup simulation

Speedtronic control systems provided with GE gas turbines from about 1970 to 1985 included two generations of controls designated Mark I, discussed above, and Mark II. Hundreds of these packaged powerplants were installed worldwide during that period, most with Mark II controls (Fig 7).

The focus here is on the Speedtronic Calibrator (refer back to Fig 1), which can be used to simulate a startup without firing the gas turbine. This could be useful to simply demonstrate that

7. Speedtronic Mark II panel (left) with sliding rack for access to circuit boards (right)

8. Speedtronic Calibrator is arranged with two digital voltmeters

9. Mark II startup and speed-control circuit boards a startup likely would be successful, or perhaps when fuel is unavailable for some reason, or if emissions are of concern.

Signals can be created on the Calibrator using the power supplies from the panel. Once plugged in at the proper locations, four final regulators on the Speedtronic panel are sent to the Calibrator.

For the Mark I they are the following:

- +12 V dc (for digital signals).
- +28 V dc (for panel relays).
- +50 V dc (analog signals).
- -50 V dc (analog signals).

For the Mark II on MS5001N and P, and MS7000B and C, engines:

- +6 V dc (for digital signals).
- +28 V dc (for panel relays).
- +12 V dc (analog signals).
- -12 V dc (analog signals).

The Calibrator has *red* and *blue* ribbon connectors, each with 51 pins, similar to the circuit boards on the Speedtronic panels; the Calibrator should be connected only to specific dedicated slot locations.

A "patchboard" is provided to jumper signals to the appropriate circuits, as well as to connect digital voltmeters (Fig 8). Resistors on the right side of the Calibrator allow for adjustments of speed (**NHP**), temperature (**TXA**), and another dc voltage source for pressure signals (**PCD** or **P2**).

The basic tasks for simulations fall into the following categories (with GE signals designated):

1. Speed signal **NHP**—0 to 100% (5100 rpm on Frame 5N or Frame 5P).
2. Speed signal to energize speed relays—**14HR, 14HM, 14HA,** and **14HS**.
3. Digital setpoint (**DSP**) for speed control and speed droop, referred to as the "called-for" speed.
4. Exhaust temperature (**TXA**) for temperature control simulation.
5. Pressure transmitter simulation (**PCD**)—voltage signal proportional to air pressure.
6. Gas fuel pressure (**P2**) for fuel controls—voltage compared to **NHP.**

Fig 9 shows Row 1 of the Speedtronic panel, which holds the startup and speed-control circuitry. Other rows hold the cards for turbine operation. The Calibrator can send signals to various circuits for simulation, as desired. A trained engineer or technician will find useful the techniques provided in the GE control specifications and other training documents.

Wrapping up, simulation is a good way to test Speedtronic Mark I and Mark II gas-turbine controls using the OEM's Calibrator. This saves time and fuel when actual turbine operation is undesirable. CCJ

Owner/operators of fired boilers, HRSGs share experiences to resolve common issues

The experiences shared at the Australasian HRSG Users Group (AHUG) annual meeting have been chronicled for the last decade in CCJ. Beginning here, and going forward, you'll also benefit from the lessons learned/best practices of fired-boiler owner/operators facing technical and operational issues closely related to those in HRSGs.

The first annual meeting of the Australasian Boiler & HRSG Users Group (ABHUG), chaired by Barry Dooley of Structural Integrity Associates Inc, attracted 75 participants from Australia, Japan, New Zealand, Thailand, UK, and US to the Brisbane Convention & Exhibition Centre, Oct 30-Nov 1, 2019. About half of the participants were users.

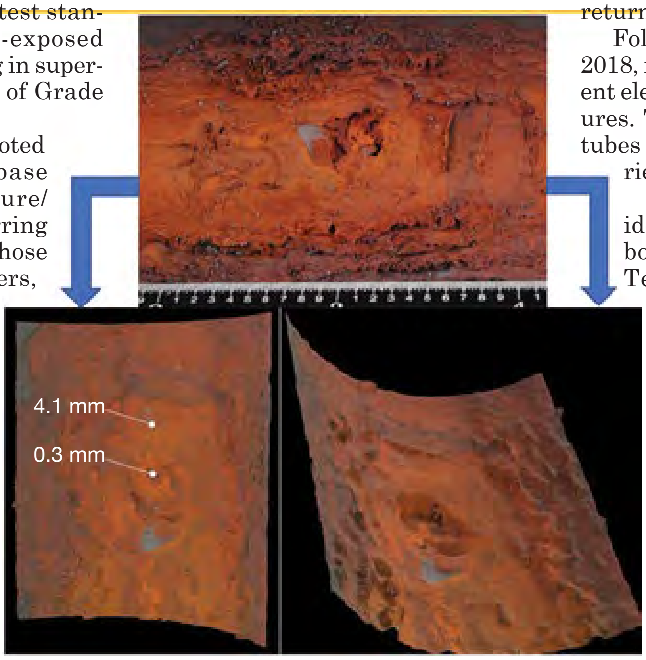
The agenda included 21 technical presentations and a welding workshop that brought together multiple experts to present on the latest standards, welding of service-exposed materials, ligament cracking in superheater headers, cold repair of Grade 91 material, etc.

The steering committee voted to expand the attendee base because many of the failure/damage mechanisms occurring in HRSGs are similar to those found in conventional boilers, and that other equipment in combined-cycle plants have many of the same issues as those in fossil stations. Dooley told the editors that ABHUG will continue to concentrate on HRSG aspects but will add the technical areas common to fossil and HRSG plants—such as tube failures, steam turbines, high-energy piping, valves, etc.

The chairman characterized the inaugural ABHUG meeting as a highly interactive forum for the presentation of new information and technology related to HRSGs and boilers, case studies of plant issues and solutions, and open discussions among users, equipment suppliers, and industry consultants.

ABHUG is supported by the International Association for the Properties of Water and Steam together with the local national committees of IAPWS in Australia and New Zealand. It is held in association with the European HRSG Forum (EHF) and the US-based *HRSG Forum with Bob Anderson*.

Two gold sponsors—Bang&Clean Technologies AG and HRL Technology Group—and seven exhibitors—ALS, Duff & Macintosh and Sentry, Flowtech Controls, Quest Integrity, Mettler Toledo, Optimum Control, and Swan Analytical—provided financial support (see end notes).



1. Large pit in reheater tube, digital view

Meeting highlights

1. Pitting corrosion

Tarong. The 1400-MW Tarong Power Station in Queensland was commissioned in the 1980s with four subcritical coal-fired boilers, each rated at 350 MW. The primary reheater is located in the back pass, composed of two sections with horizontal tube elements—126 total elements across each boiler's width. Design steam conditions at the headers are 935F/765 psig (610 psig operating).

In 2012, owner/operator Stanwell Corp announced plans to shut down two units for two years because of reduced demand and low wholesale electricity prices. When the cost of natural gas rose in 2014, Stanwell returned the units to service.

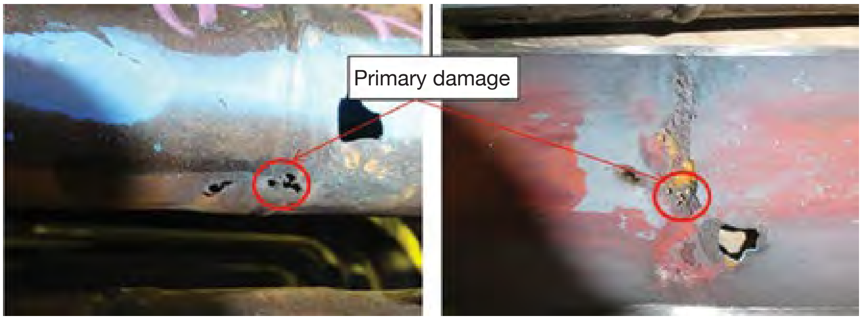
Following a Unit 3 major outage in 2018, four reheater tubes across different elements experienced primary failures. Two months later, another two tubes across different elements experienced similar failures (Fig 1).

An EPRI roadmap was used to identify, evaluate, and solve the boiler-tube failure issue—EPRI Technical Report 3002010388, "Boiler and heat recovery steam generator tube failures: theory and practice."

Stanwell adopted the process described in the EPRI document to determine the following:

1. Primary failure location.
2. Primary failure mechanism.
3. Primary failure root cause.
4. Factors contributing to the primary failure mechanism.

Both visual and tube-removal analyses revealed the key factors and mechanism:



2. Failure damage in reheater tube, external view

- Corrosion only in the bottom half of the tube.
- Partial or complete through-wall pitting corrosion on welds and randomly on tube parent material.
- Pit sites open or filled with reddish or reddish-brown corrosion products.

In this case, all pit sites were located in the center sections of horizontal tubes (Fig 2). There was no external erosion, apart from steam erosion, attributed to the primary failures. Stanwell's conclusion: Pitting corrosion attributed to inadequate layup was the primary failure mechanism.

Investigations included metallography, water sources and system chemistry, shutdown procedures, reheat spray operations, and pressure excursions.

Stanwell's G Wang stated the primary failure root cause as "condensate formed during shutdown. The accumulation of condensate at the bottom of the tubes with oxygen being subsequently introduced during the shutdown provides a stagnant oxygenated-water environment for pitting initiation and development."

Wang also reviewed relevant contributing factors:

- History of shutdowns, durations, and long-term preservation practices.
- Chemical excursions (condenser leaks, for example).
- Corrosion at welds caused by weld/tube galvanic attack.
- Sagging at center of horizontal tube elements.
- Pressure excursions.
- Lack of protection during washdown after tube failure events.

Stanwell's long-term strategy includes repair/replace option reviews, enhanced inspection methods, and a direct action for shutdown of "drying the tubes before condensate formation and maintaining RH below 35%."

Wang then listed specific future inspection methods:

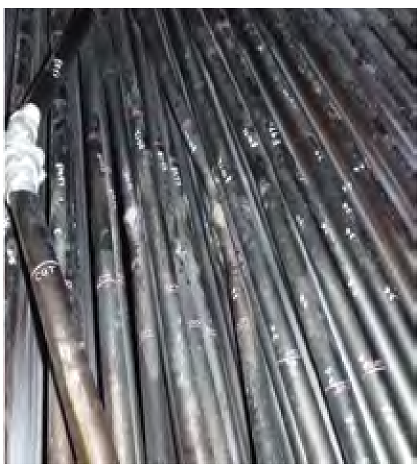
Welds. Cobra PAUT/ToFD (ultrasonic phased array and time-of-flight diffraction) ultrasonic.

Tube parent material. EMAT and FMC/TFM (electromagnetic-acoustic transducer and full-matrix capture/total focusing method).

During the discussion period, Chairman Dooley stressed the benefits of "sharing issues across combined-cycle and conventional fossil plants. Corrosion can be initiated during inadequate layup. This and other presentations illustrate just how severe pitting damage can be for both combined-cycle and conventional units."

Kogan Creek Power Station, owned by CS Energy Australia, is a 750-MW supercritical coal-fired unit in Queensland, commissioned in 2007. In 2018, a tube leak occurred in the horizontal reheater section of the boiler, causing significant secondary damage and an 11-day forced outage. Fifteen tubes were replaced (Fig 3). The primary failure was a pinhole leak that developed near the middle of the horizontal run, at the bottom of the tube. The failure mechanism was identified as pitting corrosion.

Galvanic corrosion caused by moisture and oxygen led to rapid pitting. CS Energy's Luke Smith explained that "the base of the pit, low in oxygen compared to the wet metal surface, became anodic. This occurred during shutdown when steam was allowed to condense (not during operation). In this particular case, a low level of sulfate also was present."



3. Significant secondary damage developed from pinhole leak

In 2019, the entire reheater was replaced (three banks of 196 elements), extending an outage from 56 to 77 days.

The long-term prevention objective is to replace dry steam with dry air (dry storage). Smith explained that "once the reheater has had about five changes of volume, the HP bypass is opened to allow air to flow to the superheaters. The flow of dry air will be maintained for the duration of the outage if possible. We aim for an RH below 30%."

This was followed by participant discussion on use of dehumidified air (DHA) for systems including reheaters and steam turbines. Dooley again offered input: "Unfortunately," he said, "the application of DHA is usually added after the damage has occurred, instead of proactively beforehand."

Common tube-failure approach. Pitting issues from improper shutdown protection can affect both the HRSG and the steam turbine, as discussed in the recently released report "Trends in HRSG Reliability: A 10-Year Review," by Dooley and Bob Anderson of Florida-based Competitive Power Resources (and chairman of the *HRSG Forum with Bob Anderson*). The Combined Cycle Journal's summary of this valuable reference work appeared in CCJ No. 61, p 44.

In that report, the authors discuss the importance of root-cause analysis and HRSG tube-failure (HTF) programs. They caution that a tube failure often is assumed to be a bad weld, but warn that if tube removal and analysis are not performed the problems likely will continue.

This review continues: "In many cases the actual root cause may be due to a cycle chemistry deficiency, design feature, or operating practice that has repeatedly inflicted corrosion, corrosion fatigue, or thermal-mechanical fatigue damage in the failed tube and its neighbors."

It is indeed complex. "The only way to ensure that the corrective actions are taken and will prevent a tube failure from recurring is to remove the initial failure site, have the actual failure mechanism identified via a metallurgical laboratory analysis, then determine the root cause of the failure."

The tube failure discussions at ABHUG gave examples of effective root-cause analysis.

