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User Group Reports

Performance and reliability of air-cooled condensers improve as the industry gains O&M experience. Tighter water-use regulations make ACCs the choice over wet cooling for projects that might never have considered them otherwise. Coverage of the user group's seventh annual meeting covers design and performance, O&M, and chemistry and corrosion—an insightful blend of the technical and practical.

Generator consultant Clyde Maughan, now in the 65th year of his professional career, continues to amaze. Latest accomplishment: He recognized the need for a generator users group, put together a plan, invited some of the industry's top experts to present, and with help from NV Energy, Duke Energy, Power Users Inc, and a few generous sponsors, conducted the organization's first meeting in November 2015—just a few months before Maughan turns 90.

Those who helped make the conference an unqualified success included the following: Kevin Geraghty, Mark Severts, Kent Smith, Ryan Harrison, Leopoldo Duque Balderas, John Demcko, Dave Fischli, Joe Riebau, Jagadeesh Srirama, Marques Montes, Mladen Sasic, Mike Bresney, Jim Timperley, Greg Stone, Matthias Svoboda, Bert Milano, Bill Moore, Izzy Kerszenbaum, Neil Kilpatrick, Matt McMasters, Rogerio Scharlach, Steve Kilmartin, Dave Charlton, Justin England, Tony Arrao, and John Yagielski.

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February 21-24
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San Antonio, Tex
Contact: Caren Genovese, carengenovese@charter.net
http://501f.users-groups.com

26th Annual Conference & Exposition
March 20-23
Renaissance Hotel/Palm Springs Convention Center
Palm Springs, Calif
Contact: Charlene Raaker, raaker.charlene@prodigy.net
www.wtui.com

Spring Conference & Trade Show
April 3-7
Renaissance World Golf Village Resort
St. Augustine, Fla
Contact: Ivy Suter, ivysuter@gmail.com
www.ctotf.org

2016 Conference & Vendor Fair
May 9-13
Rosen Shingle Creek
Orlando, Fla
Contact: Sheila Vashi, sheila.vashi@sv-events.net
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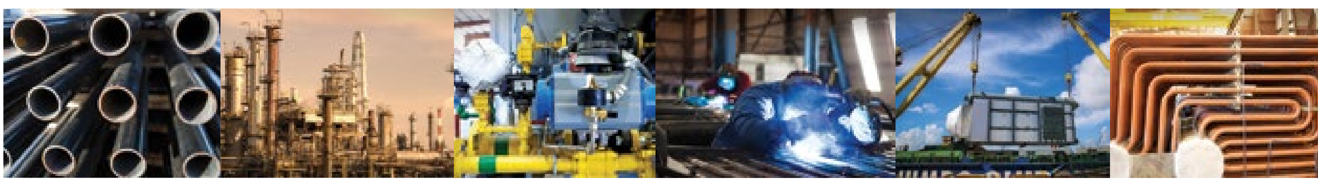

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Make user-group meetings a priority in 2016

February 2-4, 501G Users Group, Winter Meeting, Orlando, Fla, Hyatt Regency Orlando International Airport. Chairman: Steven Bates, steven.bates@gdfsuezna.com. Agenda at http://501g.users-groups.com.

February 10-11, 501D5-D5A Mid-Year Meeting, Savannah, Ga, Hyatt Regency Savannah. Chairman: Gabe Fleck, gfleck@aeci.org. Registration and other details at www.501d5-d5ausers.org.

February 21-24, 501F Users Group, Annual Meeting, San Antonio, Tex, La Cantera Hill Country Resort. Chairman: Russ Snyder, russ.snyder@cleco.com. Details/registration at http://501f.users-groups.com. Contact: Caren Genovese, meeting coordinator, carengenovese@charter.net.

March 20-23, Western Turbine Users Inc, Palm Springs, Calif, Renaissance Hotel/Palm Springs Convention Center. Chairman: Chuck Casey, ccasey@riversideca.gov. Details/registration at www.wtui.com. Contact: Charlene Raaker, raaker.charlene@prodigy.net.

April 3-7, CTOTF Spring Conference & Trade Show, St. Augustine, Fla, Renaissance World Golf Village Resort. Chairman: Jack Borsch, jborsch@lakeworth.org. Details/registration at www.ctotf.org. Contact: Ivy Suter, ivysuter@gmail.com.

May 9-13, 7F Users Group, 2016 Conference & Vendor Fair, Orlando, Fla, Rosen Shingle Creek. Chairman: Ed Maggio, efmaggio@tecoenergy.com. Details/registration at www.7Fusers.org when available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

May 9-11, European HRSG Forum (EHF), Third Annual Meeting, Prague, Czech Republic, Courtyard by Marriott Prague Flora. Details at http://europeanhrsgforum.de/html/index.php when available. Chairman/contact: Ladislav Bursik, ladi.bursik@bht-gmbh.com.

June 6-9, 501D5-D5A Users, 20th Annual Conference & Vendor Fair, location/venue TBD. Chairman/contact: Gabe Fleck, gfleck@aeci.org. Details/registration at www.501d5-d5ausers.org when available.

June 13-16, Frame 6 Users Group, Annual Conference & Vendor Fair, Palm Beach Gardens, Fla, PGA National Resort. Co-chairmen: Jeff Gillis, william.j.gillis@exxonmobil.com, and Sam Moots, smoots@coloradoenergy.com. Details/registration when available at www.Frame6UsersGroup.org. Contact: Wickey Elmo, conference coordinator, wickey.elmo@frame6usersgroup.org.

June 14-16, T3000 Users Group, 2016 Conference, Buford, Ga, Lake Lanier Conference Center. Contacts: Neal Coffey, chairman, neal.coffey@gdfsuezna.com; Elizabeth Moore, event coordinator, elizabeth.moore@siemens.com.

June 21-23, V Users Group, 2016 Annual Conference, Orlando, Fla, venue TBD. Contact: Kelly Lewis, conference coordinator, kelly.lewis@siemens.com.

July 24-28, Ovation Users' Group, 29th Annual Conference, Pittsburgh, Westin Convention Center Hotel. President, Executive Board: Wesley Whitley, wesleywhitley@alliantenergy.com. Register for membership (end users of Ovation and WDPF systems only) at www.ovationusers.com and follow website for details when available. Contact: Kathleen Garvey, kathleen.garvey@emerson.com.

August 22-25, Combined Cycle Users Group (CCUG), 2016 Conference and Discussion Forum, San Antonio, Tex, La Cantera Hill Country Resort. Meeting is co-located with the Steam Turbine Users Group and Generator Users Group; some joint functions, including meals and vendor fair. Chairman: Steve Royall, sgr8@pge.com. Details at www.powerusers.org when available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

August 22-25, Steam Turbine Users Group (STUG), 2016 Conference and Vendor Fair, San Antonio, Tex, La Cantera Hill Country Resort. Meeting is co-located with the Combined Cycle Users Group and Generator Users Group; some joint functions, including meals and vendor fair. Chairman: Bert Norfleet, bert.norfleet@dom.com. Details at www.powerusers.org when available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

August 22-25, Generator Users Group (GUG), 2016 Conference and Vendor Fair, San Antonio, Tex, La Cantera Hill Country Resort. Meeting is co-located with the Combined Cycle Users Group and Steam Turbine Users Group; some joint functions, including meals and vendor fair. Chairman: Kent Smith, kentn.smith@duke-energy.com. Details at www.powerusers.org when available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

August TBD, ACC Users Group, Eighth Annual Conference. Details at www.acc-usersgroup.org as they become available. Registration/sponsorships contact: Sheila Vashi, sheila.vashi@sv-events.net. Speaker/program contact: Dr Andrew Howell, chairman, andy.howell@xcelenergy.com.

September 11-15, CTOTF Fall Conference & Trade Show, Rancho Mirage, Calif, Westin Mission Hills Golf Resort & Spa. Chairman: Jack Borsch, jborsch@lakeworth.org. Details/registration at www.ctotf.org when available. Contact: Ivy Suter, ivysuter@gmail.com.

November 1-3, 7EA Users Group, Annual Conference and Exhibition, Hershey, Pa, The Lodge. Chairman: Jason Hampton, jason.hampton@ethosenergygroup.com. Details/registration at http://ge7ea.users-groups.com when available.

November 15-17 (planned), Australasian HRSG Users Group, 2016 Annual Conference. Details at www.ahug.co.nz as they become available. Speaker/program contact: Dr R Barry Dooley, bdooley@structint.com.

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COMBINED CYCLE Journal is published by PSI Media Inc, a Pearl Street company. Editorial offices are at 7628 Belmondo Lane, Las Vegas, Nev 89128. Office manager: Robert G Schwieger Jr.

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*Carahalios Media is the exclusive worldwide advertising sales organization for the COMBINED CYCLE Journal. Business offices are at Carahalios Media, 5921 Crestbrook Drive, Morrison, Colo 80465.

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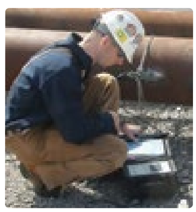

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Gut rehab turns South Jersey cogen plant into electricity market gem

"The bones of the plant were still really good," Plant Manager Jeff Zelik said, referring to the condition of the Eagle Point Power Generation facility in Westville, NJ, when Rockland Capital purchased it in April 2012. But five years of essentially no maintenance investment or capital improvement had clearly taken its toll. That was then.

Today, Eagle Point expects the plant capacity factor to approach 50% once the last of the capital improvements are finished. Those improvements include everything from a punch list of 146 maintenance activities to return the plant to a safe, reliable operating environment, as well as capital upgrades, including a new steam turbine/generator, wet compression and fogging, and a complete gas turbine optimization and augmentation package which helped avoid the $11-million cost of an SCR.

"We're committed with PJM to a June 1, 2016 deadline with our additional capacity and improved heat rate," Zelik observed.

Recent history

Many combined cycles around the country have experienced some version of this story. Eagle Point was commissioned in 1991 as a refinery cogeneration facility during the waning years of PURPA and the beginning of the IPP era. The refinery was sold in 2004. In 2009, the refinery's new owner announced its intention to shut down all but a small portion of the petrochemical operations there. When you know you are going to abandon a car or a home, you don't usually invest in it.

Expectedly, people issues were legion. Morale was low. Employees responsible for other refinery facilities (not powerplants) in the area were "assigned" to this site, after 80% of the cogen staff was let go.

"The one-mile river intake piping resembled a sprinkler system," noted Zelik, wryly, as just one example. The dry low NO_x equipment retrofit to the gas turbines prior to 2004 was "a mess," too, so much so that trying to fix it under the previous owner bankrupted the vendor. The compressor was the "dirtiest anyone had ever seen."

"We also had to rewind the steam turbine/generator stator," said Zelik. Sending 350,000 lb/hr of process steam to atmosphere (with the refinery shut-

1. Plant office entrance at time of sale (left)

2. Junction box in poor condition (above)

3. Internal shell of backwash tank (right)

4. Corroded and misaligned steam pipe

5. Insulation generally was in poor condition


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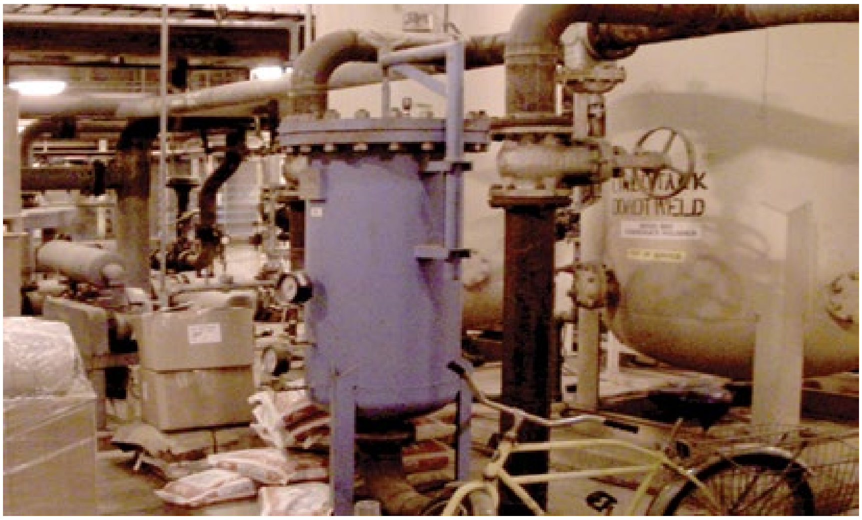
6. Do not stand on insulated pipes



7. Water treatment and chemical room when plant was sold

8. There's a desk here somewhere

9. Gas turbine area suffered from lack of attention

10. Firewater system supplied water to the plant

tered) didn't exactly make it easy to bid into the PJM market with a stellar heat rate.

However, part of the sturdy "bones" of the site were the two 7EA gas turbines, still in "pretty good shape" when Rockland got hold of them, mostly because they had seen minimal run time since the DLN retrofit fiasco.

Getting back to zero

The condition of Eagle Point at sale, frankly, was as bad as Zelik had seen for a 20-year-old facility (and seconded by the **CCJ** analyst touring the facility with Zelik based on his three decades visiting power stations all over the world and evaluating new technologies and systems). Without dwelling on how the facility reached this point, the photos of as-found deficiencies certainly makes it clear:

- Corrosion issues that started at the office door (Fig 1) and continued throughout the plant, ranging from electrical junction boxes (Fig 2), seams at tank shell welds (Fig 3), and major piping runs (Fig 4).
- Insulation issues throughout the plant and staff disregard using insulated pipes as work platforms (Figs 5 and 6).
- Housekeeping issues that ranged from safety codes concerns to creating inaccessible areas (Figs 7 and 8).
- Chemical feed and associated tanks continuously leaking into containment areas.
- Dirt, oil, and general housekeeping and safety issues around the gas turbines (Fig 9).
- Raw river water pipeline abandoned, and then tapped into the plant's fire water system (Fig 10).
- Poor sealing and failed strip heaters in bus ducts, which led to failed bus insulators.
- Block valve installed upstream of a safety relief valve on a high-pressure steam line, believed a code violation for the arrangement shown in Fig 11.
- Misaligned and poorly supported pipes.
- Plugged, scaled, and corroded HRSG tube bundles (Fig 12) and rusted outer areas (Fig 13).

One positive: Around $300,000 worth of gas turbine replacement parts were found "dumped in the main parking lot," not nearly enough, though, to offset the approximately $10-million spent to get the plant back to a safe and reliable state—$3-million alone for extensive piping fixes, insulation, and heat tracing. Compare the rehabilitated equipment in Figs 14-21 to the as-found photos.

Major upgrades

The big investment was the addition of an auxiliary 27-MW steam turbine/generator (Fig 22) to productively use the bulk of the cogen steam and convert the site into a 2 × 2 combined cycle. More interesting, perhaps, is the investment in EthosEnergy Group's ECOMAX® performance optimization system; PSM's patented Power Augmentation (PAG) system to integrate gas-turbine steam injection/inlet bleed heat (IBH) mechanically as well

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11. Locking device to prevent closure of block valve when steam system is in operation appears to be missing. A proper drain line at a low point in the steam vent system also seems to be missing (left)

12. These tubes have seen better days (right)

13. HRSG and stack have suffered neglect (left)

14. Boiler feed pump equipped with new motor driver (above)

15. Service water and many other pumps reconditioned (right)

as from a controls standpoint; and Mee Industries Inc's overspray, wet-compression capability to the existing inlet fogging system.

"This is the first EA machine with ECOMAX," Zelik said. All the upgrades have been operating for one year and a few months, "as expected," he claimed. "We're comfortable with our ability to tune the units for summer operation, although we feel we still have some learning to do for winter ops."

Tuning is critical. The original Eagle Point HRSG includes a CO catalyst but not a NO_x catalyst. The permitting authorities tried to force a NO_x SCR, but Rockland investigated other ways to gain a permit and maintain compliance. Thus, the permitted 7 ppm NO_x emissions level is met solely through combustion optimization (with the steam injection). While 7 ppm appears to be a modest reduction compared to the original 9 ppm, it does represent a 25% decrease. The larger point is there's no "big box" at the end of the pipe to rescue them if combustion tuning is out of spec.

Combined, the upgrades net about 12 MW per unit, 4 MW total from wet compression alone. In the 2 × 1 configuration, the plant's output is around 210 MW, 238 MW max in cold weather. With the new aux steam turbine/generator, max facility output is more than 250 MW. Minimum load of 105 MW is typically handled in 1 × 1 mode. In 2 × 2 mode, Eagle Point achieves a heat rate at or near 8200 Btu/kWh.

"Our traders, EDF, bid the facility into PJM and our gas buyers expect that they can secure natural gas at the price we base our electricity bid," Zelik said, "which is usually no problem because we're located in a highly industrial area with multiple suppliers and good options." This year (2015) the plant typically runs

16. Compare this junction box to the one in Fig 2

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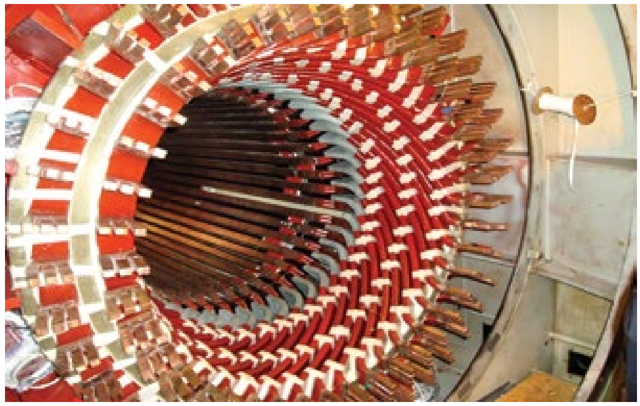
17. Main and auxiliary circ-water pumps overhauled

18. Water treatment area like new

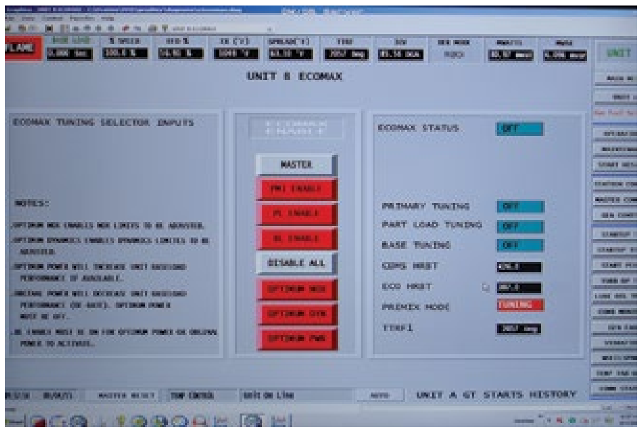
19. Eureka!

20. New raw-water line



21. Rewound generator stator

22. Existing steam turbine will be complemented by a new 27-MW steam turbine/generator destined for the prepared site behind the HRSGs



23. ECOMAX® continuously tunes the gas turbines. Its optimization routine allowed plant to avoid installation of an $11-million SCR

for 12 to 18 hours daily at or near maximum output, then shuts down. When called, Eagle Point runs for a minimum of four hours. Somewhat contrary to what one might expect, capacity factors have been higher in spring and fall. "Last September, we ran continuously the entire month," said Zelik.

The *flexibility* offered by the upgrades may prove as important over time. "We can be very responsive to real-time market conditions," Zelik added. He further noted that it is very unpredictable when the plant will be picked up by PJM. By 4 p.m. the day before, we know if our day-ahead bid has been accepted and around 4 p.m. the current day, real-time prices typically begin to rise. Eagle Point thus can optimize revenues earned between capacity and energy payments.

"We also are required to follow PJM's Lambda schedule, and have to slightly alter output during the run period." At peak loads, the facility will use a combination of steam augmentation, wet compression, and fogging to adjust the load to meet the PJM Lambda schedule. "Although the changes can be made instantaneously, it is normal to allow the ECOMAX system about 10 minutes to stabilize the NO_x and CO," said Zelik.

More on ECOMAX, PAG, fog

Zelik described the original software for gas-turbine performance like "training wheels," a flat two-dimensional spreadsheet approach, compared to the multi-dimensional capability of ECOMAX, which integrates readings from the combustor dynamics monitors (CDM), air flow, and firing temperatures (Fig 23).

The system monitors pulsations of each burner, or combustor can. Zelik noted that Eagle Point turbines have 10 cans each but the plant chose to monitor every other can so far. Based

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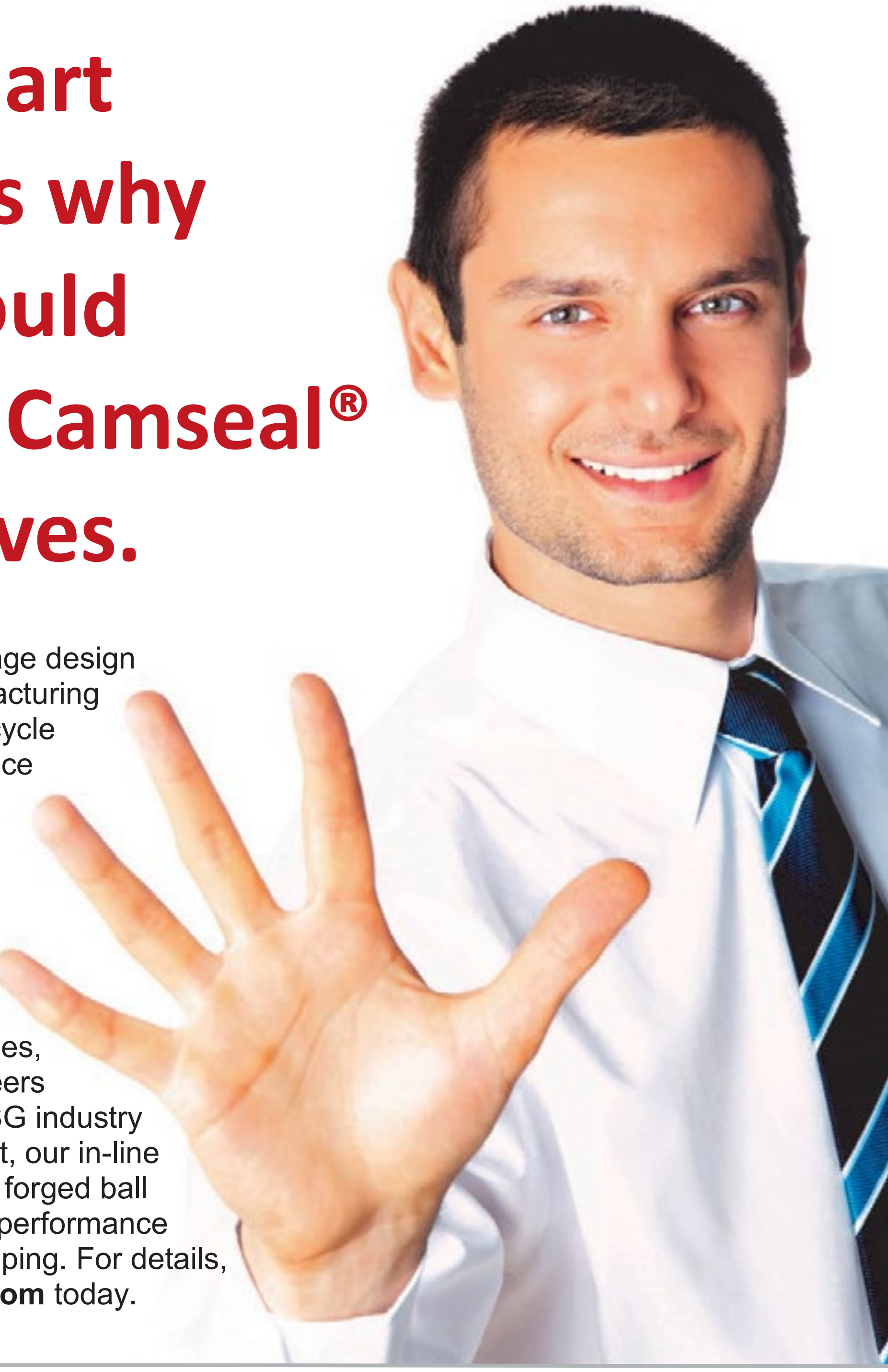

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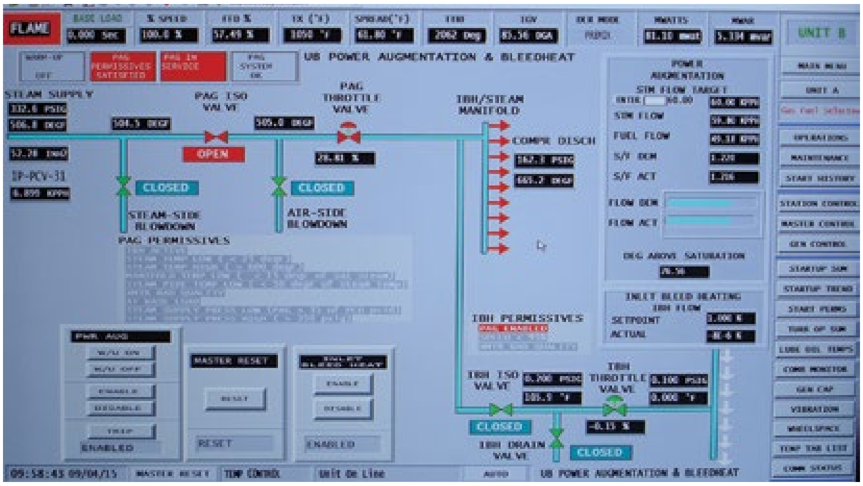
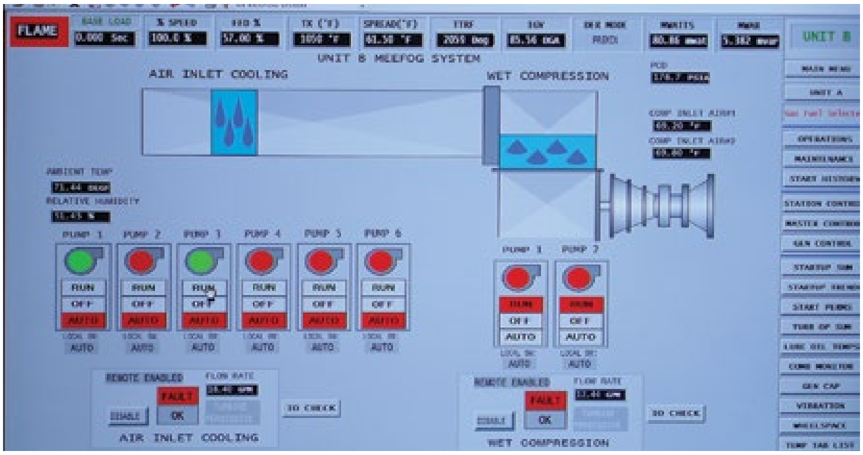


24. PAG makes use of equipment orphaned by the old steam-injection NO_x control system

25. Reverse-acting valve allows injection of steam via inlet bleed heat system to boost output



26. There are six high-pressure pumps for fogging, two for wet compression to capitalize on market opportunities

QR 1 QR 2 QR 3 QR 4

on the results to date, Zelik recommends monitoring each can for better response.

The logic adjusts both air and fuel flow to each can in real time. However, this wasn't something that happened overnight. "We started in May (2014) and it took us the whole summer to figure out the logic, before we felt comfortable." Now, plant staff knows enough that they can make their own adjustments during winter ops. Tuning for operation below 30F still has to be tweaked, according to Zelik.

Still, no one else is attempting to control DLN turbine emissions at 7 ppm or less with the DLN equipment, he emphasized. This is the reason firing temperature plays such a large role in combustion and performance optimization. The control system adjusts bypass air with the inlet guide vanes.

Essentially, ECOMAX optimizes among emissions, output, and heat rate under varying ambient conditions, fuel quality, and market economics, while remaining within the OEM's recommended setpoints (get background information by scanning QR 1 with your smartphone or tablet).

PAG makes use of existing equipment orphaned by the old steam injection NO_x control system, but with a twist (Fig 24). The existing ports used for cold inlet bleed heat on the compressors during startup were converted with reverse-acting valves to also handle injection of steam at high-power conditions (Fig 25). This upgrade alone allows the plant to redeploy up to 55,000 lb/hr of excess steam for 8 to 10 MW of power augmentation (QR 2) from each GT year-round, acknowledging the 1.3:1 hit on equivalent operating hours (EOH).

Ancillary benefit: The compressors are continuously washed. Borescope inspections show the compressors to be clean, avoiding independent online or offline cleaning.

The fogging system was existing but not functional when Rockland came in. Wet compression (WC, QR 3) uses the same equipment but at a different location. Fogging reduces temperature and adds air for compression, wet compression adds volume and density to the air. WC helps under high-humidity conditions when the fogging system is flagging. Each one adds about 2 MW, and is used primarily for operations between May and September. Below 60F, there's risk of icing and freezing.

There are six high-pressure pumps for fogging, two for WC (Fig 26). Both can now be controlled from the control room. When both are turned on, the "turbines will take as much water as we can give them." Keeping the filters clean and ensuring a good fogging pattern from the nozzles are both critical to good performance from the systems.

Controls

Part of the original controls included an ABB analog system (essentially manual controls by today's standards, says Zelik) for the VAX type steam turbine and an INFI 90 for the balance of plant (BOP). After the DLN conversion, the gas turbine Mark IV controls were replaced with a system from Turbine Technology Services Inc, at the time owned by Sermatech, which was responsible for the DLN retrofit.

Today, Eagle Point has an Ovation™ backbone and a long-term plan with Emerson Process Management to upgrade and expand it as they go (QR 4). The new Siemens steam turbine/generator will feed data to the Ovation system. Currently, the plant operators see Emerson screens for the GTs, INFI 90 screens for the BOP. CCJ

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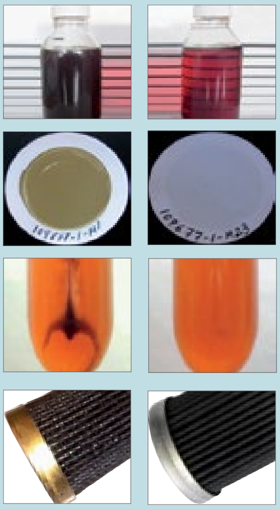

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First 7FA.05 GTs go commercial at Xcel Cherokee

Three new 2 × 1 combined cycles with the latest 7FA.05 gas turbine technology from GE, two in New Jersey and Xcel Energy's 569-MW unit at the existing Cherokee Generating Station in Denver, were in the running to declare the earliest commercial operating date (COD). Xcel won with a COD of Aug 20, 2015 (Fig 1).

The short three months after first fire May 19 is significant because of the summer peaking period and the location of Cherokee and its importance to the Denver grid. According to Gerald Kelly, Xcel project manager, 17 transmission lines tie in at the plant.

The facility also made use of a grey market D11 GE steam turbine owned by the company (Fig 2).

Kelly credits significant investment in "preventive measures" for the smooth commercialization period. "We had both GT units run through full-speed/no-load tests at the factory, conducted full-capacity performance tests on balance-of-plant critical pumps, stroke-tested every critical valve, witnessed rotor stacking and balancing tests, dedicated 1½ people to oversee the quality of the EPC work, and sent QA/AC specialists and engineers to factories as far as Korea to oversee the welding and fabrication of the HRSG components."

Both GTs were fully field performance tested at a few megawatts above their guaranteed output numbers, around 100 Btu/kWh below the design heat rate, and lower than the 9 ppm guaranteed NO_x emissions down to 40% load (Figs 3, 4).

"We checked every wire, every control loop and logic, every instrument, thousands of components, and ran every pump, ahead of first firing and it was all time and money well spent," claims Kelly, "plus the D11 is humming, no vibration issues, partly because we upgraded to GE's advanced seal components." Kelly also lauds GE's diagnostics staff, onsite and remote specialists. "If we went down, we were never down for more than an hour or two."

1, 2. First 7FA.05 in foreground above exhausts through a heat-recovery steam generator which supplies the grey market D11 steamer below

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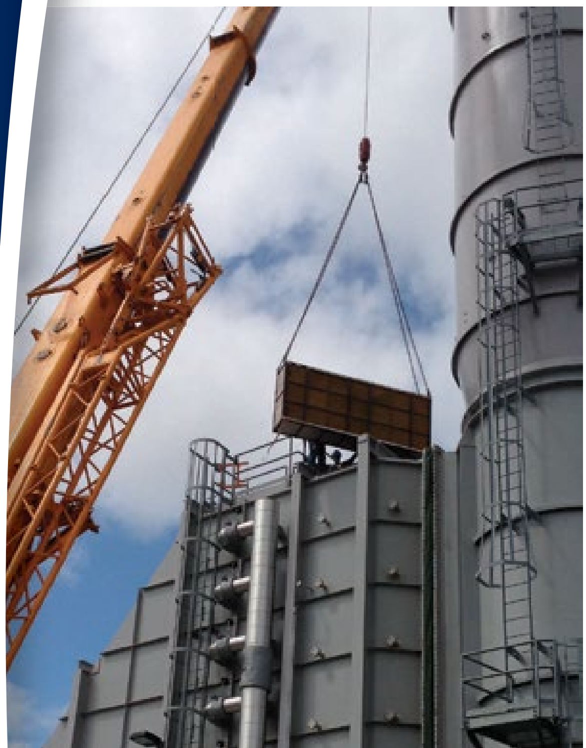


3, 4. Field performance tests showed the 7FA.05 combustion section exceeded expectations on output and heat rate, while meeting 9-ppm NO_x emissions down to approximately 40% of the full-load rating


5, 6. SCR ammonia system reflects latest design. Blowers at left direct air to the heaters used to vaporize aqueous NH_3 (left). Delivery system assures proper distribution of reagent to the catalyst bed (right)

Perhaps most notable is that testing of the units was in synch with the normal production schedule from dispatch. "We made sure to closely coordinate with our dispatchers by having a weekly plan and informing them a day ahead how we needed to operate during the commissioning period." The bargain was that dispatch would have the unit earlier if production could be coordinated with testing. "Denver's summer load is around 5000 MW," explained Kelly, "we may have given the dispatchers some white knuckle rides swinging 300 MW every few minutes to check ramping rates."

It's easy to see why. Cherokee, once a coal-fired plant, is located in close proximity to Denver's urban core. Its location in the grid is as important, perhaps more so than its output. Xcel's "three-shaft rule" governed the transition into the new plant operation. Originally, the plant had three small units totaling 365 MW and one larger 352-MW unit. The three-shaft rule postulates one unit in an outage (getting preventive maintenance), one in a potential forced outage situation, and one spinning at all times to supply load stability to the grid.

Today, the three small units have been retired; however, one was converted to a synchronous condenser for grid VAR support. The last small unit was retired when the combined-cycle unit went commercial. The last remaining large coal unit at Cherokee will stop burning coal and only run on natural gas beginning in 2017. The combined cycle counts as one shaft! Going forward, outages at Cherokee must be precisely coordinated to achieve the necessary reliability and availability performance for the Denver metro area.

"One issue faced was transmission constraints when the combined-cycle plant was fully loaded during commissioning and the third small coal unit was operating," Kelly noted, "There were times when we had to restrict coal-plant output." The restructuring of Cherokee to a gas plant with a new combined cycle was part of the Colorado PUC's Clean Air Clean Jobs Act plan (Figs 5, 6). CCJ

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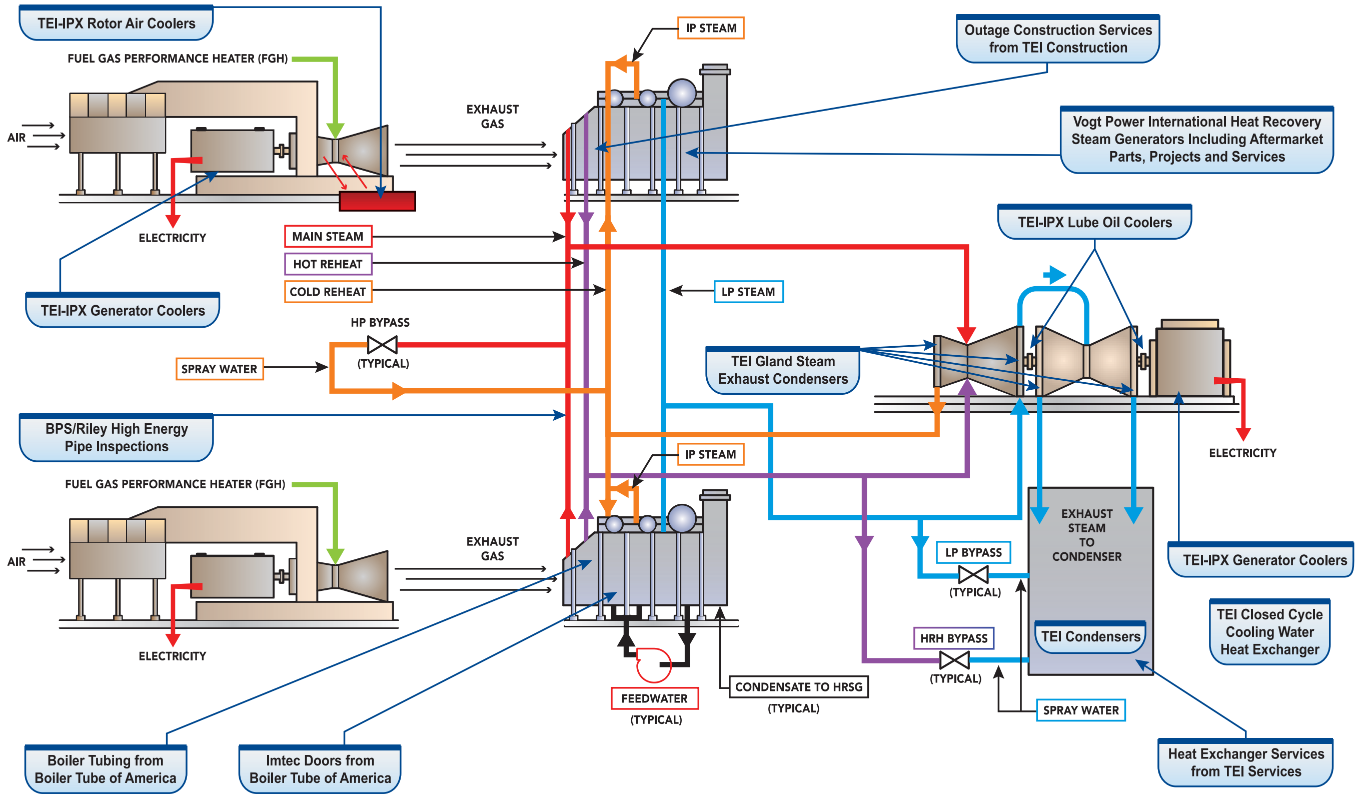




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Commercial realities complicate 7EA first-stage repair techniques

At the fall 2015 CTOTF Conference and Trade Show, Aaron Frost, Allied Power Group, Houston, gave a detailed presentation, "7EA Stage 1 Component Repairs: The Good, the Bad, and the Ugly." So detailed, in fact, that the CCJ content team felt compelled to visit with Frost and "translate" the material for those in on repair/replace decisions but who do not have a metallurgical or turbine design background.

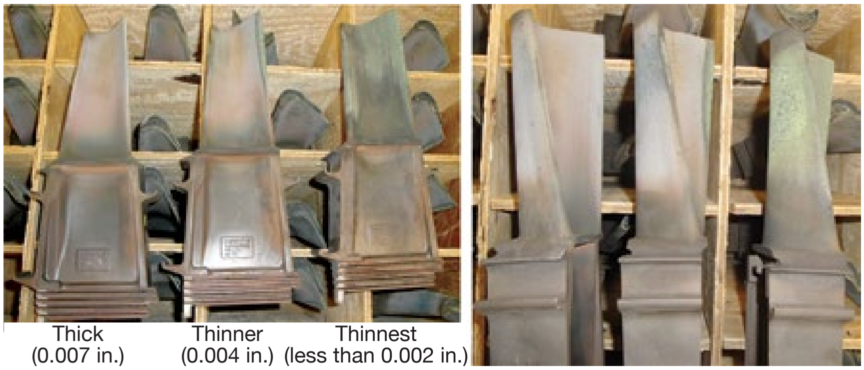
The material presented here should be considered a companion to Frost's F-class hot-parts repair clinic at CTOTF's spring 2015 meeting, which was summarized in the last issue (CCJ 2Q/2015, p 74).

Much of the "ugly" Frost refers to are the commercial realities with all stakeholders impacting the repair business and repair techniques. Owner/operators are constantly buying and selling assets and specialists are in flux, leading to poor component total-life and condition tracking. Plants also are accepting repairs which may extend the next run cycle and reduce immediate costs but sacrifice the *total life* of the component.

In earlier days, that was called "eating the seed corn."

Some repair shops may be under pricing pressure, potentially affecting repair quality, and electing to fix components multiple times rather than educate the user on previous (and often substandard) repair methods. OEMs and repair houses may be using thinner coatings which not only lead to more frequent repairs or earlier replacement of expensive parts, but reduce the overall life of the machine.