2. Boiler-tube failure mitigation

Stewart Mann, responsible for asset integrity at AGL Energy Ltd, discussed his company's corporate-wide approach to mitigation of boiler-tube failures at both gas- and coal-fired units. The AGL tube-failure reduction program records each failure mechanism and root cause, the specifics of each repair, and all planned actions.

The approach-to-mitigation discussion raised many logical but often bypassed steps needed for a complete analysis program. First, the AGL program is based on the model in EPRI Report 1013098, "Integrated boiler tube failure reduction/cycle chemistry improvement program (2006)." Second, it is produced as a fleet-wide AGL standard. Third, it is now integrated with AGL's cycle-chemistry standard."

The goal is to apply risk-based systems to minimize repeat failures, reduce failures from new mechanisms, and decrease the number of failures at new locations for known mechanisms. As Mann stated, "Unless we have recently changed how we are operating, credible inspection and analysis should enable us to confirm whether a potential mechanism is an issue at our plants."

Data gathering includes failure mode and mechanism, root cause, extent of damage to the tube with the primary failure, tubing in the vicinity of the primary failure (secondary damage), and the surface areas along the leaking tube.

"AGL is careful to preserve removed tubes for metallurgical examination, and to always consider possible removal of additional samples," added Mann. Also, every repair has strict QA provisions for:

- Welder certification.
- Inspector certification.
- Welding procedures.
- Welding materials.
- Selection of tube materials.

"All of this," he continued, "requires good collaboration among trading, operations, and engineering."

Each ALG site now has a dedicated boiler-tube failure-reduction program team that includes:

- Site boiler engineer (lead).
- In-service inspector.
- Principal engineers from the company's technical services group.
- Operations input.
- Maintenance input.
- Complete failure and inspection history reviews.
- Development of inspection strategy and action plans.

"All reports are finalized, distributed, and accessible to everyone," he said.

4. GT combustor basket spring clips showing deposit of hexavalent chromium

Mann offered an interesting concluding challenge: "Play devil's advocate, and be prepared to question any prevailing norms."

3. Update on IAPWS activities

International updates were provided on cycle chemistry, instrumentation, and flow-accelerated corrosion (FAC), plus a review of the recent IAPWS Technical Guidance Documents (TGD) in those areas—including the following:

- Applications of Film-Forming Substances (TGD11-19).

- Air In-leakage in Steam-Water Cycles (TGD9-18).
- Chemistry Management in Generator Cooling Water during Operation and Shutdown (TGD10-19).

Find these and other TGDs at www.iapws.org.

4. Update on thermal transients

International updates on HRSG thermal transients associated with attemperators, condensate return and superheater/reheater drain management, and bypass operation were well received. Get details in the special report referenced earlier, "Trends in HRSG reliability, a 10-year review."

5. Hex chrome

A practical presentation focused on hexavalent chromium contamination of high-chrome materials in gas turbines, HRSGs, steam turbines (casing bolts), and steam piping was made by David Addison, principal, Thermal Chemistry Ltd, a frequent contributor to CCJ. He covered how and where hex chrome forms, the health risks it poses, PPE requirements, best work practices, proper disposal, etc.

Recall that chromium, a common alloy element in high-temperature/high-pressure steels used in powerplants, has multiple oxidation states. To illustrate: Chromium III is essential for human health; Chromium VI (hexavalent chromium) is extremely toxic. Chromium VI is also easily managed with standard industrial hygiene and personal protection strategies applied, combined with neutralization where needed.

Risks associated with welding of high-chromium materials are well understood in the industry, as are possible hazards during some chemical cleaning procedures.

Recently, however, hexavalent chromium has been identified on gas-turbine hot-gas-path components (Fig 4), steam-turbine hot external components (bolts), and on the external surfaces of hot HRSG/boiler piping.

For gas and steam turbines, there's a link to calcium-containing anti-seize pastes often used on hot components.

The yellowish appearance can be misinterpreted as sulfur deposits from the fuel. "Bright yellow HRSG gas-side deposits should be considered a major warning sign, and treated with significant caution," noted Addison.

Although understood and manageable, this alert involved one particular slide labeled "unconfirmed risk areas" and offered the following details:

Upper and lower crawl spaces with:

- High-chromium pipework.
- High-chromium liner places.
- Oxygen atmospheres.
- High temperatures.
- Insulation containing calcium oxide.
- Potential for rain water ingress that allows for calcium leaching.

For HRSGs:

- Superheater/evaporator upper and lower crawl spaces.
- Gas-turbine exhaust ductwork—mainly on the insulation side of plates.

6. Digital twin

A new inspection tool for developing a digital twin of pressure vessels and other plant components using state-of-the-art imaging and image-capture technology was described. Chairman Dooley said an interesting application of the technology might be its use in the upper ducts of an air-cooled condenser (ACC) to view, without entry into the upper ducts (streets), the tube entrances and any associated FAC. He should know: Dooley is a member of the ACC Users Group steering committee and respected for his knowledge of ACC damage mechanisms. Visit www.acc-usersgroup.org.

7. OGE index

A question/answer period included impromptu discussion of the oxidation limits for steels used in superheaters and reheaters. Dooley announced that a new index on oxide growth and exfoliation (OGE) is in preparation. It will discuss the formation of steam-side oxide, how the characteristics of oxide exfoliation vary from one material to another, and the various types of damage caused by different exfoliated oxides. OGE had piqued the interest of attendees at the 2019 meeting of the *HRSG Forum with Bob Anderson* as noted in the report for that event in the last issue (CCJ No. 62, p 41).

8. Tube cleaning

Experiences with pressure-wave cleaning of fireside/gas-side surfaces in fossil boilers/HRSGs were shared at the same forum perhaps for the first time. Pressure-wave cleaning of HRSGs was a "hot" topic at the 2019 meeting of the *HRSG Forum with Bob Anderson* as mentioned in the report for that event in the last issue (CCJ No. 62, p 42).

2020 meeting

ABHUG returns to the Brisbane Convention & Exhibition Center next year, in early December. Follow the organization's website for announcements.

Sponsor, exhibitor briefs

The sponsors and exhibitors active in ABHUG may be unfamiliar to readers in the Western Hemisphere. What follows are summaries of their activities:

ALS is one of Australia's leading providers of asset reliability and integrity services geared to help power producers maximize production, extend asset life, and assure top operational performance.

Bang&Clean Technologies AG specializes in cleaning boilers and HRSGs by way of pressure waves created by closed and controlled gas explosions. The Swiss company's patented system reportedly has been used in more than 20,000 cleanings since 2001.

Duff & Macintosh has specialized in the area of sample conditioning for the last 50 years. It is the exclusive agent in Australia Pacific for **Sentry Equipment Corp.**

Flotech Controls provides valve solutions, specializing in severe-service isolation and control applications.

HRL Technology Group focuses on laboratory testing, asset integrity, materials engineering, power and combustion performance engineering, and process and energy efficiency engineering.

Quest Integrity is active in the development and delivery of asset integrity and reliability management services.

Mettler Toledo Process Analytics specializes in inline analytical process solutions. Its Thornton unit provides state-of-the-art technology in conductivity, sodium, silica, chloride/sulfate, pH, ORP, ozone, dissolved oxygen, and TOC measurement.

Optimum Control Co represents a range of valve and actuator manufacturers and has a facility in Sydney to repair those components.

Swan Analytical Instruments offers a range of analyzers for pure, ultra-pure, and cooling-water applications—including pH, conductivity ORP, dissolved oxygen, silica, sodium, phosphate, chlorine, chlorine dioxide, bromine, iodine, ozone, and turbidity.

Air-Cooled Condenser Users Group

The Air-Cooled Condenser Users Group (ACCUG) annual meeting was held outside the US for the first time, in Queretaro, Mexico, Oct 21-24, 2019.

Sessions began with a review of information on flow-accelerated corrosion (FAC) and cycle chemistry prepared by Barry Dooley, Structural Integrity, and presented by EPRI's Andy Howell, chairman of the group. In-depth discussion covered typical ACC damage and consequences, plus steam-turbine deposits. Timely issues of film-forming substance (FFS) research and application also were addressed.

ACCUG annual meetings began in 2009. The collaborative environment fostered by this focused organization helps chemists, engineers, and O&M personnel expand professionally and return to their plants with best practices for reducing operating expenses and improving system performance.

The following reviews highlights of selected presentations. To learn more, visit the group's website at www.acc-usersgroup.org.

Complexities of filming substances

EPRI's Brad Burns highlighted cycle-chemistry experience at an ACC-equipped 2 × 1 baseload combined cycle in Mexico. Burns is senior technical leader for EPRI's Program 64, *Boiler and turbine steam and cycle chemistry.*

The subject plant was commissioned in 2010 "with minimal sampling and analysis, and no clear pH target." After several years of operation, iron in condensate and feedwater exceeded 50 ppb, an unacceptably high value. Outage inspection showed a Dooley Howell Corrosion Index of 4C, indicating the significant corrosion damage shown in Fig 1. Details are presented in the user group's report ACC.01, "Guidelines for Internal Inspection of Air-Cooled Condensers," available online at no cost at http://acc-usersgroup.org/reports/.

In 2014, improvements were made in the plant's sampling and analysis panels and a pH target of 9.8 was set using ammonia. After a year of unsatisfactory results at pH 9.8 (iron remained high), the owner/operator attempted to feed a blended filming amine to a target residual but was unable to verify results. The target pH was changed to 9.4.

Treatment was changed in January 2017 from ammonia-only to a 2:1 ammonia/ETA blend, increasing the pH target to 9.6. The blend was eventually changed to 4:1, achieving a pH of 9.2 to 9.3.

As measured in the 2017 outage, the DHACI remained at 4C.

This presentation showed the complexities of filming chemical utilization, noting thermal decomposition of neutralizing amines and difficulties in achieving an optimum feed rate.

Lessons learned included the following:

1. Either increase liquid-phase pH with ETA feed upstream of the ACC (not at the condensate pump discharge), or maintain at least pH 9.8-10 consistently with ammonia at the CPD.
2. Apply standalone LP drum and IP drum pH control with trisodium phosphate (TSP).
3. If using a filming amine or filming product (film-forming substance, FFS), choose one with minimal blended constituents so that target residual can be achieve without dramatic increases in cation conductivity caused by the breakdown of chemicals in the blend.

Saavi Energia

Oscar Hernandez, O&M manager for Saavi Energia, and a member of the user group's steering committee, discussed fleet-wide system chemistry programs for the Mexico City-based private power producer. Saavi operates several combined cycles—including three with ACCs (El Bajio, San Luis de la Paz, and Chihuahua).

Corporate chemistry guidelines are based on the recommendations of both EPRI and the International Association for the Properties of Water and Steam (IAPWS). One principal objective, Hernandez explained, is an ideal pH level which "must be controlled properly within the recommended range." He noted two plants with pH targets of 9.4 and 9.6, both showing acceptable iron levels.

Accurate benchmarking, monitoring, and treatment are critical, he explained. The presentation offered details and background on treatment options, monitoring, and diagnostics. Hernandez also described Saavi's experience with ACC decay tests and finned-tube cleaning methods.

The speaker strongly recommended challenging the cost/benefit claims of contractor-proposed chemical programs (cost versus unit capacity factor).

Emmauel Luévano, a manager at Saavi's Chihuahua III plant, subsequently reviewed the company's ACC best practices—including fan start/stop sequencing, fan performance monitoring, vibration analysis, infrared imaging for steam flow distribution, mechanical inspection, etc.

1. The 2017 inspection of an ACC's lower header, hotbox, and upper horizontal duct-tube inlets (left) revealed corrosion of about the same severity as that found during the unit's 2014 inspection (right)—the DHACI remaining at 4C. Findings: (1) Filming-amine residual was too low to form a protective barrier. (2) Ethanolamine and the cyclohexylamine decompose at the high temperature of the HRSG and were not helping the ACC. Plus, decomposition products lower the liquid-phase pH

Modifications at Rio Bravo

Hector Moctezuma, Falcon Group, presented on the windscreen project at Central Valle Hermoso, a 500-MW facility added in 2005 as part of the 1490-MW Rio Bravo Energy Park.

Design plant output had been "unattainable during the summer months because of high backpressure. The significant reduction in power output was attributed to ACC under-performance in hot and windy conditions."

Moctezuma added that "even though the condenser was sized, specified, and supplied correctly, there had been degradation from severe fouling and tube damage. Performance was affected more by higher temperatures and winds."

The owner/operator considered options and selected a wet/dry parallel condensing system (Fig 2). This was based on considerations that included:

1. ACC enlargement was a very expensive option with marginal benefit, and
2. Additional water sources were available in the vicinity for the limited need.

In this system, "exhaust steam is simultaneously condensed in both a wet evaporative and existing dry cooling system." The goal was to "remove the steam-turbine backpressure limitation during all periods with ambient temperatures higher than 86F—about 1000 hours per year."

Advantages of the parallel system included:

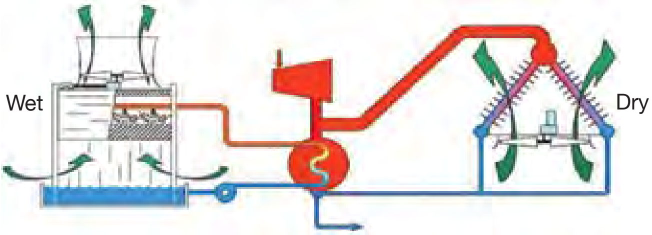
- Combines the performance of a wet evaporative system with the water savings of an ACC.
- Optimizes water use to minimize condensing system costs.
- Sized to meet cooling-water availability.