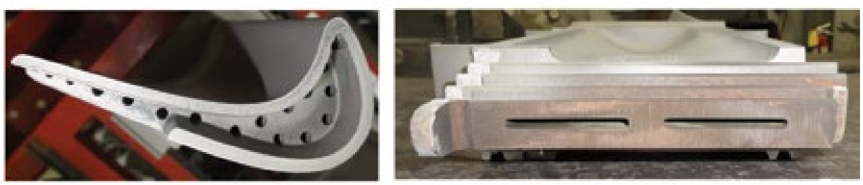
Frost, a metallurgical engineer and 30-year industry veteran whose experience base includes equal parts component repair (Chromalloy) and OEM manufacturing (GE), cautions that the objective of "Six Sigma" or other quality program is not highest quality per se but rather an optimization around quality, cost, life-cycle revenues, competition with other services providers, and other factors. That



1. Effect of poor coating thickness appears visually (and dramatically) after a base-load HGP period of operation at 2035F. Coating was non-OEM "GT33 equivalent"

About 1992: 11-hole EQ GTD-111 with GT29+/GT33+ coating

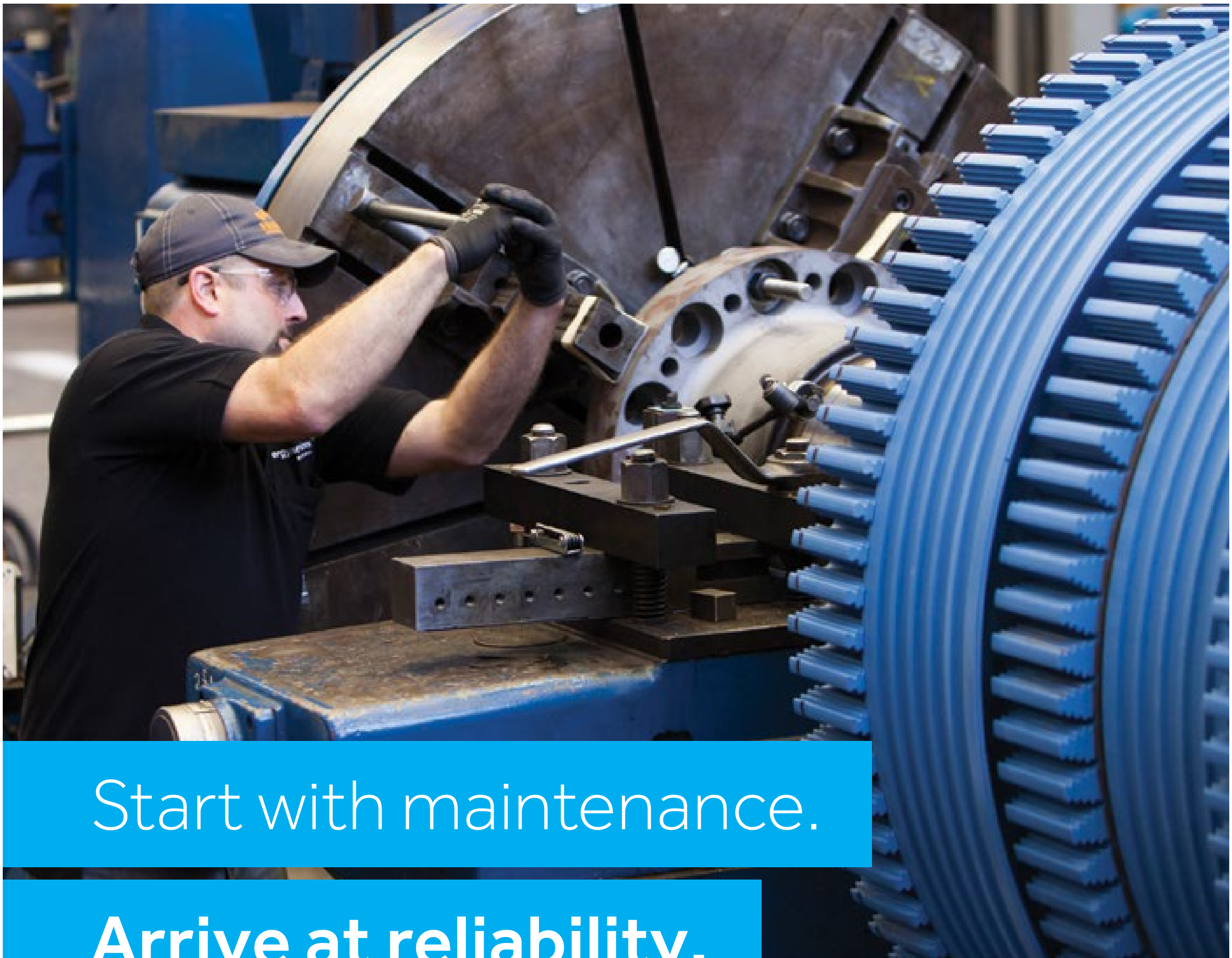
About 1998: 12-hole DS GTD-111 with GT33+ or GT33 coating



About 2006: 16-hole shank core and new airfoil shape with GT33 coating

About 2013: 12-hole DS GTD-111 with GT33 coating (same 15-yr-old part number)

2. Subtle but critical differences are noted in the 20-year evolution of the 7EA first-stage bucket



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noted, he puts "robust OEM designs" in the "good" category.

However, Six Sigma manufacturing rules for a "mature" product are different from the early designs. Parts may not have changed dimensionally but they are produced differently. For example, new casting flaw limits, based on thermal mechanical computer analysis, make certain defects on mature parts acceptable today. Historically, these parts would have been rejected.

Also, the tantalum content in some new materials, like the proprietary alloys GTD-241™ and GTD-741™, has been removed to save on raw material costs. Formal alloys GTD-222® and IN-738, which contained tantalum, have industry-proven hot corrosion resistance. Early field experience with "tantalum absent" alloys indicates greater surface oxidation and hot corrosion, compared to their historical counterparts.

OEMs also practice "technology flow back," or incorporating design changes and upgrades from the most recent turbine families into earlier designs, such as from the F-class platform to the E-class machines. As with all "systems," there may be unintended system effects from such changes which can only be fully understood with field experience.

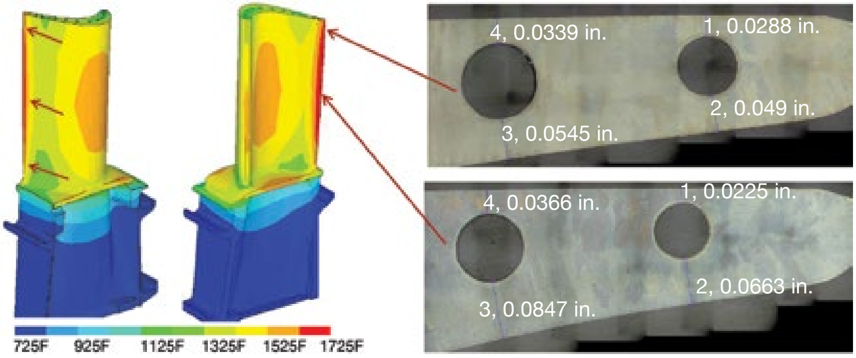
Coatings offer another good illustration of repair vis-a-vis original design. The turbine design spec may call for a specific coating thickness for a given part, say 0.007 in., but production variation can be from 0.005 to 0.015. It is incumbent on the user through QA/QC to ensure that the OEM provides coating thicknesses as promised.

Until recently, there had been no technique to validate coating thickness without chopping the part. As machine designs mature, the OEM may factor in less design margin as its understanding of field performance grows and its share of technology risk is lowered. While quality optimization is inherent in the commercial, competitive manufacturing of highly engineered complex systems, healthy skepticism also suggests it helps the OEM understand what it can get away with.

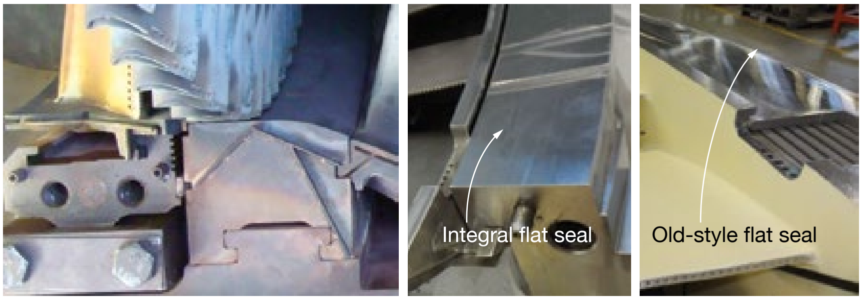
Frost referred to one utility which bought three extra "buckets" for an upgrade in 2013. They come in handy to validate and analyze problems down the road. "This should be considered a best practice," Frost suggests.

One of the big challenges in the repair business, stresses Frost, is that loss of metal from necessary repair operations can have a greater impact on eventual component/machine life than on how the machine is operated. Each repair of a first-stage bucket, for example, takes away some total life in an effort to guarantee operation to the next scheduled hot-gas-path (HGP) outage.

For one thing, the part has to first

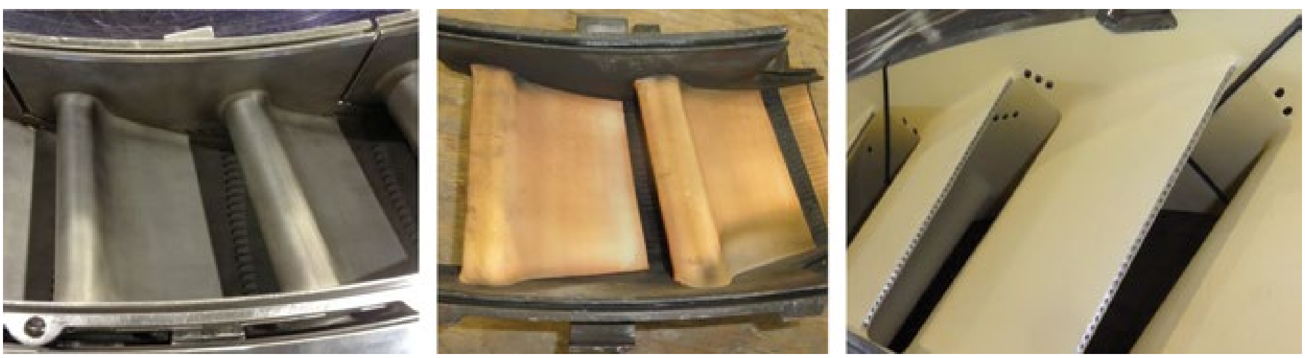


3. Thinning of buckets after multiple repair cycles is often most severe where the thermal profile is the hottest



4. New integral seal is much more difficult to repair correctly, even for normal wear, than the old style replaceable seal

5. Nozzles begin to fail "from the inside out" after significant operating hours as red-dye crazing on the internal surface of this first-stage nozzle reveals



No coating, as supplied by OEM

TBC repair patch by OEM

Full robotic high-density TBC repair by Allied Power Group

6. Multiple challenges are presented in coating techniques for first-stage nozzles, among them achieving good TBC coating with double vane geometry. Repair shops wanting owner/operators to loosen their quality specs might use one or more of the following arguments: nozzle flow area changes, design does not require it, too costly for the market

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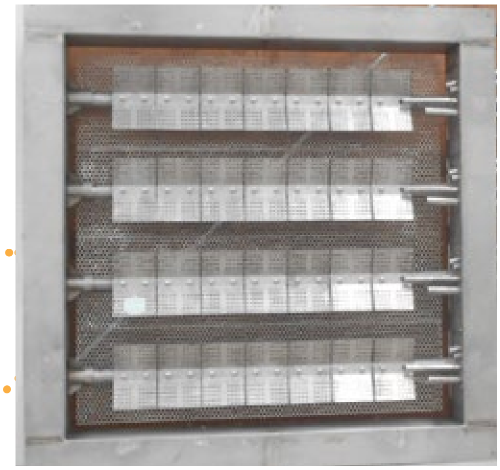

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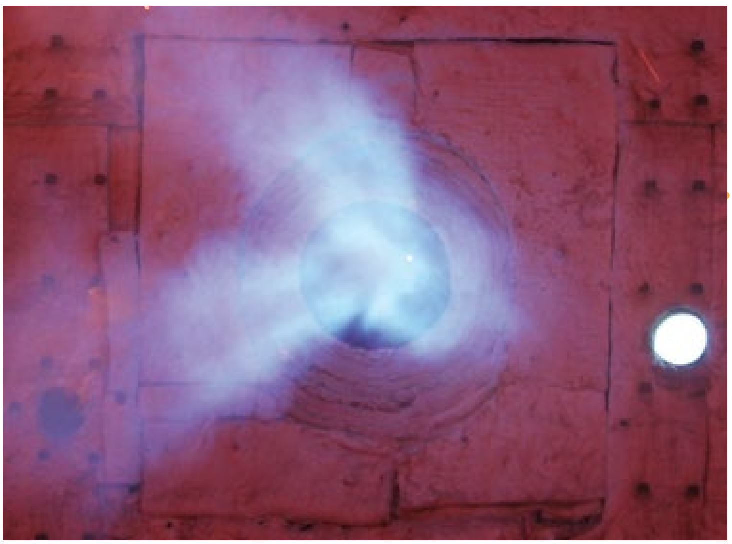

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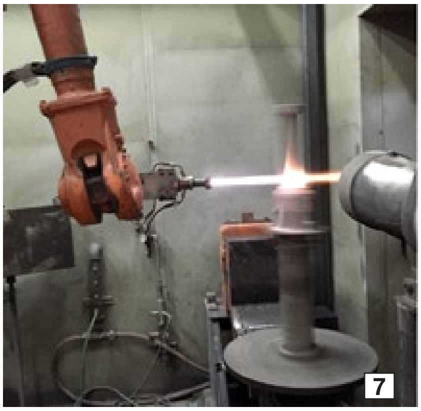

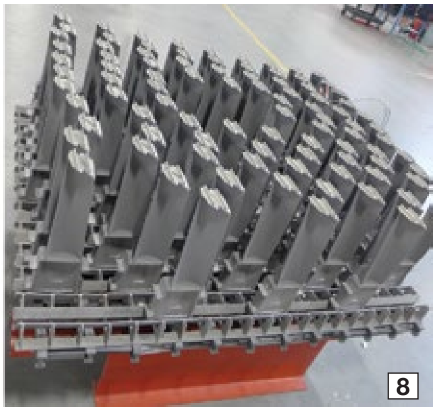

7-10. Shop tour. Metallic coating is applied robotically with high-velocity oxygen fuel (7); engineered rack (8) is constructed of Haynes® 230 material for high-temperature vacuum heat treatment without risk of airfoil positional movement on long turbine buckets/blades; vacuum furnaces (9), internals in Fig 10, consist of all moly hot-zone construction rather than graphite. This provides the lowest oxygen content (ppm) during elevated temperature cycles

be stripped (blast, blend, water jet, or chemical strip) before it can be recoated. Invariably, some of the base metal is lost. Frost recommends that the owner/operator insist on a qualification record to protect against loss of base metal.

For another thing, coating material is not cheap, as owner/operators know too well. Repair houses can pinch real money by reducing the thickness of the metallic coating (Fig 1) and adding a thermal barrier coating (TBC) on top. TBC "protects the repair houses from their own 'thin sins,'" notes Frost. For a 7EA first-stage bucket, a 0.009-in. coating requires 210 pounds of MCrAlY powder; a 0.003-in. coating requires only 70 pounds. Coating production time is also reduced by two-thirds.

Frost has observed re-coatings to only 0.004 in. (with TBC added) whereas the original bucket had 0.010 to 0.015 in. metallic bond coat with no TBC.

Design of first-stage-bucket cooling is another example. Frost compares four approaches over a 20-year period (Fig 2). While the changes may appear to be subtle, the circa 2006, 16-hole design "did not work well," notes Frost, "especially in cycling duty." The others exhibit differences in airfoil shape and cooling-hole dimensions. In a given machine, each will also exhibit differences within fabrication tolerances but critical to the life of the part. A few fractions of an inch in metal thickness at the trailing edges of first stage buckets can be significant (Fig 3).

Because of inconsistencies with original cooling-hole dimensions and placement, the buckets become hottest where the metal is thinnest after multiple repair cycles. The inconsistencies are not design flaws per se, but design constraints. The bucket's leading- and trailing-edge areas have the least amount of metal to drill a hole through. The shape is "cast in stone" but the location of the cooling holes is not. To properly cool the trailing edge, the last hole, according to Frost, has been shifted forward. Ideally, it would have been equidistant.

As an example of an OEM design change that complicates repair, Frost pointed to the flat seal to the first-stage shroud block (Fig 4). In place of the old "user-friendly" replaceable seal on the latest 7EA R1 nozzle is an integral seal. This saves the manufacturer money but can potentially cost the user seven to 10 times more to repair normal wear on the seal's surface. Likelihood of having to replace the entire outer seal ring is much higher, too.

Frost cautions that owner/operators don't fully appreciate the risk of taking aged nozzles from a base-load machine and putting them in a cycling or peaking machine. Many users tend to be "cosmetically driven," but it's what you can't see that can hurt you. For example, the gas side has relatively long life and damage can be detected visually, with dye penetrant, and other techniques. However, you can't see how much life the part may have lost *from the inside* (Fig 5).

Coupon repair with new metal is the only way to repair internal damage, notes Frost. New first-stage nozzles typically are not coated when purchased new, Frost continues, so external and internal surfaces experience increased oxidation damage. When that damage propagates inward, it's not easily fixed.

However, the original FSX-414 material, an OEM proprietary alloy, used to fabricate first-stage nozzles is "very weldable." Unless the user specifies otherwise, repair shops, to contain costs, will likely use L-605® or Haynes® 188 instead of Mar-M-918, a non-proprietary alloy that is best used to weld-repair FSX-414 parts.

Frost insists that brazed repair techniques should not be accepted until the nozzle is close to its end of useful life, such as at the third or fourth repair cycle. While these nozzles do not require a full TBC coating, users electing to coat anyway should make sure the repair shop has full robotic qualification for this process (Fig 6). Innovations in the Allied shop are shown in Figs 7-10.

Finally, owner/operators need to be aware that the OEM has obtained "airfoil coordinate" patents on new product introductions, which could significantly restrict competition in the gas turbine repair/replacement business. This means that organizations offering non-OEM competitive replacement parts are forced to (in some cases) offer airfoil shapes which may be moved slightly outside the "patent window" causing unknown turbine ramifications. CCJ


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Long-term OEM contract guides reinvigorated Bridgeport Energy

Think of it as a marriage with a timestamp and a substantial upfront investment to ensure its "performance." That's how Emera Energy, which acquired Bridgeport Energy (Fig 1) in late 2013, and Siemens Power Generation, Orlando, are walking out of the church following an extensive plant modernization program that involved major maintenance, life extension, and technology upgrades on two 84.3A gas turbine/generators (GT/G) and one steam turbine/generator (ST/G), plus replacement of the original TXP control system with Siemens Energy Inc's (Alpharetta, Ga) T3000.

Based on interviews with Plant Manager Paul Warren and Production Manager Donald Ross, the relationship is off to a good start, though the partners have made important discoveries about each other.

Most importantly, states Warren, Siemens met its technical and budgetary performance targets and got its incentive payment for doing so. Each GT/G was guaranteed to deliver an additional 13 MW but the actual is 14-16 MW at 200-Btu/kWh lower heat rate, with 10 additional megawatts available from the ST/G.

The combined cycle was commissioned in 1998-1999; plant's original capacity of 520 MW is now 560 MW. Turndown capability has been reduced from 62% to 50% while still maintaining a 10-ppm CO emissions limit (post-catalyst).

Clearly, Emera has a different attitude than the last five owners of the plant, six if you count the one firm that owned Bridgeport Energy twice. The Canadian asset portfolio operator has committed to a $180-million, 20-year partnership with Siemens. Already, Emera is looking at additional technology upgrades (sidebar).

Emera found the asset to be reliable and safe in 2013. However, to better capture grid market opportunities, to undertake major scheduled maintenance outages on all three turbines, and to deal with a saltwater intrusion event in 2012 under previous owners, the company embarked on a broad and deep modernization program (Fig 2), including:

- Increasing compressor mass flow using state-of-the-art airfoils, new inlet guide vanes (IGVs), rotor replacement/refurbishment, and new blades and vanes for rows 1 and 2.
- Use of new tiles and tile holders in the combustor, requiring less cooling air, and increasing both mass flow and flame temperature.
- Improved coatings and cooling for turbine blades and vanes.
- Addition of advanced stability margin control (ASMC) to improve combustion stability and reduce errant trips.
- Inspection and full rebuild of the ST/G (removal of the HP, IP, and LP rotors), replacement of LP rotor blades, seals, and diaphragms, and steam path valves.
- Rebuild of two of the three boiler-feed pumps (non-Siemens scope).
- Tube replacements in both HRSGs (non-Siemens scope).
- DCS upgrade/replacement.
- Replacement of obsolete static frequency converter and static excitation systems.

1. Bridgeport Energy, serving ISO New England, was acquired by Emera Energy in late 2013, then extensively rehabbed and uprated with long-term partner Siemens Power Generation

All this was accomplished in what both parties agree were two narrow outage windows of 70 days in fall of 2014 (first GT/G, ST/G, controls, and BOP items) and 38 days in May-June 2015 (second GT/G, ASMC installation both units) on a logistically difficult site (Fig 3). The facility is hemmed in tightly by adjacent industrial facilities. The more acute constraint is that only one crane is available to service all three machines. Despite these challenges, safety was stellar, report Warren and Ross; only one recordable injury occurred.

The ST/G low-pressure rotor was pulled first for fear of chloride contamination from the saltwater intrusion event. It was cleaned, balanced, and transported to and from Siemens Charlotte works (Fig 4). Transporting rotors from Charlotte to Bridgeport also proved challenging, with the numerous permits and highway escorts required state to state.

Warren stressed that Siemens is a *global* company. The logistical details of transporting major components, procuring parts from sites in Germany and the US, hand-offs from mechanical to commissioning, and communicating between Orlando (which owns the long-term agreement) and Alpharetta (responsible for the DCS) "caused some churn about meeting deadlines and delivery. At one point," Warren observed, "after we began to have issues with our grid operator/regulator, Emera had to 'come with a big paddle' to resolve the communication issues."

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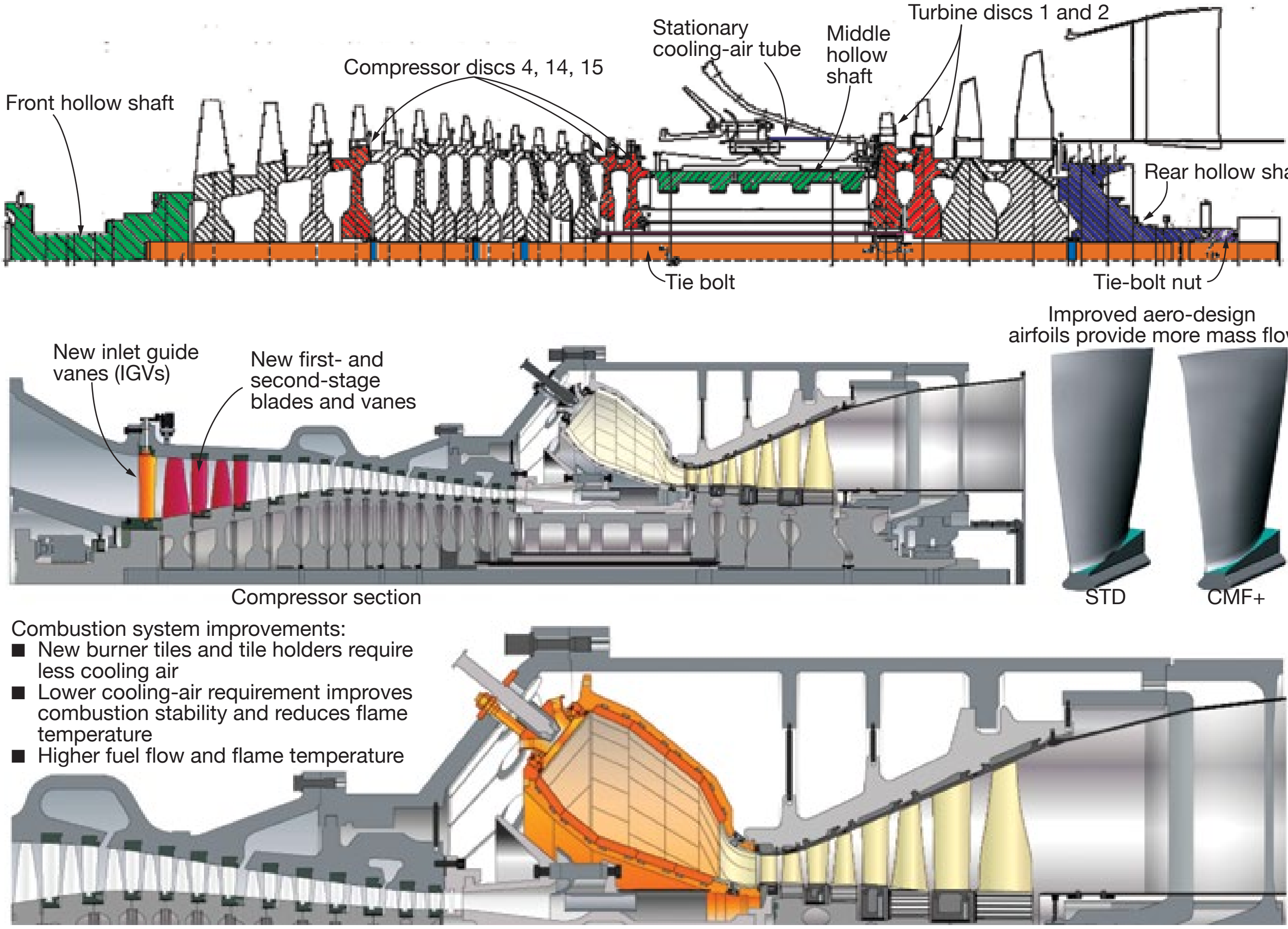


2. Three major elements of the gas turbine/generator refurbishment were replacement of parts for life extension (top); modification of the compressor for higher mass flow (center), including I&C mods for surge control and new IGV position sensor; and combustor improvements to increase output and provide better flame stability (bottom)

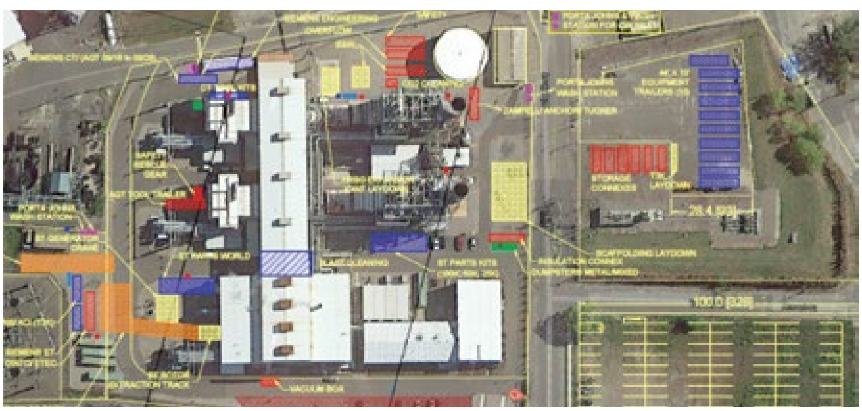
A key lesson learned, said Ross, is that you have to budget enough time during the outage for QA/QC and logic checkout during the factory acceptance tests (FAT) and for aligning loop checks with lockout/tagout procedures. "We could have used an additional week," he added. A specific issue was that the electrical-systems logic for GT11 was "copied over" for GT12, but the systems are not identical.

The hiccups were apparently well worth it. Ross said the big benefit of the T3000 is easier troubleshooting. "We can look at the logic behind the system right on the DCS, no more separate engineering workstation; we click on a point, see the graphics, and immediately pinpoint issues on the loop diagrams." Operators can now have up to 10 graphics on one monitor, compared to only one with TXP. "We have more info at our fingertips, more control over the equipment. The loops are the same but they are easier to tune." Plus, the plant has half the number of cabinets to deal with.

Bridgeport's power marketing and gas purchasing are handled by Emera out of Halifax. Lately, the market has been soft, noted Warren. "We arranged to run the plant in 1 × 1 mode during the second outage because we thought market conditions would support that." It turned out there were many days we were so close to the margin but ultimately were not picked up in the day-ahead market.

June and July were softer than expected, too, and the plant cycled much more than normal. "Our typical day is to run for 16 or 24 hours, but rarely just for an 8-hr shift. Historically the plant has had an 80% average capacity factor, which is quite high for a combined cycle today.

The ASMC systems on the GT/Gs help the plant operate at part load. New sensors on the IGVs are used to adjust the air flow to the pilot and main burners in real time, control combustion pressure and temperature, and maintain combustion stability and emissions. Warren noted that these are software upgrades, except for the IGV sensors, and involved changes to the valving logic.



3. Site is very constrained, hemmed in by other industrial facilities. More critically, only one overhead crane was available to work on the three generating units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4. New generator rotor for the steam turbine replaced the existing one, which suffered a saltwater intrusion event and other issues

Training is going to be an ongoing proposition for Bridgeport. Now that the plant has an owner that looks to stick around for a while, the staff is motivated and enthusiastic but their roles are shifting. "We have 16 of 26 professionals with new positions and responsibilities, so it's almost like starting up a new plant." The staff changes include three new patrol operators, three new control room operators, new production supervisor. "There's lots of training in our future," Ross commented wryly. Much of that is being invested with Siemens, too.

The stellar safety record is credited in part by Ross and Warren to JLN Associates, Old Lyme, Conn. We had 30-40 workers on site during the day, and while the plant management and staff are ultimately responsible, JLN people were our eyes and ears. They essentially handled confined-space permits and served as monitors, verified LOTO, performed hot-work oversight, and generally reviewed all things pertaining to safety. One key was making sure all job safety analyses (JSA) were complete and accurate.

The Emera/Siemens partnership isn't resting on its laurels. Upcoming modifications include wet compression to extract an additional 20 MW from the plant and upgrades for operation at even lower loads. "We keep looking for options to maximize the value of the asset," Warren underscored.

Other ideas are to play in the ancillary services market and supply power to Bridgeport's heating/cooling authority. "We've even negotiated a power purchase agreement for solar panels on the roof of the building, it's less than 500 kW but that's enough to supply the building," Warren said. That's good community relations, too, and complements the plant's contributions to 30 different local charities, and local business engagement.

The HRSGs still require a few million dollars of investment as that saltwater ingress incident did a number. "We have significant under-deposit corrosion from chlorides," Warren said. In May 2012, the plant operated for eight hours with significant condenser tube leaks, root cause being poor operator response to alarms. CCJ

Modernization program helps plant capture grid opportunities

Getting the full story of a partnership requires talking to both partners. A conversation with Siemen's Arne Wohlschlegel filled in some important details from the OEM perspective. Among other points of interest, this was the first outage of such complexity Siemens had undertaken in the US on this type of equipment, especially with a DCS upgrade included in the scope.

"Emera is a new customer for Siemens and we were impressed with its willingness to apply upgrade technology new to the US market," Wohlschlegel observed, "especially since the company wasn't familiar with our gas turbines." Emera conducted a broad survey of technology options and traveled far and wide to conduct due diligence. So the trust didn't come blind. He agreed that the outage time frames were ambitious for the scope. "We learned a great deal in the first outage that we could apply in the second."

Customers that embark on a two-decades service contract get benefits, Wohlschlegel said. "We provide greater coverage and an enhanced warranty, the customer gets priority on parts and repair, and everyone benefits from the economies of scale of having a *planned* maintenance program," he added. When asked whether maintenance costs were completely predictable over the two decades, Wohlschlegel answered, "for the most part, yes, about 85%, I'd say."

The real eye opener is that the upgrades also extend the GT/G hot-gas-path outage interval from 25,000 to 33,000 hours and a major outage (HGP + compressor) to 66,000 hours. Thus, there are significant availability gains in scheduled outage time as well as the incremental capacity gains and improved heat rate.

Siemens benefits from long-term service agreements because they aid in planning R&D programs and large-scale management of parts inventory. Of course, Wohlschlegel also acknowledged that the benefit of LTSAs to Siemens is that the company can better control the movement of the technical design and know-how around cutting-edge components to third-party service firms.

Part of the agreement is that Siemens also remotely monitors the machines to ensure high availability. The company can compare plant data with those from the larger fleet of machines and analyze operational conditions.

Wohlschlegel freely owned up to the challenges in communicating between Orlando and Alpharetta. "The fall outage timeline was ambitious, especially integrating I&C activities into the schedule. We learned some lessons but in the end it proved a great success."

Emera Siemens team pauses for a celebrity shot after re-installation of the rotor

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OEM engineers speak to issues, solutions, technology developments for F, G, H frames

Siemens Energy Inc's first technical conference for owner/operators of its F, G, and H gas turbines, held Sept 14-17, 2015 at Walt Disney World's Dolphin Hotel in Orlando, was rated a "success" by attendees sharing their views with the editors after the meeting (Sidebar 1). Approximately 130 users from across the globe participated. **CCJ's** editorial team, unable to attend this meeting because of schedule constraints, asked Siemens' Christie Robinson, representing the frame-owner office and product-line managers, to prepare the summary below.

Ed Bancalari, head of Siemens' large gas turbine product line opened the conference with an overview of the agenda. His presentation focused on fleet growth, global customer base, market drivers and dynamics, big data and digitalization, and the importance of operational flexibility.

Highlights of the four-day meeting included new customer orientation, presentations by the OEM's technical experts, closed user sessions, networking opportunities, a vendor fair, and a multi-day Siemens equipment/services showcase.

Mature F-class engines

Mature-F Frame Owner Shantanu Natu directed a "deep dive" on F through FD3 engines. Jonathan Mount opened the session with a presentation on spin cool/hot restart and the company's Direct Air Injection System (DAIS).

One goal was to communicate the value of blade-tip clearance analysis for the compressor and turbine sections; plus, the process changes made to better accommodate spin cool and hot restart, based on recent engine tests. Improvements planned for the DAIS was another discussion topic.

Mount was followed at the podium by Jonathan Swasey, presenting on rotor and casing inspection and evaluation (RCIE), Tarik Chehab on the air separator, and Dan Welsh on bearings.

Swasey summarized recent inspection findings and offered updated recommendations on what to look for during planned overhauls. Chehab and Welsh also presented on recent findings and made recommendations on inspection procedures, and on component repair and/or replacement.

Final topic in the first day's session was Row 4 turbine-blade seal pins, by Veronica Arocho-Pettit. She reviewed fleet findings and explained product improvements to mitigate issues experienced by some owner/operators.

Stay tuned

Siemens Energy Inc's engineering and marketing teams already are planning the next customer conference for owners of its F, G, and H gas turbines, motivated by the positive feedback received on the 2015 meeting. Users who missed the conference can access the presentations on the Customer Extranet Portal (CEP). Contact the Siemens representative for your plant if you encounter difficulty getting the information needed.

Don't miss the next meeting. Write Kelly Lewis (kelly.lewis@siemens.com) or Dawn McCarter (dawn.mccarter@siemens.com) and ask to receive details on the 2016 Siemens Customer Conference when they become available.

Track topics on the second day included operation on fuel oil, blade-path spread, turning-gear time reduction, and rotor air cooler. The deep dive concluded with presentations on plant optimization and mods and upgrades. Later, the users met in a closed session to critique content provided by Siemens; the steering committee of engine owners/operators communicated the feedback to Natu and his team.

Advanced F-class engines

Siemens' advanced-frame sessions (F4 and above), conducted in parallel with the mature-F sessions, was coordinated by Frame Owner Elizabeth Loveland. The main technical issues, addressed first, were these:

- Enhanced single-piece exhaust (Stephen Bawer).
- Compressor locking bolt (Bart Pepperman and Mark Adamson).
- Inlet cracking and expansion-joint cracking (Javier Jimenez).

The company's solution to address exhaust cracking experienced by the advanced fleet has been installed on all F4s and later models and appears to have completely eliminated the problem. The solution for the locking-bolt issue is available and recommended for installation only if the compressor cover is removed for other reasons. Finally, work to mitigate inlet cracking continues; the redesigned expansion joint is in commercial service and meeting expectations.

Other presentations on the first day included starting system, lube oil system, rotor cooling-air system, compressor water-wash recommendations, and bearings. Improvements to the DAIS were presented as well, followed by lessons learned and best practices for successful operation on liquid fuel.

On Day Two, Siemens updated users on what's new in the 501Fs coming off the assembly line today and the upgrades available for use on advanced

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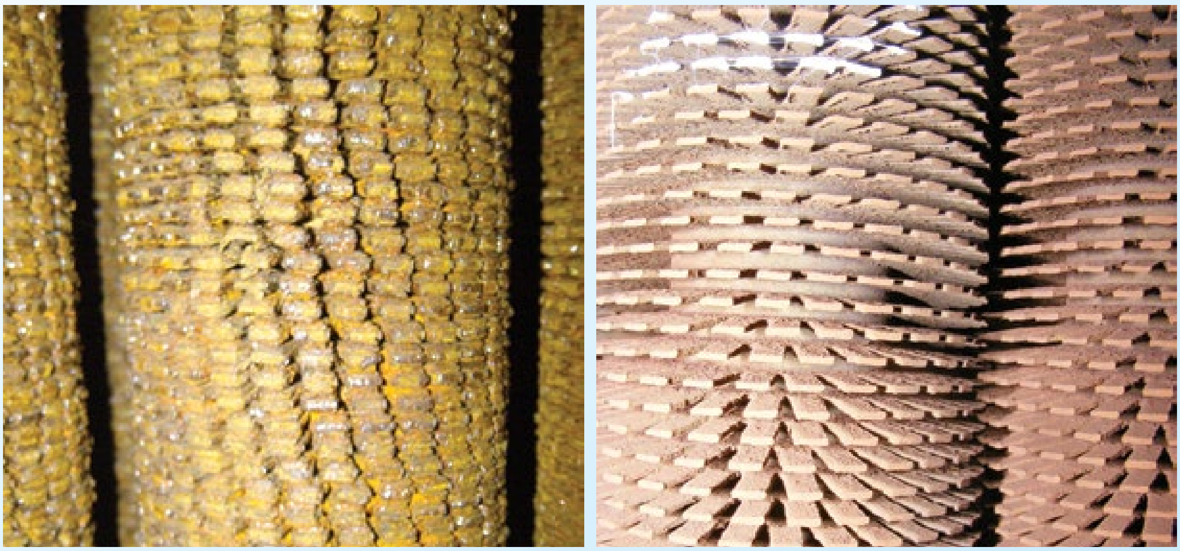

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engines already in service. Siemens' capabilities to optimize combined-cycle operation also were shared with attendees. The day concluded with a closed session for customers and presentation of an action-item list to Loveland and her team.

G fleet

The topic generating most discussion in the W501G session, chaired by Frame Owner Mark Carter, was an update on the turbine-rotor through-bolt failure issue. Rusty Van Hoose presented the latest fleet findings and mitigation program activity. Highlights since the last 501G meeting included the following:

- Report of an additional bolt fracture event.
- Comparison of findings from a rotor that had achieved a full service interval (two majors) without a bolt fracture to findings from rotors suffering bolt failures.

Root-cause findings for the most recent bolt fracture are consistent with those identified for the previous events: Specifically, debris accumulation contributing to high contact stresses which caused fretting fatigue cracks to initiate and propagate to a high-cycle fatigue (HCF) crack and eventual overload rupture.

While debris also accumulated on the through bolts of the rotor that had achieved its full service interval, those bolts did not reveal the same type of damage identified with the failed bolts. Further, they did not exhibit the same indications of iron oxide formation (magnetite versus hematite) and water staining.

Because the most recent bolt fracture occurred on a rotor that had some mitigations applied, robust discussion ensued regarding the effectiveness of those mitigations as well as on the latest recommendation of low-plasticity burnishing.

LPB is a surface treatment intended to greatly improve a through-bolt's margin against both fretting and HCF crack initiation and propagation by adding a deep compressive residual stress field to the bolt surface. A review of LPB testing was provided, highlighting very favorable results on fatigue resistance tests and open actions for additional ongoing tests—such as material debit and thermal mechanical exposure.

Jonathan Swasey followed with a review of findings and recommendations on turbine debris because of its connection with bolt fractures.

Other key presentations included a report by Dilshan Canagasaby on improvements to DLN combustion systems for increased operability and

1. What attendees thought

"Excellent conference. We appreciate the technical support from the engineering group. Presentations were very detailed an informative."

"Thanks for the opportunity and for sharing the information."

"A well-planned and highly useful conference."

"Siemens went out of its way to make the conference a success."

"Overall, the conference was very well conducted. The material presented was relevant and very well delivered."

"Outstanding conference. Siemens engineers were available from many different areas. The all-Siemens conference gives us more options if we own different machines. This was very beneficial."

2. Vendor fair participants

Access Solutions LLC
American Fire Technologies
Bearings Plus Inc
Brand Energy Solutions
Caldwell Energy
Coverflex Manufacturing Inc
Crossby Dewar Inc
Eagle Eyes Verify LLC
Fusion Babbitting Co
Hebeler Corp
Homewood Sales Inc
HydroAir Hughes
IceSolv LLC
Integra Technologies Ltd
Kingsbury Inc
Lectrodryer LLC
Macemore Inc
Miller Fall Protection (Honeywell Inc)
Mobile Mini
Piedmont Bushings & Insulators LLC
Pilgrim International Ltd
Pioneer Motor Bearing Co
PME Babbitt Bearings
Precision Iceblast Corp
Safety-Kleen Systems Inc
Safway Services LLC
Southwest Impreglon
Tex Blast Sandblasting
Thread Mill Industries Inc
Turner Supply Co
United Rentals Inc
Universal AET
Voith Turbo Inc
Williams Scotsman

durability. Shervin Rodd led an informative and lively discussion on fleet performance, comparing power output and turbine-inlet-temperature variations and their potential relationship to exhaust-temperature values. He also reviewed how performance characteristics compare with emissions and combustor flashback indications and the potential of improvement options.

H fleet

Siemens 8000H engine owners and operators came together for the first time at the Orlando conference. Because an H steering committee had not been formed prior to the meeting, the OEM directly asked its customers for help in developing an agenda. Frame Owner Dave Lawrence arranged the program in four sessions over two days, as follows:

1. Frame overview and fleet status, followed by an update on the company's global service strategy for the H frame and planned mods and upgrade products.
2. Operational issues. A Q&A session following prepared presentations allowed users to dive deeper into specific topics.
3. Updates on the steam turbine and generator product lines compatible with the 8000H gas turbine.
4. User session for open discussion and to collaborate on additional questions to present to Siemens engineers.

Steamers, generators, etc

Multiple parallel-track breakouts were conducted following the gas-turbine sessions to update attendees on generators, KN and HE steam turbines, service and repair technologies, and training. Here are some notes from each track:

Generator (air- and hydrogen-cooled) presentations/discussions covered service bulletins, field service capabilities, inspections, and maintenance practices. Also, a well-received introduction to new products—such as fiberoptic frame foot loading, high-frequency thermographic test, and generator life assessment.

Service and repair technologies focused on recent developments in welding, coating, and brazing. Hardware was displayed in different stages of repair. Technologies covered included tools for in-situ and smart inspections, tools and techniques for field service, processing of big data, and addressing the challenges of a growing global fleet.

Steam turbine sessions reviewed details of the KN and HE frames, and discussed maintenance, outage planning, and available upgrades. A presentation on maintenance scopes and typical outage findings got high marks. Other topics covered included spare parts, outage kits, valves, titanium blades, and bearings.

Safety was an interactive session led by Will Weatherford, which included an overview of Siemens' "Zero Harm Culture" and "Personal Commitment" programs. Chris Kopec and Keith Dean discussed innovations in field-service safety, highlighting human performance, hand safety, and line-of-fire/situational awareness.

The session concluded with a case study by Salman Khan on the challenges and opportunities in implementing safety programs—including best practices and lessons learned. Real-time audience polling provided feedback on content, revealing alignment on the need for an organizational safety culture and continuous human-performance improvement. Results also showed attendees acknowledged Siemens as a thought leader that walks the talk.

Controls included detailed presentations on T3K implementations, field experience, the version 7.2 upgrade, cybersecurity, and recent logic improvements for increased reliability and robustness.

The training track included an overview of the OEM's power diagnostic center and how it is integrated with day-to-day plant operations, using real-world examples. The plant training group discussed different modules offered by Siemens for personnel training. A voice-of-the-customer session was conducted for feedback and to solicit ideas for further improvements.

The equipment/services showcase mentioned at the beginning of this article continued throughout the week. Highlights included the following:

- Advanced hardware—including the H combustor and "Next Gen" G basket.
- Parts improvements: bellybands, F-frame VGP (Value Generation Program) R1 and R2 turbine blades, and F-frame exhaust configurations.
- Turbine vane repair.
- Advanced maintenance tools—including robotic crawler, vision scope, and inspection trailer.
- Advanced generator maintenance—including SIEMONplus monitoring system and FastGen tooling.
- Steam turbine blades.
- Steam turbine erosion experience.
- Field service displays—including human performance kit, tooling examples. CCJ

ACCs advance with engineered solutions

By **Steven C Stultz,** Consulting Editor

The Seventh Annual Meeting of the Air-Cooled Condenser Users Group (ACCUG), held in Gettysburg, Pa, was a historic venue in more ways than one. North meets South is obvious. But it was East meets West that drove the location. ACCs, more prevalent west of the Mississippi, are becoming more common in the East as water resources become more sacred and tighter environmental regulations grip all elements of the electric power industry.

The meeting agenda covered design and performance, O&M, and chemistry and corrosion. But within that structure were key themes of technology advancements, hands-on operating experience, trial and error, international growth, and the future. Content was an insightful blend of technical and practical. There was good audience participation, which is very important for a users' meeting and has been an increased focus for this annual event.

The overall benefits this editor brought back were the following:
- Reinforced fundamentals.
- Insight into what works, and what doesn't.
- Visions of what's down the road.
- Vigilance to expect the unexpected.

Below is a brief report on the event, including discussion points and selected participant questions. For more information, and access to the presentations, visit www.acc-usersgroup.org.

Design, performance

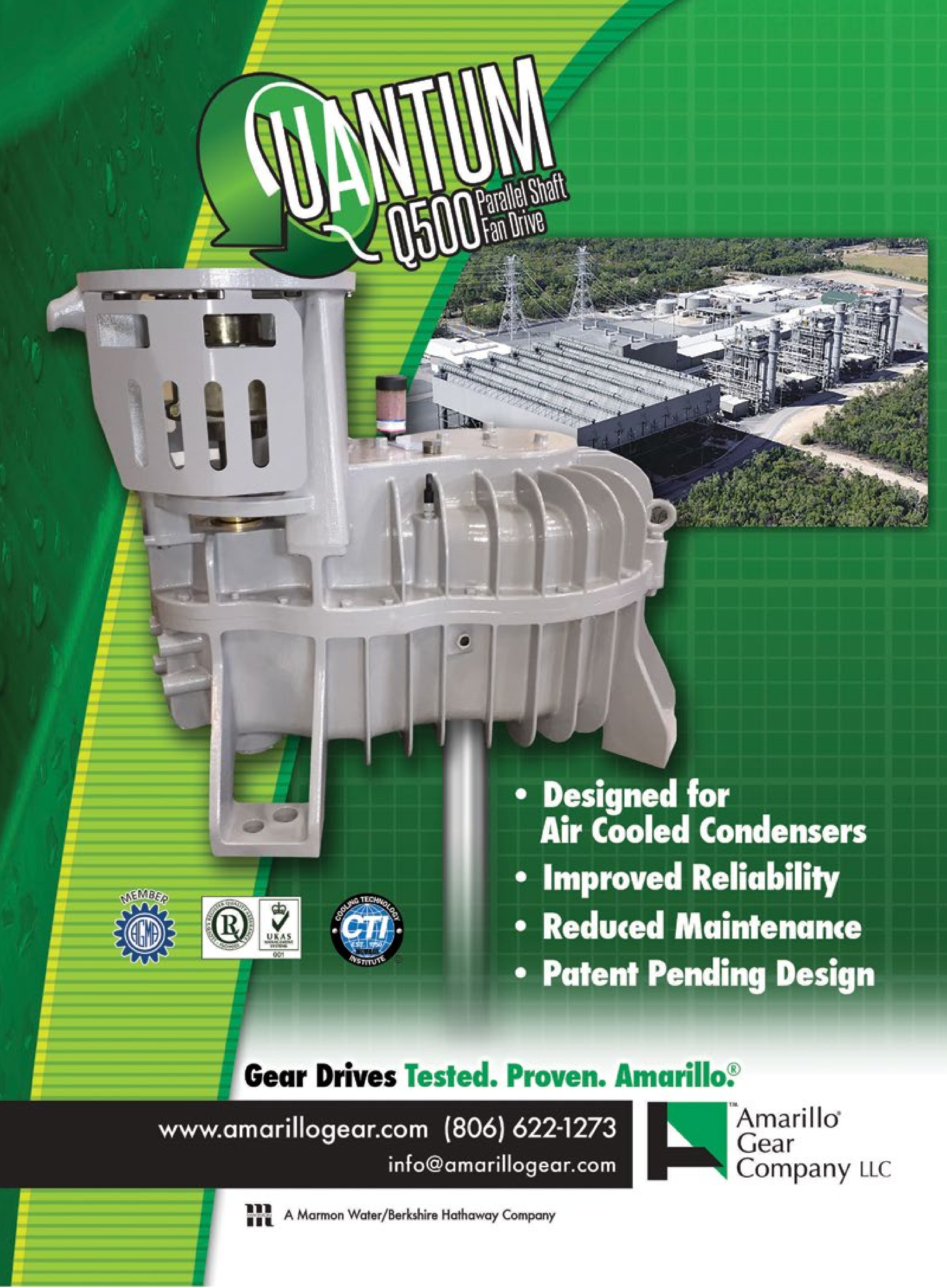
Wind screens at Mystic. Exelon Generation's Mystic Unit 8, a 2 × 1 800-MW combined cycle with a nominal 300-MW steam turbine, added wind screens to its ACC in late summer 2013. ACC configuration is nine streets, four cells per street, with a combination of variable- and fixed-speed fans. Unit 8 and its twin Unit 9 are affected by winds at this Charlestown (Mass) location, mostly during summer.

Plant management decided to try wind screens on the south and west sides of Unit 8. The incentive: A troublesome drop in summer output, and very high replacement-power costs. Wind screens have come of age over the last several years, moving from the science experiment stage to an engineered performance-enhancement tool, thanks to ongoing work and data collection.

This particular presentation offered interesting insights into the sometimes challenging retrofit installation process. The west side was straight forward, according to the presenter John Ayvazian, Exelon/Constellation Energy. But the south presented challenges with cable trays, conduit, small bore piping, structural attachments, and general equipment access (Fig 1).

1. South-side obstructions at Mystic ACC made installation of wind screens challenging (left)

2. Retractable wind screens at Caithness Long Island Energy Center (below)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3. Wind tunnel model at UC Davis (above)
4. Alpine climbers were hired for leak testing (right)

Operations before and after were reviewed in 2015. Based on similar ambient temperature and humidity, wind speed and direction, and backpressure, Unit 8 could now add 15 to 20 MW with the wind screens in place, offering a payback of two to three years. But as stressed repeatedly at the meeting, results are extremely site- and unit-specific. Analysis will continue.

Interestingly, this first presentation sparked another topic that would reappear throughout the two days of technical discussions. Such installation difficulties could be avoided if the screens were part of the original equipment. Participants knew this would mean changing both the specification and bidding processes.

Other noteworthy questions followed, including cold-weather adjustments, materials cost, and clogging. For the last, these screens have a motorized option, and some debris tends to clear during roll up and roll down.

Wind screens at Caithness. Wind effects on ACCs are drawing increased global attention; impacts include plant thermal performance, fan blade damage, and cell-by-cell fan duty, among others. What perhaps is not well known is how to quantify and measure all thermal-performance impacts, backpressures, cell-by-cell performance issues, and other specifics.

To move this knowledge forward, a comprehensive study was launched at Caithness Long Island Energy Center Unit 8. The plant features an 18-cell ACC with retractable screens, a unique feature at the time of project launch (Fig 2). This study was first reported at the Sixth Annual Meeting in San Diego, after initial site data collection.

The ongoing and comprehensive study includes field testing, wind-tunnel simulations, and CFD modeling. Participants include the University of California, Davis (wind tunnel), Senta Engineering (CFD), Howden (fans), Galebreaker (wind screens), and the California Energy Commission. John Maulbetsch, Maulbetsch Consulting, made the presentation.

Procedures include validating the wind-tunnel models with field data, extending the range of results through wind-tunnel simulations, and both generalizing and predicting strategies and outcomes with CFD modeling.

To attendees, it became clear that this was a long-term study that was perhaps just opening some new doors for further insight and development, much as actual ACC operating experience grows in depth and breadth each year.

The detailed presentation took a comprehensive, yet focused, look at data sorted by wind direction and screen position. Both the physical model and CFD results also were shown. In summary, field tests revealed potential reduced fan-blade loading, improved fan inlet uniformity, and the "possibility" of enhanced unit thermal performance. Wind-tunnel simulations (Fig 3) showed good correspondence to field results, the possibility of exploring alternatives, and a physical feel for the overall study.

CFD modeling offered a highly detailed representation and the ability to explore a wide range of cases, but also showed that quantitative results are not yet available. As the presenter candidly stated, "we have qualitative understandings, but not quantitative results."

Ensuing discussions were specific. Question and discussion points included measuring and predicting exact wind physics (difficult), the long-term benefits of modeling, and even the impact of upstream site obstructions like trees and buildings.

Caithness project participants were well represented at the meeting, enhancing the discussions and leading to more interaction during breaks and meals. The presentation had all the right elements: detailed, practical, and forward-looking.

The presenters anticipate further work, further analysis, and further discussions, specifically at the Eighth Annual Meeting in September 2016.

Screen impact on dynamic blade loading offered a transition to the next presentation.

Wind loads on fan blades. A more theoretical presentation followed: loads acting on blades with and without wind and related blade response. Three conditions were studied: wind speed of zero, constant wind speed of 60 mph, and constant wind speed of 60 mph with screens.

Although not site-specific, the data, presented by Cofimco's Nicola Romano, was wide-ranging and included loads, dynamics, and load mitigation.

The findings:

1. Wind can dramatically increase the root bending moment variation transmitted to the bridge and, consequently, the vibration level. This produces loads and stresses on the drive-train components, and could produce additional harmonic effects.
2. Wind screens can reduce wind effect significantly, both vibration level and performance. Using fans with reduced-chord blades and increased blade count can lessen wind effects as well as vibration levels. Softer blades can help, too. Embedded damping devices allow further control.
3. Reduction of blade chord together with soft shaft and embedded friction-based damping systems can benefit service life but cannot improve performance loss attributed to wind. Together with wind screens, the combination will likely achieve the optimum mitigation of wind effect on vibration, increasing drive-system life and reducing maintenance costs.

An interesting observation followed, which this editor will call a Rule of Thumb. One utility attendee stated he had been taught that an odd number of blades is preferred, reducing the impact of two blades passing under the bridge at the same time. This led to a lengthy interaction of attendees with no concrete answer, other than "when in doubt, go with odd, and as

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many blades as possible."

The Netherlands. Transitioning to a specific project, a case study offered "Enhanced ACC Performance at an Acceptable Price." This was an interesting look at a unique project, noteworthy for its common sense and economic approach. The base project was an ACC replacement in the Netherlands, with a demanding client who also wanted:

- Improved summer performance.
- Limited air in-leakage.
- No digging of pits for pumps (abundance of ground piping and cables).
- Limited steam-duct flow resistance.
- Indoor location for pumps and valves.
- Freeze protection during low steam flows.
- Vibration-monitoring gearboxes instead of vibration switches.

There were further "special requests" during the project. Huub Hubregtse, ACC-Team, took a logical, common sense, cost-conscious approach to all demands and challenges. By contract, the new ACC would be located behind the existing ACC, with the steam duct routed around the old equipment. All plant operations would continue during the entire project.

With the old ACC present, the steam duct would need to be longer than normal. At modest expense, the diameter was expanded from 48 to 56 in. with little pressure-drop difference.

One efficiency improvement example: The gearboxes and motors were upgraded from 45 to 95 kW, well within the inverter capacity supplied by the customer. Then, by increasing the frequency from 50 to 60 Hz, motor capacity allowed 61% additional air flow.

Perhaps most innovative was welding of the steam duct on top of the bundles. Local regulations would mean abnormally heavy (and expensive) labor supervision and provisions while working inside the duct.

The solution: Welding the steam duct from the outside, eliminating some safety concerns and increasing weld speed. When asked if he would repeat the welding procedure, the presenter stated: "Definitely. It's easier, healthier, faster, and cheaper."

Then, to avoid high scaffolding costs, the contractor hired "Alpine climbers" with ropes who scaled the finished structure for leak detection (Fig 4). All welds of the new ACC were subject to helium leak testing and found to be intact. Any leaks were limited to the turbine casing and gland steam condenser, not the ACC.

Aluminum-clad steel. Although manufacturer and product specific, Hans-Juergen Gauger of Wickeder Westfalenstahl introduced an important topic that is gaining global interest: coating and cladding of ACC tubes for corrosion protection.

Gauger described European technology (Feran®) noting primary current competition as Asian. But the goal is the same, to reduce or eliminate corrosion of metal by cladding the steel—specifically with the integral aluminum layer. This provides reliable heat transfer by stable bonding and brazing, and maintains the aluminum-free inner tube surface.

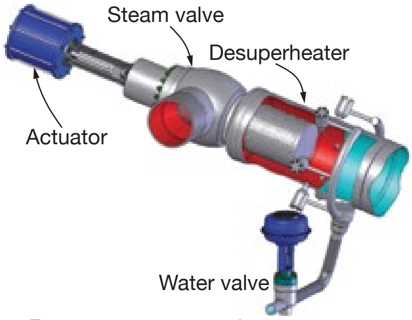
Test data were shown for both qualified and non-qualified materials, for comparisons. Traceability procedures for both material and workmanship also were covered in detail. Robust discussion followed.

O&M

Turbine bypass. The O&M session began with a high-interest presentation on turbine bypass system requirements, stressing that such a system is much more than just a valve. It is an opportunity to condition the steam for the entire unit cycle.

The presenters had these basic goals:

1. Inform and educate users on the challenges of bypassing to the ACC duct.



5. Bypass system reduces steam pressure and temperature before it enters the turbine

2. Become informed and educated by users on existing bypass stations and ducts.
3. Potentially partner with users to study the noise and vibration levels generated during startup and full bypass. This presentation appealed clearly for a "two-way street."

Ory Selzer and Farhan Ahmed, IMI Critical Engineering (IMI CCI), gave the presentation, noting this was their first ACCUG meeting. Selzer, the "valve doctor," began with the basics: A turbine bypass system is a steam conditioning arrangement that reduces pressure and temperature while bypassing the steam turbine.

The example used (Fig 5) included the steam valve, water valve, desuperheater, actuator, and discussions of the diffuser, water injection system, and interplay with other components within the bypass system. To stress the concept (and potential size) of such severe service valves, a photo was shown from the Millmerran supercritical coal-fired project in Australia (Fig 6).

For a combined-cycle plant, steam-turbine bypass options, as illustrated in Fig 7, are these:

- High pressure to cold reheat.
- Hot reheat to condenser.
- Low pressure to condenser.

Still setting the stage, Selzer offered the following common bypass-system applications:

1. During startup and shutdown. This allows controlled heatup of the boiler and steam turbine, and allows the HRSG and condenser to be fully operational before turbine roll.
2. During a steam turbine trip. This allows conservation of steam rather than wasting it (dumped to the atmosphere). Also, the gas turbine and HRSG can be decoupled from the steam turbine and generator, for their protection.

Selzer followed with an interesting perspective: "Valve designers are in the business of destroying energy, without destroying the valve." The participants seemed to appreciate his explanation of how bypass valves are able to satisfy these conflicting goals.

The presentation then turned to the critical topic of hot-reheat-to-condenser desuperheating. Hot reheat to condenser is particularly challenging. It has the highest temperature differential (more than 900 deg F) and coldest spray water (condensate at about 120F), largest pipe (24 to 42 in.), biggest change in steam density or volumetric flow (dumping to vacuum), and the largest water-to-steam ratios (greater than 30%).

With ACCs, lower temperatures are needed for flexibility requirements of the seals in the steam duct. ACC expansion joints are normally around 250F design. Thus two-stage desuperheating is common. The presenters then showed location options for the second-stage desuperheaters, highlighting benefits and cautions for each, including controls.

Noise commanded high participant interest. This presentation went beyond the basic predictors and requirements of noise issued by ISA (Instrumentation, Systems and Automation Society) and IEC (International Electrotechnical Commission) to encompass the physics of compressible fluid noise:

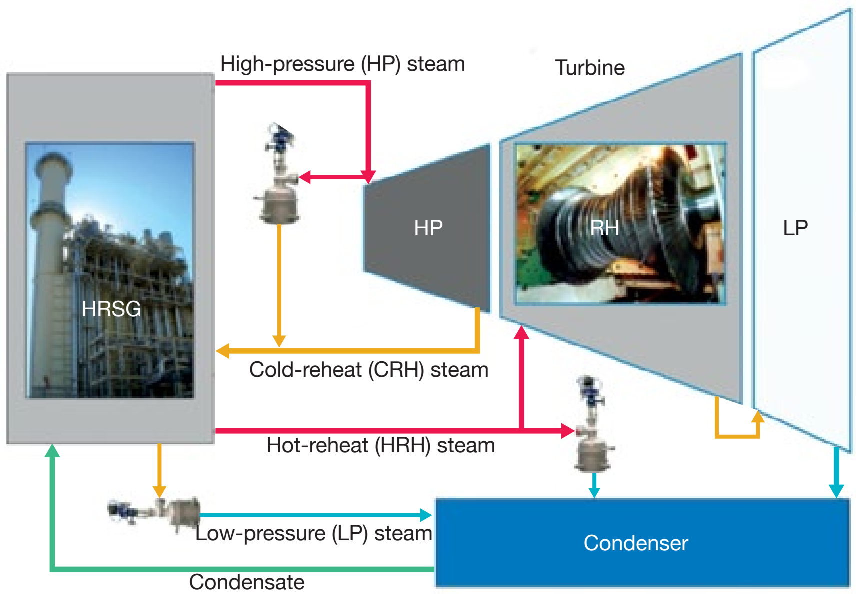
- Generation.
- Acoustic field development.
- Transmission through pipe wall.
- Propagation to a measuring point.

The participants gained insights into these four elements and then the options for noise reduction:

1. Divide total pressure drop into multiple stages.
2. Divide large-diameter jets into smaller-diameter jets.
3. Dampen the noise (absorption material).
4. Move further away from the noise (distance attenuation).

One interesting point concerned large-diameter steam ducts (to streets). These are, by design, large and thin-walled, or as the presenter highlighted, "the diameter-to-wall thickness of a beverage can." Because of size, acoustic and thermal insulation are not practical. Therefore, most noise-reduction efforts fall elsewhere.

Case Study 1 was a 779-MW 2 × 1 plant using a single-stage HRH dump tube. At a gas-turbine output of 155 MW, measured noise three meters from the steam duct was 115.0 dBA, with severe duct vibration and crack-



6. Severe service valve installed in the HRH bypass system at Australia's coal-fired Millmerran Power Station (left)

7. Typical bypass arrangement for a combined-cycle steam turbine (above)

Save the Date

USERS 501F GROUP

2016 Conference

February 21 - 25 * La Cantera Hill Country Resort, San Antonio, Tex

Exhibitor contact:

Caren Genovese, meeting coordinator, carengenovese@charter.net

User contact:

Russ Snyder, chairman, 501F Users Group, russ.snyder@cleco.com

ing of duct and reinforcement rib welds. The dump tube was redesigned with cylindrical discharge and smaller holes. Noise decreased to 106.6 dBA and the vibration was eliminated.

Case Study 2 was a 542-MW 2 × 1 combined cycle, also with single-stage dump tube. The tube was redesigned with cylindrical discharge and measured noise was 110 dBA. But local residents wanted a further reduction of 25 to 45 dB. The valve was modified, and the dump tube was replaced with a 16-stage DRAG resistor, achieving a far-field noise reduction of greater than 20 dB.

Many questions and ideas followed, indicating that this could become an annual topic.

One question drove it home: "Can you put noise in layman's terms?" The answer: "A jet aircraft engine is about 130 dBA. But at anything much above 100, you can't think. You just have to get away!"

Cold weather, heat rate, megawatts. The day continued two more ACCUG first-timers presenting. James Koch, HeatRate.com, and Chris Haynes, Power Software Associates, threatened an in-depth discussion on thermodynamics, but relented a bit.

However, they launched the basics that had meaning. Winter backpressures are too high and can result in a significant loss in steam-turbine output (up to 5%). The high backpressures are caused by high air in-leakage, metal wastage concerns, and freezing potential.

Owners know high backpressure is bad, yet it is often a summertime concern. But winter losses, in an example outlined for a 100-MW steam turbine/generator, led to $1.5 million per year in higher power costs.

Most everyone appreciates a good Rule of Thumb, and historically the adage has been a one inch increase in backpressure translates to a one percent loss in output. But, stated Koch, this is incorrect. In fact, there is no Rule of Thumb. The relationship is always unit specific.

That said, he presented two cases with very different losses attributed to high backpressure. The difference? The size of last-stage blading, relative to steam flow. This he called "end loading," or pounds per hour of exhaust steam flow divided by the exhaust flow area in square feet. This, in turn, sets the blading efficiency.

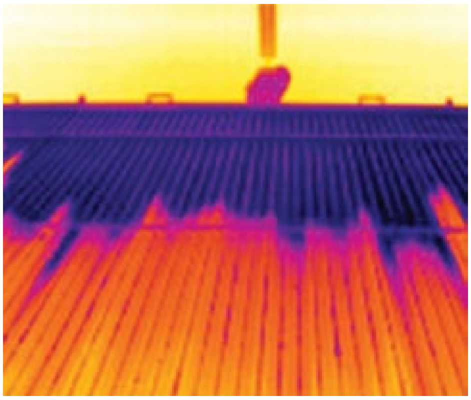
In other words, end loading determines steam velocity, steam velocity determines velocity ratio, and velocity ratio determines blading efficiency. The calculation is basic, in pounds per hour per square foot. Examples were given.

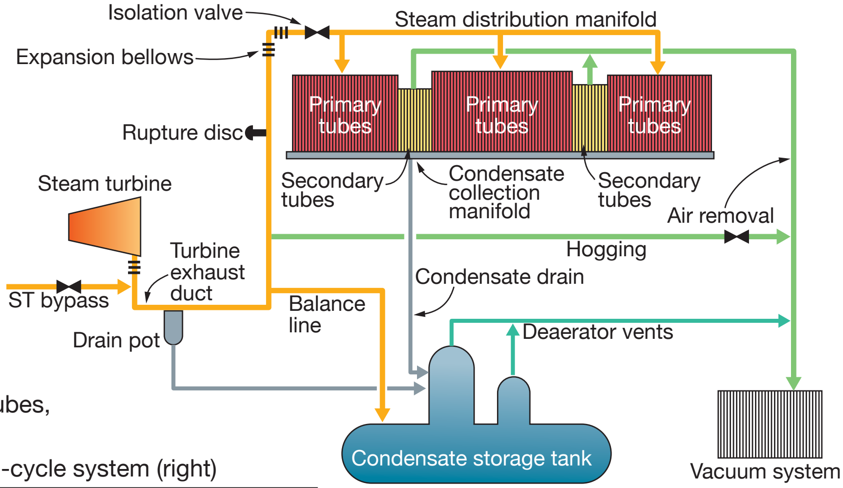
Then, the presentation focused on ambient temperatures between 32F and 40F. In highly end-loaded units there is little freeze-protection advantage in reducing backpressure. The opposite is true for lightly end-loaded units.

High air in-leakage increases backpressure and the danger of freezing. Note, too, air-removal pumps have less capacity when the backpressure is low. Erosion (both conventional and FAC) are worsened at low backpressure because velocity and moisture increase. But FAC can be reduced with proper water chemistry, making lower backpressures achievable.

One main point became the "conservative" nature of most operating-plant freeze-protection procedures. First, overly conservative procedures prevent these plants from taking advantage of achievable lower winter backpressure. Second, when "not quite freezing," these guidelines can be too restrictive. Margins can be too cautious, and operators can "leave megawatts on the table."

Looking forward, these presenters along with Dr Melanie Derby, Kansas State University, have launched development, simulation, and field testing of improved instrumentation and controls. The goal is to monitor temperatures at "a million" locations (per ACC) through IR thermography





8. IR thermography indicates "cold" ACC tubes, where air is trapped (above)

9. Typical vacuum boundary in a combined-cycle system (right)

tied to the control room (Fig 8).

Discussions of measurement methods followed, and one operator stressed the need to be conservative "to avoid even more expensive shutdowns." But the discussion was vigorous and suggested a trend that will develop through research, testing, and operating experience.

Air ingress 101. This was followed by a fast-paced yet detailed look at field examples, by Martin Cyr, SPX Cooling. Air ingress defined: Unwanted and excessive air leakage into the powerplant vacuum boundary (Fig 9), which is site specific. Steam-turbine performance then is reduced because of increased backpressure.

But who feels the impact?

- Operations staff : ACC sluggish, slow to respond.
- O&M manager: startup delays, production loss, expensive troubleshooting.
- Plant manager and owner: lost revenue.

The presenter put the topic in his field-experience terms. "Air ingress is rarely a concern until plant performance is impacted, or the ACC freezes."

And what are the common locations of ingress?

- Open valves.
- Leaking flanges.
- Mechanical seals.
- Instrument fittings.

And for the steam turbine?

- Shaft seals or shaft seal-housing flanges.
- Rupture discs.
- Crossover pipes, flanges or bellows.

To these you can add:

- Temporary steam blow or makeup-water piping during startup.
- Cracked welds.
- Leaking ACC cleanout ports.

Why should you be concerned? Poor heat transfer (air, including nitrogen and other gases, is a terrible thermal conductor), corrosion (oxygen pitting, carbonic acid attack, iron deposits, low pH), accelerated freezing, and more fans operating at higher speeds, among others.

But the hardest-hitting point was the cause. "Human error," said the speaker. "Most times it is a simple, avoidable error." Examples included failure to close a vent or drain valve, failure to align a valve, failure to replace a gasket, failure to clean a flange, and failure to properly torque flange bolts in the correct sequence. Accidents also occur (driving an alignment bar too far, dropping tools, etc).

Further, excessive cycling causes thermal fatigue (expansion joints, for example). Freezing can crack welds or bend tubes. And there are the all-too-common inferior shop or field welds.

For measurement, an interesting discussion followed on standard flow meters, noting they are sized for total capacity and may accept some leakage. The recommendation: add a meter with a more appropriate (more focused and precise) scale. Locations were also discussed.

Then there was another Rule of Thumb moment: The temperature differences between steam inlet, air takeoff, and condensate drain should all be within 10 deg F of the steam inlet pressure saturation temperature during normal (design) operating conditions. If not, you need to find the source of the leak.

One method discussed was an infrared survey of the tube bundles, as shown in Fig 8. A second was the vacuum decay test. For exact leak locations, examples included helium leak testing, pressure testing, acoustic listening devices, duct tape, and "old fashioned shaving cream."

Villafuerte

Venting systems. The next day began with ACC venting systems offering valuable, practical information and cautions. John Aglitz, PE, presented for Nitech, classifying venting systems as relatively small but essential, and suggesting there has been inadequate design cooperation with the main condenser suppliers, leading to some equipment damage.

Hogging is the quick evacuation of steam space prior to the introduction of steam, and most often with its own, separate system. Normal design calls for evacuating to 10 in. Hg abs in 30 minutes, but this is unit and operations specific.

Holding is the continuous removal of air and other non-condensable gases.

The workhorse has been the steam ejector, with no moving parts. Vacuum pumps (single-stage for hogging, two-stage for holding) are also used, but require a heat exchanger to remove the heat of compression and condensing from the seal water. The less common hybrid systems were also discussed.

Ejectors are damaged most often by poor quality (wet) steam. This is usually solved with insulation and a steam separator and trap immediately before the motive-steam inlet. Vacuum pumps are susceptible to cavitation (internal surface damage).

Heat Exchange Institute standards also were discussed.

One question focused on air-ejector flammability, notably with systems using ammonia. All ejectors are a function of what is inside the system, but the Rule of Thumb is to label the immediate area as a no smoking/no spark area.

Hybrid systems attracted the most participant interest.

General improvement considerations. Rene Villafuerte, a combined-cycle plant manager and member of the steering committee, who left the electric power industry for greener pastures shortly after the meeting, continued with a hands-on look at typical ACC prob-

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10. Wind countermeasures manufactured by local supplier

lems and solutions. The basic premise was high steam-turbine backpressure in summer, limiting power output. More notable, even though original equipment is correctly sized when commissioned, all units degrade over the years with fouling, tube damage, and related issues.

For tube cleaning, Villafuerte's common sense solution is, when possible, wash from inside to outside, then outside to inside, and seldom use chemicals. To see what you are up against, he said, look also at the local area (a nearby cement mill in one example). And you can use a manual system with pressures of 1250 and 5000 psig, but be careful and take your time.

For air leakage and bypass events, galvanized sheet metal, pop rivets and red gasket forming RTV silicone can make effective use of the escaping air and force it through the fins.

Participants quickly found that Villafuerte is good at using all available resources (and only fixing what needs repair). The presentation included some local, home-made solutions that kept interest high.

For a final tightness check, the speaker noted the vacuum decay test as perhaps the best.

According to Villafuerte, one of the most detrimental performance impacts is suction starvation (fans not pushing enough air upwards), driven by wind shear attributed to high wind velocity underneath the ACC. Therefore, he suggested consideration of wind walls or screens. Conventional screens were well covered during the meeting. But the speaker also showed locally made options (Fig 10) that offered some site-specific benefits.

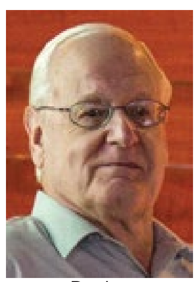
Fan upgrades then were covered in detail. One example began by comparing fan power to steam mass flow, showing that the unit was under-utilized. Fans were upgraded from 100 to 200 hp, and nine blades replaced the original four. This significantly increased performance under adverse conditions. Although auxiliary power consumption increased, results showed reduced backpressure limitation, increased steam flow through the turbine, and overall heat-rate improvement, or what Villafuerte referred to as "free power, using more of what you have already paid for."

Discussions then focused on leak-test media.

Fin cleaning. The final O&M discussion covered fin cleaning, and the general impact of fouling. Fouling by pollen, dust, leaves, insects, birds, even plastic bags, causes poor heat transfer, high operating costs, higher fan power requirements, and reduced output because of higher turbine backpressure.

Types of offline cleaning included fire hose, high-pressure hand lance, and foam or chemicals. The presentation, by Fabian Noack, JNW Cleaning Solutions, then turned to the company's fully automatic systems and related personnel requirements. Typical positive results were included.

Chemistry, corrosion



Dooley

Dr Barry Dooley, Structural Integrity Associates, introduced the chemistry and corrosion session. One dominant point: ACCs come in very many shapes and sizes and are used worldwide. But one thing is consistent—corrosion/FAC damage happens, and looks the same regardless of design or location.

Therefore, the focus remains on chemistry, concentrations of iron, pH levels, and controls throughout the unit cycle.

He began with a guide to categorize corrosion and track improvements, known as the Dooley Howell ACC Corrosion Index (DHACI), later described in detail by Dr Andrew Howell of Xcel Energy, the ACCUG chairman. Corrosion and FAC have consequences. High iron concentrations in the HRSG can lead to tube overheating, tube failures, and expensive chemical cleaning. Plus steam-turbine deposits and the need for iron removal (condensate polishing and/or filters). But overall it is the ACC that controls cycle chemistry. So the DHACI helps detect, categorize, and track iron concentrations.

Howell

Described in documents and articles posted at www.acc-usersgroup.org and www.ccj-online.com, this index is applied to key areas including tube inlets, lower ducts, and supports, among others. The benefit is knowing what to look for, because "damage is the same worldwide with all cycle chemistries." Specific examples were shown, including two-phase FAC beneath supports.

The speaker next reviewed the Dooley/Aspden pH-versus-iron relationship, stating that increasing condensate pH to 9.8 with ammonia or neutralizing amines will gradually eliminate FAC damage at the tube entries, and iron will reduce to suggested levels of 5 to 10 ppb. This takes time and can be monitored and documented using the DHACI.

11. DHACI rating 4, serious corrosion at inlets to cooling tubes

Industry guidelines were issued in 2008-2009, based on collective understandings, but there has been little development since—until now. Dooley would return later to discuss these development activities.

Particle measurement. To continue the chemistry and corrosion discussion, Ken Kuric, Hach, presented "Particle Measurement for Iron Transport and Iron Analysis." Kuric introduced FAC monitoring, offered alternatives for detecting corrosion-product transport in the steam cycle, and showed data from operating plants. He began by stressing the chemical and mechanical erosion mechanisms, emphasizing both dangers and costs. Kuric summarized protective magnetite (black) and protective hematite (orange), as well as magnetite stripping and re-deposition. Most problems arise when this protective later is interrupted, moved, and re-formed. This set the stage for some later discussions.

Traditional sampling methods were then covered. Laser nephelometry in particular was noted as a potential solution to detect insoluble iron.

Outlining the bench test method, Kuric described detections as low as 0.3 ppb through a complex system and extreme attention to detail at all levels. Access the presentation at www.acc-usersgroup.org.

Plant ACC studies included California (2 × 1 combined cycle, 600 MW), Virginia (coal, 600 MW), and Pennsylvania (Hunterstown 810-MW combined cycle). Howell commented that although trace-iron analysis is not a daily requirement, it is something that all ACCUG participants need to be aware of going forward.

Polyamine for reduced iron throw. Next was a strong and forward-looking discussion on filming amine technology from GE, conceding immediately that "polyamine is not for everyone." This "barrier technology," however, becomes more important as the depth and breadth of ACC use increase worldwide.

ACCs face common relevant challenges. They have large surface area, so a small corrosion rate leads to significant amounts of iron. Steam velocities entering the streets fluctuate, and a cold street can increase the velocity. Also, steam droplet size can vary based on temperatures and operating conditions, and droplets act in a similar manner as two-phase FAC. Cycling operation adds to these problems.

Elevating pH to between 9.6 and 10.0 with a low-volatility amine combined with ammonia and/or other amines has shown significant reductions of corrosion and iron throw.

Particle burst timing, intensity, and longevity, detailed in the proceedings of the ACCUG's Fifth Annual Meeting, set the stage for further analysis, and

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12. ACC at Ivanpah solar thermal project (above)

13. Hunterstown Generating Station, equipped with a 50-cell ACC, was the ACCUG's 2015 host site (right)

led to discussions of evolving steam-generator chemical treatment. Polyamine is perhaps the latest evolution of asset protection and has been used in both traditional fossil-fueled boilers and HRSGs. R&D and testing continue.

Three case studies were then presented: a 3 × 1 combined cycle with three multi-drum HRSGs in cycling operation, a base-load 630-MW coal unit (2600 psig), and a plant comprised of two 2 × 1 combined cycles with four multi-drum HRSGs. Results were extremely good, even after continuous operation.

Steam-cycle treatment continues to evolve and now includes this technology. Planned future work involves the impact on heat transfer, impact on polishers, thermal stability, and breakdown paths. Unit layup studies are also planned. Both EPRI and the International Association for the Properties of Water and Steam (IAPWS, pronounced "eye-apps") are involved in this ongoing program.

Lengthy discussion followed indicating both the benefits and the need for caution going forward. Said the speaker, "it's like anything else. Overdosing could be a problem."

Internal inspection guidelines. Chairman Howell presented "ACC01: Internal Inspection Guidelines of Air-Cooled Condensers." For details, see CCJ 1Q/2015, p 110, or access the original document at www.acc-usersgroup.org. Highlights included the following:

- Iron-oxide transport can introduce a large quantity of contaminants to the condensate/boiler feedwater circuit.
- Corrosion can eat through the thin walls of cooling tubes, allowing air ingress.
- Carefully planned inspections during outages are increasingly important.

Howell began with discussions of plant and ACC configurations, operation methods, inspection frequency, inspection preparation, and personnel safety.

A detailed presentation followed

outlining the Dooley Howell Corrosion Index and its rating system. This procedure was then applied to examples for the ACC upper section (Fig 11), lower section, specific inspection regions (turbine exhaust, risers), and other components.

The document available on line includes an ACC Visual Inspection Worksheet to provide organization and ensure a comprehensive scheduled look at the equipment.

Howell then invited comments on both the existing text and the worksheet, scheduled for review and revision in 2018.

In addition, related publications planned by the ACC Users Group include:

1. "External Inspection of ACCs."
2. "Fin Tube Cleaning Methods and Recommendations."

Details will be posted on www.acc-usersgroup.org.

Cycle-chemistry guidance. Dooley then returned to discuss cycle-chemistry guidance and research status, specifically work by IAPWS. He was preparing the keynote address for the recent International Conference on Air-Cooled Condensers, Xi'an, China, which included this topic. The content of "IAPWS Cycle Chemistry Guidance Documents for Plants with ACCs" would then be made available to participants at this Gettysburg meeting.