However, the performance-reducing impacts of local winds remained.

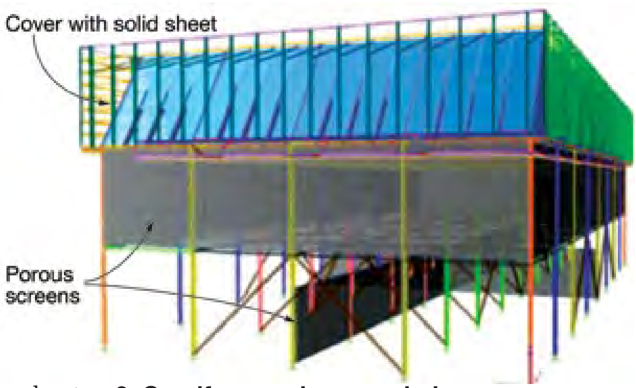
Winds were causing an ACC pressure increase of 0.44 to 0.88 in. Hg by reducing fan speed, resulting in a steam-turbine power decrease of 3 to 4 MW. This occurred with wind speeds above 9 mph (1800 hr/yr) and became very significant at speeds between 16 and 19 mph (300 hr/yr).

Windscreens were selected to reduce both wind speed and crosswind effects. All available options of type and location were considered. A combination of cruciform and suspended screens was optimal for the atmospheric conditions at the plant. ACC structural reinforcement was needed to comply with Mexican regulations. Screens were installed in May 2018.

Under worst conditions (ambient 86F and winds 19 mph), backpressure and power output improved by 0.59 in. Hg and 1.68 MW.



2. Typical wet/dry parallel condensing system



3. Cruciform and suspended screen combination often is preferred

ACC bundle replacement

Derek Silbaugh, an engineer with Black Hills Energy, reviewed plans to undertake replacement of the tube bundles in an ageing ACC. The multiple issues involved in determining a cost-effective approach for improved performance and long-term reliability are complex but relevant to others in similar situations. Silbaugh's presentation is available on the ACCUG website.

Optimizing windscreens

Cosimo Bianchini, Ergon Research (Italy), offered a comprehensive update on windscreen design and application, entitled "Deficiency reduction after installation of optimized windscreen configuration."

His presentation included motivations and objectives for windscreens at two 800-MW combined cycles, each with an ACC having nine streets and four cells per street. Screens were installed in 2014 on one ACC to allow greater capacity during hot windy days.

Suspended screens were supplied on the first unit, with performance measured one year before and one year after. Comparisons based on similar ambient temperature, relative humidity, with speed and direction, and backpressure showed an output improvement of 15 to 20 MW with the screens in place. Screens were most effective for wind speeds of 20 mph and below.

Both units were later subjected to CFD modeling for possible improvements, testing a wide range of screen configurations—both ground-based and suspended.

Bianchini's presentation provided extensive modeling details including variations in screen type and placement. Adding to the complexity, the two ACCs (windscreen options and configurations) could be studied and upgraded independently.

One interesting takeaway was visual representation of the seemingly abundant options.

Bianchini offered the following conclusions:

- Optimization of windscreen layout by CFD identifies candidates with much higher performance than the one currently installed. Some options were eliminated because of installation complexity and higher structural loads.
- The selected layout showed capability of recovering 58% of the losses of the downstream ACC capacity compared to the upstream unit.
- A simplified economic analysis showed an acceptable payback period.

Induced draft

Thomas Louagie, SPG Dry Cooling, discussed the emergent topic of induced-draft ACC designs, along with a history of development from traditional A-frame mechanical draft units. SPG offers a W-style heat exchanger arrangement for all sizes of plant output.

Features include SRC© finned tubes (aluminum-clad steel tubes with brazed aluminum fins); fan deck with perpendicular-shaft gearbox, motor, fan, and fan bell on top of the heat exchanger; short fan bridge supported in the middle by the central top manifold; and an accessible fan deck for maintenance.

Two negative effects of wind on traditional ACC performance are recir-

4. Classic air-cooled condenser arrangement is described in the top left-hand sketch in the drawing, the induced-draft ACC to its right. Illustration below explains the induced-draft concept in more detail. Photo shows the induced-draft ACC at Towantic Energy Center, owned by Competitive Power Ventures, which will be toured by attendees of the upcoming ACC Users Group annual meeting, Sept 28-Oct 1, in Danbury Conn

culation of hot air exiting the ACC, and reduced fan air flow attributed to disturbances at the air inlet. "With the W-style ACC," explained Louagie, "recirculation is reduced due to higher exit air velocity, and the fan inlet is protected from crosswinds by the tube bundles, acting like screens."

"Flow-accelerated corrosion can also be reduced," he explained, "due to lower steam velocities and less steam pressure drop."

Details presented also showed improved backpressure and higher steam turbine production at low ambient temperatures (below 50F).

What might be of particular interest to owner/operators is that the ACCUG's 2020 meeting, Sept 28-Oct 1, at the Danbury (Conn) Crown Plaza will include a tour of CPV's Towantic Energy Center, which features and induced-draft ACC (Fig 4).

Direct-drive fans

ABB's Marty Mates explained the installation and experience with permanent magnet (PM) direct-drive fan motors, first introduced to the wet cooling-tower market in 2008. ACC trial installations began in 2015 (Fig 5).

Mates discussed background development, including feedback from previous ACCUG meetings, beginning in 2012. A prototype project concept installed at Basin Electric Power Co-op's Dry Fork Station) was reviewed at the 2014 conference. Previous group discussions included reliability, size/weight, gearbox issues, and general maintenance concerns.

Environmental issues (including noise) and parasitic load (efficiency) were also discussed for the new design.

Dry Fork's prototypes were installed in 2015 and 2016, both rated at 250 hp at 104 rpm. Mates also reviewed the installation challenges and solutions for a recent installation in Jordan.

5. Fan motor of the permanent-magnet direct-drive type is ready for installation

Wet-to-hybrid conversion

George Budik, global product manager for ENEXIO Dry Cooling, explained that water demands continue to rise, offering an example for plants with evaporative/wet cooling systems. "Each 1 MWh of electricity produced in a fossil power plant requires 600 to 660 gal of makeup water to replace wet cooling-tower losses by evaporation, blowdown, and drift," he explained. There is, therefore, a trend toward at least considering "conversion to all-dry or hybrid cooling technologies."

Budik then explained various options, including what he called "the optimum solution," cautioning that each design is site- and system-specific.

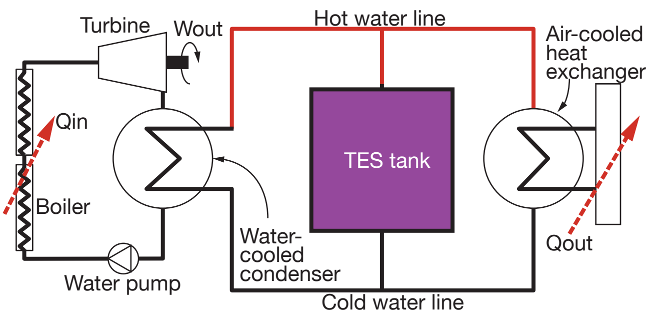
Thermal storage

Ronan Grimes, University of Limerick (Ireland), offered a low-temperature thermal storage concept designed to address the following issues with A-frame ACCs:

- The minimum temperature to which turbine outlet steam can be theoretically cooled is ambient air temperature; practically, it is somewhat higher.
- Hot climates impose a thermodynamic efficiency penalty.
- Air in-leakage (efficiency loss) is common.

One approach is low-temperature thermal storage (LTTS, Fig 6) in which a water-cooled condenser (WCC) is combined with a thermal energy storage (TES) tank and air-cooled heat exchanger (ACHEx). The goal is to "exploit the natural ambient temperature variations to condense steam at sub-ambient temperatures."

In charge mode (during low ambient temperatures), water is pumped from the tank to the ACHEx, cooled, and returned to the tank for storage. In bypass mode (moderate ambient temperature), water from the water-cooled condenser is cooled in the ACHEx then



6. Low-temperature thermal storage system exploits the natural ambient temperature "swings" to condense steam at sub-ambient temperatures returned to the WCC. In discharge mode (high ambient temperatures), chilled water is pumped from the tank to the water-cooled condenser where it condenses steam at sub-ambient air temperatures.

Feasibility studies and modeling for this concept are ongoing. One noted case study operated at eight hours of charge, eight of bypass, and eight of charge. Modeling results were explained.

Remote performance management

Sean Cusick, SPG Dry Cooling, followed with ACC360 remote performance management, which provides virtual insight into the performance and health of any air-cooled condenser. Main components are:

- Performance analytics that evaluate past, present, and future performance.
- Condition-based monitoring, including vibrational monitors, to predict potential failures.
- Integration of data with weather forecasts.

Cleaning is a must

Consultant Huub Hubretsge addressed the group on various traditional methods of ACC cleaning: high pressure wash, blasting with dry ice, etc. He also explained specific methods of calculating steam-turbine performance loss caused by ACC fouling.

Hubretsge pointed out that these losses go beyond less air available for cooling and reduced heat-transfer coefficients. "If the backpressure at the turbine exhaust increases, the enthalpy of the exhaust steam increases as well (less water in the steam). The higher the enthalpy of steam at the turbine exhaust, the less enthalpy is used for power generation."

He offered a rule of thumb: "A general rule says that the total power generation will drop 0.7% for every 0.3-in.-Hg pressure increase at the turbine exhaust."

Sample cleaning/fouling loss calculations were made available to all attendees in Excel spreadsheet format.

For a thorough review of cleaning needs and options, download at no cost Report ACC.02, "Guidelines for Finned Tube Cleaning in Air-Cooled Condensers" at http://acc-usersgroup.org/reports.

ACC performance enhancement

Andy Howell reviewed the common sources of dry cooling inefficiency (direct-condensing ACCs): steam-to-air heat-transfer efficiency, dependence on ambient temperature, and power requirements for large fans. He then reviewed further inefficiency issues:

- Air-side debris accumulation.
- Air in-leakage.
- Wind effects.
- Hot air recirculation.
- Gaps and air bypass.
- Tube fin damage.

All are common discussions at the ACCUG meetings.

He also reviewed more specialized topics from past conferences: wet cooling support, air misting (fogging), deluge cooling, and system expansion (adding streets).

Howell noted that "a variety of performance improvements are available and should be evaluated for cost effectiveness." In particular, he mentioned fan uprates, including some common uprate results for a specific scenario:

1. Auxiliaries consumption increased by about 1.2 MW because of a larger fan-drive system.
2. Complete elimination of backpressure limitation, with a significant and sustained improvement of a least 3.5 in. Hg.
3. Increase in power output because of a reduction in condenser pressure and the possibility of increasing condenser load and steam flow through the turbine.
4. Heat-rate improvement attributed to lower condenser pressure and lower backpressure on the steam turbine (which he called "free power"). CCJ

Webinars help users identify, implement solutions critical to plant betterment

If the coronavirus pandemic has taught us one thing, having the ability to access the expert information needed to perform O&M tasks at the highest level without leaving the plant (or home) is vital. With good internet connections generally available at most powerplants, the challenge might be finding the information required. You likely have several preferred websites to search, ones that may have helped you in the past.

Is CCJ's (www.ccj-online.com) one of them? Our online library, keyword searchable on the homepage, can direct you to perhaps unimagined resources on the operation and maintenance of gas turbines and combined cycles. Included among these resources is our webinar library.

At home you might access a service such as Netflix for leisure viewing; at work search CCJ's webinar library for guidance on how to identify and implement critical O&M solutions capable of helping you and your colleagues improve plant safety, availability, and performance.

To learn more about the library and its value for your facility, please skim the content summaries below of webinars added to the CCJ library in the last several months and use the QR codes to view one or two. No charge!

More webinars are scheduled for the weeks ahead; a lineup is available on the CCJ website. Included in this program is a collaborative, monthlong series of webinars presented by the 7F Users Group and vendors serving this critical fleet. If you miss the live sessions you can access the recorded versions at any time—just like Netflix.

1. A benefit of repair versus replacement is illustrated by way of correction of turbine-disc rock wear allowing rotating blades in the 501D5 rotor to lift (left). Feeler gages indicated more than 30 mils of lift, twice the standard spec. Nickel aluminum sprayed on the unloaded faces of disc fir trees, and later coated with aluminum chromate phosphate to facilitate blade installation, provided the dimensional restoration required at far less cost than disc replacement

Sulzer. Keep ageing gas turbines competitive with coatings and material upgrades, *Garret Haegelin, superintendent, HiCoat Div, Sulzer Turbo Service Houston.*

Garret Haegelin's goal is to help owner/operators of the industry's most popular heavy-duty gas turbines—including 7Fs, 7EAs, 6Bs, and 501Fs—run their machines longer and more efficiently with cost-effective quality repairs and upgrades. The editors give his fast-moving 50+-slide presentation two-thumbs up both as a refresher for experienced plant personnel and as a primer for industry newcomers.

Haegelin discusses how to protect critical components against wear (fretting, abrasion, erosion), oxidation, corrosion, temperature, and stress, and explains repair options to avoid costly replacements when components are approaching the ends of their service lives.