This was a review of IAWPS including its current members, activities, working groups, and technical guidance documents (TGDs). Specific reference was made to: "Monitoring and Analyzing Total Iron and Copper in Fossil and Combined Cycle Plants (May 2014)," and "Introduction and Rationale for Corrosion Product Sampling (CPS)." "HRSG HP Evaporator Sampling for Internal Deposit Determination" and "Film Forming Amines" are planned for 2016.

Solar, pre- and post-meeting tours

Ivanpah solar project. The technical sessions ended with a review of ACC experience at the Ivanpah Solar Thermal Project, located in a dry lake just south of Primm, Nev. It is equipped with three ACCs and three steam turbines totaling 350 MW. Each ACC has three streets of five, two-speed nine-blade fans (Fig 12).

At startup, the ACCs indicated a potential resonance near the blade-passing frequency. Modal analysis predicted resonance of the fan bridge assemblies, an issue not anticipated with fans having an odd number of blades. Through modeling, the concern was further refined to a lateral rocking mode of the motor/gearbox assembly in the parallel direction to the bridge. Further testing showed the offending structural natural frequency to be dominated by the flexibility of the I-beam support structure.

Modifications, described to the participants, were made to the upper support structure of the gearbox. Vibration levels were adequately reduced. Resonance continues but amplification is controlled.

Tours. Three optional tours were available to all participants. On the morning before technical discussions, Evapco provided a bus tour of Gettysburg National Park. In the afternoon, the company hosted a tour of its Dry Cooling Research and Development Facility in Taneytown, Md, again with transport provided.

Following the technical sessions, NRG Energy and Plant Manager John Brummer welcomed attendees to the nearby Hunterstown Generating Station, equipped with a 50-cell (10 × 5) ACC (Fig 13). This included discussions and a complete walk down of the air-cooled condenser. Items of particular interest were low-noise fans, recent steam-side corrosion evaluations and chemistry optimization, and tube leak/air in-leakage mitigation. CCJ

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1. The international ACC meeting in Xi'an hosted 85 participants with a variety of solid expertise covering design, performance, operation, and research

China hosts global meeting to share know-how, innovation

Soon after the Seventh Annual Meeting of the Air-Cooled Condenser (ACC) Users Group in Gettysburg (previous article), industry attention shifted to the International Air-Cooled Condenser Conference in Xi'an, Shaanxi province, China.

Like Gettysburg, the international meeting was a notable venue—in this case the ancient Chinese city with the eminent Tomb of Qin, known for its terracotta warriors and horses. It also is home to the Xi'an Thermal Power Research Institute (TPRI), a primary sponsor and key participant with 25 attendees and focused presentations.

Beyond TPRI, the meeting drew participants from the US, UK, Canada, Netherlands, Germany, Japan, and South Korea. Additional Chinese participants represented power generators, research groups, universities, vendors, and the Chinese affiliates of eight international companies (Fig 1).

China's expanding power-generation capacity includes more than 100 dry-cooled stations. The conference was organized to share technical information between China and the rest of the world, which has many more ACCs and decades of experience in construction and operation.

The most significant information benefiting participants included:

- Descriptions of current design and operating practices.
- Problem-solving scenarios and approaches.
- Innovative applications and future directions for dry cooling.
- Significance of overlooked operating details.

The meeting opened with welcome addresses by Dr Andrew Howell, chairman of the ACC Users Group (US) and by Lin Weijie, president of TPRI (Fig 2). Keynote reports then discussed direct ACC system developments (China Power Engineering Consulting Group Corp), an industry overview (ACC Users Group), TPRI's 2015 development plan, and an overview on corrosion and chemistry (Structural Integrity Associates Inc).

Session organization covered condensate polishing, design optimization, operational improvements, corrosion protection, and new technology. Within that structure, TPRI offered specifics on resin separation and transport for mixed-bed polishers, application of pre-coat filters, FAC influencing factors, plate evaporative condensers, and experimental plant operations. TPRI also developed the conference summary.

Meeting content included site-specific discussions on condensate polishing at Dingzhou (Guohua EPRI), ion exchange resins for ultra-supercritical plants (Mitsubishi Heavy Industries Ltd), and ACC commissioning cleaning at Eskom's Medupi Unit 6 (South Africa). Other presentations provided insight into measurement and analysis of design data (CPECC), a focus on air-side performance (Howden Group Ltd), chromatography (Thermo Fisher Scientific), current research and application of amines for steam-cycle pH and corrosion control (EPRI), antifreezing of indirect ACCs (Longyuan Power), a theoretical design called "Lotus Condenser and Hertz" dry cooling (Northwest Electric Power Design Institute), and optimization of internal walkways (Xi'an Jiaotong University).

2. TPRI President Lin Weijie (above) and Dr Andrew Howell (left) of the ACC Users Group welcomed conference attendees during their opening remarks

Some information from the Gettysburg meeting was revised and presented, including updates of guidance documents provided by the International Association for Properties of Water and Steam (IAPWS), examples of low-cost performance improvement (ACC-Team), ACC tube aluminum cladding (Wickeder Group), and hands-on guidance for ACC internal inspections (ACC User Group).

At Gettysburg, a noteworthy new application of ACCs featured the Ivanpah solar project. A similar presentation in Xi'an featured the intent to apply ACCs to new AP1000 nuclear

3. Tongchuan's direct-cooled ACC features 14 streets with six cells per street

4. Qinling's indirect-cooled ACC features nominal 50-ft-long finned tubes at the base of the natural-draft tower. High-purity water circulates through the closed-loop cooling system

units in China (Electric Power Planning & Engineering Institute).

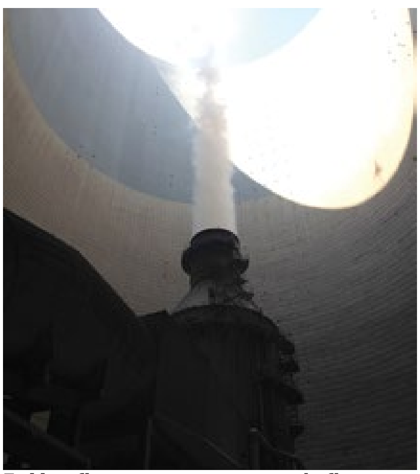
Tours of two Huaneng Power International plants completed the meeting: the direct-cooled Tongchuan Power Plant (1200 MW, coal) shown in Fig 3, and the indirect-cooled Qinling Power Plant (2000 MW, coal) shown in Fig 4. The Tongchuan ACC showed the relative design maturity that rapidly has been reached for Chinese ACCs. Basic features are similar to those elsewhere in the world, with minor variations.

The indirect-cooled ACC design at Qinling has become more common in recent years in China, partly because of efficiency opportunities. This design uses high-purity water in a closed loop that condenses turbine exhaust steam via a typical water-cooled condenser. The cooling water then travels through finned tubes at the base of a natural draft tower.

Energy efficiency is gained by elimination of mechanical fans, and the opportunity for water-enhanced cooling of finned tubes during periods of high ambient temperature. A further item of interest is the routing of flue gas into the natural-draft tower, enhancing air flow as hot flue gas exits the tower (Fig 5).

The International meeting was sponsored by the China Society for Electrical Engineering (CSEE), TPRI, ACC Users Group, CCJ-Online Inc, EPRI, and IAPWS.

According to Howell, who helped organize the event,"Our Chinese hosts did a superb job with all aspects of the meeting, from logistics to technical content. There was excitement on all sides about the opportunities to develop beneficial working relationships for dry cooling in power generation." CCJ



5. Hot flue gas promotes air flow through Qinling's cooling tower

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NV Energy, Duke help launch a much-needed forum for plant owners, operators

Compiled by Clyde V Maughan, Maughan Generator Consultants

The first annual meeting of the Generator Users Group (GUG), held Nov 4-5, 2015 in NV Energy's Beltway Complex and Conference Center, welcomed 70 participants and featured 20 presentations. The speakers, including four IEEE Fellows and one ASME Fellow, each were expert in their field, several having world-wide reputations. Four general subjects were discussed:

- Stators and magnetic cores.
- Stator windings.
- Rotors.
- Testing and general.

Topics of particularly high interest in today's powerplants included the following:

- Back-of-core burning and failures caused by iron melting at the bottom of winding slots.
- Widespread partial discharge (PD) damage on modern stator windings.
- PD damage and winding failure of global vacuum pressure impregnated stator (GVPI) windings.
- Problems related to severe cracking of rotor forgings.
- Rotor-winding fatigue cracking and thermal sensitivity issues.
- Challenges associated with the operation and maintenance of modern excitation systems.
- Catastrophic failures associated with inadequate ground protection relaying on stator and/or field windings.
- Problems associated with deficient operation and maintenance of water-cooled stator-winding cooling systems.
- Potentially catastrophic dangers associated with inadequate operation and maintenance of generator hydrogen cooling systems.

Additionally, in recognition of quality deficiencies associated with new generator production over the last four decades, two major generator manufacturers—GE and Siemens—were invited to present on design and manufacturing efforts directed at producing high-reliability generators. These presentations were responsive to the request and were followed by intense and helpful discussion.

All 20 presentations are summarized below in category of topic. You can access them online at the website maintained by the International Generator Technical Community (IGTC) by simply scanning the QR code with your tablet or smartphone.


Rex Windom

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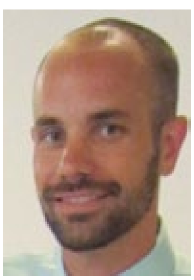
Balderas


Demcko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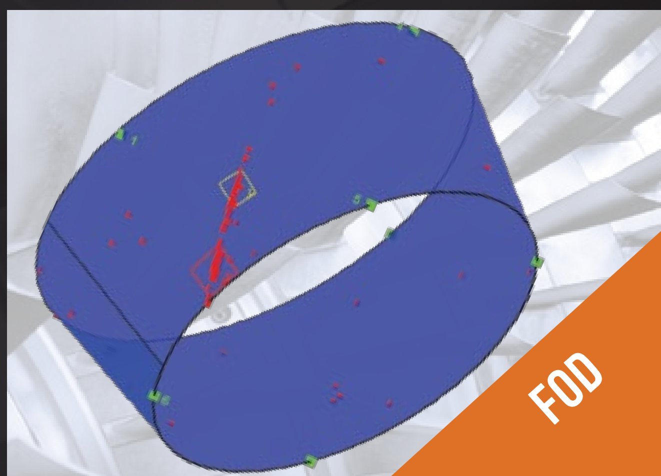

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1. Stators, magnetic cores

Stator winding/core failure

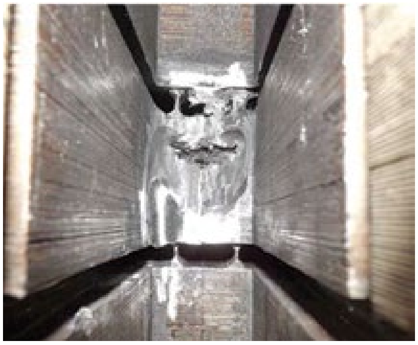
Kent Smith, Duke Energy

Smith, a longtime engineer and manager at Duke, chairs the GUG Steering Committee. His presentation focused on an April 2014 incident in which a 790-MVA generator tripped on ground relay.

This failure occurred after 44 years of service. The generator had experienced a 5-min offline over-flux incident in March 1998, ranging between 8% and 25% over-flux. In May 2005, seven instantaneous over-flux events occurred, ranging from 8% to 15% over-flux. The in-service failure occurred nine years after the last over-flux incident. Note that a hiatus between over-flux and failure had been experienced previously in the industry.

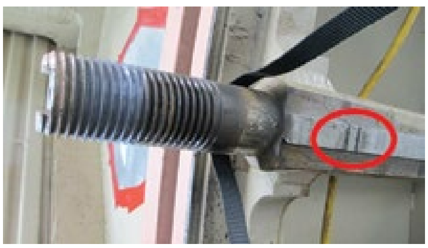
None of the over-flux events at this plant was severe, although at 20% over-flux, core iron saturation would be significant.

The winding failed near the end of the core in slot 18 (Fig 1-1); some core grinding had been done before this photo was taken. The extent of heat penetration at the core melting locations is evident in Fig 1-2. Finally, there was burn evidence at many locations on the key bars, greatest at the core ends (Fig 1-3, 1-4).



1-1. Winding failure was near the end of the core in slot 18. Some core grinding had been done before this photo was taken

1-2. With core iron removed, the extent of heat penetration at the core melting locations is easy to see



1-3, 1-4. Burn evidence was found at many locations on the key bars, with burn damage greatest at the core ends

1-5. Inner frame was upended to install new a core in a "cage" machine—a long, complicated process

To make a reliable repair, the core was removed, restacked with new laminations, and a new winding installed—a long, complicated process. It was necessary to build a temporary structure for workspace. This was a "cage" machine and the inner frame and core required removal, a difficult task on such a large and heavy component. Special equipment was required for rotation up and down. The temporary structure with the up-ended inner frame and new core is shown in Fig 1-5.

After return to horizontal and reinsertion of the inner frame/core component, a new winding was installed. The outage was about a year in length, but the stator essentially was returned to as-new condition.

Kevin Geraghty, VP generation for NV Energy (left), accepts the Generator User Group's Industry Leadership Award from Chairman Kent Smith of Duke Energy for the Nevada utility's major role in the launch of the new organization. NV Energy is a proactive supporter of user groups. Seven years ago, the company launched the ACC Users Group, which typically attracts more than 100 participants to its annual meetings. Today, its engineers serve on the steering committees of GUG, CTOTF, ACC Users Group, Combined Cycle Users Group, and Steam Turbine Users Group.

Clyde V Maughan (right), the force behind the formation of the Generator Users Group, is recognized by Chairman Kent Smith for a "lifetime of sharing selflessly his extensive knowledge in the design, operation, and maintenance of electric generators."

Core mechanical isolation problems

Marques Montes, Arizona Public Service Co

Montes, a young and highly regarded engineer at APS, works closely with the respected John Demcko, a member of the GUG steering committee.

Redhawk Generating Station, equipped with two F-class 2 × 1 combined cycles, entered commercial service early in 2003. From the begin-

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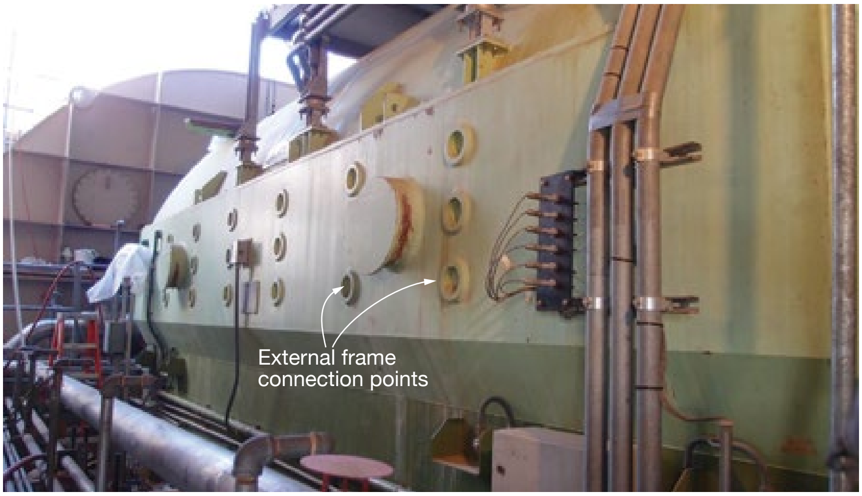
1-6. Stator-bar fracture caused a single phase-to-ground failure. Winding immediately tripped on ground relay, but current continued to flow through the arc as field current decayed causing substantial damage (left)

1-7. Access to the back of the core during cooler repair revealed there was no core vibration isolation horizontally to the frame (right)



1-8. Frame connection points are at the six axial locations shown in the photo

1-9. Investigators identified severe internal and external partial-discharge damage on high-voltage bars. Note damage to surface tapes and grounding paint

1-10. Total destruction of internal insulating materials is in evidence: Cross-over putty is completely eaten away and the strand insulation has been attacked

1-11. Voids visible at the bottom of the bare bar were caused by internal PD

ning, the generators serving the two steam turbines (STs) were exceptionally noisy—about 116 dBA at all load conditions.

In June 2003, the OEM recommended immediate shutdown for stator end-winding modifications following the failure of another unit in the fleet because of end-winding vibration. With summer peak-load demand a concern, APS proposed instrumenting the end windings with vibration detectors, monitoring the values, and shutting down if the safe limit was exceeded. This was acceptable to the OEM.

The monitor readings were marginally acceptable. In April 2009, the ST generator for Power Block 2 went single phase to ground because of a stator-bar fracture. The winding tripped immediately on ground relay, but current continued to flow through the arc as field current decayed. Damage was substantial (Fig 1-6).

A third-party service company repaired the winding by splicing in new copper strands and insulating the repaired bar area with mica tape. Additional support components were added and the winding continues to operate safely.

In March 2013, a cooler leak developed following a vane fracture from high vibration. While performing this repair, the cooler was removed, allowing access to the back of the core. Inspection of the structure revealed there was no core vibration isolation horizontally to the frame (Fig 1-7). Specifically, the core was supported by key bars, the key bars were connected directly to a section plate, and the section plates were connected directly to the frame. The frame connection points are at the six axial locations seen in Fig 1-8.

Options were evaluated—including harmonic dampeners and wrapper reinforcements proposed by the OEM. None of these options seemed practical or effective. New generators were purchased from another OEM and these replacements are operating quietly.

GVPI issues

Leopoldo Duque Balderas,
Comego SA de CV (Mexico)

Balderas, a member of the GUG steering committee, has many years of experience in powerplant operation and maintenance.

Comego recently has had considerable difficulties with a line of globally vacuum pressure impregnated (GVPI) 187-MW, 16.5-kV generators after about 13 years of reliable service. Problems have included in-service failures, hipot failures, and major inspection concerns. There appears to be no satisfactory corrective action short of difficult stator rewind or replacement.

Balderas described the GVPI process in detail, offering drawings of the various steps, and discussing the

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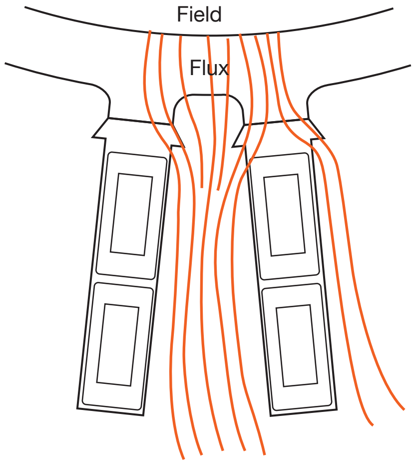
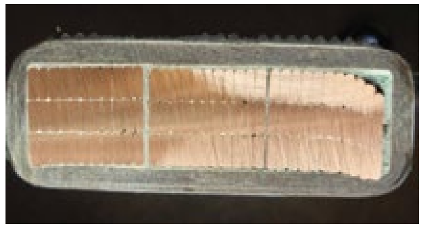
8525 Freeland St, Houston, TX 77061 | Ph: 713-364-7500 | Fax: 713-364-7450 | sale@act-texas.com | www.act-texas.com pros (low cost, mechanically sound) and cons (danger of voids, which may lead to severe PD attack) of the GVPI stator winding.

In the process of failure root-cause investigation, severe internal and external PD damage was found on high-voltage (HV) bars. External damage to the surface tapes and grounding paint is clearly visible in Fig 1-9. The total destruction of internal insulating materials can be seen in Fig 1-10. Note: Cross-over putty is completely eaten away and the strand insulation is heavily attacked. In the Fig 1-11 cross section, voids at the bottom of the bare bar caused by internal PD are visible.

Corrective action still was being considered at the time of the meeting. Reversing of high- and low-voltage leads is not practical because of the extent of damage suffered by the windings. The procurement cycle for replacement stators is long and it is doubtful the existing windings can be repaired such as to remain in service until new stators can be obtained. In sum, this line of GVPI generators represents a major maintenance challenge to users.



1-12. Magnetic flux moves quickly into tooth iron after crossing the air gap



1-13. On hydro-generators bars are not set deep in the slot, thus the air-gap flux cuts the top strands in the top bar. Photo shows the upper-most strands of the top bar have moved sideways within the ground-wall insulation and caused winding failure

1-14. There is a concern relative to the top strands of the top bars at the core ends in generators of recent design that rely on large core-iron stepdown at the core ends

1-15. Key-bar currents want to connect through three parallel paths: core flange, core laminations, and frame components. OEMs have tried to bridge these currents via shunting straps and silver plating as shown

1-16. Hot spots are created because of poor contact surface at the core ends where current is transferred from the key bars into the laminations

Stator magnetic cores: design, deterioration, failure

Clyde V Maughan, Maughan Generator Consultants

Maughan has more than 65 years of experience in the design, manufacture, inspection, failure analysis, maintenance, and repair of generators rated up to 1400 MW from the leading suppliers in the US, Europe, and Japan. He has written numerous technical papers, plus a digital book on generator O&M.

This presentation summarized core design and duties, emphasizing the sometimes less-well-understood aspects. Maughan began by noting that the function of core iron to shield copper strands from electromagnetic forces often is not discussed. But except for this feature, no insulation system in use today could survive.

As shown in Fig 1-12, the magnetic flux moves quickly into the tooth iron after crossing the air gap. On hydro-generators, with the wedge at the very top of the tooth, some small amount of flux may intersect the upper-most strands and cause the strand displacement illustrated in Fig 1-13. With this in mind, there is a concern relative to the top strands of the top bars at the core ends in generators of recent design with large core-iron stepdown at the core ends (Fig 1-14).

Maughan's presentation focused primarily on the more recent, and not yet well understood, problem of core burning and failure attributed to key-bar currents. OEMs have been using designs for over 15 years with reduced depth of core back-iron. The result is increased leakage flux cutting the key bars. This flux creates a robust voltage that wants to drive current in the key bars.

Industry consensus points to current flow between adjacent key bars—that is, current flows down one key bar and returns through the adjacent key bar. However, the speaker proposed that the current flows as it does in an amortisseur winding—that is, down the key bars on one side of the stator and back 180 deg away on the opposite side.

In either case, the key-bar currents want to connect through three parallel paths: core flange, core laminations, and frame components. OEMs have tried to bridge these key-bar currents via shunting straps and silver plating (Fig 1-15). But regardless of shunting attempts, the voltage is robust and will want to flow current in all three paths. This leads to the local burning between key bars and core iron shown in Fig 1-16.

If this current flows only between adjacent key bars, it should not be of serious concern—that is, burn damage would be at the core OD where the laminations already are shorted via

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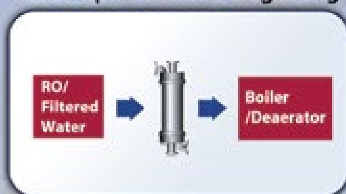

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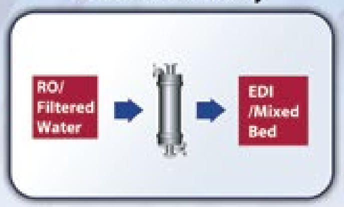

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1-17. Arc heating occurred at the end of the core

the key bars (on the common uninsulated key-bar structure).

However, a large generator of new design recently failed from core-iron melting at the bottom of the slot. Apparently, this failure was very similar to the Duke unit where failure was caused by the over-fluxing discussed earlier by Chairman Smith. Core failure at the bottom of the slots is exactly where failure would be expected if the key bars act as an amortisseur winding.

There are eight more units similar to this failed generator in the US and others have the key-bar-to-core-iron heating (Fig 1-17). Maughan expressed hope that this all would be better understood soon.

Testing of wedge tightness and stator cores

Mladen Sasic, IRIS Power

Sasic has the respect of the generator community for his long and illustrious career in instrumentation for condition monitoring. In particular, he has had a focus on core-lamination insulation testing and wedge-tightness assessment.

This presentation included well-received tutorials on both wedging and core function. Integrity evaluation of both components also was included. With respect to stator slot wedging, typical tests include visual inspection for wedge or filler migration, evidence of greasing or dusting, ripple-spring compression (on some designs), and wedge-tightness assessment by manual or mechanized tapping.

Wedge tightness is a subjective call: There is no industry-wide agreement on what constitutes a tight wedge. For a particular mechanized test device, a Relative Tightness Index can be assigned by the manufacturer, but only for that device. If it can be concluded that the output is meaningful, then this reading can be important both for assessing the tightness of individual wedges and for assessing the overall wedge-tightness spectrum between subsequent tests.

But for manual testing, the accuracy of results depends completely on the skill and experience of the individual performing the test. The bottom line: There is a lot of uncertainty with any method. Personal "feel" often is considered more accurate than instruments; there is no agreement on what constitutes tight and loose; and introduction of online methods may be helpful.

Relative to core-tightness testing, inspection is important in the search for evidence of local dusting or greasing. Suspected loose areas can be assessed using the so-called knife test: Will a knife enter between laminations with a recommended maximum force of 25 to 30 lb?

Relative to lamination insulation evaluation, two methods are common: high- and low-flux tests. On high-flux testing, a heavy excitation cable is used to pass the necessary high current to excite the core back iron to a level below rated flux. Eddy currents will flow in local spots where lamination insulation is degraded. The resulting heat is measured. But there is no agreement on excitation levels, test duration, and acceptance criteria.

There are several concerns with the high-flux test, including: dangers from use of high voltage and current, local core burning, general core overheating, temperature attenuation for damage deep in the core and costly in time, material, equipment, and labor.

The most commonly used low-flux test is ElCid. It has numerous advantages over high-flux testing, including: low power and voltage, low risk to personnel or core, fast and easy, hand portable equipment, instant interpretation of results, convenient to perform repetitively, can be done with rotor in place.

But there are disadvantages to low-flux testing, too. It requires competent, trained personnel; output can be misleading, and it has an imperfect correlation with the high-flux test.

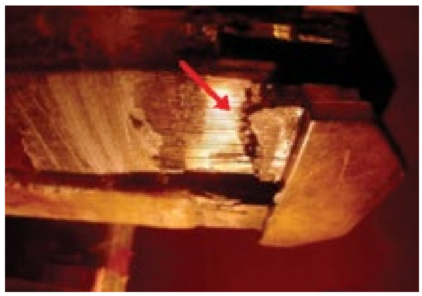
2. Stator windings

Stator winding problems

Mike Bresney, AGTServices

Bresney's career in generators spans 35+ years—including stints at an OEM and a third-party services firm before starting AGTServices in 2000.

Bresney began his presentation by showing photos of generator failures attributed to stator end-winding vibration, such as that in Fig 2-1. Next, he discussed criteria to prevent serious end-winding vibration—specifically,



2-1. One of several photos shown by Bresney to illustrate stator-bar cracking caused by high end-winding vibration

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2-2. End-winding and slot partial-discharge indications are evident in this series of photos

2-3. "Sniffer" is a special AM radio used to measure radio-frequency energy. Ear phones are necessary to hear an identify an EMI signal in high-noise environments

avoid the following:

- Resonance in the range of +10% to -5% of driving frequency—or 132 to 114 Hz on a 60-Hz machine.
- Relatively low response amplitude.
- End winding responding as an integral system.

An example of a poorly integrated end-winding support system was shown, along with modifications made to fully correct the problem. Access this and other presentations summarized here by scanning the QR code in the opening section with your smartphone or tablet.

Finally, Bresney discussed options for in-situ repairs of water-cooled stator bars that had suffered cracked strands away from the water-box braze, somewhere within the bar itself. Repair options were explained that would return the existing bar to reliable service versus replacing the bar, as typically recommended.

Partial-discharge problems

Ryan Harrison, P Eng, ATCO Power (Canada)

Harrison, a senior electrical and I&C engineer, serves on the Generator Users Group steering committee as vice chairman.

ATCO installed six generators (nominal 100 MVA/13.8 kV) at three plants in 2003 and they have shown heavy indications of surface partial-discharge (PD) attack (Fig 2-2). No failures have occurred in these windings to date, but vendors have offered to perform "repairs"—that is, a temporary fix to reduce PD at sites where the solution is applied in the end windings. Hipot also was recommended but not performed pending purchase and delivery of a spare rewind kit.

Actions taken by the owner included the following: purchase of a spare winding, installation of PD monitoring capability, crawl-through inspections when possible, participation in the Generator Users Group, and third-party consultation.

Readings from the PD instrumentation gave somewhat confusing results. Plant personnel found that "repairs" can make things worse, the huge amount of data collected can be difficult to summarize, specific conditions at different plants may influence PD production, and the predominance of positive data suggested surface PD (as expected).

One unit then was "repaired," with pre- and post-maintenance DC hipot,

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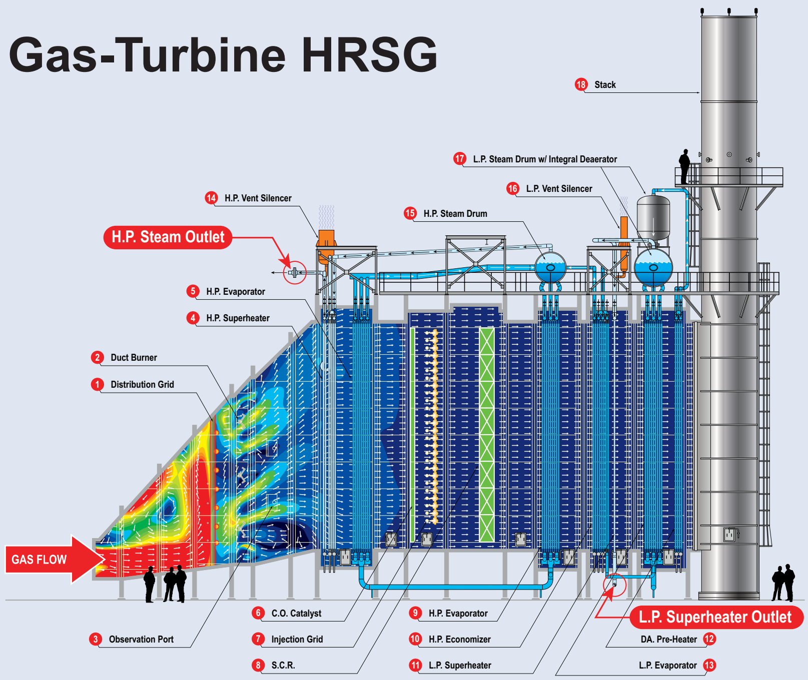

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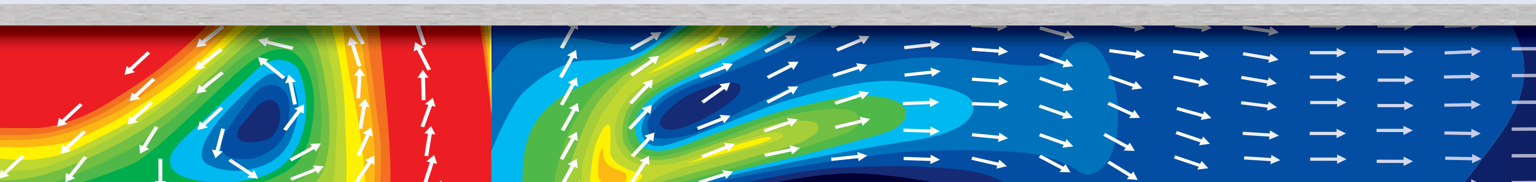

2-4. Winding deterioration was caused by bar vibration in the slot (vibration sparking)

2-5. Insulation delamination and tracking in contaminants is shown here

2-6. Inadequate spacing between bars in the end windings contributes to partial-discharge attack

without failure. A second unit was rewound. Before removal of the damaged winding, a hipot test at 2E+3 was conducted and did not fail.

The plan going forward is to keep on hand a spare winding, perform diagnostics on bars from the windings removed, attempt to understand the impact of deferring rewinds past the next major inspection, and rewind based on site risk and opportunity.

Electromagnetic interference testing

Jim Timperley, Doble Engineering Co

Timperley, one of four IEEE Fellows presenting at the meeting, is considered by colleagues as the "father" of the current approaches to EMI testing. His presentation focused on the EMI hand-held "sniffer," an instrument experts recommend that every powerplant have in its diagnostic arsenal.

Two methods are used for detecting EMI:

- Radio-frequency (RF) current transformer reading the frequency spectrum of the ground current for the machine being inspected—usually a motor or generator.
- A small hand-held instrument, the so-called "sniffer," to measure radiated energy from any powerplant component.

For the former, obtaining the signal is not difficult, but interpretation of the output is complicated and may require considerable technical background and training. By contrast, the "sniffer" test is easy to perform and the output easily interpreted.

Timperley told the group RF energy is conducted and radiated from every PD or arcing event location. The "sniffer" in Fig 2-3 detects and measures the strength of this energy in operating equipment, providing guidance on where to look for problems. The technique is fast and safe. No doors are opened, no flash hazard, no connections made to energized systems.

The "sniffer" has been used for years to locate, and correct before failure, many potentially serious problems with generators, excitation equipment, motors, transformers, switchgear, bus, bearings, and other equipment.

PD testing of stator windings

Greg Stone, Iris Power, a Qualitrol company

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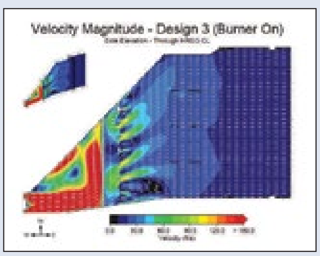

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Dr Stone is recognized worldwide for his extensive contributions on the use of PD testing for generator condition assessment. He has been very active in the creation of IEEE and IEC rotating machine standards and is an IEEE Fellow.

Stone explained that PD is a symptom, or cause, of several winding deterioration processes—specifically, bar vibration in the slot (Fig 2-4), insulation on and tracking in contaminants (Fig 2-5), and ground-wall voids and inadequate spacing between bars in the end windings (Fig 2-6).

Attempts to use PD for the detection of stator winding problems date back to the early 1950s, but problems of electrical interference resulted in the need for experienced experts to interpret the data. As late as the late 1980s, an EPRI program manager called online PD testing of stators "witchcraft"—and many utilities agreed.

However, much progress was being made in noise separation, sensor reliability, signal interpretation, and relationships between PD signal and winding condition. Today, after six decades of work in technology development, PD monitoring generally is regarded as a standard method for condition assessment of stator windings, with instrumentation installed on over 15,000 generators and motors.

2-7. Effects of restricted flow caused by oxide formation are in evidence here

Copper oxide issues in water-cooled stator windings

Matthias Svoboda, SvoBaTech AG (Switzerland)

Svoboda joined Alstom in the early 2000s where he helped to develop methods for trace analysis of feedwater and steam. Later work focused on the chemical aspects of water-cooled generators, including the chemical cleaning of generator stator coils and related consulting and engineering. Svoboda formed SvoBaTech in 2014 to provide services related to stator cooling-water systems.

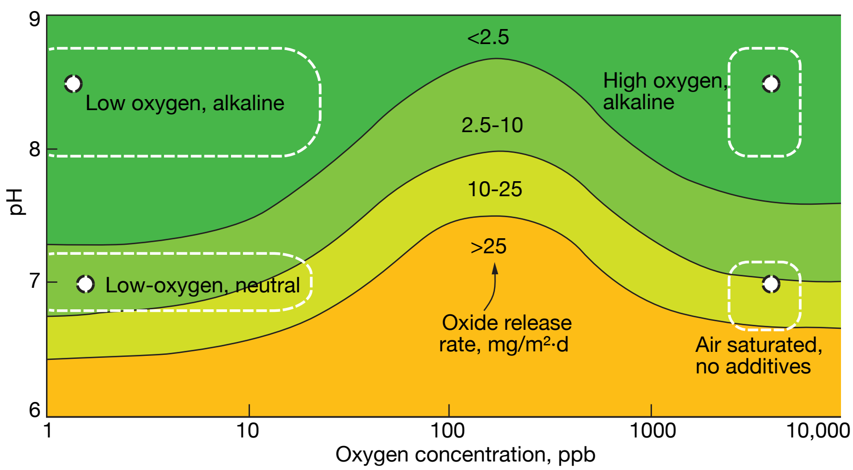
Water cooling of stators has been used since the 1950s for large generators, introducing several problems in the process—including the build-up of copper oxide on heat-transfer surfaces (Fig 2-7). Svoboda's presentation focused on detection of oxide formation and methods for its removal and prevention.

The ability to monitor heat exchangers for oxide formation is limited, he said. No direct method is available. However, indirect monitoring is possible. Example: Migrating oxides caught in filters, if excessive, are an indicator of possible problems. Use of thermocouples to monitor water temperature from individual bars is another indirect indicator. But the reliability of this method is questionable for designs with flows combined from pairs of bars. Use of slot RTDs generally is not recommended.

Copper in water is prone to oxidation but the reaction proceeds slowly at low concentrations of oxygen. Intermediate concentrations of oxygen are problematic as shown in Fig 2-8. Note, also, the impact of pH: as it increases, oxide releases decrease except for intermediate concentrations of oxygen. Svoboda's experience indicates that pH control has both advantages and disadvantages.

Removal of oxide buildup can be challenging. Chemical cleaning is reliable if the accumulation is not severe. But if passages are completely plugged, chemical methods by themselves are ineffective and a combination of mechanical and chemical cleaning is required. This is time-consuming and expensive, and satisfaction is not guaranteed.

Chemical cleaning itself can be relatively simple and may be done online. If cooling passages are not blocked and the process is done correctly, all build-up can be removed from the system. Cleaning with ethylenediaminetetraacetic acid (EDTA) generally is recommended. It removes only copper oxides, not other materials in the system—such as silver brazing. But expert know-how in the use of EDTA is recommended to minimize risks and assure effectiveness.



2-8. The basics of stator water chemistry: High-purity water is a good insulator, copper in water is prone to oxidation, the rate of oxide release depends on pH and oxygen concentration

Stator winding tests

Bert Milano, consultant

Milano is well respected in the industry for his knowledge of generator maintenance. He has extensive experience in the testing of windings.

The consultant began his presentation with a review of general AC and DC test procedures followed by an explanation of engineering principles behind the polarization index (PI) test. With this understanding it becomes clear that considerably more information can be obtained by plotting the data rather than simply taking readings at 1- or 10-min intervals.

High-potential testing was discussed in detail. Two methods are used: DC and power-frequency AC. The latter is a go/no-go test. If the winding fails to hold the voltage, repair will be necessary. As a result, many utilities will not perform this test. But a winding that passes with an appropriate test voltage is likely to be safe for operation another three to five years.

Milano discussed three types of DC tests: fixed-increment, time-graded, and ramp. Each may allow interruption of the test prior to winding failure, and for this reason (and the small, light test set used) many owner/operators prefer the DC test. The speaker focused on the ramp test, discussing its advantages and providing examples of its use. One company has used this test for more than 30 years, he said, and has completed more than 5400 tests. Of those, only four sudden failures occurred—that is, the test was not interrupted before the winding failed.

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3. Rotors (fields)

Rotor winding problems

Bill Moore, PE, National Electric Coil

Moore, an ASME Fellow, is respected industry-wide for his knowledge of generator inspection, maintenance, and repair. His work is well documented in technical publications.

Moore's presentation provided an overview of winding design and duties. This was followed by a comprehensive summary of field-winding failure modes—including root causes and what owner/operators can do to reduce the likelihood of occurrence of a particular problem. Each of the failure modes was described and illustrated with photographs showing the damage that a given type of failure can inflict on a winding.

Failure modes discussed included the following:

- Shorted coils—turn/coil distortion, foreign material.
- Shorted turns—cracked turn insulation, turn insulation extrusion and displacement, foreign material.
- Ventilation path restriction—turn insulation migration, turn distortion, block migration, coil migration.
- Restricted coil growth—improper blocking.

3-1. Failure modes discussed by Moore included the pole-to-pole crossover failure shown here

- Various conditions of winding open circuits—cracked turns, failed brazes, failed J-straps, failed turn-to-turn, failed coil-to-coil, failed pole-to-pole (Fig 3-1).
- Grounds—conductor fracture, braze failure, insulation misassembly or failure.

Common tests were mentioned—including short turn detection via flux probe and by RSO test, and running impedance test.

Electrical and mechanical tests

Izzy Kerszenbaum, PE, consultant

Kerszenbaum, a double IEEE Fellow, is respected worldwide for his knowledge of generator testing and maintenance. He has authored a book and many papers on these topics.

Generator rotor tests are covered extensively in IEEE and IEC publications and Kerszenbaum's presentation identified seven such documents. He reviewed three overall approaches to assure generator reliability: monitoring, protective relaying, and testing. Kerszenbaum then identified 25 tests and their conditions of application—for example, online, offline, running, idle. Individually and collectively the documents noted provide extensive information of the purposes of, and procedures for, rotor testing.

The consultant provided expanded coverage of rotor testing, offering the following experience and lessons learned regarding electrical tests:

- *Winding copper resistance.*
  - Measurement accuracy requires significance to a minimum of four decimal places—typically with a digital low-resistance instrument.
  - Purpose is to assess for shorted turns, bad connections, wrong connections.
  - Rotor should be at room temperature when the test is performed.
  - Compare with original factory data and previous test results, if any.
- *Winding insulation resistance to ground.*

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- Insulation in good condition will be in the megohm range.
- Acceptable minimum reading, in MW, by IEEE Standard 43 is the line voltage in kV + 1.
- The rotor winding must be completely dry before any testing is conducted.
- Readings are sensitive to humidity, surface contamination, and temperature.