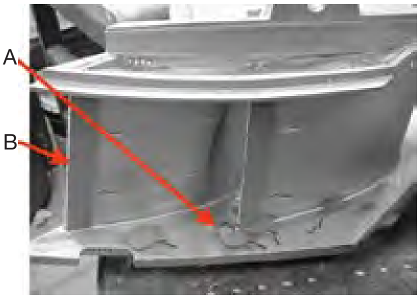
Next, he shows how coatings (1) help prevent high-temperature oxidation in the turbine section, (2) mitigate thermal fatigue of vanes, (3) protect against hot corrosion caused by off-spec fuels, etc. A review of coating application technologies follows. The optimal method among HVOF, plasma, arc wire, cold spray, Haegelin says, depends on the part and type of coating, and he gave examples.

Case studies on (1) ways to make components more robust, (2) the benefits of repair versus replacement (Fig 1), (3) how to reduce degradation, and (4) approaches to extend service runs are particularly valuable for deck-plates personnel and should be considered by plant managers for lunch-and-learn sessions in the break room. All you have to do is access the presentation using the QR code (scan with your smartphone or tablet) and share it with participants.

Photos of damage to transition pieces and combustion liners—such as oxidation attack, linear indications, etc—and the techniques Sulzer uses to increase the robustness of these parts kicks off the case-study portion of Haegelin's presentation. Results of the shop effort are provided by way of photos showing indication-free welds after the service run following repairs, significantly reduced corrosion and oxidation attack, less degradation, etc.

Liburdi. 7F gas turbine nozzle repair: Proven LPM technology for cycling units, *Doug Nagy, PE, manager, IGT component repairs, Liburdi Turbine Services.*

Doug Nagy, who manages industrial steam- and gas-turbine component



2. LMP superalloy in putty form is used to fill local voids and ones of arbitrary shape (A); in sheet form, the superalloy is used to build up thinned areas (B)

repairs at Liburdi Turbine Services, says the company's LPM® technology saves users money by extending the lives of critical turbine parts. The high-strength metal-replacement process was developed for the repair of gas-turbine components over 30 years ago.

Since that time, Nagy contends, Liburdi Powder Metallurgy has proven itself a useful and cost-effective process applicable to both repairs and new-component manufacture on polycrystal, directionally solidified (DS), and single-crystal superalloys.

As turbine owner/operators find their operating profiles shifting to starts-based maintenance cycles, the component life-limiting damage mechanisms have shifted from creep and coating consumption to thermal-fatigue cracking. Such cracking, Nagy says, is not well addressed by braze repairs, is tedious to rectify with weld repairs, and is very expensive to patch by couponing.

LPM technology, he continues, is a unique way to repair damage that is sufficiently ductile and has low distortion. The filler metal is a superalloy that can be varied in composition to provide specific properties; it can be used on cracked, crazed, and oxidized surfaces.

Capabilities include the following:

- Gaps of more than ½-in. wide can be filled without the distortion often identified with weld repairs (Fig 2).
- Surface areas of more than 10 in.² can be built up in thicknesses of up to 5 mils per layer.
- Heat treatments can be tailored to match the substrate.
- LMP repairs can be welded and re-repaired.

Alloys familiar to turbine owner/operators that have been repaired by LMP include GTD111, GTD222, FSX414, GTD741, and IN738.

The webinar explains the process and materials, how and why proper preparation is critical to success, and shows practical results from prior repairs.

Conco. Practical application of tracer-gas leak detection and cleaning methods of air-cooled condensers, *Gary Fischer, national sales manager, Conco Services Corp.*

Every owner/operator of a plant with an air-cooled condenser (ACC) might benefit from listening to Gary Fischer on the value of an ongoing condition-assessment program and how the experts find performance-robbing leaks quickly. His presentation is fast-moving, easy for both new and experienced employees to understand, and answers the question, "Why do we *not* want to try doing this with plant personnel?"

Fischer begins with several slides on the importance of cleanliness, the sources of fouling, and how to remove external deposits. He dismisses the use of fire hoses (too much water, minimal cleaning effect) and high-pressure hand lances (damage to fins and galvanized surfaces) in short order and touts the value of automated cleaning illustrated in Fig 3 (tight process control, uniform cleaning, no need for scaffolding).

3. Automated cleaning machine has nozzle beam optimally matched to tube-bundle geometry with a constant jet angle. Nozzle design, distance from surface, and jet energy are adjustable. The carriage moves at constant speed

For identifying the source of air in-leakage, Fischer says non-hazardous helium wins hands-down. Detection is quick and reliable for most leaks at 1 part in 10 million above background (5 ppm). Perspective: Sometimes you're looking for a leak less than the size of a dime in a surface area equivalent to three or four football fields. Helium can help you find that.

Oftentimes leaks are not where an inexperienced person might believe they are. A leak can be outside the ACC proper and in the hogger or hogger exhaust, the gland-seal drain/trap, the crossover bellows, or at welds in retrofit projects.

Indicators of in-leakage are high backpressure, dissolved oxygen, and continuous hogger use. Don't be surprised to find an air leak in a new unit, Fischer says. In one case, installers "simply forgot" a gasket on a jet isolation valve.

Tracer-gas leak detection, concludes Fischer, is a very cost-effective method for maintaining Rankine cycle efficiency where ACCs are installed.

CECO Environmental. It's probably not the catalyst: Why your SCR system is underperforming, *Vaughan Watson, director of aftermarket sales and service, and Tim Shippy, VP/GM, CECO Peerless.*

Vaughan Watson and Tim Shippy, both with decades of emissions-control experience, begin by urging listeners to "think beyond the catalyst to improve your plant's emissions performance." They review (1) areas of an SCR system (Fig 4) susceptible to performance issues, (2) the importance of proper design and maintenance of ammonia injection grids (AIG) and how to avoid plugging, (3) the impacts of cycling and load changes on emissions performance and how to address them.

You will learn from in-depth case studies where AIG upgrades improved SCR performance; also, from the case study of a repowered combined-cycle plant to meet especially stringent emissions limits.

The presenters provide guidance on

4. Ammonia injection grid supplied by the SCR system (photo) is designed to provide the desired ammonia distribution across the entire duct to assure optimal NO_x control the reagent quality necessary for top performance, maintenance best practices, and SCR equipment and controls necessary to support fast-start/cycling operations. The use of in-situ tuning grids for optimizing AIG performance is included. They alleviate the need and expense of scaffolding, traverse testing, and reiterative adjustments.

Cutsforth. Presentation 1: Integrated generator condition monitoring, *Kent Smith, Kent N Smith Consulting Services LLC, and David Jahnke and Steven Tanner, Cutsforth Inc.* Presentation 2: Detecting defects in generators with continuous shaft voltage and ground current monitoring, *David Jahnke, software/electrical R&D manager, Cutsforth Inc.*

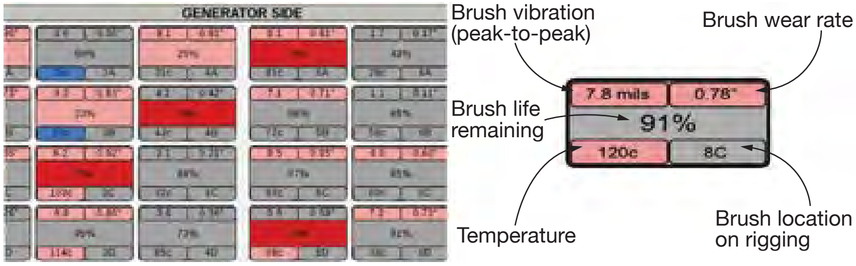
Cutsforth is an industry leader in the development and implementation of tools for generator condition monitoring—including brush condition, electromagnetic interference (EMI), and rotor flux. This two-part webinar updates personnel with generator responsibilities on the latest developments in diagnostic technologies and their commercial experience.

Subject Matter Expert Kent Smith of Kent Smith Consulting Services, the first chairman of the Generator Users Group (www.genusers.org) opens the program with a definition of electromagnetic signature analysis (EMSA): The capture and analysis of both controlled and uncontrolled electromagnetic emissions absorbed by generators and other electrical equipment to determine if there are any uncontrolled sources of discharge being emitted from a given powerplant's electrical equipment. The uncontrolled discharge signatures can be used to determine the electrical health of medium- to high-voltage equipment.

Electrical defects in generators that have been detected with EMSA include the following:

- Slot discharge resulting from the deterioration of side packing.
- Loose endwindings (broken ties), stator bars (loose wedging), and phase rings (circuit rings).
- Shaft oil/hydrogen seal rub.

Permanently installed EMSA detection equipment, developed in a collaboration between Duke Energy and National Instruments for implementation fleet-wide by the utility, replaces "portable," bulky and high-cost data acquisition gear. The new instrumentation can capture and trend data hourly or more frequently and store it for analysis without wasting technician time in the field gathering of information.



5. Cutsforth's brush condition monitoring system effectively eliminates the risk of ring fires caused by short brushes. Alarming for brushes with high vibrations, or similarly low or high temperatures, prevents cascading failures associated with poor maintenance of the collector ring

The webinar illustrates time domain analysis of defect signatures, power spectrum trending and comparison, and signal strength comparison across 8000 frequencies.

Jahnke follows Smith with details on brush-condition (Fig 5), rotor-flux, and shaft-ground monitoring. The first allows plant personnel to perform maintenance based on actual brush condition rather than on calendar- or walkdown-based inspections.

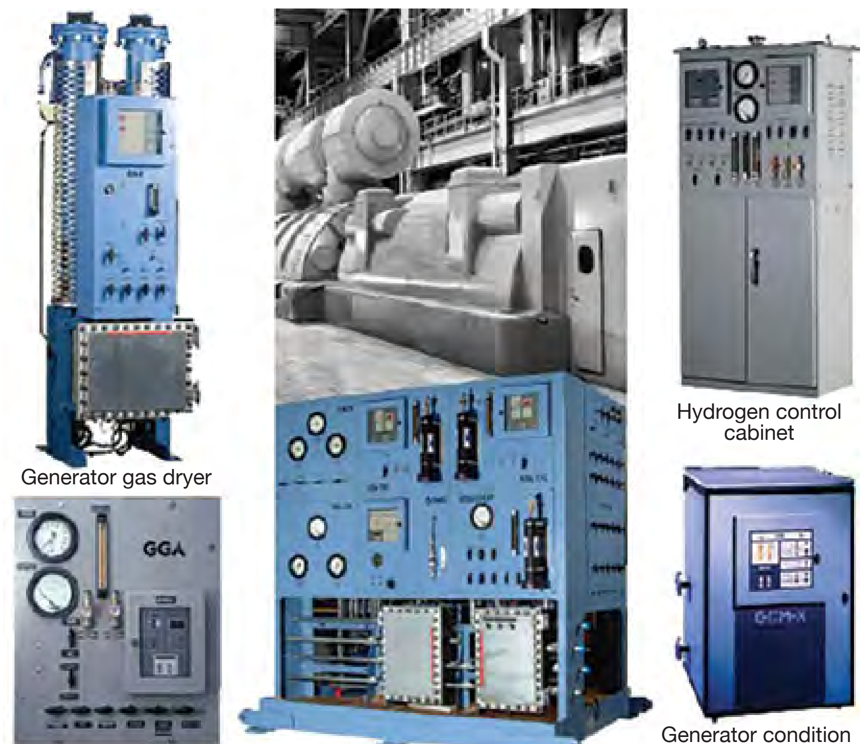
Rotor flux analysis captures high-speed flux signals to identify shorted turns and their severity. Plus, flux waveforms and generator loads are archived for historical trend analysis. Installation of flux probes reportedly is relatively simple and not requiring an outage.

High-speed waveform ground monitoring is said to provide superior ability to analyze and assess shaft grounding conditions while also providing insight into broader generator conditions—such as these:

- Shaft rubbing.
- Shaft axial magnetization.
- Electrical discharges via bearing oil film.
- Vibrations.
- Isophase neutral faults.

Several failure and fault conditions described by screen shots illustrate the value of robust generator monitoring.

Environment One. FPL case study discussion: Automating your generator degas process, *Gary Griffin, generator engineering and operational support services leader, Florida Power & Light Co, and Gus Graham, director of products and markets, and Mark Williams, region-*



6. Instrumentation and condition-monitoring tools help assure generator safety, efficiency, and risk mitigation *al manager, E/One Utility Systems.*

If you're considering the automation of your generator's degas process, this webinar was made to order. FPL's Gary Griffin, in his fourth decade of serving the electric power industry, presents a case study that answers questions such as:

- Why automate the degas process?
- What safety elements can be achieved from the project?
- What technical requirements should you consider? This includes such considerations as logic location (DCS or local panel), size or presence of the CO_2 vaporizer, time to vent/purge, fill time, generator pressure at CO_2 fill, seal-oil pressure control during vent/fill, valve and tubing specifications, etc.
- What challenges might arise in project implementation?

E/One instrumentation and condition-monitoring tools available to assure generator safety, efficiency, and risk mitigation (Fig 6) are summarized.

Nord-Lock. Solutions for turbine/generator coupling seize-up, *Peter Miranda, director, business development, Nord-Lock Group.*

Turbine pro Peter Miranda looks at the critical-path threat that occurs in turbine/generator coupling flanges when fitted bolts seize in their bores, plus other risks associated with using conventional coupling bolts. He explains the principles of mechanical expansion bolts—what they are, how they work, and how they alleviate the problems often experienced with conventional bolts. Case studies demonstrate how mechanical expansion bolts have been used successfully to eliminate the concerns with conventional bolts (Fig 7).