■ *Polarization Index (PI).*
- When the insulation system is clean and dry, the IR value tends to increase as the dielecric material in the insulation absorbs the charge.
- When the insulation is dirty, wet, or a gross insulation problem exists, the charge does not hold and the IR value will not increase.
- PI is the ratio of the resistance reading at 10 minutes to that at 1 minute.
- The recommended PI value is 2.0.

■ *Other electrical tests:*
- Repetitive surge oscillograph (RSO).
- Open circuit test.
- Winding impedance test.
- C-core test.
- DC voltage-drop measurements.
- Pole-drop (voltage drop) test.

Several rotor mechanical tests were discussed as well. Kerszenbaum divided these into surface and volumetric nondestructive examination techniques. Surface NDE, he said, can be visual, magnetic particle, liquid penetrant, and eddy current; volumetric NDE tests are radiography and ultrasonic.

Plus, mention was made of the following specific tests:

- Rotor-bore pressure test.
- Fretting-fatigue cracks in slot dovetails and wedges.
- Pitting of retaining rings, zone rings, fan hubs, and other shrunk-on members.
- Tooth-top cracking.
- Bearing-oil wipers-hydrogen seal running surfaces.

Forging cracking issues
Neil Kilpatrick, Siemens Energy

Kilpatrick's 45-yr career in metallurgy has focused on generators and other industrial equipment. Failure analysis, problem solving, supplier audits, forging quality, training/mentoring of employees are among his current responsibilities.

The speaker began with a focus on retaining rings, discussing numerous deterioration/failure modes, including these:

- Runaway over-speed expansion/rupture.
- Ring/rotor/end-plate fretting on some designs.
- Excessive damper winding and body currents caused by asynchronous or unbalanced stator phase currents, possibly resulting in one or more of the following:
  - Arc damage.
  - Metallurgical transformation/embrittlement.
  - Retaining ring/rotor welding.
- Corrosion and stress-corrosion cracking.

Next, Kilpatrick illustrated and discussed numerous causes of damage to, and possible failure of, the main field forging, including the following:

- Tooth/wedge fretting and galling.
- Potential for rotating/bending fatigue.
- Double-ground catastrophic current flow.
- Excessive damper current flow, possibly causing:
  - Arcing, melting.
  - Metallurgical transformation/embrittlement.
  - Wedge/rotor tooth cracking.
  - Retaining ring/rotor welding.
- Tooth-top cracking.
- Metallurgical discontinuities—including flaking, porosity, segregation.

Shaft extensions, the consultant said, are sites for a surprisingly large number of problems. He mentioned friction rubs, loss-of-oil events, bearing failure, journal wear, electrolysis and

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mechanical damage, rotating bending fatigue, electrical faults related to the collector and connections, coupling-bolt galling, and torsional fatigue, discussing a few in detail. Which issues, if any, are experienced, he said, depends in part on shaft configuration and operating duty.

Excitation systems

John Demcko, PE, Arizona Public Service Co

A member of the steering committee for the Generator Users Group, Demcko willingly shares with colleagues his 43 years of experience gained at GE, New York Power Pool, and APS. Among his current responsibilities is the development of techniques and instrumentation to enable predictive maintenance, troubleshooting, and upgrading of excitation systems.

Demcko began his presentation with the basics, first asking and then answering the question: What does an exciter do?

- Provides a source of magnetizing current for a synchronous generator's rotor.
- Controls generator voltage.
- Supplies or absorbs MVARs from the power system.
- Enhances power-system transient stability.

Additionally, supplemental signals may be added for other purposes.

The APS senior consulting engineer went on to illustrate and discuss each of these topics and then continued his coverage of fundamentals by identifying the three types of excitation systems and their characteristics:

- Brushless. No collector rings and carbon brushes to wear out; vibration issues; electrically complicated and relatively slow to respond; new designs are low maintenance.
- Static. No rotating components, but collector rings and brushes are present; high performance; fast and mechanically simple.
- Rotating alternator/DC generator. Collector rings and brushes are present; vibration issues, complicated and obsolete.

Regardless of the type, excitation-system parameters include the following:

- Ratings of from a few hundred to many thousands of amps DC, depending on the machine.
- Must be capable of forcing 141% of the steady-state rating for several seconds.
- High reliability is a must.
- Redundant systems are common.
- Must enhance transient stability and not harm dynamic stability.

With the foregoing fundamentals in place, discussion turned to photographs illustrating system components and function, and requirements for reliable collector performance. An example of a modern static-exciter retrofit was presented, illustrated by photographs of the many components involved.

The presentation closed with a description of power-system stabilizers (PSS), a requirement of NERC and the Western Electricity Coordinating Council (WECC). The modern high-speed excitation system that solved the transient stability problem created another problem: dynamic instability. A properly tuned PSS will enhance the dynamic stability of the power system and increase local mode rotor damping of the machine it is controlling.

The PSS originated in the late 1960s as a supplemental excitation damper control (to prevent rotor forging damage/failure from torsional resonance). In effect, the system is a "cruise control" for turbine/generator rotor speed deviation from synchronous speed. The PSS is tuned by compensating for the measured phase lag measured between automatic voltage regulator's summing junction and generator terminal voltage deviation.

4. Testing, general

Hydrogen system safety

Matt McMasters, Duke Energy

McMasters, a senior engineer, has managed several hydrogen-system assessments and improvements for the company's fossil and hydro fleets.

McMasters' presentation focused on safety concerns associated with use of hydrogen to cool large generators. Hydrogen cooling has been used since 1938 and there have been a some dramatic and costly fire events over the years—a few involving personnel injury and death. These events generally have been associated with a failure to use proper caution and procedures during operation and maintenance.

The speaker began by pointing out that a 12-pack of standard hydrogen gas cylinders is equivalent to about 420 lb of TNT and a tube trailer is equivalent to about 5600 lb of TNT. Hydrogen is odorless, explosive in the range of about 4% to 74% mixture with air, auto ignites at about 1050F, ignitable by static electricity, and burns with a nearly invisible flame.

These characteristics mean that safety considerations are top priority and would include maintaining flammable/combustible materials at least 25 ft from hydrogen systems, adequate ventilation, and extreme caution in attempting to extinguish.

A fatality occurred at a Duke plant in 2011 and, in response, the company focused on several corrective actions—including confined-space program revisions, standardization of confined- space monitors, improving procedures for purging generators and auxiliary systems (that is, dryers, core monitors, purity analyzers, etc), developing procedures for handling incoming hydrogen supply, standardization of painting and labeling of hydrogen systems, purchasing dedicated hand-held hydrogen leak detectors for system purging/leak checking, and use of intrinsically safe tooling around hydrogen systems.

In performing this review, the following industry standards were referenced:

- OSHA Standard 1910.103, Hydrogen.
- ASME B31.12, Hydrogen piping and pipelines.
- ASME B31.1, Power piping (for hydrogen systems designed and installed before the adoption of B31.12).
- NFPA 2, Hydrogen technologies code.
- NFPA 55, Compressed gases and cryogenic fluids code.
- CGA G-5.5, Hydrogen vent systems.
- OEM design specifications.

Protective relaying: Stator and rotor

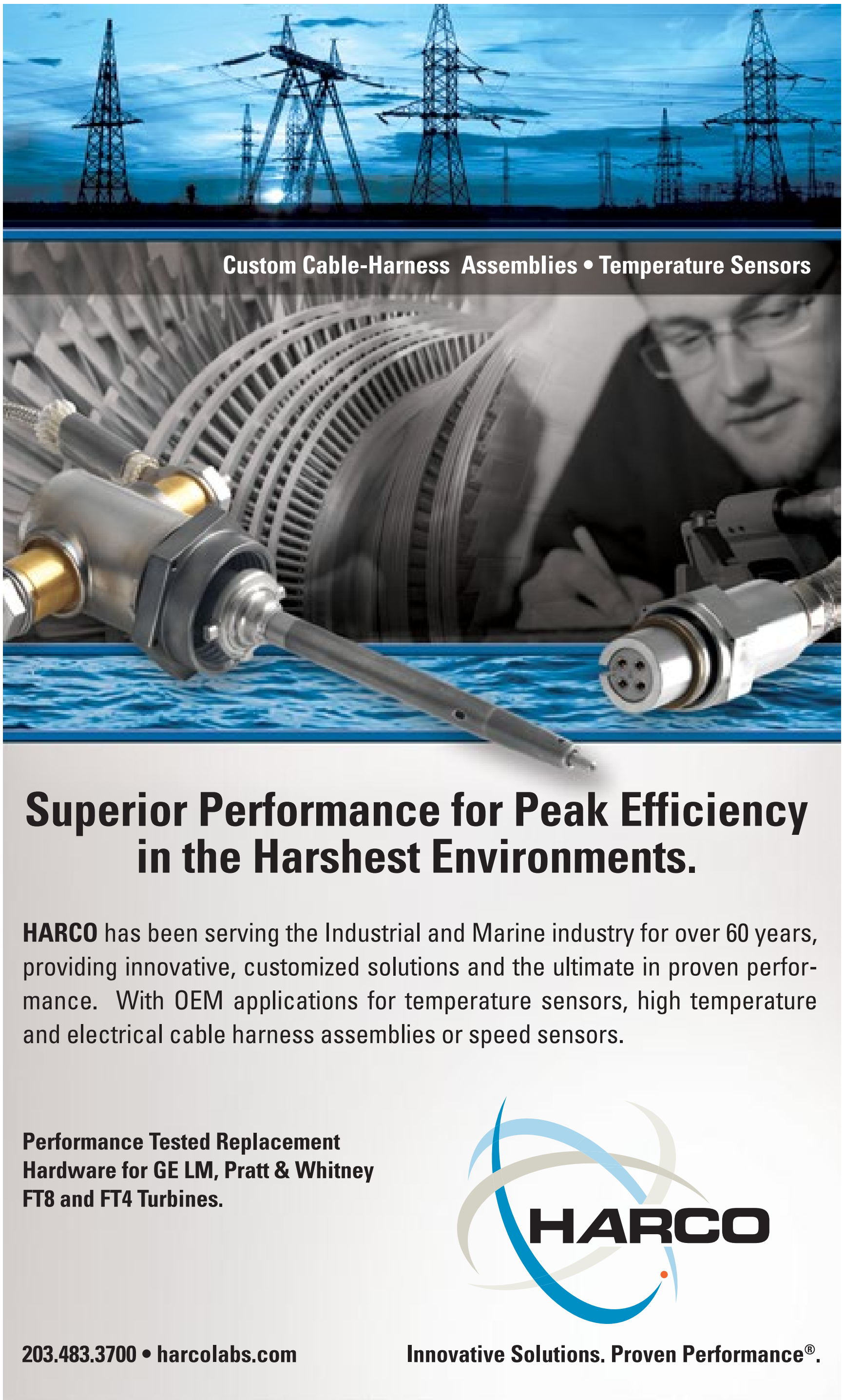
Rogerio Scharlach, Schweitzer Engineering Laboratories

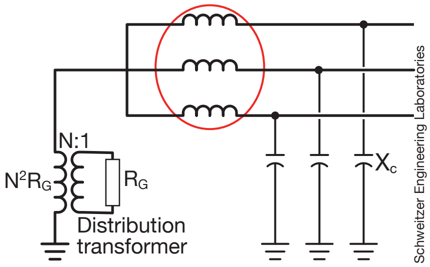
Scharlach spent 13 years at a major generator OEM before transferring to work in the field of relaying. He is an acknowledged expert in this field.

The ground protection relay systems for stator and field windings recommended in the current version of IEEE Standards C37.101 and 102 are both deficient. For stators, relay 59GN, will not detect grounds in the bottom 5% to 10% of the stator winding.

For fields, the standards say that a single ground is a concern because of the possible exposure to a dangerous failure in the event of a simultaneous second ground. But a single ground, if caused by a broken conductor, can be extremely dangerous itself. Scharlach addressed this misinformation and described relay systems that eliminate the associated exposure to extreme generator damage.

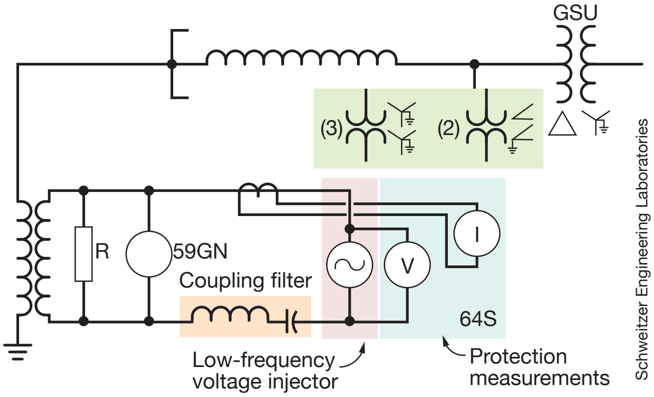
He began his presentation showing the common stator ground-detection relay system in Fig 4-1, where relay 59GN is connected in parallel to relay





4-1. Stator windings of large generators typically are wye-connected and high-impedence-grounded through a distribution transformer

4-2. Failure to ground caused by the fracture of a stator conductor is not rare. Winding and core damage attributed to a burned open bar in a slot is shown at left and right, respectively



4-3. Voltage-injection ground protection can be functional when the generator is shut down (standstill or turning gear), during startup, and at speed offline and online

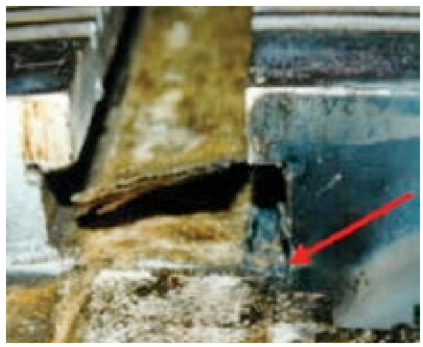
R_G. This relay system leaves undetected grounds in the low-voltage end of the winding. Examples are shown in Fig 4-2. Four such recent failures in a two-year period involved repair costs of close to $500 million. Full winding protection can be obtained by using an injection relay, 64S. But the more common update involves leaving 59GN in place and adding a 64S relay (Fig 4-3).

Field-winding ground detection systems typically use AC or DC voltage injection. These systems will detect winding grounds reliably provided they are installed correctly—specifically, connected to the correct polarity.

Broken conductor or other types of single grounds are somewhat common—unfortunately. A striking example of a single ground failure is shown in Fig 4-4. Left-hand photo is of a single ground resulting from the shorting out the two largest coils on one pole. The companion photo shows the resulting burn damage to the retaining-ring forging caused by the flow of current bypassing the coils. (This ring was believed to be close to catastrophic failure.)

Fig 4-5 shows damage to the forging at one ground point of a double ground. In this case, the damage at each ground point was minor and easily repaired. Given the danger associated with the misinformation in these two IEEE standards, both are currently under revision.

4-4. Arc damage from shorting between two coils (left) effectively removed the coils from the excitation circuit. The single ground lasted for a significant period of time because the detection circuit was connected incorrectly. Result: Near-fatal burn damage to the retaining ring (inside diameter)



4-5. Minor rotor-forging burn damage in an area of low mechanical stress is relatively easy to correct by light grinding of field iron

4-6. Generator condition monitor is very sensitive and will pinpoint the location of minor core overheating (left and center) and will easily detect at a very early stage any major damage (right)

Generator condition monitor

Steve Kilmartin, EnvironmentOne

Kilmartin has published numerous technical papers on generator-related topics in his nearly 30 years of association with EnvironmentOne.

The generator condition monitor (GCM) was introduced in the 1960s to detect hot-spots in generators caused by various malfunctions. The device is extremely sensitive and will detect very minor locations, as shown in the left-hand and center photos in Fig 4-6. In addition, it detects the onset of major damage (Fig 4-6, right).

Because of the inherent sensitivity of the instrument, early versions of the GCM were subject to false positive failure alarms, thereby gaining a reputation for unreliability. Versions since the late 1980s have eliminated these problems and are considered quite reliable.

Two versions of the GCM are manufactured. The GCM-X version is for hydrogen-cooled generators and operates with an ion chamber for signal generation. The GCM-A is for air-cooled generators and uses a cloud chamber for signal generation. The operating principles of both were explained by Kilmartin using illustrations.

Modern stator-core design/robotic core stacking

Dave Charlton, PE, and Justin England, Siemens Energy

Charlton has 25 years of industry experience including leadership at Siemens on process improvement efforts for generator field rewinds and factory production.

Charlton and England described current approaches to stator core design and ventilation arrangements. Robotic equipment is used to stack the core laminations in sections which are then placed within an inner frame to make up the stator core assembly.

Global vacuum pressure impregnation (GVPI) is used for the stator windings on all but the largest units. This process greatly simplifies winding assembly; however, GVPI has gained a reputation for lack of consistent reliability. In answer to a question, the speakers said Siemens has used the GVPI process on these sizes of generators since the early 1980s and have had no significant service issues relating to the process.

Among these hundreds of generators there have been rare GVPI windings requiring replacement because of failures unrelated to GVPI. Winding replacement of a GVPI stator winding is difficult, costly, and calendar-time consuming. But overall, Siemens believes the advantages override the potential disadvantages.

Improvements in modern generator design

Tony Arrao and John Yagielski, GE

Arrao, the OEM's senior engineering manager for generator stator technology, has been a GE employee for 35 years. Yagielski has worked for the company in generator design engineering and manufacturing quality for 25 years. Currently, he is the consulting engineer for generator systems integration.

The speakers reviewed the differences in design philosophy of GE's new modular generator designs compared to its historic design approach—for example, standard centerline height, coolers in the fan inlet bay, no high-voltage bushing box. A standard cross section is used today with rating increase accomplished by increasing the core length. Core ventilation is radially outward for the entire core.

Long-time proven components and systems are used throughout the new design—for example, slot wedging system, core spring isolation system, Micapal stator-bar insulation, TetraLoc™ stator end-winding support system. CCJ

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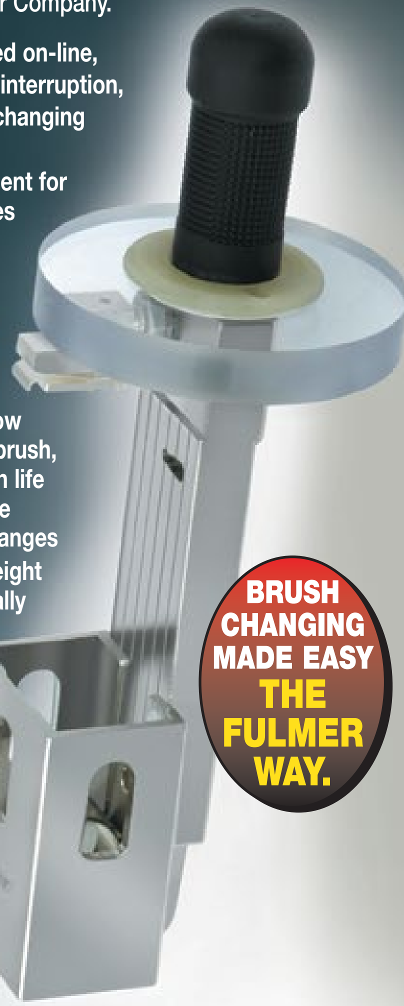

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High-voltage electrical emerges as a top interest area among GT users

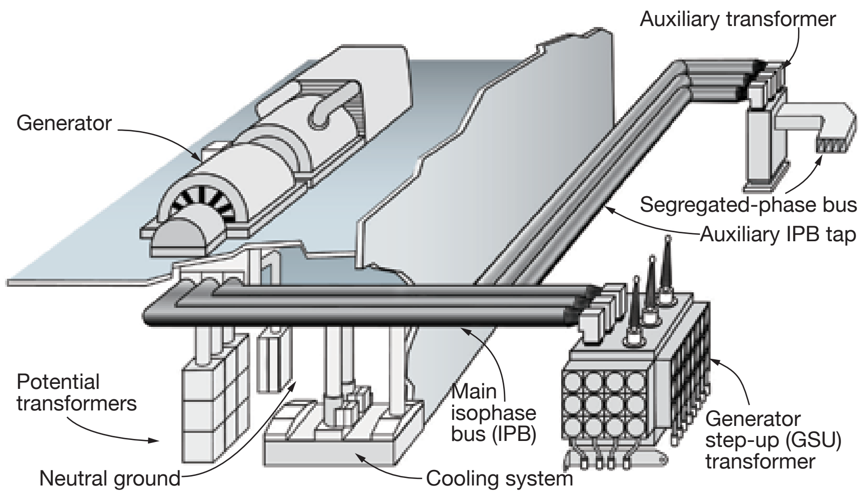
Until relatively recently, the technical programs at user-group meetings focused almost exclusively on gas-turbine problems and solutions. But as issues were resolved and items crossed off punch lists, the reliability and availability of the basic engine improved to the point where other plant equipment was at least as likely to cause an outage—more so in some cases.

New topics appeared on meeting agendas. CTOTF™ may have been the first user group to expand beyond the engine; its willingness to add sessions to cover the total-plant information needs of supervisory and management personnel made this possible. Under Former Chairman Bob Kirn's leadership, the program expanded to include environmental, NERC/FERC, and high-voltage (HV) equipment roundtables, etc. Some others evidently believed the idea a good one and followed suit.

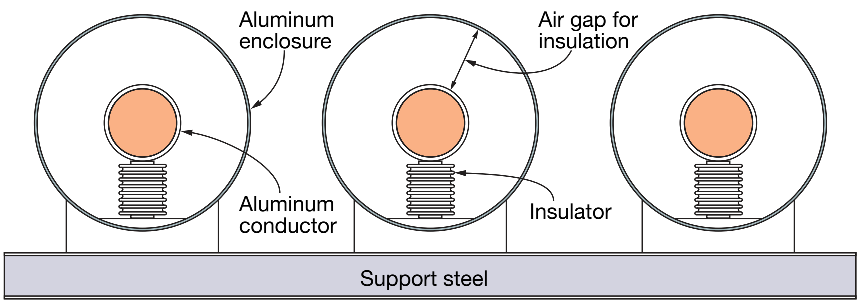
At its last spring meeting (April 2015), CTOTF invited NAES Corp's Chief Engineer, Bill Lovejoy, PE, to provide guidelines on the inspection and maintenance of isophase bus (IPB). (Access details in CTOTF's Presentations Library by scanning the QR code with your smartphone or tablet.) Neglect of this component at some plants has contributed to avoidable outages.

A month later, Gary Whitehead of Electrical Builders Inc, a service firm operating in the HV space, spoke about the causes and prevention of bus failures at the 7F Users Group meeting in Denver (sidebar).

Then, at the 2015 meeting of the 7EA Users Group in Santa Fe last November, Bruce Hack of Crown Electric Engineering & Manufacturing LLC, which designs, fabricates, installs, and provides field support for HV bus reviewed the various equipment options available to owner/operators for both new and retrofit applications.



1. Electrical energy produced by the generator is moved via isophase bus to transformers that boost voltage for export to the grid or for in-plant use



2. A look inside typical isolated-phase bus duct

Given user interest, and the success of the start-up Generator Users Group (report, p 50), which held its first meeting the week before the 7EA conference, perhaps it's time to launch an HV Users Group—to share information on all the equipment between the generator and the transmission line.

Recall that when the industry was regulated, this equipment generally was maintained by the utility's electrical department. Deregulation has transferred responsibility to generating-plant personnel in most cases and they typically do not have deep technical backgrounds in HV work.

Hack began his 7EA presentation saying that in the electrical industry there are few products as rugged and reliable as bus duct, and among the bus-duct options, there is no product with the integrity and long lifetime of isophase bus. He then put up on the screen a typical system drawing to get everyone in the room on the same page. In Fig 1, note that electrical energy produced by the generator is moved via IPB to transformers that boost voltage for export to the grid and via segregated-phase bus for in-plant use.

Hack next reviewed the three basic types of bus construction described in the ANSI/IEEE Standard for Metal-Enclosed Bus (C37.23-2003):

- Isolated phase. In this arrangement, the conductor for each phase is enclosed by an individual metal housing separated from the adja-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3. In segregated-phase bus, conductors for each phase are housed in a common metal enclosure but separated by metal barriers between the phases

4. Non-segregated phase bus has no barriers between the phases. Rectangular configuration shown here is most popular

cent conductor housing by an air space (Fig 2). The bus may be self-cooled or forced-cooled.

- Segregated-phase bus. Conductors for each phase are housed in a common metal enclosure but separated by metal barriers between the phases (Fig 3).
- Non-segregated phase bus. All phase conductors are in a common metal enclosure without barriers between the phases. There are two configurations: rectangular (most common, Fig 4) and circular (Fig 5).

IPB is specified for applications with highest voltage and ampere requirements. One leading manufacturer designs its IPB for voltages between about 15 and 38 kV and ampere ratings to more than 40 kA. The same supplier offers segregated- and non-segregated-phase bus for 600-V to 38-kV applications at ampere ratings up to 8 kA. Another manufacturer of segregated-phase bus offers ANSI ratings up to 12 kA for 600-V class bus and up to 6 kA for 15-kV class bus.

Reinforcing his belief that isophase bus is the "top of the line" but perhaps not economically justifiable at amperages below about 8 kA, Hack's goal was to make users aware of *circular* non-seg bus as an alternative to the conventional rectangular bus configuration illustrated in Fig 4. He said the circular design, pioneered by Westinghouse Electric Corp in the 1970s, offers most of IPB's advantages while avoiding issues often associated with rectangular non-seg bus.

To set the stage, Hack asked how many attendees have had issues with non-seg bus. A few hands went up. Next question: Has anyone had issues with IPB? No hands visible. Point made.

Then, to illustrate some of the problems identified with conventional non-

Design inspectability, maintainability into isophase bus to

The failure to properly inspect and maintain isophase bus (IPB) regularly can lead to problems no plant manager wants, Gary Whitehead of Electrical Builders Inc (EBI) told attendees at the 2015 7F conference in Denver, May 11-15.

He began his presentation with the basics, describing two basic types of IPB designs—continuous and non-continuous. Virtually all attendees had the former, in which the enclosures are electrically continuous throughout the bus system and bonded to each other at the bus ends. With this design, the enclosure for each phase absorbs nearly all the induced currents of that phase. The bonding at the ends of the bus allows the induced currents to cancel out each other. The system then is grounded at one end only. This design shields the majority of induced currents from the support steel.

A. Insulator failure. Note that the ceramic insert is completely out of the insulator

B. Expansion and contraction of shunts can lead to cracking and failure

IPB failures, the speaker continued, generally are caused by (1) a failure in connected piece of equipment—the transformer, for example, (2) inadequate design or improper installation, and last, but certainly not least, (3) by improper inspection and maintenance. Regarding the first, the speaker said, the root cause may be difficult to determine; it might be in the connected equipment or in the IPB system itself.

The three most common failure causes attributed to inadequate design are limited maintenance access, enclosure expansion joints using cables for enclosure grounding, and single-insulator bus designs where the insulator supports the conductor in suspension. The time to deal with each of these, Whitehead said, is at the specification stage and to recognize that the cost of enhancements to a basic design is minimal in a lifecycle cost assessment. Example: If no access points (such as a removable IPB cover) are provided for proper maintenance of internals, how can you expect to operate problem-free?

The speaker stressed the need for access on *both* sides of seal-off bushings. Dirty insulators, or seal-off bushings cause tracking, which eventually leads to failure. Another thing he recommended "designing out" at the specification stage: Use of sliding covers as an expansion joint with multiple cables for enclosure grounding.

Here's the failure scenario: The cable with the best connection has the lowest resistance and will carry more of the ground current than others. This cable will overheat and fail, eventually. That current then is transferred to the cable with the next best connection. It, too, will overheat and eventually fail. Finally, as more cables fail, the overheating and failures accelerate, compromising the grounding system.

IPB designs using insulators in tension should be avoided as well. The vibration inherent in all generation equipment will degrade ceramic inserts of bus insulators over time, Whitehead said (Fig A). Failure of one insulator insert puts additional stress on the remaining insulators. If two adjacent insulators fail, the conductor will fall to the bottom of the enclosure.

As you might expect, the reasons for improper inspection and maintenance are independent of the equipment or system of concern. They include the absence of regularly scheduled inspection and maintenance, improper procedures, and the

5. Circular non-segregated phase bus is an alternative to the rectangular design shown in Fig 4 and offers many advantages of isophase bus

6. Blown non-seg bus at right is rare, but it happens; at left, damage caused by insulation break-down

seg bus, the speaker put up a couple of ugly photos (Fig 6) and offered the following reasons for why such damage might occur:

- Neglect was at the top of the list. Many plant employees had not been made aware of inspection and maintenance requirements of bus duct.
- Design was a mitigating factor. As a rule, Hack said, bus duct is supplied in sections of about 8 to 12 ft in length. Reasons: Copper and aluminum conductors typically are offered commercially in this size range and manufacturers have invested in facilities and tooling compatible with it.

With such short sections, each of which is joined to the next by an array of splice plates and bolts that require torqueing, micro-ohm resistance measurements, and insulation with tape or boots, a nominal run of say 100 ft might have as many as 15 or so joints for each of the three

maximize reliability

use of untrained electricians and/or inexperienced contractors.

Things to look for include cracking and failure of shunts (Fig B), peeling or discolored paint from overheating (Fig C) confirmed by infrared inspection (Fig D). Whitehead explained that it was important to check for cracks in expansion joints because they allow moisture ingress and severe corrosion can occur when excessive ground currents are present, as shown in Fig 11 (main text).

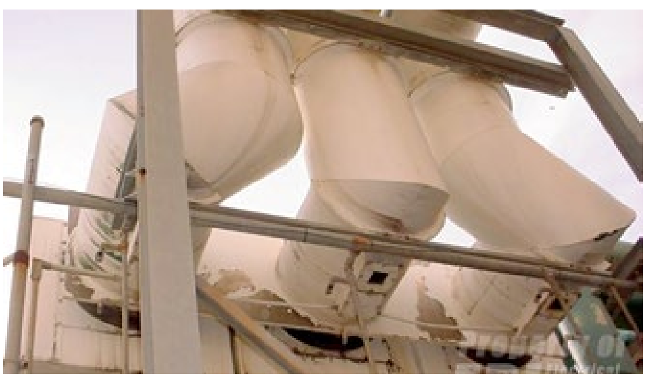
Safety was a recurring message during the presentation. Make a mistake around live bus duct and you might not get a second chance. What seemed to concern the speaker most were jobs involving non-electrical personnel unfamiliar with IPB. One example he gave was the possible need for HVAC technicians when the plant was running in cases where cool air must be forced through the bus duct to control temperature. He urged careful supervision by plant staff.

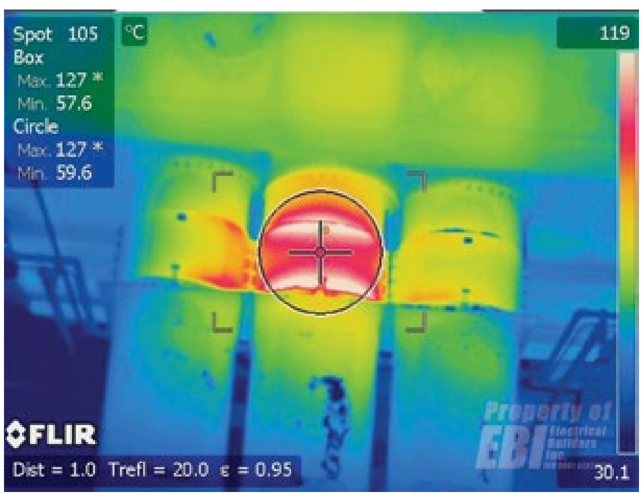
In closing, Whitehead suggested attendees adopt EBI's full-spectrum five-point inspection and maintenance cycle to keep their IPB in good condition. It consists of the following:

- Online EMI assessment of the bus duct to provide insight into impending issues.
- Rigorous offline inspection.
- Thorough cleaning (EBI recommends environmentally friendly cryogenic cleaning for the best results).
- Repair/refurbish/replace components as necessary.
- Final verification and testing.

Some of the points made by Whitehead mirrored those of NAES Chief Engineer Bill Lovejoy, PE, at the spring 2015 CTOTF CT-Tech™ workshop. The latter recommended annual inspections of isophase duct and used an engineering drawing and photos to show attendees where to look for problems. Lovejoy said expansion joints are prone to cracking on cycling units because they typically are designed only for 1000 cycles. It doesn't take long to get there on a daily-start unit.

Also, he urged users to be sure drains are clear because water will accumulate over time and freeze in winter. Lovejoy noted that if you inadvertently ground isophase bus in a second spot you'll burn off the paint. He suggested infrared thermography scans under load to identify second grounds.





C. Peeling or discolored paint typically warns of excessive heating (above)

D. Infrared inspection points to heating issues requiring attention (right)

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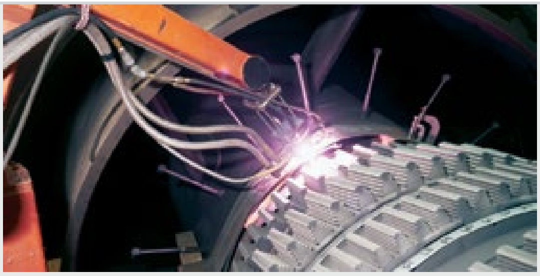

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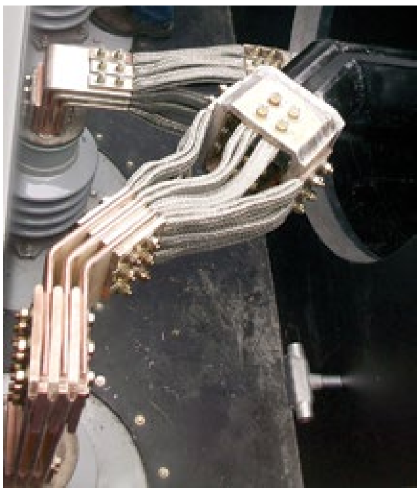

7. Flexible braid connections to capital equipment should be inspected regularly

phases. All of these joints, plus the associated flexible braid connections to the capital equipment (Fig 7), demands inspection and maintenance at regular intervals.

- Cycling impacts. Conductors historically have been insulated with sleeving or heat shrink, both performing well if not mechanically stressed. But stress is what some designs caused by bracing conductors using a method known as "choking" the bus. Specifically, the need to brace the bus to accommodate the specified fault forces, required that heavy strips of GPO-3 (red insulating fiber material) or Micarta (for older bus) be bolted to the tops and bottoms of the conductors and then to bracketing angle supports on the inside wall of the bus duct.

  Over time, rubbing caused by thermal expansion and contraction (a particular concern in plants powered by gas turbines and starting daily), wears away conductor sleeving and ultimately can fail the insulation at each location so affected. Hack also mentioned that GPO-3 is hygrocopic. If this material gets wet and dirty, a tracking path to ground is created.
- Bus-duct enclosure section joints create opportunities for water to enter the bus and puddle, possibly saturating insulation. In cold climes, slow-building icicles develop and eventually could flash over.

The circular non-seg bus described by Hack avoids the issues identified above by design. It is of welded all-aluminum construction, the same as the industry standard, isophase bus, and makes it virtually impervious to contaminants. It also promotes rigidity, allowing transport and installation in sections 40 to 50 ft long (Fig 8). The inherent rigidity also minimizes structural support requirements (Fig 9).

Conductors, supported by high-strength porcelain, are air-insulated. The only regular maintenance required—annually or less frequently—is to wipe down the insulators. Both the conductor and enclosure use effective shunt (Fig 10) and expansion (Fig 11) assemblies similar to those found on IPB.

Hack conceded that welding of the conductor and enclosure during installation does require a higher skill level than bolting. However, he said, the total man-hours for joining bus sections are comparable.

Options available for non-seg rectangular geometries are available for the circular non-seg offering—including space heaters and connections to all types of capital equipment (steam and gas turbines, transformers, etc). Plus, bus taps for auxiliary connections and high-amperage disconnect switches for isolation and grounding of the connected transformers when maintenance is required.

Economics. Hack closed with the suggestion that users would likely find circular non-seg bus more attractive financially over its lifecycle than the alternatives in the range of 3.5 to 7.5 kA (up to 110-kV BIL)—especially so if the plant is located in a difficult envi-

8. Circular non-seg bus has rigidity to facilitate transport and crane lifts

9. Inherent rigidity of circular non-seg bus minimizes structural support requirements (above)

10. Shunt assembly is similar to that for isophase bus (left)

11. Cracks in expansion joints allow moisture ingress and severe corrosion can occur when excessive ground currents are present

ronment and/or must perform at a high level of reliability.

Example. If the condition of the non-seg bus serving your gas turbine suggests replacement would be a good idea to improve plant reliability, here's how to determine if a circular non-seg retrofit is worth considering:

Assume the engine is a 501D5A, which has a nominal ISO rating of 121 MW. Dividing by the power factor (0.85 in this case) translates to 142 MVA. For the line voltage of 15 kV, phase current is 142, divided by 15, divided by the square root of 3 = 5.5 kA. This is in the middle of the "sweet spot" for circular non-seg bus suggesting consideration be given to this alternative. CCJ

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Leading power and automation technologies that enable utility and industry customers to improve performance while lowering environmental impact. Turbine-automation control systems are based on ABB's field-proven control platforms that deliver safe and reliable control.

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Specializes in cleaning heavy-duty equipment, power generation facilities, and electric utility plants. Options of cleaning include dry-ice blasting, soda blasting, and media blasting depending upon the project.

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Offers new and innovative filtration products for the GT/CC power industry. Invest to save with inlet air filters that are high efficiency, low back-pressure, and long lasting. As the largest stocking distributor of industrial air filters in the West, AFC is equipped to meet your most urgent GT inlet filtration needs. Turnkey installation available.

Advanced 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.

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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.

Allied Power Group

Earned a reputation for high-quality repairs of IGT and steam turbine components. APG specializes in hot-gas-path and combustion components from GE, Siemens/Westinghouse, and other leading OEMs. Shop staff includes engineers and expert technicians who work together to determine the best method of repair.

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.

AmertechTowerServices

Single source supplier of cooling towers, cooling tower spare parts, repair, and maintenance services; offering competitive prices with expert technicians to oversee the installation, restoration, and preservation of your towers.

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.

BASF Corp

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Full-service industrial maintenance contractor since 1976. Company experience in combined-cycle projects includes header, tube, and complete panel/harp replacements. We also have significant experience in liner repairs/upgrades, duct-burner repairs, penetration seals, and stack-damper installations.

C C Jensen Oil Maintenance

Manufactures CJC™ kidney-loop fine filters and filter separators for the conditioning of lube oil, hydraulic oil, and control fluids. Our extensive know-how ensures optimal maintenance of oil systems and equipment reliability.

Caldwell Energy

Power augmentation, including inlet fogging and wet compression solutions, boosts the output and efficiency of gas turbines. With more than 400k hours of operating experience in power generation, these systems offer proven performance and are backed by a three-year warranty.

Camfil Farr Power Systems

A world leader in the development, manufacture, and supply of clean air and noise reducing systems for gas turbines. A correctly designed system minimizes engine degradation, leading to lower operating costs, optimum efficiency, and less environmental impact.

Chanute Manufacturing

Contract fabricator of HRSG products—including finned tubes, pressure-part modules, headers, ducting, casing, and steam drums.

CLARCOR Industrial Air

Formerly GE Power & Water's Air Filtration business, CLARCOR helps customers achieve air quality and plant performance goals with products and solutions for gas turbine inlet filtration, industrial filtration, and membrane technologies. Company is committed to improving plant performance and enabling users to realize their operating goals.

Cleaver-Brooks

Complete boiler-room solutions provider that helps businesses run better every day. It develops hot-water and steam generation products aimed at integrating and optimizing the total boiler, burner, controls system to maximize energy efficiency and reliability while minimizing emissions.

CMI Energy

Known globally for HRSGs and aftermarket solutions that are engineered to tackle the most stringent power industry demands, company serves its customers with experienced teams, advanced designs, and reliable operation. Count on CMI for proven technologies, expert project execution, and top-quality support for the life of every job.

Conval

Designs and manufactures high-performance valves for the world's most demanding applications, including power generation. Company has a series of power generation case studies that demonstrate the unique features and benefits of forged valves.

Cormetech

The world's leading developer, manufacturer, and supplier of catalysts for selective catalytic reduction (SCR) systems to control emissions of nitrogen oxides from stationary sources. Cormetech SCR catalysts are highly efficient and cost-effective where systems must be capable of reducing NO_x by more than 90%.

COVERFLEX Manufacturing

Offers superior removable insulation systems for an array of gas and steam turbines. Based on OEM turbine designs and feedback from plant managers, insulation systems are custom-designed to provide comprehensive thermal protection.