The photos and drawings (especially) used throughout the webinar enable you to quickly understand torque transmission by friction and shear drive, issues faced when using fitted bolts, and the benefits of expansion-bolt technology.

7. Superbolt replacements for 12 fitted studs on a 400-MW steam turbine: 12 EzFit mechanical expansion bolts, each secured by two multi-jackbolt tensioners. Torque required was only 55 ft-lb

EthosEnergy. You can run longer: What to do when your GE gas turbine is reaching the designed rotor end-of-life limit, *Kale Dreymala, gas-turbine rotor project manager, EthosEnergy Group.*

If your plant is equipped with a GE industrial gas turbine (Fig 8)—Frame 3, 5, 6, 7 (A, B, C, E, EA, and/or F)—and mention of the OEM's Technical Information Letter 1576 doesn't make your ears perk up, you need to listen to this webinar. Even if you've heard about TIL-1576, it's worth listening to for a refresher.

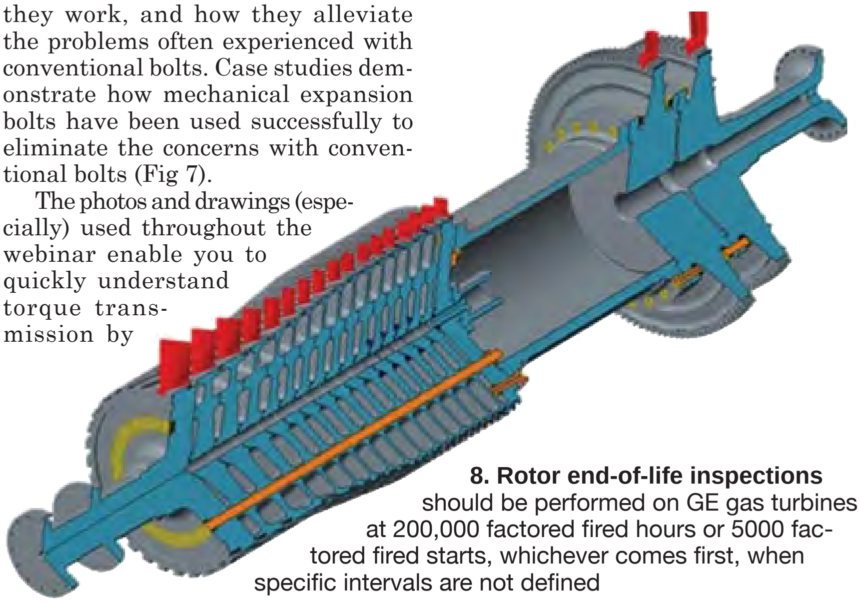
TIL-1576, released in 2007 and updated in 2011, identifies the equipment and personnel risks associated with operating gas-turbine rotors beyond 200,000 factored fired (FF) hours (144,000 for F-class units) or 5000 FF starts, whichever comes first, when specific intervals are not defined.

Kale Dreymala takes you through the inspection scope recommended by EthosEnergy Group (EEG) for turbine wheels, distance piece/spacers/stub shaft, and compressor wheels. If there are no findings, the rotor is reassembled with new bolts and your engine receives a certification for an additional 50,000 FFH (one time only).

If there are findings, the speaker says the OEM is likely to suggest buying a new rotor or possibly a replacement wheel or disc if that is the life-limiting part.

An affordable aftermarket solution suggested by EEG probably would be to obtain a used rotor with a documented history and refurbish it in the shop. The additional life certified (from 50,000 to 200,000 FFH) depends on an engineering review.

Dreymala went on to describe EEG's capability for manufacture and qualification of new rotor components as might be required during the refurbishment process get the best balance between cost and additional life. Other rotor options also were presented during the webinar. CCJ



8. Rotor end-of-life inspections should be performed on GE gas turbines at 200,000 factored fired hours or 5000 factored fired starts, whichever comes first, when specific intervals are not defined

Make sure cyber issues don't overwhelm an acquisition

Plant digital systems are not necessarily top of mind when acquisitions are undertaken, observes Tyler Ward, VP security of Infinite Group Inc, reflecting on "Is the plant worth the price?" an article by Jeff Schroeter of EnEx Advisors in CCJ 3Q/2016, p 50. Ward believes a cybersecurity expert should be added to the due-diligence team suggested by Schroeter. Reason: Organizations are not only inheriting equipment, employees, finances, and practices of the other party—but also the cybersecurity practices (good or bad) and accompanying potential cyber risks.

Yet very few M&A processes measure the cyber-maturity and cyber-risk levels of organizations prior to, and during, the standard M&A due-diligence process. This can prove costly, leaving the most secure organizations exposed to unexpected risk (see later example), force them out of compliance, and even result in taking on an active network compromise or data breach.

To begin to address this gap in M&A due diligence, Ward suggests considering the following questions:

- Are we inheriting a compromised network or unsecured information or non-compliant security posture? What are the potential penalties?
- What new cybersecurity and privacy regulations are we subject to?
- Will we inherit "reputation damage" based on a data breach from the acquired or merging organization?
- Will we be able to control the cybersecurity posture of the new enterprise post M&A?
- Is our current staff and budget sufficient to scale the new enterprise under a larger scope of regulatory and cybersecurity responsibilities?
- Does the poor cybersecurity posture of the acquired or merging organization offer leverage to negotiate a better price?
- Should we give the acquired or merging company an ultimatum to raise the cybersecurity posture prior to M&A or deal with it afterwards?
- When was the last cybersecurity assessment performed and what were the results? Should we demand a cybersecurity gap assessment as part of the Letter of Intent?

This is just a start. The list can go on and include lengthy reviews of specific metrics to gain a complete understanding of the new risks, alignments, and benefits.

Forewarned is forearmed. So, how can the existing M&A due diligence integrate cybersecurity and information security processes? These are the generic activity buckets: Choose a trusted set of standards and cybersecurity framework, conduct a thorough cybersecurity gap analysis and risk assessment, estimate costs around the risks and mitigation, as well as potential penalties for non-compliance, and formulate a comprehensive cyber risk mitigation plan.

Only by delving deep into the risks associated with people, processes, and technologies can you paint a clear picture for informed decisions. By placing the cybersecurity and regulatory posture of organizations under the microscope, businesses can forecast costs associated with various compliance requirements.

Better to learn from others. The following example is presented in the spirit of "learning from your mistakes is good, but learning from the mistakes of others is better."

A power generation organization with 10 remote sites and staff of nearly 100 faced a challenge in acquiring several remote facilities. Directly after the acquisition of the smaller firm's IPP facilities, the parent organization set out to conduct an audit of the IT networks with three main goals: Assess security, functionality, and compliance among the independent sites.

The audit resulted in multiple egregious findings that did not conform to NERC-CIP protocols and standards. Several systems were found to be running outdated and unsupported operating systems, personnel were not properly vetted for performing maintenance activities, vulnerability remediation was not taking place, and most importantly, the IT environments were not properly segmented from the operational networks.

The findings were taken to the board room at the parent company, which had begun to schedule and budget for the necessary changes. Immediately linking the smaller and more vulnerable networks to the parent company was not an option because of the risks posed. The mitigation strategy would require several million dollars and tie up company resources. The parent organization subsequently decided to "kick the can down the road" until the next fiscal year with a larger budget.

This proved a costly mistake. Shortly after the acquisition was finalized, an incident occurred. After some suspicious activity on a desktop, several pieces of malware were found that did not have active signatures in known anti-malware databases. This indicated the malware was either new or specifically obfuscated for reasons of stealth.

The malware in question was quickly able to exploit the workstation on which it was residing because of a combination of poor vulnerability management and improper protections at the desktop level. The attackers were able to compromise four other workstations before being detected by an employee. Since the organization did not have strong vulnerability and patch management practices, this left it open to malicious attacks.

The incident response team spent more than two weeks sifting through logs, examining systems, interviewing staff members, and formulating a report. The total engagement cost the organization tens of thousands of dollars in lost employee time, incident response fees, and subsequent mitigation.

This case study confirms what's already known: Critical infrastructure sectors are under heavy attack by both domestic and foreign adversaries. Many independent power producers, energy brokers, and distribution entities are prime targets and vulnerable to such attacks. Robust cybersecurity processes within the due-diligence program will help ensure that the parent organization isn't victimized by the oversights and cyber inadequacies of the acquisition target. CCJ

Disparate 'no starts' offer chance to review for single points of failure

Two recent unrelated field events at separate sites had a common factor: A single point of failure originating in one device out of a redundant set. Together, they offer an opportunity to tighten up start sequences and avoid failures to start, noted Abel Rochwarger, chief engineer, Gas Turbine Controls Corp.

The first case involves a site with four simple-cycle frame gas turbines, the second a site with two aero GTs in a combined cycle.

TCs located too close to the filter housing walls led to spurious trips in the start sequence

Ambient temperature TCs. At the frame site, a high differential among ambient-temperature thermocouples (TCs) was causing a "not ready to start" situation.

Ambient temperature is measured with three TCs in the inlet filter house having a centerline oriented north-south. When the sun is in the West, the west-side thermocouple (W-TC) reads higher than the other two. This creates a differential that is interpreted as a "failure" resulting in a "not ready to start" status.

Examination of the inlet filter house revealed that the W-TC (photo at left), was much closer to the wall than the east-side thermocouple (E-TC, photo at right). The third thermocouple was on the centerline. The W-TC reading was affected by the proximity to the inlet-filter sidewall.

There were two compounding problems. The first is sub-optimal location of the thermocouples. For ambient-temperature measurement, it should be acceptable to install all three thermocouples about 2 ft apart in the center of the filter house. The second is that the sequence used a "no high differential" as a permissive to start—that is, a high differential would result in a "not ready to start" condition.

Thus, one thermocouple reading much differently than the other two resulted in a "not ready to start," a single point of failure.

Two-part solution. The first recommendation is that, at first opportunity, the site should locate E-TC and W-TC closer to the center of the inlet filter housing, about two feet from the centerline TC. This has the added advantage of allowing maintenance on all three without maneuvering a step ladder while also avoiding the nuisance alarm during sunny periods of the day.

The second recommendation is to replace the "no high differential" from the permissives-to-start with a "two out of three TCs failed." Having triple redundant TCs use the differential between the highest and lowest reading to determine start readiness does not make sense. With this simple mod, when one TC fails, the site gets an alarm but will still remain ready to start; two failed TCs will interrupt the start sequence.

Speed pickups on aero GTs. At the second site, during startup, one of the two LP-compressor speed pickups feeding the control core (not the protective) was spiking to 128% (max scale) momentarily, but long enough to trip the unit. The spikes occurred only during startup and at below 40% speed.

Site personnel changed the speed pickup, rechecked all the wiring, shields, and wiring and shield terminations, and, as expected, found nothing damaged, loose, or wrong. Yet the situation persisted. Curiously, after the spike induced the first overspeed trip, the operator could restart the unit, consistently, with no second spike.

Other specialists could not find any physical evidence of malfunction, or wiring errors, either, so the sequencing was investigated. These units have two, not three, control speed pickups per shaft. A high-select block, the higher of the two speed pick-ups, determines the LP-compressor shaft speed.

If one of the two speed pickups spikes, even momentarily, the high-select block will read the spike as the shaft's speed and trip the unit. This is the single point of failure.

However, there is a selectable option with better functionality for checking I/O status. When the signals are within acceptable limits, the output can be the average (Avg) instead of the maximum (Max) of the two input signals (the "high select" block).

This method will also detect high differential and discard the first "too high or too low" device using the other device's value as the block's output through the Max function instead of Avg. If both devices read too high or too low, the block detects an "all devices failed" condition.

This not-so-widely-used block, compared with the "high select" block, allows the unit to survive the speed spike without a trip during the start. The corresponding one-bad-signal alarm is dropped during the momentary spike.

After making this mod, the units have gone through several starts without trips.

Wrapping up. It is not clear why the OEM's sequence considered the "no-differential" as a permissive to start with three physical redundant thermocouples, or why the TCs were located so close to the walls. Why the OEM used the "high select" block instead of the alternative one at the aero site is also a mystery. But independent review can discover valid options to resolve single-point-of-failure conditions. CCJ

How adjustable peak firing can improve your plant's bottom line

Depending on your plant's power purchase agreement, adding peak-firing capability to simple- and/or combined-cycle gas turbines can provide significant economic benefit—provided the peak-fire capability is used strategically at times of high demand to avoid unnecessary maintenance.

Recall that *traditional* peak firing increases the firing temperature a fixed, incremental amount above the rated baseload value. This increase can equate to at least a 2.5% bump in output above baseload for the latest GE units not suffering compressor or turbine performance degradation. Because an increase in firing temperature boosts NO_x production, the degree of incremental firing achievable above baseload may be constrained by NO_x emissions limits.

Adjustable peak firing can be a valuable tool where emissions exceed allowable limits before the gas turbine reaches its standard peak-firing limit. It allows you to increase load and take advantage of periods of high electricity prices while holding emissions within permit limits. This capability is especially meaningful for merchant plants equipped with SCRs.

When enabled, the adjustable peak-firing option from Turbine Technology Services Corp, included with TTS's Dynaflex Performance™ toolkit, allows operators to incrementally increase output in steps of 0.1 to 0.2 MW. Note that the TTS adjustable-peak option maintains an upper firing-temperature limit equal to the standard peak-firing temperature for the unit.