Creative Power Solutions

CPS is a group of engineering companies in the power generation and energy utilization sector. Its mission is to provide advanced, efficient, and customized technology solutions to clients ranging from OEMs to plant operators and energy consumers.

CSE Engineering

Specializes in gas, steam, and hydro turbine control system upgrades, <ITC>® HMI replacement for GE Speedtronic™ MK IV and V, gas and steam turbine field services, Woodward parts and repairs.

Cust-O-Fab Specialty Services

Provides the latest technology in exhaust plenums, exhaust ductwork, and exhaust interior liner upgrades that will drastically reduce external heat transfer, making the unit safer and more efficient and easier to operate and maintain.

Cutsforth

Our experience and innovative designs have brought best-in-class brush holders, collector rings, shaft grounding, and onsite field services for generators and exciters to some of the world's largest power companies.

DEKOMTE de Temple

Manufactures fabric and metal expansion joints which compensate for changes in length caused by changes in ductwork temperature. Axial, lateral, or angular movements can be compensated for. Company has gained a global reputation for ingenuity of design and quality of products.

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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.

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Offers professional dry-ice contract cleaning services performed at your facility. Company provides a full range of dry ice blasting machines and capabilities to accommodate any size job by its team of trained, certified, and experienced operators.

EagleBurgmann Expansion Joint Solutions

Leading global organization in the development of expansion-joint technology; working to meet the challenges of today's ever-changing environmental, quality, and productivity demands. Company's flexible products are installed on equipment where reliability and safety are key factors for operating success.

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Offers R-MC and PowerBack gas turbine and compressor cleaners to eliminate compressor fouling. Additionally, ECT designs specialty nozzle assemblies and custom pump skids for the proper injection of chemicals and water for cleaning, power augmentation, and fogging.

Emerson Process Management

Ovation™ control system offers fully coordinated boiler and turbine control, integrated generator exciter control, automated startup and shutdown sequencing, fault tolerance for failsafe operation, extensive cyber security features, and embedded advanced control applications that can dramatically improve plant reliability and efficiency.

ep3 LLC

Brings 25 years of organizational intelligence and software expertise to the toughest challenges of plant operations. Quad C® is an advanced software platform for optimizing plant pre-commercial and acquisitions, maintenance and engineering, asset management, and operations.

Eta Technologies

Consulting services for all types of GTs, especially in the areas of component manufacture, repair, RCA, component remaining life assessment and metallurgical evaluations, with extensive and unique experience on Siemens V engines. Eta also provides replacement aftermarket parts for V engines.

EthosEnergy

This JV between Wood Group and Siemens is a leading independent service provider of rotating equipment services and solutions. Globally, these services include EPC; facility O&M; design, manufacture, and application of engineered components, upgrades, and re-rates; repair, overhaul, and optimization of gas and steam turbines, generators, pumps, compressors, and other high-speed rotating equipment.

Falcon Crest Aviation

Distributor of ZOK27 and ZOKmx gas-turbine compressor cleaning detergents. ZOK27 is a single cleaner and inhibitor in one that cleans and protects the engine—and also inhibits corrosion. ZOKmx is a power cleaner formulated to replace solvents providing exceptional cleaning without the health and environmental risks associated with solvents.

Frenzelit North America

Specializes in providing long-term expansion-joint solutions for gas-turbine exhaust applications. In addition to manufacturing superior quality expansion joints, Frenzelit also makes HRSG penetration seals, insulating materials, and acoustic pillows for silencers.

Fulmer Company

Provider of brush holders, machined components, and assemblies for the OEM, power-generation, and industrial markets. Fulmer is the largest North American manufacturer of brush-holder assemblies, offering single- and multiple-brush units for power generation OEMs and aftermarket customers.

Gas Turbine Controls

World's largest stock of GE Speedtronic circuit boards and components for the OEM's gas and steam turbines. GTC stocks thousands of genuine GE-manufactured cards for the MKI, MKII, MKIII, MKIV, MKV, MKVI, and LCI controls, as well as EX2000, Alterrex and Generrex excitation.

Gas Turbine Efficiency

Provides solutions involving the application of electrical, mechanical, and process-related equipment and components for optimizing system performance. GTE's experienced team of engineers and designers has solid industrial process backgrounds with expertise in fluid systems, instrumentation, and system controls.

GEA Heat Exchangers

From design to construction, replacement towers to spare parts, GEA has built, repaired, replaced and upgraded field-erected cooling towers for over 40 years for the power and process industries.

Graver Technologies

Designs, develops and manufactures a variety of technologies and products that enable and enhance the separation and removal of trace contaminants. Strengths include, but are not limited to, both ion exchange and filtration for condensate polishing and other power generation applications.

Groome Industrial Service Group

Offers a variety of SCR and CO catalyst cleaning and maintenance services nationwide and has formed strategic alliances with industry experts and catalyst manufacturers to ensure that Groome offers the most widely supported, comprehensive, turnkey service available.

GTC Services

Field engineering company offers gas-turbine owners and operators worldwide "Total Speedtronic Support." Engineers have decades of experience servicing and troubleshooting all GE Speedtronic systems.

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HRST

Specializes in technical services and product designs for HRSGs, waste heat boilers, and smaller gas or oil fired power boilers globally. Experience on over 200 boilers annually and able to provide quality inspections, analysis work, design upgrades, professional training and more.

Hydro

Engineered solutions enable combined-cycle plants to achieve pump reliability and reduced O&M costs. As the largest independent pump rebuilder, Hydro works hand-in-hand with pump users to optimize the performance and reliability of their pumping systems.

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JASC

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KnechtionRepair Tools

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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.

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Advanced repairs employ the latest technologies and are proven to extend the life of components for all engine types. Company specializes in high-reliability component repairs and upgrades for blades, vanes, nozzles, shrouds, combustors, and transitions.

M & M Engineering

Provides failure analyses and related services to industrial and insurance-company clients. M&M's expertise includes corrosion in boilers, steam turbines, generators, combustion turbines, deaerators, feedwater heaters, and water and steam piping.

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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.

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One of the world's largest independent providers of operations, construction, and maintenance services, provided through a tightly integrated family of subsidiaries and operating divisions. NAES services include O&M; construction, retrofit, and maintenance under dedicated long-term maintenance or individual project contracts; and customized services designed to improve plant and personnel effectiveness.

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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.

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A leading engineering company operating globally in the field of steam generating equipment. NEM supplies custom-made solutions regarding industrial, utility, and heat-recovery steam generators for power generation and industrial plant applications.

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Backed by the strength and reach of the America's largest independent power generation company, NRG Energy. Company provides plant maintenance solutions to minimize downtime, increase asset availability, reduce ownership costs, and boost profits. Company delivers custom-tailored O&M solutions to meet any generation need, on any scale.

Pneumafil

Major air-inlet filter-house supplier to all major turbine manufacturers for over 45 years. Company manufactures certified, high-efficiency filtration products for all brands, pulse style or static style inlet housings, to ensure maximum turbine output and efficiency.

Powergenics

Leading supplier of industrial electronic circuit-card and power-supply repairs to industrial and power generation customers. Company provides a very high-quality repair at a substantial cost savings from the OEM and other competitors while maintaining a warranty service second to none.

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Leading global supplier of surface-enhancing processes and materials, as well as an innovator in thermal spray, composite electroplating, diffusion, and high-performance slurry coatings processes. Company produces and applies metallic and ceramic coatings that protect critical metal components such as in gas turbines.

Precision Iceblast

World leader in HRSG tube cleaning. PIC cleans more HRSGs than any other ice blasting company in the world. It ensures that HRSGs operate efficiently by providing the cleanest boiler tubes possible.

Proco Products

Supplies rubber expansion joints to the power industry in sizes ranging from 1 to 120 in. ID. Proco keeps joints up to 72 in. ID in stock at its Stockton (CA) warehouse and works through an agent/distributor network to supply products to combined-cycle plants.

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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.

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Provides competitive, efficient, and flexible gas-turbine packages rated from 25 to 120 MW. PWPS offers a full range of maintenance, overhaul, repair and spare parts for other manufacturers' GTs with specific concentration on the high-temperature F-class industrial machines.

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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.

ROBLICORP

Serves the industrial gas-turbine aftermarket by supplying an extensive range of renewal items—including ancillary, auxiliary, accessory, and control room spare parts and material. Supplier of new gas turbine spare parts, accessories, components, hardware, filtration, and consumables for LM5000/LM6000, FR5/7/9 HD, GG3/GG4/GG4C/FT4/GG8/FT8/ST6 IGT aftermarket.

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.

Sentry Equipment

Engineers, manufactures, and services components for collecting representative samples of steam, water, gas, liquid, slurry, and bulk solids. This enables analytical and operational professionals to gain samples safely and simply, and with repeatable results.

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Provides engineered silencers and systems for new and replacement gas-turbine applications—including turbine inlet silencing, turbine enclosures, bypass systems, and HRSG inlet shrouds and stack and vent silencers.

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.

Stellar Energy

Leading provider of energy plant systems, including turbine inlet-air chilling and TIAC with thermal-energy storage, district cooling, modular utility plants, and CHP. Steller offers a complete range of in-house analysis, design, fabrication, installation, startup and commissioning, and maintenance.

Strategic Power Systems

Provides products and services focused on capturing powerplant operational and maintenance data to develop reliability metrics and benchmarks for end users—including some of the most recognized organizations in the global energy market.

Sulzer

Provides cutting-edge maintenance and service solutions for rotating equipment dedicated to improving customers' processes and business performances. When pumps, turbines, compressors, generators, and motors are essential to operations, Sulzer offers technically advanced and innovative solutions.

TEC-The Energy Corp

Our skills and experience assist GT owners with front-end engineering, procurement of major equipment, and management of engineering, construction, and commissioning of new facilities. From due diligence to detailed design, TEC covers all phases of complex power projects.

Technical Training Professionals

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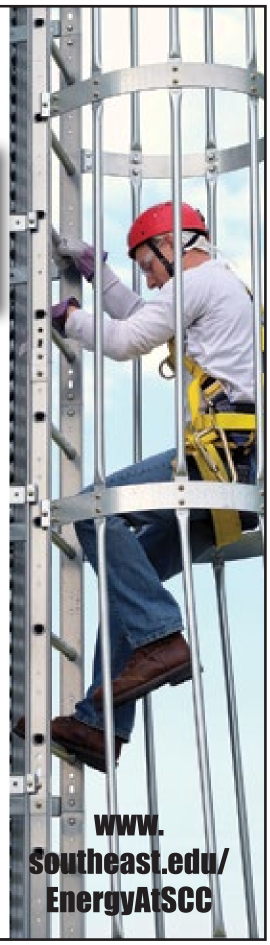

Flying solo after sharing meeting space with the 501F users for several years

Nothing lasts forever. After sharing meeting space with the 501F users for several years, the 501G Users Group will host its own annual meeting in 2016. The new arrangement was prompted by Siemens' launch of a customer conference for F-, G-, and H-class users last fall (turn to p 32 for details).

Steve Bates, the 501G chairman, arranged for the organization to meet at the Hyatt Regency Orlando International Airport, February 2-4, three weeks before the 501F users gather in San Antonio.

The value of independent users groups to gas-turbine owners—the 501G organization, in particular—cannot be overstated. Small by industry standards because there are only 24 Siemens (Westinghouse) engines at 13 sites in the US and one in Mexico, it is the rare G meeting that doesn't have at least one representative from each location; attendance typically is in the mid-30s, or an average of 1.5 attendees for every machine in the fleet. No other user group comes close to that level of commitment from owner/operators.

The organization's size, capable leadership (sidebar), and collaborative nature allow it to think and act as a unit to resolve issues experienced on the deck plates and with the OEM. Minimal turnover in the top positions at G facilities, at least compared to the industry at large, means most attendees know the other participants and are aware of their plants' idiosyncrasies, minimizing the need for "reviews" and repetitive discussion. In effect, each of the semiannual meetings picks up where the previous one ended.

A closed session for G users at the 2015 501F/G conference in Savannah was held the day after Siemens Day. The OEM's technical program updated owner/operators on progress in resolving turbine rotor bolt, compressor through bolt, and R4 blade locking hardware issues, and included status reports on activities concerning combustion systems, quality improvement, disc-cavity thermocouples, bellybands, and generator spring bars.

501G steering committee

Chairman: Steven Bates, plant manager, Wise County Power Co LLC, GDF Suez Energy Generation NA Inc.

- Scott Wiley, fleet maintenance manager, GDF Suez Energy Generation NA Inc.
- Greg McAuley, VP, Turbine Maintenance Group, Calpine Corp.
- Kevin Robinson, operations manager, Lakeland Electric.
- Dan Jorgensen, maintenance manager, Granite Ridge Energy LLC, Calpine Corp.
- John Wolff, technical support/compliance manager, Ironwood, TransCanada Corp.
- Mark Winne, plant manager, Millennium Power Plant, Millennium Power Partners LP.

The user-only program began with an open-discussion review of Siemens Day to identify issues requiring clarification, follow-up with the OEM, etc. A turbine bolt failure at one G plant and Siemens' redesign of that component was the first topic of discussion. RCA (root cause analysis) results and the plan for installing new bolts in the fleet obviously were on the minds of attendees.

Iron oxide found in the compressor section of at least one unit was another concern raised. What's the cause? Might it be water washing, carryover from evap coolers, or what? You got the sense this would be a topic of ongoing interest until the gremlin was uncovered. Another concern: Large (12 in.) spiral-wound gaskets failed in service shortly after a gas-turbine outage. A user reported that all gaskets provided for the outage were manufactured in China. Suggestion was to specify US-manufactured gaskets.

Headaches associated with wear and tear of disc-cavity (DC) thermocouples (t/c) were in evidence. A user reported that one failed on his unit; wiring was fine, but the tip broke off because of wear. The guide tube also revealed wear. A Siemens technician was required to remove the tip section at the bottom of the tube. Another attendee said the t/c for DC3 lasted only a couple of months; guide-tube wear also was experienced at his plant.

General comments on the quality of parts (belly bands, gaskets, etc) and workmanship kept the discussion lively for more than just a few minutes.

Plant reports

Most independent users groups serving GT owner/operators organize their technical programs by sections of the engine—for example, compressor, combustion section, turbine, etc. The G users begin with an "annual report" from each plant and follow that half-day program with user presentations on emerging and significant plant-wide issues of importance to the fleet. Notes taken during the plant reports follow:

Plant 1, equipped with three 501Gs, each with about 50k equivalent base hours (EBH), said one unit suffered a R4 locking-hardware failure which forced it out of service for several weeks. Damage to the R2 interstage seal also was mentioned.

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Plant 2, equipped with two 501Gs, each with about 20k EBH (one near 650 starts; the other, more than 700) reported three R4 locking-hardware incidents.

Plant 3, equipped with one 501G at about 75k EBH/750 starts, reported no new issues but ongoing challenges operating at 50% of rated load. Some dynamics issues (low, medium, and high frequency) are expected at low loads and low ambient temperatures. Wintertime dynamics were said to be "all over the lot" with no consistency in frequency.

Plant 4, equipped with two 501Gs, both north of 70k EBH/1500 ES, reported a slight performance improvement from installing refurbished baskets with uniform liner gaps on both engines. Cracks in the exhaust ducts required weld repair. Key issues included these: Plant unable to achieve full-load operation on the original (design) firing curve, oil leakage at steamer No. 2 bearing, extensive weld repairs required to restore hookfits (unexpected) during most recent combustion inspection (CI).

Plant 5, equipped with three 501Gs having EBHs ranging from 21k to 25k and ESs from the mid-500s to more than 700, reported on the first HGP for one of the gas turbines. Material liberated from wear and tear of turbine R3 Z shrouds went downstream and damaged R4 blades beyond serviceable limits. Also found was significant cracking inside the inlet scroll where the strut bolts up to the wall; this was mentioned as an ongoing issue.

The steamer for this three-unit 1 × 1 combined-cycle facility continues to experience binding in the HP turbine section during hot starts. Plant is installing heating blankets to reduce the temperature differential between the upper and lower casing halves to a maximum of 10 deg F. Additional work includes stiffening the turning-gear platform and recommissioning of the system. A couple of users in the room thought turning-gear maintenance would be a good presentation/discussion subject at a future meeting.

Plant 6, equipped with two 501Gs having 57k EBHs and about 1600 starts each, reviewed its experience cleaning the ammonia injection grids and NO_x catalyst for both units. The presenter mentioned that the plant had changed out two combustors (7 and 11) on one engine because of flashback damage. Exhaust temperature was derated by 28 deg F on that unit because of the flashbacks. Earlier, a GT had suffered a forced outage because of flashback damage to baskets 9 and 10. The DC3 t/c failed on one GT two months after replacement in both the spring and fall outages.

Plant 7, equipped with two 501Gs, both slightly beyond 30k EBH and 500 ES, learned of a cooling-air flow issue in DC2 of both units during a modified HGP inspection on one engine. Problem was discovered when R2 vanes suffered premature failure because of overheating. The replacement new-style vanes require less cooling air flow. An RCA suggested an improper flowmeter setup during site commissioning: The setting gave indication of proper flow but actual flow was about 30% less than indicated.

Plant 8, a 1 × 1 facility, mostly had positive O&M results to share over the years, but the tables turned in 2014. More specifically:

- Combustion hardware issues were identified following a switch to 12k parts. The most serious was TBC (thermal barrier coating) delamination from a transition piece attributed to a steam coupling failure. A borescope inspection revealed three baskets had signs of flashbacks, suggesting a modified CI was needed. Metal spatter also

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was in evidence. Inspection of the steam circuit revealed debris.

- HRSG fouling forced a GT backpressure derate. This initiated a brief discussion on the causes of fouling. An attendee with expertise in this area said that ammonia slip is known to increase during low-load operation, contributing to greater deposition.
- LP economizer tube leaks.
- A crack of significant size was found near a weld in the 18-in.-diam P22 hot-reheat pipe at a turn downstream of the attemperator. The spool piece was replaced.
- A turbine through-bolt failure was found at 77.5k EBH/2500+ starts. Unit tripped on high vibration, which began at the exhaust bearing and cascaded through the other bearings. A borescope inspection revealed a broken bolt; a major inspection ensued. An unbladed replacement rotor was borrowed from another plant to reduce downtime. The outage took 43 days, about a month less than estimated for a repair without benefit of a replacement.

  Back in the OEM's shop, ultrasonic testing confirmed the cracked bolt. NDE was said to be of little value for identifying a crack before it propagates to failure, which reportedly can occur within about four hours after crack initiation. Machining of the GT and generator couplings was necessary for proper fit-up; new coupling bolts were required as well.

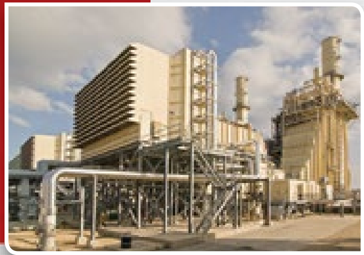
Plant 9, equipped with two 501Gs at about 25k EBH (one having more than 1000 starts, the other 750), required controls changes and reported on a disconnect between Alpharetta and Orlando for this work. This has been an ongoing user criticism for at least six years that the editors know of.

Plant 10, another 1 × 1, reported no major GT issues since the 2014 meeting. The facility ran more the past winter that it had in recent years. A positive was the installation of a new hydrogen dryer skid which has improved H_2 purity to a consistent 97%-98%. The plant representative said the old dryer had no scavenge capability; dump and add was the method used to keep up purity. No payback period was reported for the new dryer, but better generator performance was evident. For example, less windage loss contributed a few hundred kilowatts of additional output.

The speaker also reported that rotor air cooler leaks have occurred; they were expected at some point given fleet experience. Other highlights: the plant's alarm-reduction effort is nearing completion; elevated bearing temperatures experienced were thought possibly caused by an accumulation of varnish; erosion/corrosion (unusual wear pattern) of blade-path t/cs is under study.

Plant 11, equipped with two 501Gs in mid 70s EBH/about 1500 ES, noted steam-turbine trip issues, and processor failures, following conversion to T3000 controls. Failures of new-style DC t/cs were reported as well. Leaks were experienced in the IP rotor air cooler just before the meeting. Unit was refurbished onsite with an all Type-304 stainless steel system—including tubesheet and tubes. Failure mechanism was stress corrosion cracking. Water seeps in between the tube OD and tubesheet hole and attacks the weld.

Two plants with a common owner, total of three 501Gs, reported on HGP outages. Two of the three engines were operating with 8k hardware, now all three have 12k. At the two-unit plant, after 24k EBH only five R1 vanes had overheating indications and showed only minor wear on R1 vane rails. One transition revealed TBC delamination; pilot nozzles were burned up and missing pieces



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Linear indications were identified in a total of 35 R3 turbine blades on the two units, but after chemical stripping those indications were found in the base coat. The OEM cleared the blades for 48k service. Factory belly bands were replaced with the U-clip style, new seals provide for borescope access. Exhaust system weld repairs were required in the strut area. A Hastelloy backing bar/weld solution has given early success—no re-cracking in the first year of service.

Open discussion. A question was raised regarding the correlation between low-load turndown (LLT) and thrust-bearing vibration. An attendee with knowledge of the subject said that as thrust clearances open up you can get damaging vibration as you reduce load below about 50% of rated output. He had personal experience of severe vibration at 42% load.

Clearances in the high teens (mils) are not problematic if you do not implement LLT, he continued. But if you want to operate at such low loads, suggestion was to install a machined plate (not shims) to close up the clearance to about 8 mils. There would be no overheating concerns at that clearance, the expert said, and you can go down to 30% of rated load without vibration.

Planning. A user presentation on the benefits of good planning in terms of safety, cost, plant availability, and equipment reliability was a segue to meaningful discussion. For most in the room, this was not new material, but reviews of this type serve as great reminders for O&M personnel overburdened with "must do" activities. Here were some of the reminders presented:

- Well-planned work reduces, and may even eliminate, expediting fees.
- Planned work is conducive to organized and time-efficient access to tooling, parts, procedures, and craftsmen with the proper skillsets.
- Employees know what is expected of them each day, giving them meaningful goals.
- Reduces stress: Having a list of tasks relieves the employee of the responsibility for making decisions on what work to do.
- Doing planned work and preventive maintenance reduces "firefighting" issues and changes the concept of how work gets done.
- Planned work reduces downtime for critical equipment.

Summary of benefits: Reduce backlog of work orders to a manageable level, increase the amount of productive work completed each day, allow timely ordering of critical and long-lead-time items, reduce "firefighting" by increasing the number of PMs completed.

The cost of poor quality. If there was any doubt in your mind regarding the value of user groups—the small, tightknit 501G users in particular—consider the following results of a three-year study undertaken by one of the members. Unselfish sharing of information among the plants pointed to 105 "quality occurrences" experienced by the fleet. The combustion section was the source of 46% of these problems, the turbine section 42%.

The project leader calculated that the OEM cost its customers 187 outage days (47 days parts only, 32 days parts and service, and 26 service only). The dollar value associated with these outages was estimated conservatively at about $12 million. The speaker point out that this figure assumes the cost of a cover lift at $1 million, but that number could easily double depending on specific circumstances. Example: An unplanned cover lift is sure to cost more than $1 million and take more than 10 days.

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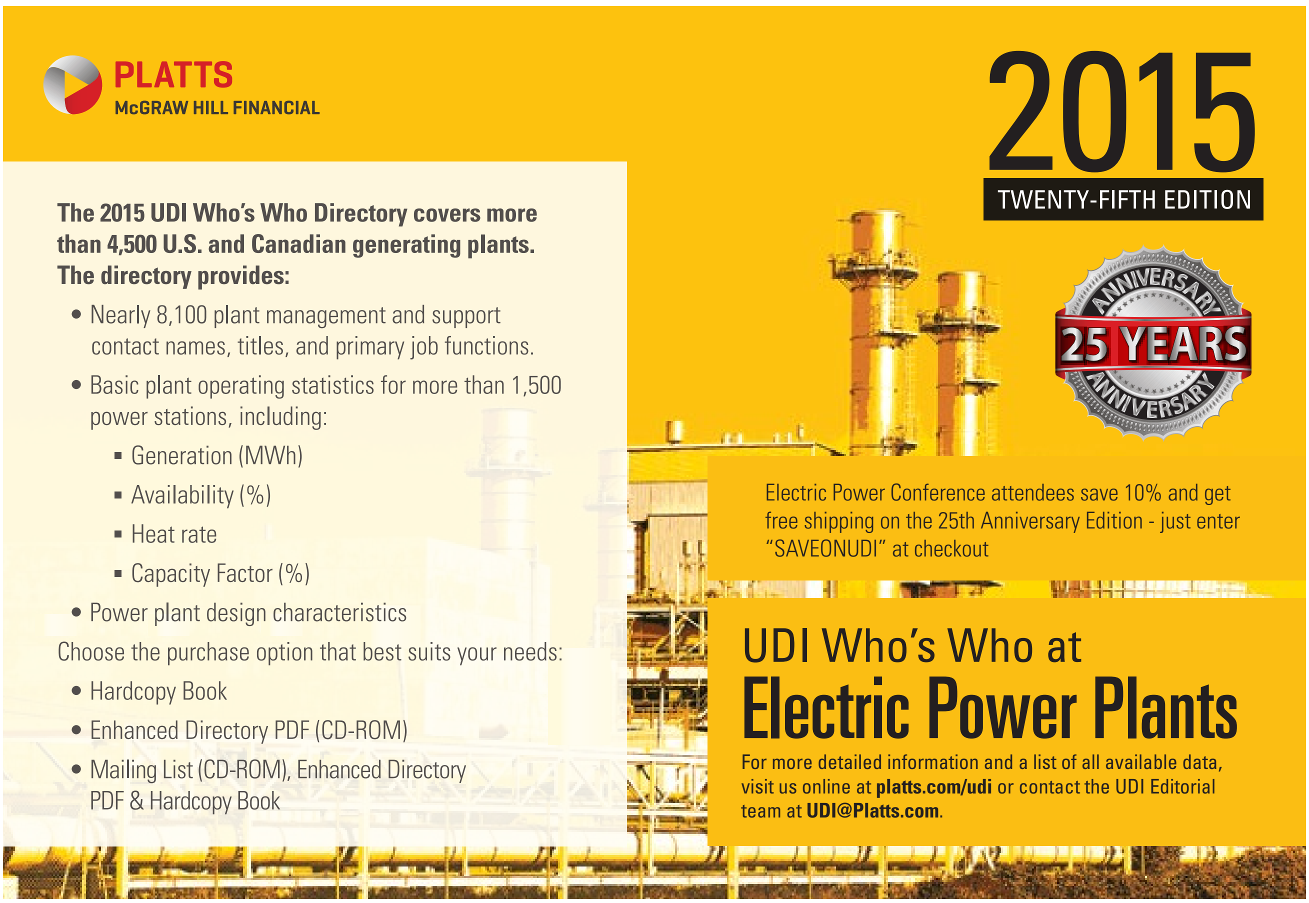
The Best Practices Awards program, launched in late 2004 by **CCJ**, has as its primary objective recognition of the valuable contributions made by owner/operator personnel to improve the safety and performance of generating facilities powered by gas turbines. The program continues to evolve by encouraging entries pertinent to industry-wide initiatives. In 2015, plants were recognized for water management, workforce development, O&M, performance improvement, fast start procedures, monitoring and diagnostics, outage management, and safety.

There are two levels of awards to recognize the achievements at individual plants: Best Practices and The Best of the Best (BoB). The five BoB awards presented this year were profiled in the 1Q/2015 issue. **CCJ's** Best Practices coverage continued in the 2Q/2015 issue with recognition of four plants powered by 7F gas turbines (Emery and Riverside Generating Stations, Green Country Energy, and Effingham County Power). This issue features best practices from 11 more plants. Profiles of 2015 best practices concludes in the next issue.

In this section:



Athens

Redesign of Athens' electric system improves operating flexibility, emergency response

Athens was constructed with emergency systems, of course, but they had limitations regarding emergency response and maintenance, as plant personnel came to learn with experience (photo). The following shortcomings were identified with the facility's electric distribution system:

- Inability to cross-connect unit power distribution during emergency and maintenance situations.
- Emergency diesel/generator (EDG) was not loaded to its design capability.
- Battery charger was undersized and battery installation was inadequate.
- Lack of power feed from the essential service bus to critical loads.
- Single source of power to critical maintenance equipment.

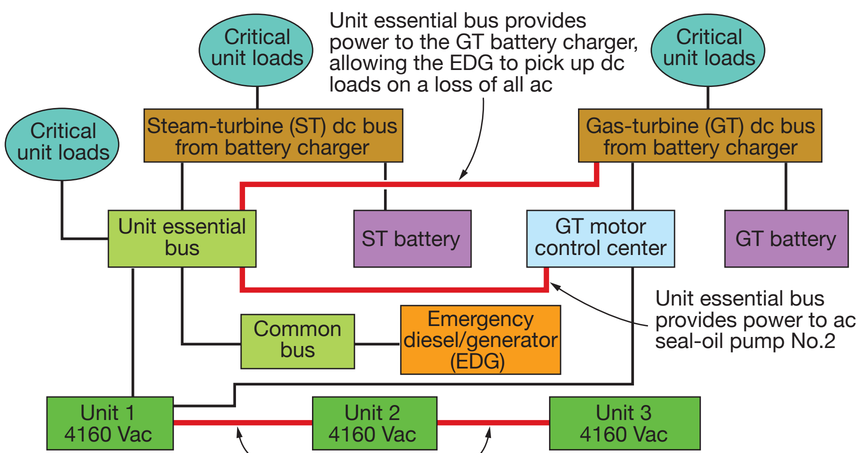
The original design (black line-work in diagram) impacted both emergency response and maintenance activities. For example, if a unit lost power, the gas-turbine (GT) batteries had to carry all critical loads—including GT dc lube oil, turning gear, and dc air-side seal oil—without any backup source of power. If power was not restored in approximately eight hours, the GT would lose all seal oil and lube oil.

Unit maintenance outages also were affected by the original electrical line-up: Without the ability to cross-connect 4160-Vac busses among units, a block had no power once it was disconnected from the switchyard. Hence, all heat-trace, welding outlets, and crane service were de-energized. This made winter maintenance outages very challenging.

First step in the solution: A plan was developed to cross-connect power among units (red line-work at bottom of diagram), enabling a block to receive power from a neighboring unit's 4160-Vac bus while it was disconnected from the switchyard backfeed. This required (1) a distribution study; (2) installation of interlocking relays, potential transformers, current transformers, and DCS logic; and (3) operator training.

The lack of power feed from the plant's essential service bus to critical plant loads was addressed next. The existing battery charger was supplied via the GT ac motor control center (MCC) or, on loss of ac power, from the batteries. This electrical configuration adversely impacted emergency recovery. Restoration was particularly challenging when the fault was offsite and power could not be restored promptly.

Key Athens personnel involved in the redesign of the plant's electric distribution system included Plant Engineer Hank Tripp and EI&C Technicians Rob O'Connell and Bob Robinson (l to r). Also involved, but camera shy, were EI&C Technicians Todd Wolford and Eric VanZandt



Redesign of the distribution system at Athens corrected an electrical service deficiency. The thick color lines trace the unit essential bus and cross-tie additions that have greatly improved operating flexibility and speed of recovery from emergency conditions

Existing spare service was identified on the unit essential bus. Service then was pulled from the unit essential MCC to the GT battery charger and a single ac seal-oil pump. The existing GT valve regulated lead-acid batteries (VREL) then were replaced with flooded lead-acid batteries. In addition, the original battery charger was upgraded from 175 to 300 amp. These upgrades ensured that the GT had a reliable source of dc power during all plant conditions.

Finally, the single source of power to plant maintenance equipment was addressed. Power originally sourced from a single unit now is sourced from two.

Very positive results were realized in the plant's maintenance activities and emergency response. First, the plant conducted three GT major inspections from 2011 to 2013 and replaced the control systems. Two of the majors and the control-system upgrades were done during the winter months. Using the 4160-Vac cross-tie, power was maintained among neighboring units. This kept all lighting, crane, welding, and heat-trace services available during these complex maintenance evolutions. Outages were completed on schedule with no major deficiencies.

Second, the plant has experienced several unit power disruptions since the modifications were completed. In all cases, the EDG starter was connected to the unit essential MCC and began supplying power to GT and steam turbine critical loads.

During emergencies, the EDG now is loaded closer to its design point. Once the cause of a disruption is identified, the unit is placed on the cross-tie feed, eliminating the need for emergency pumps, dc systems, and EDG. This flexibility significantly decreased the duration of forced outages. In sum, the units are more flexible and more reliable because of the electrical enhancements.

Granite Ridge

Arc-flash mitigation measures at GRE greatly reduce hazard risk to staff, equipment

Granite Ridge Energy (GRE) conducted an arc-fault assessment in 2010 as part of NFPA 70E compliance to determine the arc-flash potential of site electrical equipment and to assign Hazard Risk Categories (HRC) in accordance with NFPA recommendations. Although changes in protective device settings were made in an attempt to reduce all HRCs to Level 2 and below, six main electrical buses were identified at a Level 5 for which there is no safe arc-flash protection; many devices remained at HRC 3 and 4 which had the potential for severe arc-flash events.

This possibility posed a serious risk to employees working on or near the equipment, requiring the use of full flame-resistant (FR) suits and hoods. In addition, an arc-flash event could cause severe damage to electrical equipment which ultimately could affect plant reliability and availability.

Risk mitigation approach. Maintenance Manager Dan Jorgensen and other plant personnel worked with power systems specialists at Three-C Electrical to implement arc-flash mitigation measures in three phases. The project took four years to complete because of the need to coordinate work with full plant outages.

Phase One was completed in 2010, in conjunction with the initial evaluation. It focused on changes in the relay systems settings to improve trip response time.

Phase Two, conducted in 2013, involved installation of an optical relay system in the three main MCC (motor control center) rooms. The ABB system, called REA, is designed to give split-second trip commands to all circuit breakers that may feed an arc fault in low- or medium-voltage air-insulated metal-clad switchgear. The system uses an unshielded bare-fiber sensor that detects light along its entire length. Fiber loops were run through each of the 480-V main switchboards.

On detection of an arc fault, the REA delivers trip commands in less than 2.5 milliseconds to all circuit breakers feeding the fault zone. In addition to arcing short circuits, arcing earth faults with current levels below the normal load current can be detected and interrupted. In the event of a fault, indicator lights on the REA panel guide personnel to the exact fault zone for troubleshooting and corrective maintenance.

The system protects the feeder breakers, main switchboards, and the substation transformers. Although this system greatly reduced the arc-flash potential, it was determined that many feeder breakers for the MCC rooms had antiquated trip kits and were thus missing instantaneous protection.

Phase Three, the final step of the project, was completed in 2014 with the installation of secondary digital trip kits on eleven 480-V feeder breakers to allow for instantaneous overcurrent protection on the MCCs fed from the main switchboards.

Safety was improved dramatically by installation of the multi-phase arc-fault protection system: Arc-flash level on the majority of HRC 3-, 4-, and 5-rated electrical devices requiring live interaction were effectively reduced to HRC 2 or below. Operating procedures were developed for the remaining devices to de-energize upstream and eliminate the need for live work. This greatly reduced the hazard risk to employees and equipment in the event of an arc fault. As a result of the lower HRC, Granite Ridge was able to standardize to a single clothing protection system which greatly increased the safety to our employees.

RO addition at Granite Ridge reduces sulfate discharges, boosts demin water production

Granite Ridge Energy (GRE) discharges wastewater to the sewer system under a local discharge permit which includes a pounds-per-day limit for sulfate. The plant's wastewater stream includes cooling-tower blowdown, sand-filter backwash water from the grey-water pretreatment system, and demineralizer-resin regeneration water. Note that the plant uses treated effluent (grey water) from the city wastewater treatment plant as cooling-tower makeup.

Challenge. High sulfate levels in plant wastewater originating primarily from sulfuric acid use in demin resin regeneration were reaching permit limits and causing GRE to take remediation measures that negatively impacted operating costs. A reduction in sulfate loading of at least 20% was needed to alleviate the problem. Factors affecting the sulfate loading evaluated during the assessment phase of the project included the following:

- Increased conductivity of potable water used to produce demin caused shorter production runs and increased regenerations of the demineralizer resin, which uses sulfuric acid.
- Poor-quality grey water required excessive pre-treatment filter backwashes which increased wastewater discharges, thereby increasing mass sulfate output.
- Sulfuric acid used in cooling-tower pH control is discharged in the blowdown.

In addition to increased sulfate, the plant also was facing challenges (1) maintaining sufficient cooling-water production through the grey-water pretreatment filtration system, and (2) providing sufficient potable water to meet demin-water production requirements.

Solution. Operations Manager Jim Barrett and GRE staff looked to address all three challenges with one solution: The installation of a single-train, 80-gpm reverse-osmosis (RO) system ahead of the existing demin system. It provided a 50% increase in demin water production. Redundancy was not needed at GRE because the demin water tank holds a nominal seven-day supply and the demineralizers can be operated without the RO system

To ensure optimal performance, GRE opted for a modular approach, keeping the RO system segregated from the existing demin system by installing a 1500-gal storage tank between them. The modular approach allowed engineers to locate subsets of the RO system in different locations within the water-treatment building for optimal use of floor space.

The RO system sends permeate to the storage tank as a standalone operation in which the tank level controls RO on/off. A permeate booster pump supplies water from the storage tank at the pressure needed to operate the demineralizers. Permeate flow is regulated with a manual bypass valve. Operationally, the systems are balanced to provide continuous operation of the RO by matching its output to demineralizer demand.

High-quality water produced by the RO system is polished in the existing cation/anion demineralizers. The reduction in total dissolved solids and conductivity achieved by the RO system allows the demineralizers to produce 50% more high-purity water than previously. An increase in demin production is achieved because the existing demineralizers can now be operated in parallel, reducing system pressure drop and increasing flow. RO permeate is 98% cleaner than the potable water available to GRE, extending demineralizer throughput 16-fold and increasing the time between resin regeneration cycles from hours to days.

Results. Approaching the sulfate-reduction challenge with other plant improvements in mind allowed GRE to resolve sulfate permit-limit concerns and increase both cooling-water supply and demin production. Additionally, GRE entered into a long-term lease agreement for the RO system which includes scheduled maintenance and remote monitoring to support optimum RO efficiency 24/7, while reducing overall budget dollars. The RO system has reduced GRE's monthly demin water cost by $2000 to $12,000, depending on demand. Year-round monthly average saving is $6300.

In sum, RO system benefits include the following:

- Reduction in sulfate discharges by 25%.
- Increase in demineralizer throughput between regenerations of 40,000 to about 650,000 gallons.
- Reduction in demineralizer regeneration chemical costs of 93%.
- Increase in daily demin water production capability from 80,000 to 120,000 gal/day. CCJ

Faribault

Steam-turbine warming blankets enable faster starts

Faribault Energy Park

Owned by Minnesota Municipal Power Agency

Operated by NAES Corp

265-MW, dual-fuel, 1 × 1 combined cycle located in Faribault, Minn

Plant manager: Bob Burchfield

Challenge. A cold steam turbine limited the plant's ability to start-up in time to capture real-time market prices; plus, significant extra fuel was required to warm the unit prior to ramping to target load. Faribault Energy Park's 117-MW A10 steam turbine features an HP turbine separate from a combined IP/LP rotor section. Both turbine inlets operate at 1050F. Starts after shutdowns of more than 24 hours required turbine warming; after a 48-hr shutdown, the plant was entering a cold-start phase requiring even more warming time.

Recall that steam turbines (ST) must be warmed slowly to prevent rotor stress and differential-expansion issues. Rotor stress, calculated by the plant DCS, is caused by heating metal components too quickly. Differential expansion here refers to the difference in rotor length when compared to the shell. A long, or short, rotor can be problematic and cause rubbing or binding of rotating and stationary components.

The turbine shell has a large mass and grows in length at a slower rate than the rotor. If the steam temperature is too high, or steam is admitted to the turbine casing too fast, the unit will trip to prevent damage. Faribault's goal was to minimize warming time while maintaining rotor stresses within allowable limits, and reducing startup fuel cost.

Solution. Plant personnel initiated a capital improvement project to install insulated electric heating blankets (Fig 1) under the ST insulation to maintain turbine shell temperature while offline in standby mode. In 2010, heating blankets were installed on both the HP and IP turbines (Fig 2). The LP portion of the IP/LP turbine operates at a relatively low temperature and does not require continuous heating.

The project involved installation of turbine blankets and control cabinets, and DCS integration. Total power required was approximately 200 kW; however, the nominal consumption rate is less than 50 kW.

Both turbines have multiple heating zones—each equipped with three redundant blankets, allowing for some failures without impacting zone temperature. Redundant surface thermocouples in each zone monitor and control the heaters. A dedicated

1. Electric heating blankets eliminate cold starts

2. A10 steam turbine blanketed for fast starting

3. Control cabinets, one for the HP turbine, the other for the IP

4. DCS graphic showing the various heating zones

control cabinet serves each turbine (Fig 3). The cabinets are equipped with an integrated monitoring system consisting of current sensors, ground-fault indicators, etc; also, local remote switches, auto switches, on/off lamps, and alarm indicating lamps.

Automation of zone controls is incorporated in the plant DCS. All zone thermocouples terminate in the DCS; discrete outputs to turn heaters on and off also are wired to the plant DCS. Heater-status feedback, alarm indications, and on/off controls complete the DCS integration.

Control logic monitors local shell temperatures using a combination of new zone thermocouples and the turbine deep base thermocouples. Controls also monitor turbine differential expansion and can turn off heaters to prevent exceeding differential-expansion limits.

Various operating modes (maintain, warmup, startup, and cool down) are incorporated into the control logic. Operators can enter set points and ramp rates (as limited by the DCS) on graphic screens in the control room (Fig 4). Interfacing heater control cabinets with the DCS, along with detailed graphical interfaces, allows for optimal control and monitoring of the entire system from the control room or locally at the cabinet.

Results. Installation of the turbine heater blankets has *eliminated* cold starts altogether, and reduced warm-start times by nearly half. Hot-start times have been reduced by a small amount. Faster starts have saved fuel and increased the chances of being dispatched in real time.

Maintaining higher ST metal temperatures also has reduced stresses related to thermal cycling. Extensive tests were performed to determine the maximum permissible turbine shell temperature without exceeding differential-expansion limits. Results may vary from one turbine to another.

Lessons learned: Closely supervise blanket and wire installation to protect heater supply wiring against premature grounding because of the close proximity to hot surfaces. Expect some annual ST insulation maintenance cost to replace failed or grounded blankets.

Participants:
Bob Burchfield, plant manager
Shawn Flake, operations manager
Ben Garrison, maintenance manager

How to write effective procedures

Challenge. When human error leads to operational or equipment failure, RCA investigations often reveal that either a process was in place but not followed or there simply was no written process. Technicians and managers generally focus on results and may have limited experience writing procedures. Ineffective procedures complicate tasks and contribute to poor performance.

For some processes, like a complex plant startup, a checklist combined with "skill of the craft" knowledge may be more effective than a wordy procedure. However, it may be beneficial to have both a procedure for training and a checklist to better serve the experienced user.

Consider the "preflight checklist" shown in Fig 1. If it was written for an untrained crew member or passenger, much more detail would be required. As written for the captain (C) and first officer (F), it includes only minimal cues that enable a well-versed operator to complete the process more efficiently. Spare wording allows such a reader to focus on task execution, thereby reducing the probability of error.

Solution. At Faribault Energy Park, management shared fundamental procedure writing skills with plant personnel and empowered them to draft procedural checklists. Once our supervisors and technicians understood the value of these fundamental rules, they wrote more effectively which likely reduced the number of safety incidents and forced outages.

Procedure writing was distilled down to the 10 core elements identified below. An hour-long PowerPoint session was sufficient to explain them in a classroom setting. Slides included comparative examples of good and bad writing techniques. A few advanced writing skills were introduced—such as embedding pictures and graphics to aid a technician in 4-kV breaker racking operations. The value of pictures was further illustrated using an example of a store-bought item labeled "some assembly required" and reviewing how difficult the process would be without pictures.

Other more complicated aspects of procedure writing were intentionally excluded from this first phase of training to maximize retention of the core fundamentals.

Ten steps to more effective procedures

1. Generally, write one step only on each line. Human-factors studies indicate the reader is more likely to omit or miss a second step if it's started on the same line as the preceding step.
2. Use a positive action/command in each step. Avoid ambiguities, such as the word "ensure." A better word choice is "verify." Reason: The reader must confirm a desired result which may or may not require a physical action.
3. Write in a vertical format, placing each step below the previous one. If the reader's eyes must leave the procedure and return, it's more difficult to find where they left off if multiple steps are embedded in a paragraph.
4. Use "white space" to separate each step. This makes it easier on the eyes to return to the correct step in the sequence. If each step includes a sign-off line or box, it's acceptable to omit the line space between steps. The pilot's pre-flight checklist in Fig 1 is an acceptable example where no spacing is used because it has a sign-off action.

Preflight

Exterior and interior preflight	complete	C
Reset buttons	normal	C
ADIRS	NAV	C
Recorder	ON	C
Passenger signs	ON & AUTO	C
Emergency lights	ARM	C
Fire pushbuttons	IN	C
Flight and nav instruments	ckd	C & F
Altimeters	____ xckd	C & F
ECAM	DOORS, STATUS ckd	C
Landing gear	DOWN	C
Switching	NORM	C
Takeoff warning	ckd	C
Thrust levers	IDLE	C
Engine master switches	OFF	C
Parking brake	set	C
Radios, transponder, radar	ckd & set	C
Windows	closed & locked	C & F

3rd Party Report Process Checklist

VERIFY report content meets acceptance criteria specified in RFP or Purchase Order ☐
DOCUMENT each recommendation / action item as a work order ☐
VERIFY Electronic file name enables future searches to locate it ☐
DRAFT email as follows:
- NAME the email subject line to enable future searches to locate the report ☐
- DRAFT a brief message indicating noteworthy points identified in the report ☐
- ATTACH the Report ☐
- SEND to Supervisor ☐

FILE the report in designated electronic folder on the shared drive ☐

1. Preflight checklist for experienced personnel doesn't require much detail; goal is to be sure all necessary actions have been completed (left)

2. Third-party report checklist (above) assures vendor recommendations have received consideration and appropriate actions taken

5. Require a check-box or other written confirmation for critical checklists that must be performed in correct sequence—to prevent personnel injury and/or equipment damage, for example. Think about the simple requirement of installing a grounding wire or a bonding strap when connecting or disconnecting hydrogen piping to prevent sparking. Personnel may be unfamiliar with this requirement, which has been a causal factor in burns and even fatalities. A check-marked or initialed verification significantly reduces the probability of missing a safety-related step.
6. Place check-boxes to the right of the step. This forces the reader to read the text before signing off. Conversely, if you place boxes to the left, the reader is forced to read the step and then circle back to check the box—which introduces a greater risk of checking the wrong box or signing off without completing the required action.
7. Select a proper font and size. Some readers have poor vision, and field lighting conditions are almost never ideal. Inexperienced writers tend to reduce font size to fit the procedure on one page, but this defeats the purpose if the procedure is illegible. Avoid using all caps. Studies indicate sequences of upper-case letters are more difficult to read.
8. Use precautions, cautions, warnings, and notes wisely. Precautions are conditions required before starting the procedure and usually apply throughout the entire process. Example: Ambient temperature must remain greater than 40F to perform an offline water wash. Inexperienced writers will enter that precaution in the precautions section only and exclude it from the body of the procedure.

   Here's the problem with this approach: The "results oriented" operator has a tendency to skip over the precautions and jump to Step 1. In this case, the precaution also qualifies as a verification step. It's acceptable to duplicate it in multiple sections of the procedure.

   This requirement could be written three or more times: (1) as a *precaution,* because it should be known before starting offline water wash. (2) It also should trigger a *caution* statement placed immediately prior to applicable step advising that ice may damage compressor blading if temperature is less than 40F during the wash. (3) Immediately below the *caution* should be a numbered or check-off step requiring forecasted temperature to be *verified* less than 40F throughout the duration of the water wash.

   Cautions and *warnings* typically are not numbered or treated as an action step but they are "step specific" and must be placed immediately before the step to which they apply. If failure to follow a step can result in injury or death, it should be preceded with a *warning* statement. *Caution* statements are used when equipment damage may result.

   Notes are amplifying or helpful information and may be placed before or after the applicable step. If failure to follow the "note" can lead to adverse consequences, then it's probably *not* a note.
9. Decide if a written control process is needed when reviewing incidents and poor performance issues. Plant personnel are not programmed to recognize a new checklist or procedure may improve the quality of a process. Example: Faribault experienced a few incidents after failing to address recommendations in various third-party reports. Had plant personnel processed each report using a quality control process, these incidents could have been avoided.

   Third-party reports—such as borescope reports, lube-oil analysis, etc—may contain extensive recommendations dispersed throughout dozens of pages. Failure to act on recommendations can lead to undesirable outcomes, such as fines and forced outages. Fig 2 is a checklist developed by Faribault as a guide for processing third-party reports.
10. Field-validate procedures before issuing as "approved" documents. No procedure is ever 100% accurate, especially a brand new one. Test its accuracy and effectiveness in a controlled manner by assigning an experienced person to accompany the user and make corrections.

Results. Human errors have been reduced measurably using procedural checklists formatted under these basic rules. The plant is consistently started up and shutdown in an error free manner.

In another more specific example, an insurance auditor recently asked managers to produce a startup procedure for a randomly selected piece of equipment. The system expert produced the checklist which may not have been written had he not been trained. The plant owner received a discount on the annual premium following the audit based on superior O&M records—including being able to produce all requested procedures.

Participants:
Bob Burchfield, plant manager
Shawn Flake, operations manager
Ben Garrison, maintenance manager

Washington

Addition of a valve and test port facilitates hook-up of test instruments to verify proper operation of equipment

Facilitating pressure-switch troubleshooting during unit starts

Challenge. Washington County Power is a peaker plant with four 7FA simple-cycle units called to start on short notice. It's important they run safely when dispatched because of the reliability clause in the plant contract.

During very cold weather the pressure switches on the exhaust-frame blowers do not always operate correctly during startup, causing the blowers to swap to the lag motor. At times when this happens, the pressure switches on both motors will stick causing the control system logic to swap motors back and forth.

This causes the machine to unload when neither pressure switch makes. If a unit unloads, the plant does not make the megawatts it is tagged for, affecting the all-important reliability number.

The switches were installed on the exhaust-frame blower-motor frame with ⅜-in. stainless tubing connected directly to the switch. With this arrangement, technicians did not have any way to check if the switch was sensing the correct air pressure to make and hold the switch to indicate the motors were running.

The only way to check the switches was to unwire them and remove them from the equipment, which cannot be done while the equipment is running, making troubleshooting difficult.

Solution. Plant added a valve and test port to the ⅜-in. tubing which allows technicians to connect test instruments and check the pressure to the switch while the equipment is operating (photo).

Force lists were created in the Mark V control system allowing the control room operator to monitor the pressure switches and quickly force them to the correct state once it has been determined that the blower motors are working correctly.

Results. Adding the test ports has eliminated blowers shifting back and forth multiple times which improves equipment life and also has eliminated machine runbacks because of temperature issues. Stopping machine runbacks caused by exhaust-frame blower pressure switches has increased plant reliability during cold weather.

Project participants: Derek Boatright and Randy Morton

Washington County Power LLC

Owned by Southeast PowerGen, LLC

Operated by Consolidated Asset Management Services

605-MW, gas fired, four-unit, simple-cycle peaking facility located in Sandersville, Ga

Plant manager: Mike Spranger

CEMS shelter mods reduce voltage spikes, relay chatter

Challenge. The plant's CEMS shelters must be maintained at a relatively constant temperature to ensure accurate monitoring; both high- and low-temperature alarms are included in the shelter. Monthly functional testing of both alarm control circuits is required as outlined in the QA/QC procedures and the manufacturer's publications.

The shelter high-temp alarm normally is a closed contact while the low-temp alarm normally is open. Testing for the high-temp alarm requires one leg of the wiring to be lifted from the temp sensor thus creating an opening, but in so doing, grounding of the 24-Vdc control power is common.

Testing of the shelter low-temp circuit required a jumper wire to connect between the positive and negative poles of the normally open temp switch. When testing the low-temp alarm, grounding of the 24-Vdc control power also was common. Such grounding causes voltage spikes on the PLC and chattering of the alarm relays, creating unnecessary wear and tear on the equipment.

Solution. Plant personnel looked at options to find the best ways to conduct the required testing without the risk of grounding the 24-Vdc system. After meeting with the production manager, the decision was made to install switches allowing for testing without the need to lift or jump out switches in a live dc circuit.

One toggle switch was wired into each circuit to allow for testing. The shelter high-temp test switch was installed in the positive lead going to the high-temp alarm switch. To install the shelter low-temp test switch, an additional wire was landed on the shelter-temp alarm switch's positive and negative terminals and then run up to the toggle switch. Both test switches were mounted into the front panel of the CEMS control panel.

Results. Adding test switches to the CEMS control panel enables plant technicians to conduct monthly CEMS shelter temp alarm testing quickly and safely without creating voltage spikes to the PLC. Another added benefit is that there is no longer a need to use a step stool to reach the high-temp alarm wiring therefore removing a fall hazard.

Project participants: Joe Vaughn and Randy Morton

Colusa

Combined-cycle study for plant reliability

Challenge. The power industry's future suggests a continued increase in renewables generation. California mandate under the Renewable Portfolio Standard (RPS) requires 33% of total power procurement to be renewable energy by 2020.

One way to ensure a reliable power grid is to have backup, on-demand power generation. This support function will change the operating profile of combined-cycle plants, increasing the number of startups by a factor of two or three. The new paradigm in operations will increase thermal and mechanical stresses, impacting the plant's lifecycle.

Solution. PG&E solicited bids to perform comprehensive engineering analysis of critical components and operational procedures for impacts of significantly increased cycling and to provide recommendations to mitigate and/or eliminate those impacts. Work was done in two phases. The gas turbines and generators were excluded from the study because the utility has a long-term service agreement with the OEM.

Scope of the Phase 1 effort included the following:

- Baseline inspection of HRSG condition and review of O&M procedures and past issues.
- Review of DCS operating data for hot, warm, and cold starts, as well as two typical transient conditions (full load to minimum load both in 2 × 1 and 1 × 1 operation).
- Comparison of "predicted" performance based on heat-balance and performance-test results, and the "actual" performance according to DCS data.
- Close evaluation of critical areas—such as desuperheaters, steam headers, and the HP steam drums.
- Review and provide recommendations based on an analysis of historical outage/maintenance/repair/replacement reports, as well as of past commissioning/operational issues.
- Review and provide recommendations regarding pressure-part configurations; identify critical components.
- Review water-chemistry program based on responses to a pre-determined consultant survey.
- Provide an order-of-magnitude estimate of the cost for implementing recommendations suggested by the study.
- Systems and components specifically addressed during Phase 1 were:

1. Closed cooling-water system—including pumps, tanks, heat exchangers, fin-fan coolers, minimum circulation valves.
2. Condensate system—including pumps, gland-steam and steam-jet air ejector condensers.
3. Feedwater system—including boiler-feed pumps, hydraulic couplings, minimum-flow valves.
4. Raw water system—including makeup pumps and ultrafiltration system.
5. Filtered-water system—including forwarding pumps.
6. Condensate makeup-system pumps.
7. Wastewater collection system—including sump pumps and oil/water separator.
8. Filtered demin-water system—including pumps, filter modules, demineralizers.
9. Service water system.
10. Fuel gas heater.
11. Air-cooled condenser—including fans, gearboxes, motors.
12. Ammonia injection system.

Second phase of the scope covered the following:

- Finite element analysis (FEA) of critical components at specifically identified transient points.
- Development of a "life assessment tool" based on the FEA to compare repair-versus- replacement costs for operating under different scenarios.
- Surveys of control-valve suppliers to coordinate recommendations regarding equipment changes and maintenance plans to support increased cycling.

Results. The conclusions confirmed some industry-wide concerns of cycling—for example, desuperheater piping stresses are greatly increased by temperature changes during cycling. The conclusions also relieved concerns in some areas—for example, steam outlet headers see minimal temperature changes and are not significantly impacted by cycling.

The major benefit of the engineering analysis was to provide recommendations ranging from further studies to installation of additional components. The cost estimates for the recommendations served as budgetary estimates for the planning process. The recommendations and conclusions included a risk evaluation of low, moderate, or high.

Risk and budgetary estimates allowed PG&E to critically prioritize projects for a five-year plan aimed at increasing the reliability of Colusa. Key recommendations included enhancements to the following systems, as well as others: water treatment, aux steam, ACC non-condensable-gas removal, and 230-kV electrical.

Project participants:
Stephen G Royall, director of fossil and renewables
Ed Warner, senior plant manager
Jim Moen, senior plant engineer

Colusa Generating Station

Pacific Gas & Electric Co

660-MW, gas-fired, 2 × 1 combined cycle located in Maxwell, Calif

Plant manager: Ed Warner

Online transformer monitoring and dissolved-gas analysis

Challenge. Oil monitoring is key element of a transformer predictive maintenance program. Typically, this is done by analyzing oil samples monthly, quarterly, and/or annually. Purpose of an online DGA monitor is to detect and measure fault gases found in transformer insulating oil as soon as possible. The ability to detect and correct small issues minimizes the possibility of failures conducive to long outages.

Solution. Plant personnel installed Serveron TM8 online DGA monitors on all five 230-kV transformers at Colusa. The analyzers communicate via Modbus. By daisy-chaining the communications, a single communications cable is used to connect the TM8 to the plant distributed control system. This allows plant staff to monitor the transformers in real time and collect data historically.

Continuous trending and alarm management of key fault gases gives early and immediate notification of incipient faults that can lead to transformer failure. The online TM8 transformer monitor is a gas chromatograph designed to measure the fault gases H_2, O_2, CO_2, CO, methane, ethylene, ethane, and acetylene, plus nitrogen, oil temperature, ambient temperature, transformer load, and moisture-in-oil.

Results. Installation of the TM8 analyzers ensures the transformers remain safe and reliable. Any changes in the combustible gas levels are addressed promptly and all of the history is properly documented in the work management system. Early warning helps to identify internal faults.

Project participants:
Ed Warner, senior plant manager
Dave Engelman, maintenance supervisor

Startup emissions calculator

Challenge. Colusa's PSD permit specified emissions limits during startup that went beyond what was typical in the industry at the time they were issued. It identified three startup categories—cold, warm, and hot—each having emissions limits and time constraints. Compounding startup complexity was that each criteria pollutant had pound-per-hour as well as pound-per-event limits. The latter generally was the sole permit-limit standard for the industry when Colusa went through its PSD review.

The complexity of the permit requirements, along with the relatively restrictive emissions limits, created challenges during GT starts. Initially, operators put a significant focus on air emissions and on preventing an exceedance, which meant less time was available to deal with other startup-related challenges.

Experienced operators know that the sensitivity of a gas turbine during startup is impacted by specific ambient conditions, load levels, and actual startup processes. Example: Ramping the unit during the transition from startup to normal operation, can cause emissions to spike quickly, risking an excess-emissions violation.

Solution. Plant personnel developed an "emissions calculator" to assist operators during startup, allowing them to focus more attention on plant systems. The control/monitoring tool set up to track NO_x and CO emissions uses an existing board screen through the DCS which controls and monitors ammonia injection for NO_x control in the HRSGs. The tool works in the following manner:

- When a startup is initiated, the emissions calculator illuminates the startup category and its permit limits.
- The calculator monitors the time in startup, time remaining in the startup period, and emissions—including the cumulative lb/hr and lb/event totals for NO_x and CO, as well as the current emissions rates based on data being fed to the DCS from the CEMS data acquisition and handling system. Important to note is that the only one GT is allowed to start at any time. Cold starts are limited to 270 minutes, warm starts 180 minutes, and hot starts 90 minutes. Shutdowns must be completed in 30 minutes.
- The rate limit of time remaining also is available to tell the CRO the highest emissions rate he or she can operate at and still be in compliance at the end of the hour or event.
- Projected NO_x is calculated as well to predict for the operator the emissions expected at the end of the event based on the emissions accumulated to that point in the monitored time period and the current emissions rate.
- Time-to-exceed limit tells the operator how long he or she has until the emissions limit is exceeded. This helps determine if there's time to correct the issue or shut down to avoid a violation.
- The calculator also tracks quarterly and annual cumulative emissions.

Results. The emissions calculator is a predictive tool that allows operators to make real-time decisions to avoid out-of-compliance conditions. There have been no exceedances to date.

Project participants:
Charles Price, environmental compliance manager
Stephen G Royall, director of fossil and renewables
Ed Warner, senior plant manager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Newington

Evap-cooler pump relocation facilitates maintenance

Newington Energy LLC

Essential Power LLC

525-MW, dual-fuel, 2 × 1 combined cycle located in Newington, NH

Plant manager: Thomas Fallon

Challenge. Essential Power Newington started commercial operation in 2002 as a base-load plant. Since 2008 the facility has cycled, typically averaging around 200 starts annually—until recently. Fuel-availability challenges in northern New England significantly reduced the number of plant starts in 2013-2014.

The two 7FA.03 gas turbines were supplied with evaporative coolers, used seasonally when ambient temperature is above 60F and the units are operating at base load. The evap-cooler module for each GT is equipped with two 200-gpm centrifugal pumps and both must operate for the evap-cooler to meet expectations; there is no spare pump.

Traditionally, the evap coolers are commissioned in the spring when overnight ambient temperatures are consistently above 40F. When temperatures drop in the fall, they are decommissioned and drained to prevent freeze damage.

A couple of years ago, an additional semi-annual preventive maintenance procedure was established to remove each evap-cooler pump and motor from the module during the winter to complete a shop inspection and rebuild.

The modular design of the inlet filter house and evap-cooler did not provide easy access for preventive or corrective maintenance. The evap-cooler pumps were installed in a structural steel frame beneath the walkways for each unit. In addition, the modules are located on the roof of the turbine hall which is only accessible to personnel by fixed ladders or manlift.

Solution. Site personnel worked with a local mechanical contractor to design and build a new evap-cooler pump support frame to make the pumps and motors more accessible. It was fabricated, galvanized, and attached to existing inlet filter-house structural steel (Fig 1). Plant personnel also installed new quick-disconnect plugs for the 480-V power source to facilitate removal of the pumps.

1. Original location of evap-cooler pumps is shown at left, new location at right

Results. The evap-cooler system modifications were performed in 1Q/2014. The new installation better supports the site's semi-annual PM program for the pumps. The new location provides improved ergonomic access while also reducing the time needed for mechanics to remove and install a pump. The new 480-V quick disconnect frees up valuable I&C resources and eliminates the need to bump rotate the pumps each time they are reinstalled.

Project participants:
Chad Harrison, maintenance manager
Ted Karabinas, maintenance mechanic
Pat Torra, I&C technician

Liquid fuel recommissioning

Challenge. New England's reliance on natural gas has been an increasing challenge over the past several years and has experienced greater scrutiny because of recent nuclear and conventional steam-plant retirements in the ISO-NE market. Prior to 2014, the price of oil and energy pushed Newington plant's oil capacity out of the market, which drove the site to semi-retire its liquid fuel system after winter 2010. Natural-gas price volatility in early 2013 and a "Winter Reliability" program instituted by ISO-NE for the winter of 2013-2014 justified recommissioning fuel-oil capability.

Solution. The oil system is comprised of the following major components:

1. Fuel storage and transfer. The site inventories up to 1-million gallons of ultra-low-sulfur diesel fuel. The onsite storage tank is directly connected via a 1.5-mile underground monitored pipe to a local oil terminal. Recommissioning included a complete checkout of transfer equipment, transfer protection devices, and control scheme, as well as tank inspection/repair and relining.
2. Fuel forwarding system includes three pumps, several hundred feet of above-ground insulated pipe, a fuel meter, a pressure control valve, and two electric heaters for each gas turbine. Recommissioning included fuel forward component checkouts, pipe integrity inspection including

insulation and coating repairs, heat-trace integrity testing, heater testing, and a complete system flush.

3. Fuel flow control and atomizing air. Each GT's liquid-fuel atomizing-air compartment consists of a positive-displacement fuel pump, corrosion-resistant fuel flow divider, integral stop and control-valve assemblies with hydraulic actuation, duplex fuel filter, and an atomizing-air compressor with control piping and valves. Recommissioning included an oil flush and upgrades to a corrosion-resistant flow divider and a duplex-strainer changeover valve with access improvements.
4. Liquid fuel, water injection, and gas purge systems. Each dual-fuel GT has 46 purge valves (12 gas, 17 water, and 17 liquid fuel). Recommissioning included upgrading control-air supply fittings from rigid tubing to a flex design, replacement of purge-valve actuators, setting up a purge stroking protocol, and creating purge screens for the Mark VIe control system.
5. 7FA.03 combustion hardware—including check valves for liquid fuel and water injection and false-start drain system. Combustion hardware includes liquid-fuel and water-injection check valves (14 each, one each per can), end-cover fuel cartridges, and upper-half liquid-fuel check valve cooling sleeve system. Recommissioning included a flush, end-cover inspection/checkouts, purge-air piping inspection/cleaning, false-start drain valve replacements/checkouts and cooling-system operation checkout/integrity.
6. Water-injection control system. Each GT has an off-base water-injection skid—including a variable-speed injection pump, duplex water filter, a water-actuated stop valve and associated water-injection metering equipment. Recommissioning included replacement of the water-actuated stop valve, calibration and testing of redundant flow instrumentation, and system flush.
7. Water storage, including city water makeup and demineralized water transfer. Newington has a 5-million-gal city-water storage tank for processing demin water onsite. Tank makeup flow rate depended on incoming water pressure from the city of Portsmouth and reliability of supply during fuel-oil operation was called into question; system modifications were made to assure adequate supply for fuel-oil operation.

During full-load operation on distillate, each GT consumes approximately 250 gpm of fuel and a similar volume of demin water to reduce machine NO_x. The site was designed with two anion exchange demin trains, each capable of approximately 120-150 gpm. This wasn't enough demin water to sustain liquid-fuel operation for an extended period.

In 2004, the plant installed a mobile DI system capable of producing 300-350 gpm of demin water, enough to support liquid-fuel operation. In 2014, the entire system was upgraded to support more frequent operation on oil (Fig 2).

2. Storage building for two DI trailers was built in 2004

Results. Recommissioning of Newington's liquid-fuel and demin-water systems was extremely time consuming and expensive. However, the plant now has a reliable dual-fuel unit in a region where fuel diversity is in demand.

Engagement by the entire plant staff throughout the recommissioning process contributed to success. Each gas turbine is tested on liquid fuel biweekly to ensure operational reliability. During the testing, typically just prior to plant shutdown, plant personnel verify proper operation of (1) liquid-fuel check valves, (2) adequate air removal from the fuel piping, (3) absence of fuel leaks in the turbine compartment, and (4) proper control by the Mark VIe control system. When offline, purge valves can be tested easily via Mark VIe screens when oil operation is anticipated.

In the 2013-2014 winter season, Newington transitioned fuels approximately 125 times and operated approximately 900 hours on liquid fuel, consuming over 10-million gal of ULSD. During the "Polar Vortex" in January 2014, the plant ran on liquid fuel around the clock for five consecutive days—a first for this site.

Project participants: Entire Newington plant staff

Smart drains eliminate potential for piping damage

Challenge. Newington's heat-recovery steam generators were designed with reheaters to improve overall combined-cycle efficiency. By design, cold reheat steam (CRH) flows from the HP steam-turbine exhaust to the HRSGs where it combines with superheated IP steam, as well as HP-superheater bypass flow during startup and shutdown, and flows through two reheater heat-transfer sections. The resulting hot reheat steam (HRH) then flows to the IP section of the steam turbine to generate additional power.

The original CRH steam piping incorporated two methods for removing collected condensate. The first two CRH locations off the steam turbine relied on "smart drains." This installation includes a drip leg for collecting condensate, a thermowell and temperature sensing device, a temperature transmitter, and an air-operated metal-seated ball valve with feedback position switches to remove condensate from the dripleg.

The balance-of-plant DCS controls operation of each smart drain's temperature control valve. At plant startup, the temperature control valves remain open until steam-turbine output reaches 20 MW. At that point, the valve control function changes to maintain 45 deg F of superheat in each individual CRH header dripleg. At three other CRH locations, steam traps were used to remove condensate from CRH driplegs (Fig 3).

During a cold start in mid-2013, a water-hammer event occurred in one CRH header. While no serious damage was inflicted on the piping or equipment from the event, plant staff recognized it as a significant near-miss incident that could have resulted in equipment damage and potential injury to plant personnel.

An incident investigation revealed the root cause as a steam-trap failure at the CRH dripleg intended to protect a 62-ft vertical run of piping to the reheater inlet. This was the first such incident experienced at Newington.

Solution. CRH driplegs are critical to safe operation of the facility. The "smart drain" design has proven itself to be a solid, reliable solution for removing condensate from driplegs

3. Steam trap arrangement used in Newington's cold-reheat piping

4. Insertion-type thermowells in SA106B carbon-steel piping rely on an Inconel weld filler

5. Smart drain valves replaced steam traps in the cold-reheat system

in the HP, HRH, and CRH steam systems. Thus the plant decided to retrofit this design on the three CRH drip legs equipped with steam traps.

Site staff worked with an engineering firm to review the weld design for insertion type thermowells currently in CRH steam service (Fig 4). The application involved a full-penetration weld for the SA-240, Type-410 stainless steel thermowell in the SA106B carbon-steel piping using an Inconel weld filler. A weld procedure and qualification process was completed as part of the QA/QC package by the piping contractor.

Nondestructive examination of the weld root pass was completed, along with visual examination of both sides of the weld. A borescope was used to visually inspect the backside of the root pass. The installation required post-weld stress relief and NDE was completed once the system had properly cooled.

For the condensate-removal temperature control valve, the plant selected a 2-in., 600-lb ValvTechnologies Inc socket-weld standard-bore metal-seated ball valve equipped with a Max-Air Technology spring return actuator and limit switches from Moniteur Devices Inc (Fig 5).

DCS logic was adapted from the other CRH system smart-drain installations by a plant I&C technician. Valve status and temperature indication was added to the DCS operator interface graphic for each of the three installations, with the data saved in the site's PI historian.

Results. The valve installation was completed during the October 2014 planned outage. The new smart-drain valves have performed as designed in several cold, warm, and hot starts. While the new valves negligibly increase plant heat rate during startup, the benefits far outweigh this additional cost. The smart-drain valves provide the following long-term benefits:

1. Eliminate the potential for excess condensate collection in CRH system driplegs thereby reducing the likelihood of a water hammer event.
2. New instrumentation provides continuous condition monitoring in CRH system driplegs—information previously unavailable to operators.
3. Eliminate maintenance costs associated with replacing failed steam traps.

Project participants:
Eric Pigman, plant engineer
Scott Courtois, I&C technician
Gerald Murchison, I&C technician

Replacement of station battery, plus ventilation upgrade

Challenge. The original plant design included a valve-regulated lead-acid (VRLA) station battery string to supply critical loads on the 125-Vdc/120Vac plant system. The inherent short lifespans and premature failures of VRLA batteries, plus requirements set forth in IEEE 450-2010, dictated load tests every two years.

Newington implemented a complete "in kind" cell replacement in April 2009 when load tests indicated significant signs of capacity deterioration. Testing following the retrofit revealed similar deterioration rates for the new battery string; the plant opted to abandon VRLA technology in 2013.

Solution. The site started the process in February 2014 by engaging an engineering firm to assist with battery sizing, bid specifications, and storage-room code compliance review for converting to a traditional flooded lead-calcium battery system. Equipment bids were received by late June and C&D Technologies Inc's LCR-31 product was selected.

Also purchased: Two-tier seismic storage racks for use in UBC Zone-2B locations according to requirements set forth in the site's design basis; Enviro-Guard spill containment system with neutralization/absorbent pillows; two ventilation fans with duct-pressure switch; Sensidyne H_2 monitors; and dual-channel controller to enable operator notifications via the DCS.

The ventilation ductwork, fans, fan controller, duct pressure switch, and redundant H_2 monitors/controller were installed as an additional upgrade not required by code for this installation but installed as a best practice. Ventilation fan controls and feedback are integrated to the DCS along with continuous H_2 concentration feedback to the DCS via a 4-20 mA loop.

Results. The new battery string was installed during planned shutdown in October by a local contractor; a complete acceptance load test was conducted after initial equalize charge was completed. All results were acceptable with a rated capacity of greater than 100%, according to OEM and IEEE 450-2010 guidelines. Ventilation fans and ductwork had a full air balance to comply with the National Environmental Balancing Bureau.

While the new battery string increases plant reliability and safety, the true long-term benefits are these:

1. Eliminate the potential for premature cell failures and loss of battery power because of failed cells not identified until load is applied. The expected life of traditional flooded lead-calcium acid batteries is approximately 20 years which far exceeds the nominal five-year life experienced with VRLA technology.
2. New positive ventilation system for the battery storage area provides a slightly negative draft in the room to mitigate any hydrogen accumulation. With the redundant hydrogen gas sensors installed and wired to provide feedback to DCS for operator awareness, this is a significant safety enhancement.
3. Eliminate costs associated with testing VRLA batteries every two years; tests of the new system are conducted at five-year intervals.

Project participants:
Chad Harrison, maintenance manager
Gerald Murchison, I&C technician
Scott Courtois, I&C technician

AMP Fremont Energy Center

Owned by American Municipal Power

Operated by NAES Corp

700-MW, gas-fired, 2 × 1 combined cycle located in Fremont, Ohio

Plant manager: Royd Warren

Electric distribution equipment identification improvements

Challenge. After the dust settles following commissioning of a new generating facility, plant employees often find drawings that are hard to read, short on information and/or lacking clarity. At COD in January 2012, Fremont Energy Center, a 2 × 1 501FD2 facility, found itself with an accurate, but cumbersome, set of one-line diagrams.

In addition, site personnel had experienced challenges matching individual pieces of equipment with the specific electrical sources feeding them. This had the potential of leading to mistakes while performing lock-out/tag-out (LOTO) evolutions.

Plant management wanted to ensure that all LOTO exercises were performed on the correct equipment, in every instance, knowing there was a large number of redundant pumps, fans, and valves at the site. A solution was sought both to improve the clarity of electrical drawings and to better label motor control center (MCC) and low-voltage panelboard line-ups.

Solution. To address the challenge, staff embarked on a project to create a set of MCC and panelboard drawings that more clearly identified what auxiliary loads were fed from which line-ups, specified in which cubicle each load's breaker or starter was located and present all this information in an easy-to-read format.

The project expanded from just creating new drawings to adding color-coded labeling to the MCC and panelboard line-ups and listing which upstream circuit breakers each line-up was fed from. Finally, it was decided to build a searchable, master spreadsheet that would list all of the site's electrical loads in an easy-to-find format.

2. Color-coded labeling adopted for MCCs

During summer 2014, a student intern was assigned to take the existing one-line diagrams and build equipment layout drawings. These drawings presented a visual representation of the physical layout of the MCC or panelboard. Each drawing listed the MCC/panelboard's name and number, where it was fed from, the name and number of each load, and the cubicle location (Fig 1).

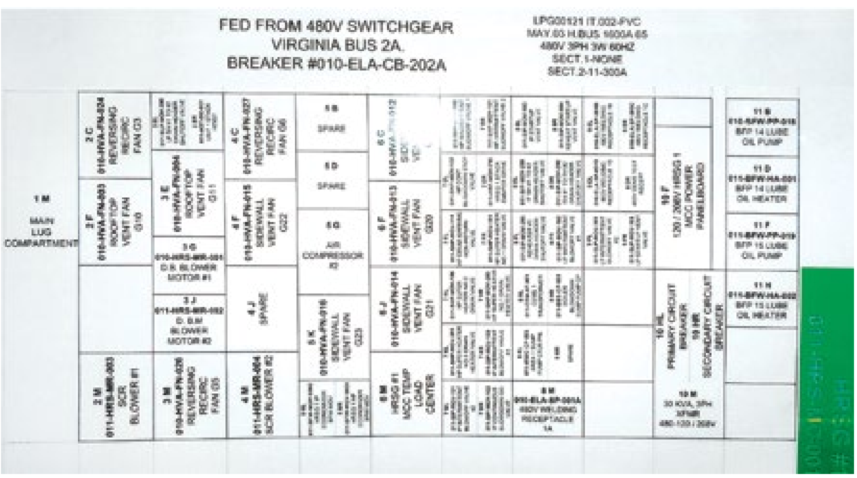
A second set of drawings was created taking the information found on the layout drawings and placing them in a list format. The intern worked closely with the plant engineer and an IC&E technician to ensure accuracy between the drawings and the field equipment.

For each MCC, a copy of its drawing was placed on a blank door for easy reference to anyone looking for the location of a breaker or motor starter. Copies of all the drawings were made available for reference by site employees.

After the drawings were completed, plant personnel printed larger, easy-to-read labels for each MCC and panelboard. These labels identified the MCC/panelboard name and number, location of the upstream feeder breaker, and each breaker or starter's cubicle number.

The labels used on each MCC/panelboard were color-coded, with matching colors on their respective drawings. In addition, matching color labels were placed on the upstream breakers feeding each MCC/panelboard (Fig 2).

Through the labeling process, it was decided to create a sortable list of all site electrical loads that would indicate the location of their electrical feeds. The list was built to show each piece of equipment, its equipment ID number, the MCC from which it's fed, and the MCC cubicle where the feeder breaker/starter resides. Since the list was created in MS Excel, plant personnel now have the ability to filter or sort by any of the parameters to quickly find the location of the equipment's electrical isolation device (Fig 3).



1. Typical layout drawing developed for an MCC

Results. Since completion of the drawings and installation of the upgraded

Fremont Energy Center MCC Load-Location List

MCC #	MCC Name	MCC Location	Cubicle	Equipment Name	Equipment ID #
010-ELA-MC-004	Gen. Building Essential MCC	Main Electrical Room	9 F	120 / 208V ESSENTIAL SERVICES MCC POWER PANELBOARD	
011-HRS-MC-001	HRSG #1 MCC	North of HRSG #1	10 F	120 / 208V HRSG 1 MCC POWER PANELBOARD	
012-HRS-MC-002	HRSG #2 MCC	North of HRSG #2	9 F	120 / 208V HRSG 2 MCC POWER PANELBOARD	
011-HRS-MC-001	HRSG #1 MCC	North of HRSG #1	10 M	30 KVA, 3PH XFMR 480-120 / 208V	010-BFW-PP-018
012-HRS-MC-002	HRSG #2 MCC	North of HRSG #2	9 M	30 KVA, 3PH XFMR 480-120 / 208V	
010-ELA-MC-004	Gen. Building Essential MCC	Main Electrical Room	9 M	45 KVA, 3PH XFMR 480 – 120 / 208V	
011-HRS-MC-001	HRSG #1 MCC	North of HRSG #1	9 DR	480V CEMS TEST RECEPTACLE	011-SLP-MOV-101
011-HRS-MC-001	HRSG #1 MCC	North of HRSG #1	8 M	480V WELDING RECEPTACLE 1A	010-ELA-SP-001B
011-HRS-MC-001	HRSG #1 MCC	North of HRSG #1	9 BL	480V WELDING RECEPTACLE 1B	010-ELA-SP-001C
011-HRS-MC-001	HRSG #1 MCC	North of HRSG #1	9 BR	480V WELDING RECEPTACLE 1C	010-ELA-SP-001D
011-HRS-MC-001	HRSG #1 MCC	North of HRSG #1	9 DL	480V WELDING RECEPTACLE 1D	
[illegible]	[illegible]	[illegible]	[illegible]	480V WELDIN[illegible]	[illegible]

3. MCC load-location list enables faster, error-free preparation of LOTOs

equipment labeling, feedback from site employees has been positive. They have noted the following:

- The LOTO process has been streamlined. Operators have been able to use the new drawings to more quickly populate LOTO permits and to create standardized LOTO forms.
- The new labeling on the MCCs and panelboards, along with drawings posted on the doors, has reduced the time taken to find electrical feeds when hanging locks for LOTO operations.
- Color coding of the different MCCs has helped reduce potential errors when identifying loads on redundant MCCs—for example, HRSG 1 versus HRSG 2, GT1 versus GT2.
- During the most recent planned outage, dozens of LOTO evolutions occurred. The upgraded identification system helped site staff to quickly and accurately perform preparation and execution activities for the LOTOs.

Project participants: Ed Malone, George Danko, Caitlin Malone

Fire system upgrades enhance GT reliability

Challenge. Modern gas-turbine systems require highly dependable fire-protection equipment to ensure personnel safety, meet NFPA standards, reduce insurance costs, and maintain high reliability. Typically, fire protection equipment includes heat detectors, FM200 extinguishing systems, CO_2 systems, dry chemical systems (usually in the exhaust-bearing tunnel), and combustible-gas detectors.

At Fremont, the combustible-gas detectors operated erratically during commissioning and had a negative impact on unit reliability. There are eight combustible-gas detectors in each of the 501FD2 packages. They were wired in series; if any detector sensed a combustible-gas concentration above 25% of the Lower Explosive Limit (LEL), the fire system would alarm to alert the operator.

If any detector sensed an LEL of 60% or more, the fire system would trip both the GT and the fuel-gas feeds to the package. While this appeared to be a dependable arrangement, several issues existed with the design, including these:

- The catalytic combustion-gas detectors installed tend to drift over time and should be recalibrated every six months.
- Because the eight detectors are spaced around the package to detect gas, they are not easily accessible to determine the extent any one of them may have drifted since the last recalibration.
- Any electronic component can have problems (processor failure, grounding issues, and/or lose wires).
- The design had all eight digital 24-Vdc signals connected in series. This led to making quick identification of the actuated, and sometimes faulty, sensor more time-consuming.
- Site personnel found that catalytic combustion sensors can be poisoned by the fumes released from a volatile sealer used to finish concrete floors.