However, certain unit configurations or NO_x permits may enable some DLN turbines using the adjustable-peak tool to achieve incremental outputs above those possible when limiting the upper firing temperature to that recommended by the OEM.

Two scenarios illustrating the value of the TTS adjustable peak option follow:

- A plant with 7FA DLN2.6 gas turbines restricted to NO_x emissions of 9 ppm on a 30-day rolling average basis is allowed to release 10 ppm NO_x on a 1-hr rolling average. Typical baseload NO_x emissions for this owner's units are about 8 ppm.

  Enabling the TTS variable peak-firing solution on these units would allow the user to increase output above baseload by up to 2.5% while still maintaining NO_x emissions at just below the 10-ppm, 1-hr limit. When used strategically, this capability would significantly increase revenue without putting the 30-day rolling-average limit of 9 ppm at risk.

- In many locations, DLN gas turbines in combined-cycle systems use an SCR in the HRSG to reduce NO_x emissions from 9 ppm to low-single-digit levels—2 to 5 ppm is typical. For these units, emissions permits put specific limits on NO_x at the stack exit. Thus, use of variable peak firing on SCR-equipped units may allow operators to deliver more than a 2.5% increase in incremental output provided the plant has adequate ammonia injection capability.

Your interest in peak firing piqued, the first question you have might be: "What would I have to do to implement the peak-firing option at my plant?" Simple answer in general terms:

- Verify your plant-specific air permit allows such modifications and obtain state approval.
- Make some control-system logic modifications.
- Modify the HMI screen to allow an operator to select adjustable peak fire.
- Make the combustion tuning adjustments necessary to install peak-firing capability.

Your second question might well be: "Who has done this and what were the results?"

One experience is shared in the case history below.

Rock Springs Generation Facility, equipped with four simple-cycle 7FA.03 gas turbines (744 MW), operates in the PJM capacity market and has NO_x emissions limits of 9 ppm (30-day rolling average) and 10.5 ppm (hourly average). Cogentrix Energy Power Management LLC operates the Rising Sun (Md) facility for owner The Carlyle Group.

General Manager Ralph Jones, who has been at the facility since 2008, said that the plant began life as a joint venture between Old Dominion Electric Co-op (ODEC) and Essential Power LLC, an IPP. Jones was an Essential Power employee (operations side) before Carlyle acquired the facility and remembers being challenged by management to decrease operating expenses and potentially increase unit capacity.

During that period, the units required remote tuning seasonally, possibly more frequently, to control NO_x or combustion dynamics. GE would perform remote tunes when requested, adding significant unplanned expenses. In many instances, a remote "tuner" was not available to immediately tune the engines. This caused the operator to reduce load to maintain compliance or correct combustion dynamics.

In 2014, Jones continued, plant staff was searching for a solution that would minimize having the units remotely tuned for a minor emissions or combustion dynamics issue. Turbine Controls and Excitation Group (TC&E), Yarmouth, Maine, was invited to the plant and John Downing made some small adjustments at baseload to PM1 and PM3, which were effective. But this would not be a viable solution over the long term because of its cost, so Downing and his team developed logic and an operator interface screen that enabled so-called Manual Adjust Fine Tuning (MAFT) through the DCS.

Using MAFT allows operators to adjust fuel flow by ±1% on PM1 or PM3 gas valves with a small set of written instructions. This way, operators can make adjustments when emissions are trending toward noncompliance, to avoid a NO_x excursion while also providing a means to suppress combustion dynamics within certain frequencies/tones. The method was very successful and minimized the number of remote tunings required and kept the units at baseload.

During the plant's first decade, give or take a few years, the recommended way to increase peak output was by using GE's peak-fire product. Jones described it as the equivalent of an on/off toggle switch. When a unit approached the emissions limit in "Peak On" mode, the operator would have to flip the switch to "Peak Off," thus missing the commercial opportunity.

In 2015, Rock Springs asked TTS if it could provide an adjustable peak-firing system for its two gas turbines that would maintain combustion dynamics and NO_x emissions during peak-fire operations. The design of the system would allow for simple "on the fly" adjustments by the operator. The TTS solution was implemented and delivered 4 MW of summer peak-load capacity per engine and worked in complete harmony with MAFT.

Fast forward to September 2018: The Carlyle Group purchased from ODEC the remaining two units at the site and hired TTS to install its adjustable peak-firing solution on those engines. The benefit was 3.5 MW of summer peak-load capacity each, bringing the total for all four units to 15 MW. In the PJM capacity market the 15-MW increase translates to significant financial gain.

One final note: TTS Senior Systems Engineer Mitch Cohen, well known to many CCJ readers for his valuable editorial contributions over the years, was onsite at Rock Springs to analyze fuel-flow curves and other data required to develop the successful adjustable peak-firing logic modifications. Jones concluded his interview with the editors saying the project went off "without a hitch" and offered the owners an excellent return on their investment. CCJ

Come up to speed fast on batteries with this no-cost resource

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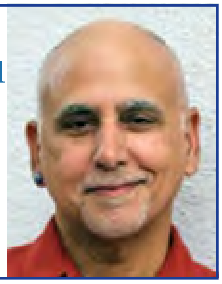


Some veteran gas-turbine (GT) asset managers have already been given responsibility for grid-scale storage facilities. Others may find their asset portfolio shift in this direction soon.

If you are in this camp, or if you just want some technical guidance around this new asset class, get a copy of the Advancing Contracting in Energy Storage Working Group's (ACES) *Best Practice Guide* (BPG), available online at no charge (https://www.mustangprairie.com/index.php/aces-best-practice-guide).

According to lead investigator and storage sector veteran consultant Richard Baxter, the ACES BPG was written primarily for non-technical stakeholders in storage projects—lenders, lawyers, new project developers, and others—to help them "define what it is they are being asked to participate in, ask the right questions, and evaluate and compare project opportunities."

Baxter further notes the overall objective is to "more quickly get the sector to coalesce around generally accepted practices."

Grid-scale storage is a wholly new electricity asset class being developed primarily around exciting, but complex, new battery technologies. It's on the cusp of rapid growth. GT veterans might liken it to the early to mid-1990s when IPP and merchant generation projects around advanced gas-turbine technology were entering the industry.

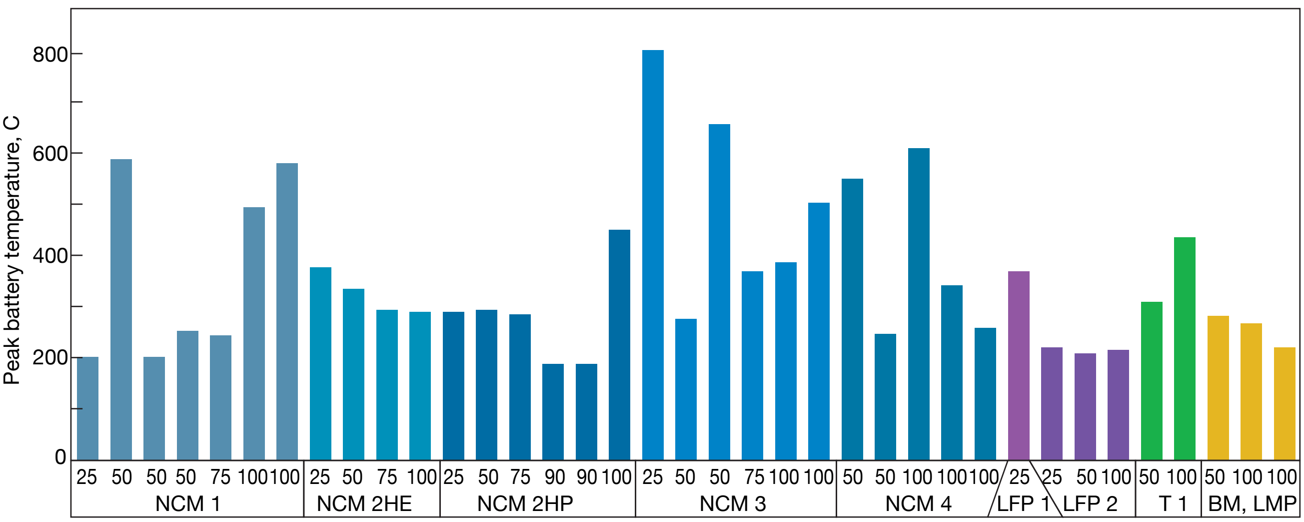
One thing's for certain: You can't pick up your operational practices from other less dynamic energy technology projects, warns Baxter, whether GT, solar, or wind, and impose them on battery storage. Energy storage is "more akin to a living organism" and standardized maintenance protocols will only come with far more field experience than the sector has today.

Still, GT experts will recognize some analogies to their facilities. For example, performance of lithium-ion batteries, the prevailing technology, is affected by ambient temperature. For GTs, it's efficiency and output.

Batteries, however, chemically and physically degrade; deviations from ideal operating temperature can have "severe consequences" on battery cell life (chart)—just think of your digital devices. Parasitic energy is consumed to maintain that ideal temperature within the enclosure. Assuring uniform flow of coolant around battery pack outer enclosures is essential, but a challenge.

ACES's BPG confirms what was learned last year at storage-industry meetings: There is little consensus deriving basic grid-scale battery performance parameters—such as reliability, round- trip efficiency, and degradation rates. Safety is in the same category. The BPG quotes an earlier 2014 DOE report, "It is almost impossible to have a meaningful technical discussion about ESS [energy storage system] performance or reliability."

While the report acknowledges there has been progress within storage communities to address these gaps, the CCJ summary from last year (CCJ No. 60, p 3) suggests there is still a ways to go. The Energy Storage Association's (ESA) Corporate Responsibility Initiative also is addressing safety and reliability issues. CCJ



Peak battery temperature by cathode chemistry, sourced from Consolidate Edison Co of NY's "Battery Testing Report," published in 2017. Note that the number under each bar in the chart represents the state of charge

Maintenance critical to assure top gas-turbine performance

Air inlet systems—including filter houses, evaporative coolers, cooling-coil support structure, silencers, ductwork, etc—seldom get the respect they deserve. Properly maintained, they help assure maximum output and high availability of your gas turbines. Yet, they are almost an afterthought at many plants, the focus being primarily on rotating equipment.

Annual inspection of the air inlet system by plant personnel typically is recommended by owner/operator colleagues participating in discussion sessions on the subject at user-group meetings. Those discussions typically focus on air filtration alternatives and inlet cooling systems (evaporative coolers, foggers, chillers), paying minimal attention to the structural elements of the filter house and bellmouth.

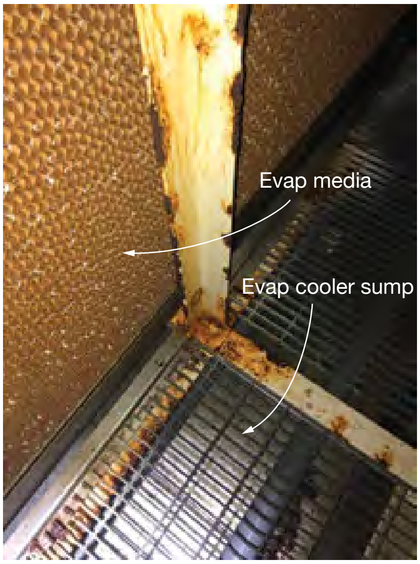
Air inlet systems can be divided into four parts: (1) bellmouth or inlet scroll, (2) inlet plenum, (3) clean-air side, and (4) dirty-air side. It's very important to inspect for coating failures on the carbon-steel surfaces within the filter house and plenum, and downstream to the bellmouth,

Rust, paint chips, and debris released on the clean-air side downstream of the filters (Fig 1), are swept along by the high-velocity air stream and can impact and damage critical components—such as the bellmouth (Fig 2) and compressor airfoils.

Corrosion can be a troublesome problem where filter houses are installed near wet cooling towers and/or when fogging systems are used for evaporative cooling. When corrective action is necessary, users should give special consideration to the outage window, degree of surface preparation, quality of the coating system specified, and the painting contractor's qualifications and competency to maximize maintenance intervals.

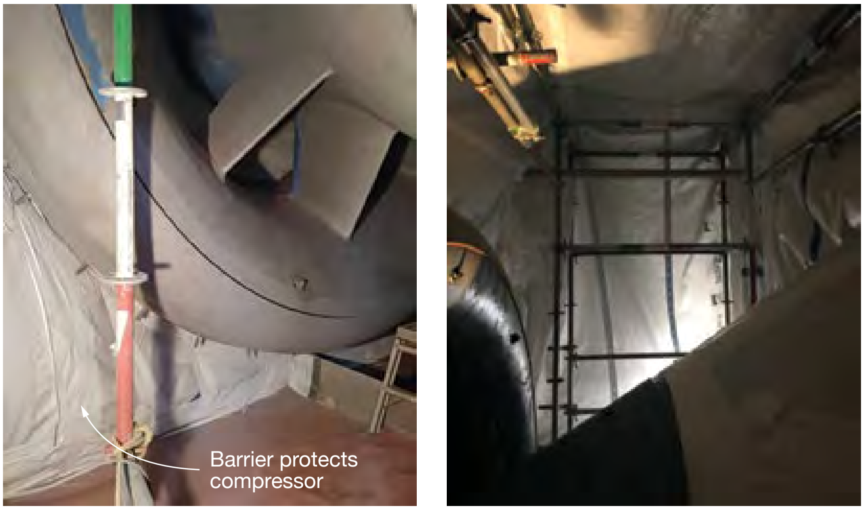
Options for steel preparation are determined by the condition of the material and the existing coating system. Proven options, according to the experts at Taylor's Industrial Coatings Inc (TIC), are (1) high-pressure water blasting with spot power tooling of severely corroded areas, and (2) grit-blasting.

OEM coating specifications typically call for an inorganic zinc primer, epoxy intermediate, and/or top coat. This is a respected coating system for shop-applied products—when done correctly. However, Troy Waters, TIC's field superintendent, explained that zinc primers sometimes are not applied

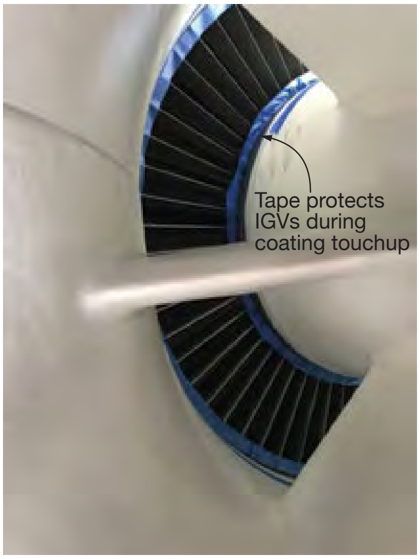


1. The high-moisture environment created by evaporative cooling systems attacks carbon-steel components when holidays occur in coating systems

2. Bellmouth coatings can be shredded by particulates entrained in the high-velocity clean air stream flowing to the gas turbine

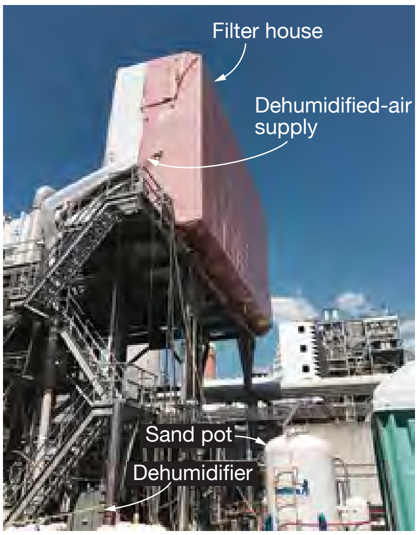


3. Barrier at left prevents grit and coating chips from entering the compressor. Complete isolation of the work area keeps debris contained (right)



4. Masking tape protects moving elements of the inlet guide vanes during strip-coat step

5. Bellmouth looks like new following three-step coating process



6. Filter house is wrapped like a holiday gift to contain grit and coating chips during the blast step (left). Note the dehumidified-air line to mitigate oxidation of freshly grit-blasted surfaces and the sand pot for collecting spent grit and other debris

7. Filter-house tubesheet, grit-blasted and coated, is ready to receive filters and return to service

in accordance with the manufacturer's instructions and may not maintain their integrity for the expected service life.

Reasons include the failure to (1) adhere to the manufacturer's recommended 24-hr minimum recoat time, (2) remove loose zinc dust from fall out/overspray, and/or (3) take the extra step in promoting adhesion of the subsequent coat by screening the zinc prior to the epoxy intermediate or top-coat application.

To protect against delamination and corrosion, TIC created a proprietary coating system which it says has been validated in the harshest of environments—including coastal, high humidity, and highly polluted atmospheres.

TIC's management strongly recommends against recoating the bellmouth until inspections are performed upstream by its experts and they confirm the coating is well-adhered to metal surfaces. Were coating material to release into the air stream it could quickly compromise the new asset protection coating system downstream.

Figs 3-7 illustrate work by TIC personnel on the filter house of a 7FA about halfway through the engine's nominal design life of 30 years. In this case, particles of rust and coating released from the bellmouth and upstream components were damaging the smooth profiles of airfoils, therefore reducing compressor efficiency. **CCJ**

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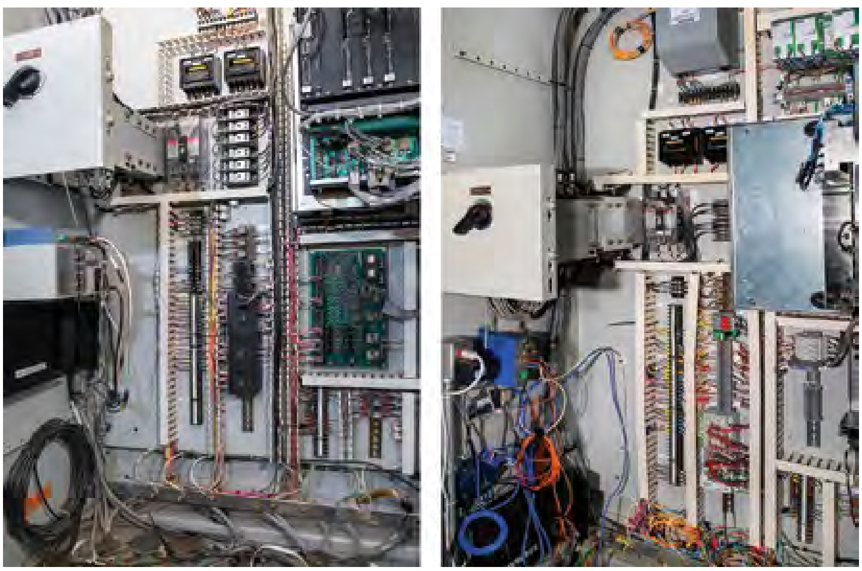
Solutions for more reliable GT starts

Rock Springs lauds start system retrofit

The turnkey digital front end (DFE) solution for aging, unreliable, or obsolete gas turbine load-commutated inverter (LCI) starting systems, described last year in CCJ No. 60, p 26, now has a user testimonial and operating experience supporting it.

Rock Springs features four 7F peakers; plant began commercial operation in 2003

1. Rock Springs avoids GT start risk with innovative digital front-end retrofit to the original load commutated inverter (LCI) system (left). Larger screen on front of cabinet makes life easier for the plant crew (right)



2. New controls feature redundant power supplies and new I/O modules, PLC, and controller module. Original system is at left, upgrade at right

John Chaya, operations manager at Cogentrix Rock Springs (Maryland), reports that the installation by Turbine Controls & Excitation Group Inc (TC&E), Denver, Colo, went "as expected," testing proceeded with only the normal number of "bugs" to sort out, and all machine starts since Nov 8, 2019 have been successful. All acceleration and ramp rates were matched to the original OEM specifications.

All four 7F peakers at Rock Springs (commercial in 2003) will soon be served by two DFE LCIs, with the second unit install to occur this year.

Chaya notes that the motivation for the retrofit was that the majority of unit unavailability was attributed to the LCI. The precipitating event occurred in October 2017 when two units were out of service for 12 hours. Obtaining spare parts was becoming an issue as well. The units experienced 120 starts in 2019, mostly in the summer.

"The TC&E/TMEIC team was very professional and did the work in the time frame promised," The timeline was three days for component change-out, two days for testing and commissioning during the 2019 fall outage.

Other benefits attributed to the project by Chaya: startup procedures remained the same and the electronics and interface screens are much larger and easier to read (Figs 1 and 2). One piece of advice he offers the next users: Be sure to request training for troubleshooting, even though "it's pretty intuitive to get through the manuals."

TC&E/TMEIC completed three DFE LCI upgrades last year.

Perryville adds big GE battery for 7F peaker black start

In what GE claims to be the largest gas turbine black-started by a modern battery, Entergy Louisiana has added a 7.4-MWh lithium-ion (nickel-magnesium-cobalt chemistry) unit at its Perryville power station to restart a 2001-vintage, 150-MW 7F.03 peaking gas turbine/generator should grid power be lost.

To re-energize the grid, black starts typically require separate gas or diesel generators to first start the larger generator. When you avoid a diesel generator, you also avoid other complications, especially the liquid fuel storage and delivery system. Also, black start assets typically are tested more than they are called upon to operate.

The 11-month project reflects several current trends. First is the growing and diverse grid-scale applications for large batteries, primarily lithium-ion. Second is the "hybrid" concept of pairing them with traditional generation and T&D assets. Many storage system engineers consider black start to be the most difficult grid-scale battery application.

According to GE specialists, the storage unit includes a grid-forming inverter, whereas most storage (and solar) assets employ grid-following inverters. The grid-forming inverter essentially creates a voltage source reference point the turbine can synchronize to. In other words, the inverter can operate in stand-alone mode, as its own grid.

"The voltage source inverter control is specifically designed to coordinate with the GT controls, in this case the familiar Mark VIe," said Troy Miller, head of sales for GE Energy Storage, a subset of GE Renewable Energy Hybrids.

The battery system consists of three 40-ft shipping containers with 21,400 battery cells connected to a series of controls to convert DC power to AC.

GE expects interest in its hybrid storage solutions to grow, including solar, wind, and thermal plants, and even for competitor gas turbines. Earlier, GE pioneered the first commercial application of battery storage to LM6000 machines to convert a non-spin peaking unit into spinning reserve at Southern California Edison's Center Peaking facility (CCJ No. 53, p 68).

Entergy Louisiana declined to comment for this article, but was quoted in the GE press release on the project as follows: "This is an innovative use of battery technology that provides another tool to buttress the overall reliability and resiliency of our system."

The utility's 2019 Integrated Resource Plan noted that energy storage, particularly in the case of battery-enabled storage, provides a range of attributes including: The ability to store energy for later commitment and dispatch, ability to discharge in milliseconds and fast ramping capability, rapid construction (on the order of months), modular deployment, portability and capability to be redeployed in different areas, small footprint (allowing for flexible siting), and low round-trip losses compared to other storage technologies (such as compressed air). The IRP made no mention of the Perryville project. CCJ

Under new management

The 7EA Users Group has joined Power Users, the umbrella organization for managing and coordinating the technical programs for many of the electric power industry's leading user groups—including 7F, Combined Cycle, Steam Turbine, Generator, and Power Plant Controls. Sheila Vashi of SV Events will coordinate the 2020 conference and vendor fair at the J W Marriott Houston Galleria, October 19-22.

Over the next year, the current 7EA email forum at www.users-groups.com will move to www.powerusers.org. This transition is not expected to require any action by plant owner/operators. Gregory Carvalho of Simplified Technology Co is working with Power Users to ensure that the 7EA history and subscribers are integrated into the new website.

The 7EA gas turbine's many attributes—including generally high reliability and availability, and good efficiency in a wide range of applications on a variety of fuels—help make it the most popular mid-size (nominal 85 MW) industrial gas turbine. There are said to be about 1200 of these machines in service.

Annual conferences of the 7EA Users Group attract upwards of a hundred attendees, representing owner/operators from across the globe, to share experiences. Inspections and overhauls typically are a focal point of interactive discussions among users. Virtually everyone in the room wants to know what issues to be aware of, where they are likely to occur, what the indications look like, how frequently their engines should be inspected, etc.

Inspection findings. At the 2019 meeting, the editors spoke to Mike Hoogsteden, director of field services for Advanced Turbine Support LLC, which inspects scores of these machines 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.

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:

7EA Users Group

2020 Conference

J W Marriott, Houston Galleria
Houston, Tex • October 19-22

Steering Committee

Dale Anderson, *East Kentucky Power Co-op*
Tracy Dreymala, *EthosEnergy Group, San Jacinto Peakers*
Guy LeBlanc, *First Energy Group*
Tony Ostlund, *Puget Sound Energy*
Mike Vonallmen, *Clarksdale Public Utilities*
Lane Watson, *FM Global*

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.

1. Generator circuit breaker cabinet after breaker in Fig 2 has been removed

2. GE Magne-blast breaker at NBS shop for rehab and upgrade

There are many more TILs that demand your attention, to be sure. One is 1090-2R1, "Compressor R17 Blade Movement."

Blending to Stage 11. When compressor inspections point to the need for blending to remove stress concentrations or cracks that could contribute to the liberation of a blade or pieces of one, Hoogsteden recommends it be done in-situ. This saves time and cost by limiting the extent of unit disassembly required to make the repair. He said that Advanced Turbine Support is now able to perform in-situ blending on 7EA compressor rotors from the inlet guide vanes to Stage 11.

Summaries of several other presentations made last year follow.

Emerson's Patrick Nolan, well respected by GE 7EA users for his knowledge of the gas turbine and its control, focused on fast starting and fast loading of a simple-cycle engine to take advantage of market opportunities created by recent industry changes. While starting in 10 minutes or less and/or loading at up to 30 MW/min can create new revenue opportunities, he noted, the lifetimes of hot parts would be reduced. There is no free lunch.

Nolan's charts compared a typical 12-min normal start to a fast start of about 8 min possible with control-system modifications. Stepwise, the fast start he described would look something like this:

- Start to purge speed, less than 0.5 min.
- Purge, 1.5 min.
- Ignition and warmup to reach 25% speed, less than 0.5 min.
- Acceleration from 25% to 100% of rated full load, about 5 min.
- Synchronization, about 0.5 min.

Taking advantage of NFPA-85 purge credits on shutdown, which requires additional, but affordable hardware, eliminates the need for a startup purge, saving significant time when trying to satisfy market demands.

Logic to test field devices when the turbine is in standby and receive positive feedback that the entire control system is functional also is required. The owner/operator is responsible for evaluating the safety associated with this activity and when to perform testing, given any operational constraints.