During commissioning, multiple trips were attributed to sporadic alarm indications. The alarm would activate for a few seconds then clear, but not before tripping a GT. The sporadic nature of the trips made it difficult to determine which sensor had faulted—an, intolerable situation.

Solution. One option considered was to replace all detectors on the two GTs with new infrared sensing units. However, this option was rejected because of cost and lead-time considerations. Management decided to run all eight sensors on each GT to a new PLC panel after converting the digital 24-Vdc signals to analog 4-20-mA signals. The detectors were capable of this change and the only modification required was to pull new signal wires to the eight detectors.

Once the signals were changed, they could be displayed on the HMI panel, which then provided quantitative measurements of the combustible-gas levels in each section of the package. This feature alone has assisted operators in determining the source of small leaks that occur periodically.

Results. With signals going to a PLC panel, it is easy to log any transient event. Plant personnel eventually identified two combustible-gas sensors with microprocessor issues which had caused erroneous trip indications. The electronics were replaced and there have been no such indications since.

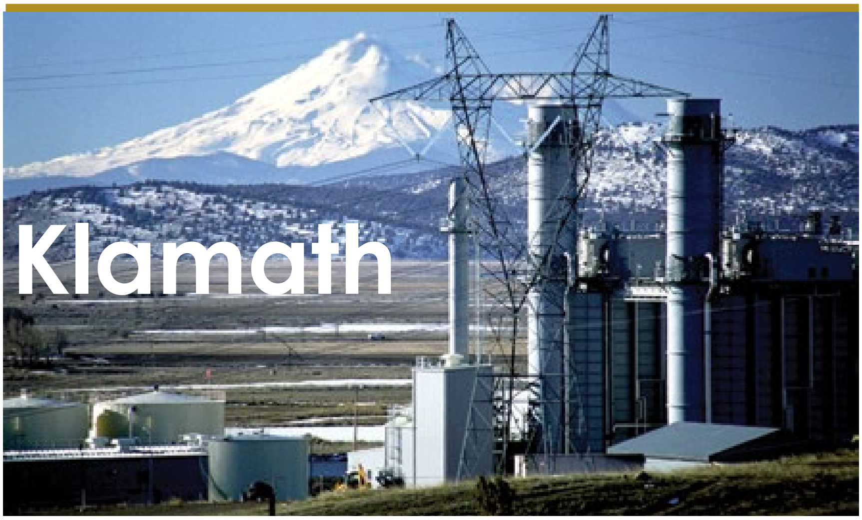
In addition, the enhanced PLC controls permitted design changes to increase reliability. The system was improved to alarm locally at the new PLC panel, at the enclosure fire panel, and in the control room if any sensor detects 25% of the LEL limit; at 60%, alarms sound again to alert the operators.

Additional logic incorporated in the upgrade prevents the units from tripping until two of the sensors exceed the 60% LEL limit. This change eliminated the false trips and allowed personnel to locate the malfunctioning combustion sensors. Typically, the sensors indicate values from 0% to 2% LEL as they drift between calibrations that are performed during every planned outage (approximately every six months).

The system has experienced no issues to date and has responded as expected to two actual high-gas-level events in the packages since the upgrade. Both cases were the result of minor gas leaks found following unit overhauls. In each instance, the systems tripped the GTs quickly and allowed personnel to determine where the gas leaks originated.

The bottom line: This small, inexpensive change has greatly improved GT reliability.

Project participant: Ed Malone



HRSG access improvement

Klamath Generation Peakers/Klamath Cogeneration Plant

Iberdrola Renewables

Site consists of a 100-MW, gas-fired, four-unit, simple-cycle peaking plant and a 500-MW, gas-fired, 2 x 1 combined-cycle cogeneration plant located in Klamath Falls, Ore

Plant manager: Ray Martens

Challenge. Klamath regularly experiences failures inside the HRSG transition duct between the gas-turbine exhaust and the first set of superheater tubes. The diffuser panel (baffle wall), expansion joint, walls, and floor all require regular maintenance. To support this work, scaffolding, welding equipment, insulation, and personnel had to transit through a small 18- × 24-in. opening (Fig 1). This slowed down repairs, limited the size of materials, and contributed to the possibility of back and/or other injuries.

Solution. The solution was a simple: Install a larger door, but that idea proved a difficult challenge. Staff engaged several HRSG and duct manufacturers and could not find one that had completed a project like the one it was considering; however, one vendor was willing to work with plant personnel to find a solution.

There were many things to consider, including the following: how large to make the door, how to insulate it, how to attach it, how to install and remove

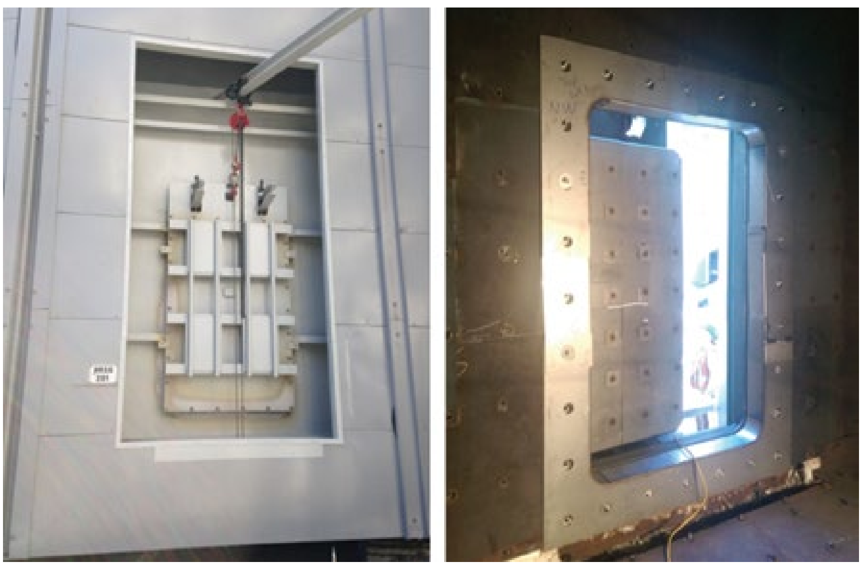
1. The original HRSG access door was not conducive to quick entry/exit

it. Obviously, at about 600 lb, it is too heavy for workers to remove by hand so a trolley system was installed to carry the weight. Jack bolts were installed to pull the door out of the hole and guide rails on the top ensure that the door comes out straight, minimizing the possibility of damage to the mounting studs.

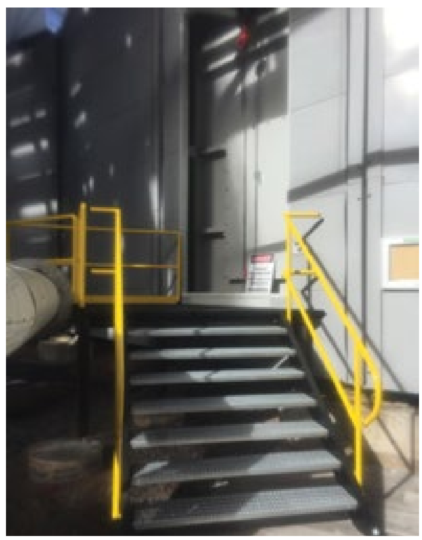
The door is approximately 1-ft thick, including interior insulation and protective steel. Its weight causes the door to tilt forward when hanging from the removal chain fall. So a large counterweight had to be installed on the exterior to allow the door to hang straight (Fig 2). The trolley rail is angled to allow the door to be stored to the side of the opening, permitting unobstructed movement of workers and equipment.

Klamath has a noise restriction, mandating a sound panel system around the transition duct. This panel required modification to accommodate the larger opening. Additionally, the gap between the panel and the door opening had to be covered to eliminate a fall hazard (Fig 3).

The new doors arrived toward the end of the outage window because of manufacturing delays caused by the complexity of door construction. This allowed the plant only enough time to install



2. The new door required a trolley system for removal/replacement (left); door interior is at the right



3. Generous access was provided at the door entry along with a temporary blank panel to muffle noise

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one door; a blank panel was mounted on the other HRSG. The second door will be installed during the next outage.

Results. Instead of crawling through an 18- × 24-in. hole on hands and knees, personnel can comfortably walk through the new 48- ×78-in. door. The platform installed outside the door is large enough to accommodate an entire rack of scaffolding gear; the door is large enough to allow for a full sheet of steel. The handrails are removable and the stairs are wide enough that two workers can carry heavy materials side by side. Given the amount of work routinely done in this area, better access will reduce both the risk of injury and the cost of labor.

Project participants:
Ray Martens, plant manager
Tim Kelly, EH&S engineer
Greg Dolezal, maintenance manager
Bruce Willard, operations and engineering manager

Dedicated emergency phone line enhances safety

Challenge. When numerous contractors were onsite, the plant had no sure way for individuals to notify the control room in the event of an emergency. The facility had a limited number of two-way radios and would routinely issue them to the supervisor of the individual contracting groups. This would require a worker to find his supervisor to contact the control room and report an emergency. In the event of a serious emergency, site management believed the time to complete this effort was excessive and had to be reduced.

Solution. The plant safety committee reviewed several options—including purchasing more two-way radios and installing emergency phone booths. The radios proved too expensive and accountability too difficult as the facility may have as many as 150 contract personnel onsite during a large outage. The remote phone booths were an acceptable option but they also were too expensive.

In today's world, almost everyone carries a cell phone. The committee decided Klamath would install a special communications line and connect it to a dedicated phone in the control room. This phone was located on the opposite side of the control desk, away from the other phones—its ring an obvious indicator of a problem. Operators are trained to drop whatever they are doing and respond to an incoming call on this line.

Contractor indoctrination training now includes instruction on how this program works. At the completion of the training, each worker receives a hardhat sticker and business card with the emergency number. They are also encouraged to program the number directly into their phone at that time. Additionally, signs with the number have been posted throughout the plant for easy reference.

Results. This was a simple remedy for a lingering problem. Using the dedicated line, a worker can call in an emergency from the top of the cooling tower or inside the HRSG without the need to find his supervisor. Although Klamath has not experienced a major emergency, the program has received a warm welcome from our contractors. The additional expense of another phone line is minuscule compared to the reduced response time in the event of a real emergency.

Project participants:
Ray Martens, plant manager
Tim Kelly, EH&S engineer
Greg Dolezal, maintenance manager
Bruce Willard, operations and engineering manager

Monroe

Switchyard cable trench repairs

Monroe Power, LLC

Owned by Southeast PowerGen, LLC

Operated by Consolidated Asset Management Services

380-MW, gas-fired, two-unit simple cycle located in Monroe, Ga

Plant manager: Mike Spranger

Challenge. The 230-kV switchyard at Monroe uses trench boxes to route low-voltage cables to various yard components for control and feedback. The trench covers were designed as walkways and are used by technicians to perform daily logs, check transformer bushing levels and winding temps, etc.

A technician was walking down the trench covers while completing a set of daily logs when a cover gave way causing him to fall in the trench. The cover had slid off, causing the right side of the box to collapse inward from lack of support. The tech hit his shin on the next cover in line resulting in a severe laceration

The trenches consist of approximately 100 separate 4-ft-long boxes. Over the years, the soil surrounding the boxes compacted and pushed in the sides of the boxes, causing the lids to shift out of position. Fig 1 shows the lip on the bottom of the lid no longer fit securely inside the box causing the lid to shift to the side.

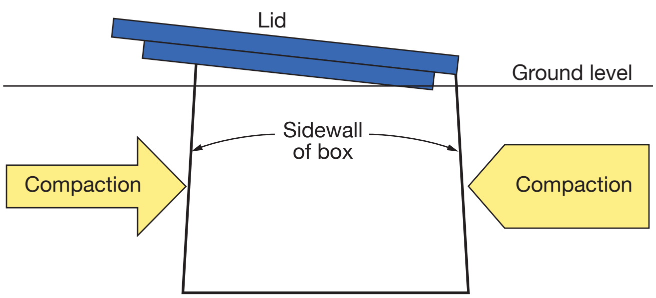
Further inspections of the trench revealed five of the boxes were broken beyond repair and needed replacement. As for the rest of the boxes, their sides had been pushed together about 3 in. on average, causing the improper cover fit-up.

Another problem with the Monroe trench boxes: Concrete lids are heavy and could have caused damage to the cables if they fell in. The worst-case scenario, other than personal injury: A broken wire or a short could have tripped the yard, interrupting power supply to the grid.

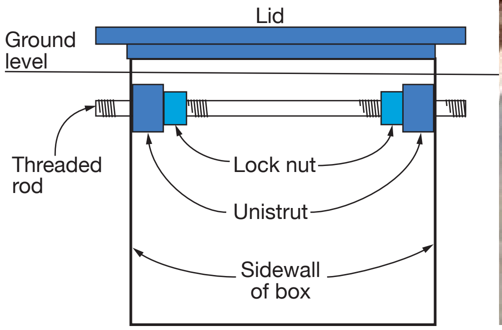
Solution. Plant personnel concluded the boxes had to be spread back to their original positions and locked down in a way to prevent future accidents or cable damage. They brainstormed and came up with several ideas to accomplish this goal.

- The first was to frame-up the inside of the boxes using wood. Although this was a cost-effective method, it would not be a long-term solution because of the potential for rot and decay.
- The second was to attach Unistrut bases to the sides of the boxes and put a piece of Unistrut between them. This met the long-term solution requirement, but it was not cost-effective.
- The third idea, and the one selected, was to use Unistrut and threaded rod to build a spreader that could be left in place but easily removed if necessary.

First step was to dig alongside the trenches to allow the sides of the boxes to be spread apart. Holes then were drilled in the sides of each box so the threaded rod could pass through, preventing the support from falling to the bottom of the trench. A 4-in. piece of Unistrut was installed on the threaded rod along with jam nuts to prevent loosening of the support. Two spreader bars were installed in



1. Trench-box cross section before repair is at left, actual movement of trench-box lids is evident at center, effects of compaction on trench-box side walls are shown at right



2. Trench-box cross section after repair is at left, repaired trench box is in center, completed job at right shows level trench-box lids each box. If for some reason the cover did slide over, it would rest on the support and not fall in. The project was designed and completed by plant technicians for $1,536.

Results. Five of the boxes were replaced because they had been severely damaged; the remaining boxes were restored to their original shape ensuring this accident would not happen again. Modification benefits include: (1) straighter, more-even walking surfaces to reduce trip hazards, (2) lids are unable to fall inside the boxes, thereby preventing personnel injury and or cable damage, and (3) ease of support removal, if necessary.

Project participants: Charles Gibson, Wes McMillan, Michael Gilbert, Christopher Harris

Automate water injection for emissions control

Challenge. Water injection is used on Monroe's two 501F gas turbines for NO_x control. The original WDPF control system relied on an f(x) function block to adjust injection flow based on unit output. This approach did not take into account ambient conditions, or bias based on actual NO_x values.

The control system was upgraded in 2009 to Emerson Process Management's Ovation™ and the process was carried forward as designed in the WDPF system. The operations staff corrected for major changes in ambient temperature (for example, summer to winter) by entering a new f(x) value in the control logic and then during a normal operating day made minor adjustments when the NO_x values were not at the desired value.

With the system in place, an out-of-range value could be added into the f(x) function block and cause large swings in the water-injection rate. A possible outcome if this occurred: A significant load swing, perhaps even loss of flame and unit trip.

This method of operation took a great deal of hands-on time, requiring an extra person in the control room to monitor and maintain balance-of-plant operations.

Solution. New logic was written and installed to control water flow based on load and NO_x level. To adjust for ambient changes from day-to-day and season-to-season, logic also was added to allow the CRO to trim water injection and stay within a specified band, thereby preventing over- and underspray. The new logic also includes a manual function to give the CRO direct control of flow, if necessary.

Results. The new logic allows a single CRO to adjust NO_x water in three ways without the need to go into the logic and adjust the f(x) function block. This prevents the possibility of an inadvertent automatic trip of the turbine during operation, conserves water, and extends the life of combustion hardware.

The new logic also eliminates the need for an additional operator in the control room while units are in operation to adjust water injection during ambient changes. The automatic control reduces instantaneous NO_x excursions caused by changes in load as well as total emissions.

Project participants: Wes McMillian, Charles Gibson, Christopher Harris, Scott Hobbs

CCGT / HRSG Chemistry Experts
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+ New Project Specifications
+ FAC Management
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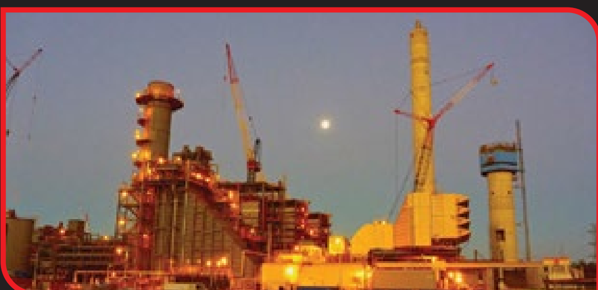
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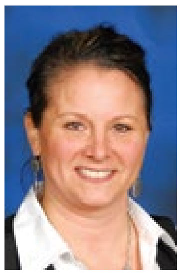
Amy Sieben opens her own shop to serve HRSG users
A registered professional engineer with more than 25 years of boiler-related and power-industry experience, Amy Sieben, PE, launches ALS Consulting LLC.

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604-MW, gas-fired, 2 x 1 combined cycle located in Hobbs, NM

Plant manager: Roger Schnabel

Lube system improvement for BFP motor driver

Challenge. Lea was designed with two 100% boiler-feed pumps for each power block. The four 2750-hp motor drivers were supplied with split sleeve bearings and oil bath/oil ring self-lubricating oil systems that had a tendency to operate at elevated temperatures during summer, contributing to higher-than-expected journal-bearing wear. Frequent bearing replacement was a result.

Self-contained oil reservoir/cooler/pump skid reduced wear and tear on motor bearings

Solution. Plant personnel worked with a local motor shop to install a self-contained oil reservoir/cooler/pump skid to provide cooler lube oil to each motor bearing (foreground in photo). The self-contained oil skids each have a 20-gal oil sump; cooling is by way of a motor-driven fan and finned-radiator type of heat exchanger.

Results. Motor-bearing summer operating temperatures dropped by approximately 20 deg F, reducing both wear and maintenance, and pump downtime. The new oil coolers also eliminate the need for external misters during summer operation, saving both water and time.

Project participants: Kevin Mendenhall and Richard Shaw

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Hawk Road

Hawk Road Energy Facility

Oglethorpe Power Corp

487-MW, gas-fired, three-unit simple cycle located near Franklin, Ga

Plant manager: Tracy Robinson

Gas-turbine instrument-ring retrofit

Challenge. Critical gas-turbine (GT) instrument wiring, as provided by the OEM, was snaked through a makeshift system of conduit and fittings (Fig 1 left) which did not provide adequate support and protection for the wiring. Premature failure of equipment and inadvertent GT trips were a result. Also, during major maintenance activities requiring wiring removal, the original design proved labor-intensive; plus it increased the possibility of wire damage.

Solution. Plant personnel redesigned and replaced the original system with one that provides adequate support and protection of critical GT instrument wiring (Fig 1 right).

Results. The plant has realized a dramatic reduction in thermocouple and equipment failures since installing the new wiring system. Unit trips associated with the original design have been eliminated. Other benefits include shorter outages and cost reduction—the latter because the new system saves more than 40 man-hours spent previously each time instrumentation and wiring had to be removed in support of outage activities.

Project participants: GT technicians Robert Robinson, Randy Cole, Greg Peeples, Jason Merrill, Mike Lambert, Trent Meadows

GT exhaust-door redesign

Challenge. GT exhaust-stack access originally was provided via a bolt-on hatch which poses a significant personnel safety risk during removal and installation because of its excessive weight and awkward lifting position (Fig 2 left). Access to the

1. Plant personnel redesigned and replaced the original instrument wiring system (left) with one that provides more robust support and protection (right)

2. Replacing bolt-on access hatch (left) with pivoting door at right dramatically reduced the risk of injury to maintenance personnel

exhaust stack is necessary to perform routine and emergent maintenance activities.

Solution. Plant personnel brainstormed ideas and decided on a redesign and replacement of the existing bolt-on exhaust-stack access hatch with a pivoting stainless-steel door that does not require removal or lifting by personnel (Fig 2 right).

Results. Results have included dramatic reduction in personnel injury risk during door removal. An additional benefit obtained was a reduction in door removal man-hours from four to only 15 minutes for one unit. The project leveraged across the fleet has realized 100 man-hours saved annually.

Project participants: GT technicians Robert Robinson, Randy Cole, Greg Peeples, Jason Merrill, Mike Lambert, Trent Meadows

Best Practices Award gets smiles from Tracy Robinson (plant manager), Trent Meadows (GT tech), Mike Lambert (GT tech), Leisa Guilledge (staff assistant), Jason Merrill (GT tech), Greg Peeples (GT tech), and seated Robert Robinson (GT tech)

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◆ **An exhibition** that brings together nearly 200 providers of products and services for LM aero engine operating plants. Learn about new offerings, get product updates, evaluate in-service experience.

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Upgrade activity brisk where benefits are predictable

There certainly wasn't much "news" for owner and operators of gas-turbine assets (simple- and/or combined-cycle) at the 2015 Power-Gen International event, held December 7-10 in Las Vegas, outside of that provided by GE Power. Other major players in the GT sector were in attendance, as evidenced by logos visible high above the show floor, but little information of value to users was shared via the **CCJ** editorial team.

GE's program for industry editors was an informal roundtable with Gas Power Systems President & CEO Joe Mastrangelo (the OEM's new organizational structure is explained in the following article) and Chief Technology Officer Steve Hartman. It was in sharp contrast to the tightly choreographed press conferences of yesteryear and far more productive. Some highlights from the exchange involving North American projects:

- Enhanced Steam Path (ESP) upgrades on two D11 steam turbines are scheduled for early 2016. The first, at Entergy Rhode Island State Energy LP's plant in Johnson, has the potential for increasing the site's average revenue by more than $4 million annually over the next five years while eliminating ST vibration issues. The upgrade at Elk Hills Power LLC, Tupman, Calif, is expected to add about 3 MW of output, increase efficiency by 1%, and eliminate shaft vibration. **CCJ** will keep you informed on both these projects as they move forward.
- Exelon announces plans to upgrade its West Medway Generating Station near Boston with the addition of two dual-fuel LMS100PA+ simple-cycle units. The nominal 200-MW project includes new plant controls.
- Exelon and GE also announce an agreement to implement the OEM's Predix-powered suite of enterprise software technology in support of several pilot programs aimed at delivering significant customer benefits.
- Caithness Energy LLC and Moxie Energy LLC jointly develop the first plant using GE's high-efficiency 7HA.02 gas turbines in Luzerne County, Pa. The Caithness Moxie Freedom Project will produce 1029 MW with two single-shaft combined cycles; commercial operation is expected in 2018.
- Xcel Energy's Black Dog Power Plant specifies a 7FA.05 gas turbine to replace the plant's existing coal-fired boiler in 2018. Black Dog represents the 65th order for the 7FA.05.
- Iberdrola Generacion SA de CV orders 6F.01 gas turbines for two cogeneration projects in Mexico (Altamira, Tamaulipas state, and San Juan del Rio, Queretaro state). Commercial operation is expected in 2017. Contract includes long-term services agreements for both plants.
- Dynegy Inc orders eight sets of Advanced Gas Path (AGP) upgrades and OpFlex*Peak Fire software for the 7FA.03 gas turbines at the company's Hanging Rock and Washington energy facilities in Ohio and the Fayette Energy Facility in Pennsylvania. Significant improvements in reliability and output (total of 210 MW) are expected.

Done deal: GE completes its acquisition of Alstom's power, grid businesses

When GE announced its intention to buy Alstom more than a year and a half ago it was unlikely many, if any, industry veterans doubted the industrial behemoth would not seal the deal, which finally happened Nov 2, 2015. The process stretched out as competitors, unions, government agencies in 20 countries and regions, and others jockeyed to be heard and to influence the proceedings.

Interestingly, after daily blow-by-blow coverage in the *Wall Street Journal* and other business papers during critical weeks of the negotiations, the public blather all but ceased a couple of days after the ink dried on the agreement. Integration of the two companies is well underway; it could take years to achieve the goals Jeff Immelt, GE's chairman and CEO, had in mind when the deal was struck.

However, the restructuring is behind the curtain. The GE owner/operators of generation assets knew before the acquisition is the same company today. The OEM's representatives stressed this to their customers at user-group meetings in fall 2015; it's business as usual going forward.

Some facts of interest to power generators that may have been missed in the hailstorm of press releases:

- GE Power & Water and Alstom Power have been combined to form GE Power, headquartered in Schenectady. The 65,000-person organization, headed by President/CEO Steve Bolze, has a presence in more than 150 countries and estimated annual revenue of $30 billion. Recall that GE Power was headquartered in Schenectady before moving to Atlanta and later changing its name to GE Power & Water. Everything old is new again.
- GE Power is divided into these six business units:
  Gas Power Systems, headquartered in Schenectady and led by Joe Mastrangelo.
  Power Services, Baden (Switzerland), Paul McElhinney.
  Steam Power Systems, Baden, Andreas Lusch.
  Distributed Power, Jenbach (Austria), Lorraine Bolsinger.
  Water & Process Technologies, Trevose (Pa), Heiner Markhoff.
  GE Hitachi Nuclear Energy, Wilmington (NC), Jay Wileman.
- The Distributed Power business unit focuses on distributed-power and CHP applications involving Waukesha and Jenbacher engines. Prior to the Alstom acquisition, this unit also had responsibility for GE's LM engine product lines which the editors have been told are now are part of the Gas Power Systems portfolio.
- Ansaldo Energia reported it had signed a binding agreement with GE to acquire certain Alstom assets as directed by regulatory authorities in the European Union and US. Most significant among these acquisitions for power generators served by **CCJ** is PSM. Important: As part of the agreement, Ansaldo would license to GE, PSM's intellectual property for Siemens and Mitsubishi gas turbines, and also for those portions of Alstom's heavy-duty gas business being retained by GE. This deal, according to Ansaldo, is expected to close early in 2016 following receipt of required regulatory approvals.

MHPS recent announcements

- Iberdrola SA orders two M501J gas turbines and one steam turbine for the 850-MW Noreste combined-cycle plant that the Spanish firm is building for Mexico's CFE in Escobedo, Nuevo Leon. COD is expected in July 2018.
- More than five-dozen industry

leaders representing electric utilities, IPPs, developers, investment bankers, and lenders tour MHPS's Savanah Machinery works to celebrate the start of production on the first J-series turbine to be manufactured in the US. The unit is slated for installation at Grand River Dam Authority's Grand River Energy Center in Oklahoma; COD is planned for 2Q/2017. Seven more M501Js are expected to roll off the SMW assembly line in the next year. The OEM says the M501J is the world's most efficient (more than 61% in a combined-cycle arrangement) and reliable gas turbine; 17 of these engines already are in service at six powerplants worldwide.

- Virginia Electric & Power Co orders three M501J gas turbines and one steam turbine for its 1600-MW, 3 × 1 Greensville County Power Station, pending regulatory approval of the project. Project completion is planned for yearend 2018.
- The two-shaft H-80, a 100-MW-class engine, is renamed the H-100 to more accurately reflected its rated capacity. Other engines in the product line are the H-25 (28-42 MW) and the soon-to-be-released H-50 (nominal 50 MW). There are more than 200 H-series GTs in operation or under contract.

Siemens recent announcements

- Panda Power Funds orders the power island for its 1124-MW Hummel Station, a combined cycle slated for early-2018 operation in Snyder County, Pa. Package includes three SGT6-5000 gas turbines with air-cooled generators, one SST6-5000 steam turbine with hydrogen-cooled generator, three NEM DrumPlus heat-recovery steam generators, and SPPA-T3000 control system.
- A consortium of Spanish and Mexican companies order two SGT6-8000H gas turbines and an SST6-5000 steamer, together with a T3000 control system, for a new combined cycle in Acolman, Mexico. COD is scheduled for December 2017.
- Tim Holt is appointed CEO of the Power & Gas Services Business Unit within Siemens Power Generation Services Div, based in Orlando.

- Recently released RB211-GT30 for either 50- or 60-Hz application is optimized to accommodate the needs of oil-and-gas industry customers—offshore applications, in particular. Recall that Siemens recently purchased from Rolls-Royce the company's land-based engine portfolio.
- First 10-MW-class steam turbine operating almost entirely without lubricants successfully completes its trial run in BFP-drive service at a Vattenfall lignite-fired station in Germany's Brandenburg state. Oil-free bearings are of the air-cooled, electromagnetic type. Only valve actuators require a minimal amount of oil to ensure reliable turbine operation.
- SGT-800 gas turbine is upgraded to produce up to 53 MW at 39% efficiency in simple-cycle operation. In a 2 × 1 combined-cycle configuration, output is 150 MW at 56% efficiency with a DLN combustion system capable of holding NO_x emissions below 15 ppm.

Inspection guide for drum-level instrumentation

The 2016 edition of "Boiler Inspection Guidelines for Drum Level Instrumentation," issued by Clark-Reliance Corp, concisely presents inspection requirements for ease of reference by O&M personnel. The basis for the seemingly indestructible, spiral-bound 5.5 × 8 in. book is Section I of the *ASME Boiler & Pressure Vessel Code*. It includes requirements for water columns, water gage valves, gage glass, remote level indicators, magnetic water-level gages and water-column isolation shutoff valves.

The information is up-to-date and incorporates 2015 Code changes, and recommendations from Section 7. Additionally, the guidebook lists the most common non-compliant drum-level equipment arrangements and recommended solutions. The book is free to qualified recipients; order at www.boilerinspectionguide.com.

Industry briefs

Emerson Process Management now offers generating-plant owner/operators native machinery health-monitoring and protection capability within its Ovation™ distributed control system. Company engineers told attendees at Power-Gen International that the Ovation Machinery Health Monitor is easy to install: Just insert the module shown in the photo into a spare I/O slot. Operators receive alerts from a single set of common plant HMIs and no longer need to manually check machinery functions through a separate system (www.emersonprocess.com/OvationMachineryHealth).

AGTSI, Aeroderivative Gas Turbine Support Inc, known for its substantial inventory of parts for all models of the LM1600, LM2500, TM2500, LM5000, LM6000, and LMS100 gas turbines, announces that Miguel (Mike) Trejo has joined the company in a sales and customer-support role.

Trejo has more than 40 years of applicable experience and will have direct access to aero customers in the West from his Arizona office (sales@agtsi.com). In related news, Alan Mibab recently celebrated his 11th anniversary with AGTSI, Linda Gibson 10 years. Finally, Quality Director Rick Butler, who spent almost a decade at the company, has retired.

NV Energy. This announcement fell behind the desk and just found: Around mid-year Josh Langdon was appointed manager of maintenance for the company's Walter M Higgins Generating Station in Primm.

TEServices opens registration for its 2016 "Metallurgical Aspects of IGT Component Repair" training courses. The editors give this workshop a "two thumbs up" and recommend it to plant personnel responsible for writing hot-section repair specs and for following work through repair shops. Contact Hans van Esch (hvanesch@teservices.us) for more information.

Ludeca Inc has been recognized by the Society for Maintenance and Reliability Professionals as an approved provider of continuing education and training. Visit www.ludeca.com/training.php to register for training courses on shaft alignment and balancing.

Oil Filtration Systems LLC announces a significant expansion of its rental fleet of oil and fuel purification equipment now with more than 100 systems available for immediate mobilization (http://ofsrentalfleet.com). The company recently moved into a new and expanded manufacturing facility and announced the opening of an online store for ordering replacement filter elements (http://parts.clark-reliance.com).

ESCO Tools announces the availability of a pneumatic saw and pipe trolley system that stabilizes the saw for a perfectly square cut on pipe up to 60 in. diam of any schedule. No special operator training is required.

MISTRAS/Triple 5 Industries hand-held leak detection system, SteamPAC™, identifies and *quantifies* through-valve loss of normally closed steam valves while your plant is in operation. The ability to quantify the magnitude of the leak is vital for prioritizing maintenance activities. Instrument can store readings and wirelessly transfer them to a computer for trend analysis (http://mistrasgroup.com).

CLARCOR Industrial Air launches a new website at www.clarcorindustrialair.com that seamlessly integrates its industrial business segments on a common platform.

Olympus Scientific Solutions Americas introduces the portable, rugged, "intuitive" EPOCH 650 digital ultrasonic flaw detector (www.olympus-ims.com/EPOCH650).

Dresser-Rand, a business unit of Siemens Power & Gas, receives an order from Elizabethtown Gas for two 13,500 gpd natural-gas liquefaction systems. The portable production unit comprises four skid-mounted modules for power, compressor, process, and conditioning.

Vaisala Inc, announces shipment of its first commercial MHT (moisture/hydrogen/temperature) 410 transmitter following months of beta testing. The instrument is designed to minimize transformer-related downtime. Its ability to measure the hydrogen content of transformer oil, and the speed of its formation, allows users to detect and assess the severity of a fault situation. Monitoring of moisture is an important indicator of the condition of transformer insulation paper as well as of the oil's ability to act as an insulator.

Steam power: precisely explained, practically considered

The first edition of *Steam / its generation and use*, published in 1875, set the stage with its opening page: *The Generation of Steam, Practically Considered.* The 15-p volume introduced topics that would expand in each edition. Beyond mechanical details of steam boilers, the first edition explored steam and water circulation, combustion efficiency, heat absorption, water chemistry, and the need for cleaning and repairs. Most important at the time, it covered safety.

One hundred forty years later, Babcock & Wilcox has issued the 42nd edition, making this the longest continually published engineering text of its kind in the world. (As a point of reference, Lionel Simeon Marks first issued his prominent *Marks' Handbook for Mechanical Engineers*, now in its 12th edition, in 1916.)

Steam 42 was edited by Greg Tomei, who benefitted from a close association with Steve Stultz and Bucky Kitto, co-editors of the 40th and 41st editions, published in 1992 and 2005, respectively. Stultz continues to share his extensive knowledge of boilers and Rankine cycle equipment with the industry via the pages of **CCJ** as a consulting editor.

Steam, now at 1200 pages, has evolved into a comprehensive reference for advanced steam generation and emissions control technologies, steam fundamentals including thermodynamics and fluid mechanics, metallurgy, advanced materials science and related subjects (including welding), and is used by educators, students, engineers, and other industry professionals worldwide.

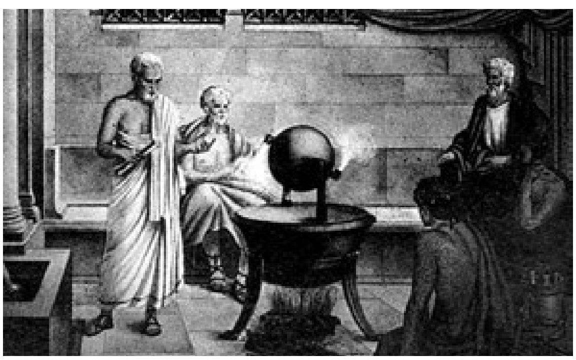
The hefty tome helps characterize the modern power generation facility, one of the most complex systems ever designed by mankind. It explains the essence of Rankine cycle performance

Steam—a historical perspective

Mists of unrecorded history veil the beginnings of man's knowledge of steam. More than 2000 years ago (150 BC), Hero of Alexandria described in his *Spiritalia seu Pneumatica* steam-using devices of men of his time and earlier.

Hero clearly described three methods for using steam as a source of power: raising water by elasticity, elevating a weight by its expansive power, and producing rotary motion by reaction on the atmosphere. The last was exemplified by "Hero's engine," or whirling aeolipile, illustrated here. It consisted of a hollow sphere supported over a cauldron (boiler) by two trunnions, one of them hollow and connecting sphere and boiler.

Steam from two right-angled projecting jet pipes spun the sphere when the cauldron was heated. Or, explained Hero, simply take a cauldron full of water, put a jet pipe on it, and heat it. The jet will turn paddlewheels or blow horns.



Hero of Alexandria proposed his idea for the aeolipile (rotary steam engine) in Spiritalia seu Pneumatica nearly 2000 years before Babcock & Wilcox Co was founded

Lacking a "commercial market," the steam boiler and engine work of Hero and colleagues were swept into the dustbin of history for more than a thousand years. It really wasn't until about the 1500s and 1600s when interest in steam power resurfaced. Thomas Newcomen's steam engine was the first true commercial product, serving to pump water from deep mines in the UK.

Then along came James Watt, Jonathan Hornblower, George Corliss, and many others dedicated to the process of continual improvement regarding boilers and steam engines. It wasn't long after that the Babcock & Wilcox Co was formed; its first boiler patent was awarded in 1867.

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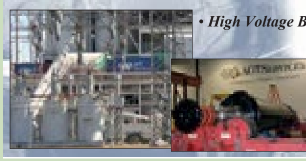

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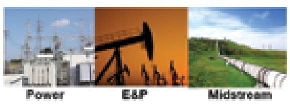

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in today's combined-cycle plants, where superheated high-pressure steam is produced in an HRSG and piped to a turbine/generator to produce electric power. And it provides industry newcomers with a way to get up to speed on the fundamentals quickly, regardless of fuel, heat source, or plant specifics.

Content

The first eight (of 53) chapters cover the fundamentals and core technologies for both design and performance. This includes the thermodynamics of steam, fluid dynamics, heat transfer, and the complexities of boiling and steam/water flow. The section ends with computational numerical analysis, materials science and structural analysis. Section II applies these fundamentals to boilers, superheaters, economizers and air heaters, and includes critical combustion calculations. Discussion of common combustion systems leads to the control of byproduct emissions. Enclosures and auxiliary equipment complete the section.

Section III covers the application of steam, spanning both large and small utility and industrial units, as well as those for small electric power, cogeneration, combined-cycle, and other specialty application—including renewables.

Up-to-date environmental protection equipment and strategies form Section IV, including new chapters on hazardous air pollutants and carbon dioxide; both combustion and post-combustion technologies are discussed. The section ends with measurement, monitoring, and reporting, and technologies for flue-gas monitoring.

Section V discusses specification, evaluation, and procurement for capital expense items, including scope, terms and conditions, and bid evaluation. Also here are the manufacturing processes, and quality control. The section ends with construction techniques, labor requirements, on-site considerations, safety issues, and post-construction testing.

Adherence to basic operating principles is the focus of Section VI, including instrumentation to monitor the key parameters of pressure, temperature, and flow. A key chapter is the in-depth look at water and steam chemistry, deposits, and corrosion. Control theory and modern integrated systems are also examined. This is followed in Section VII by details on both service and maintenance of steam generating systems, again covering the common issues of corrosion, stress, leak detection and analysis.

Although Section VII is dedicated to nuclear energy, manufacturing and life extension discussions are relevant regardless of fuel. The edition ends with two appendices and a comprehensive index. Appendix 1 offers conversion factors, SI steam properties, and useful tables. Appendix 2 is an updated discussion on codes and standards—in particular, the *ASME Boiler and Pressure Vessel Code.*

Steam 42 includes a CD; an ePDF version also is available

Publisher

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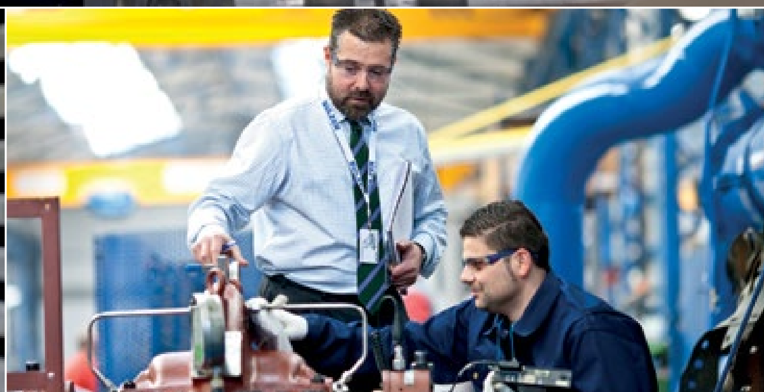

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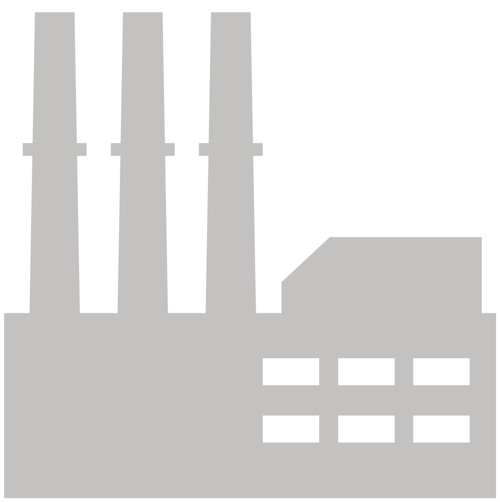

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