Old GCB made new. There's often no substitute for the experience gained at user-group meetings. Consider the case history, presented by a West Coast utility at the 2019 7EA conference in Louisville, on the rehab and upgrade of a 35-year-old main generator circuit breaker (GCB) that simply wore out after three decades of dependable service.

You probably could count on one hand the number of plant personnel who had seen the GCB out of its cabinet since COD. So why would you expect someone on the current staff to know anything about this piece of equipment and how to troubleshoot it, and then what to do when a subject matter expert said it should be replaced?

There almost always are options. In this case, you could buy new—the easiest, and most expensive, option—or you could rehab and upgrade the superannuated breaker and save, perhaps, 75%. A pitfall of buying new is that it likely would require a new cabinet, new foundation, etc. Old-made-new allows use of existing infrastructure and you just pay for the breaker.

Here's what was involved in this project:

1. Pull the old 15-kV GE Magne-blast circuit breaker from the cabinet (Fig 1) and ship to National Breaker Services (NBS) for rehab and upgrade (Fig 2).
2. Rebuild as a modern vacuum breaker and return to the plant (Fig 3).
3. Roll the NBS Citadel-4000 breaker into the cabinet without having to make any changes to the existing infrastructure (Fig 4).

Inlet and exhaust systems, when neglected, are gas-turbine performance thieves. Jeff Cozeby and Laqunnia Lawson identified for 7EA users some of the problems Schock Manufacturing finds when performing inspections on, and making repairs to, these systems. The presenters piqued the interest of conference attendees by offering free inspections through the company's website at www.schock-mfg.com.

Cozeby and Laqunnia began by pointing to corrosion and dirty-air bypass as major contributors to problems found with inlet filters and the inlet duct system. They typically trace the source of these problems to poor design and lack of maintenance and housekeeping. Telltale signs of trouble include corrosion, loose internal parts, leaking gaskets, failed expansion-joint belts, loss of fill in silencer panels, among other things.

3. The three-decades old circuit interrupter rebuilt as a modern vacuum breaker

4. Rebuilt breaker fits in the cabinet like the original

The heart of the exhaust ducting, the pair continued, is the internal liner and insulation system. When not properly designed and/or maintained, or repaired improperly, failures occur. Among the things Schock personnel look for during an inspection are casing hot spots (paint peeling or discolored), sheared or broken studs, exposed insulation, liner cracks, wear and tear of expansion joints, gasket failures at access doors, and loss of fill in silencer panels.

The speakers showed more than three-dozen photos to illustrate their points, providing attendees a valuable library of findings to make operator rounds more meaningful. The key takeaway was for staff to catch problems early when repairs usually are easier and less expensive to make.

Busduct replacement. A utility user provided an overview of a project involving replacement of rectangular non-seg busduct with circular non-seg busduct at two generating units in the Midwest. The former was susceptible to failure from water ingress; water would pool on the top of the busduct and leak inside at joints. Over the years, electrical shorts became more frequent. The first corrective action was to replace internal duct insulators with ceramic ones. This worked, but only for a while.

The speaker said circular non-seg busduct had evolved as the industry's standard long-term solution to the water-ingress problem. He offered the following advantages of circular busduct over the rectangular non-seg configuration:

- Geometry allows it to shed water quickly.
- All flanges are welded, not bolted.
- The connections between the duct and stationary items (generator circuit breaker, step-up transformer, and generator) are flexible, thereby reducing vibration stress points.
- Aluminum housing resists rust and corrosion.
- Reuse of the existing busduct structures was possible with only new mounting hardware.

Crown Electric was selected to manufacture and install the circular bus, which included internal heaters to prevent condensate formation. As to schedule, the speaker said equipment was delivered to the site about three months after the purchase order was issued.

Demolition of the rectangular busduct and installation and commissioning of the circular replacement took two weeks. CCJ

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International Association for the Properties of Water and Steam

IAWPS is a global non-profit association involving 25 countries in all aspects of the formulations of water and steam and seawater, as well as in power-plant cycle chemistry. It provides internationally accepted cycle-chemistry guidance for power generation facilities in Technical Guidance Documents freely downloadable from the organization's website at www.IAPWS.org. Specific TGDs for combined-cycle/HRSG plants include the following:

- Procedures for the measurement of carryover of boiler water into steam.
- Instrumentation for monitoring and control of cycle chemistry.
- Volatile treatments for the steam-water circuits of power plants.
- Phosphate and NaOH treatments for the steam-water circuits of drum boilers.
- Steam purity for turbine operation.
- Corrosion-product sampling and analysis.
- HRSG high-pressure evaporator sampling for internal deposit identification and determining the need to chemical clean.
- Application of film-forming amines in power plants.

FIND A VENDOR, FIX A PLANT

Your direct connection to CCJ's Online Buyers Guide

at www.ccj-online.com/bg

Products and services from over 60 companies support new unit construction, retrofit and maintenance activities at existing facilities, and plant operations. Solutions span gas and steam turbines, HRSGs, pumps, valves, piping, cooling towers, condensers, etc

Advanced IAQ Care USclenblast.com

Dry ice blasting of HRSGs, stators, rotors, turbines, substations, and other power equipment. ISN "A" rating for safety. 21 years of references from plants including Emera, NRG, Dominion, NY /NJ plants, NAES, and EthosEnergy. Price competitive and guaranteed excellent results.

Advanced Turbine Support

Has delivered unbiased fleet experience and superior customer service for more than a decade. Company provides users high-resolution borescope inspections, cutting edge ultrasonic and eddy-current inspections, and magnetic-particle and liquid dye-penetrant inspections in accordance with OEM Technical Information Letters and Service Bulletins.

Aeroderivative Gas Turbine Support

AGTSI offers a full range of aeroderivative gas-turbine, off-engine, and package parts from the most basic to the most critical. An expansive inventory of spares and replacement parts is maintained at our warehouse for all models of GE LM2500, LM5000, LM6000, and LMS100, as well as P&W GG4/FT4.

AGTServices

Over 200 years of combined, proven OEM engineering, design, and hands-on experience; known in the industry for its schedule-conscious, cost-effective solutions with respect to generator testing and repairs.

American Chemical Technologies

Provides state-of-the-art synthetic lubricants to the power generation industry. Founded more than 30 years ago in the US, ACT has grown to become an international supplier of value-added lubricants that provide superior benefits to equipment, the environment, and are worker-friendly.

AP+M

One of the largest worldwide independent stocking distributors of both heavy-duty and aeroderivative gas turbine parts. A reliable partner with an extensive inventory of more than 10,000 parts quickly delivers genuine OEM parts for operators, end-users, depots, and repair facilities.

ARNOLD Group

With more than 550 installed insulation systems on heavy-duty gas and steam turbines, company is the global leader in designing, manufacturing, and installing the most efficient and reliable single-layer turbine insulation systems.

Bearings Plus Inc

Provider of repairs and custom technology upgrades for turbomachinery. Designs and manufactures an integrated solution to meet specific requirements for every operating environment, applying the latest fluid film bearing and high-performing seal technology to legacy equipment to optimize performance.

Bremco

Full-service industrial maintenance contractor since 1976. Company experience in combined-cycle projects includes header, tube, and complete panel/harp replacements. We also have significant experience in liner repairs/upgrades, duct-burner repairs, penetration seals, and stack-damper installations.

C C Jensen Oil Maintenance

Manufactures CJC™ kidney-loop fine filters and filter separators for the conditioning of lube oil, hydraulic oil, and control fluids. Our extensive know-how ensures optimal maintenance of oil systems and equipment reliability.

Caldwell Energy

Power augmentation, including inlet fogging and wet compression solutions, boosts the output and efficiency of gas turbines. With more than 400k hours of operating experience in power generation, these systems offer proven performance and are backed by a three-year warranty.

Camfil

A world leader in the development, manufacture, and supply of clean air and noise reducing systems for gas turbines. A correctly designed system minimizes engine degradation, leading to lower operating costs, optimum efficiency, and less environmental impact.

Catalytic Combustion Corp

Designs, engineers, and manufactures the catalyst – the heart of an effective emissions system. CCC also manufactures the housing and all the critical components at our Midwest facility. Our process of producing folded catalyst substrates is a proven method to quickly manufacture robust catalysts.

Chanute Manufacturing

Contract fabricator of HRSG products—including finned tubes, pressure-part modules, headers, ducting, casing, and steam drums.

Crown Electric Engineering & Manufacturing

Engineers, designs, fabricates, and installs isolated phase bus, large bus duct systems, and outdoor switchgear. Specializes in rapid response needs such as IPB for GSU change-outs, quick-ship fabrication, and emergency on-site service needs.

Cust-O-Fab Specialty Services

Provides the latest technology in exhaust plenums, exhaust ductwork, and exhaust interior liner upgrades that will drastically reduce external heat transfer, making the unit safer and more efficient and easier to operate and maintain.

Cutsforth

Our experience and innovative designs have brought best-in-class brush holders, collector rings, shaft grounding, and onsite field services for generators and exciters to some of the world's largest power companies.

DEKOMTE de Temple

Manufactures fabric and metal expansion joints which compensate for changes in length caused by changes in ductwork temperature. Axial, lateral, or angular movements can be compensated for. Company has gained a global reputation for ingenuity of design and quality of products.

Donaldson Company

Leading worldwide provider of filtration systems that improve people's lives, enhance equipment performance, and protect the environment. Donaldson is committed to satisfying customer needs for filtration solutions through innovative research and development, application expertise, and global presence.

ECT-Engine Cleaning Technologies

Offers R-MC and PowerBack gas turbine and compressor cleaners to eliminate compressor fouling. Additionally, ECT designs specialty nozzle assemblies and custom pump skids for the proper injection of chemicals and water for cleaning, power augmentation, and fogging.

Environex Inc

Engineering and consulting experts in post-combustion NOx and CO control technologies. Primary focus is SCR and oxidation catalyst testing and system maintenance, catalyst management and selection, troubleshooting, and design.

Emerson Automation Solutions

Ovation™ control system offers fully coordinated boiler and turbine control, integrated generator exciter control, automated startup and shutdown sequencing, fault tolerance for failsafe operation, extensive cyber security features, and embedded advanced control applications that can dramatically improve plant reliability and efficiency.

EthosEnergy

This JV between Wood Group and Siemens is a leading independent service provider of rotating equipment services and solutions. Globally, these services include EPC; facility O&M; design, manufacture, and application of engineered components, upgrades, and re-rates; repair, overhaul, and optimization of gas and steam turbines, generators, pumps, compressors, and other high-speed rotating equipment.

Groome Industrial Service Group

Offers a variety of SCR and CO catalyst cleaning and maintenance services nationwide and has formed strategic alliances with industry experts and catalyst manufacturers to ensure that Groome offers the most widely supported, comprehensive, turnkey service available.

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.

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.

IC Spares

Specializes in the supply of new, remanufactured, and repair services of GE Speedtronic turbine controls for GTs, STs, and drive controls with an extensive stock of new and remanufactured parts available for next day delivery and backed by 2-year warranty.

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.

Lambda Technologies

Providing complete surface enhancement solutions and specializing in understanding, measurement and control of local residual stresses, Lambda is an established leader in materials testing and life extension technology. An integrated total solutions approach improves component life and performance.

Liburdi Turbine Services

Advanced repairs employ the latest technologies and are proven to extend the life of components for all engine types. Company specializes in high-reliability component repairs and upgrades for blades, vanes, nozzles, shrouds, combustors, and transitions.

Mechanical Dynamics & Analysis

One of the largest turbine/generator engineering and outage-services companies in the US. MD&A provides complete project management, overhaul, and reconditioning of heavy rotating equipment worldwide.

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.

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.

Nord-Lock Group

World leader in secure bolting solutions, strengthening industrial and public infrastructures with high-quality, safe, and innovative solutions. Products include wedge-locking washers, mechanical tensioners, hydraulic tensioners, and expander systems.

Parker Hannifin Gas Turbine Filtration

With over 50 years of experience delivering innovative solutions for GT inlet filtration and monitoring fleet-wide performance data, our industry and applications experts will select the appropriate filter for your site designed to meet specific operating goals.

Power and Industrial Services

P&I was founded in 1978 with the goal of providing improved replacement parts for the electric utility market. P&I offers a complete range of duct burner solutions from simple replacements to complete turnkey projects as well as a complete line of HRSG access door solutions.

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.

Proco Products

Global leader in the design and supply of expansion joints for piping/ducting systems. For over 30 years, Proco has manufactured the highest quality rubber and molded PTFE expansion joints, braided flexible hose assemblies, low torque sealing gaskets, and rubber check valves.

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.

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.

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.

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.

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.

Trinity Turbine Technology LP

Provides innovative, cost-effective and reliable gas and steam turbine maintenance solutions to industrial operators worldwide. We provide high quality and reliable turn-key outage support and component repairs with unmatched responsiveness and dependability.

Umicore Catalyst

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.

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.

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.

Young & Franklin

Premier fuel control supplier for combustion turbines for both long-term hydraulic solutions and, more recently, innovative all-electric controls solutions. Product scope supports natural gas, liquid, syngas, and alternative fuels as well as providing air controls to provide proper fuel to air mixtures.

Zokman Products

Distributor of ZOK27 and ZOKmx gas-turbine compressor cleaning detergents. ZOK27 is a single cleaner and inhibitor in one that cleans and protects the engine—and also inhibits corrosion. ZOKmx is a power cleaner formulated to replace solvents providing exceptional cleaning without the health and environmental risks associated with solvents.

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