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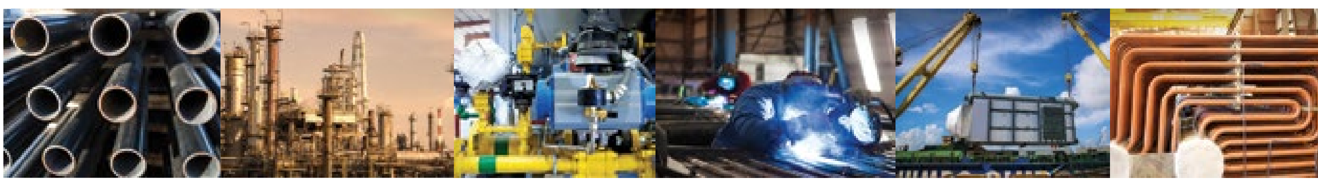

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Remembering the Alamo

The National Academy of Sciences defines academy as "a society or institution of distinguished scholars, artists, or scientists that aims to promote and maintain standards in its particular field." In January I considered this while attending the Heat Recovery Steam Generator (HRSG) Academy, alongside the historic Alamo in San Antonio.

It was not a stretch. From in-depth knowledge and design experience to inspection techniques to metallurgy and cycle chemistry, the experts at HRST Inc have crafted and refined this semi-annual three-day event (www.hrstinc.com). The HRSG Academy highlights, explains, and discusses important lessons learned by engineers, designers, and technical advisers dedicated to HRSG operation and performance.

The venue-shifting event gives site operations, maintenance, and engineering personnel up-to-date information and interaction with hands-on professionals who are willing to share specifics about their experience. Below is just one of the many cycling-related concerns discussed at the January 2016 event.

Cycling and fatigue. Like our colleagues in Australasia (see AHUG 2015 report, p 6), many plants in the Americas and Europe are experiencing the challenges of cycling their equipment. Flexibility is the new operating mode. And for plants originally slated for base load or traditional CHP cogeneration, there are hidden consequences. Repeated cyclic stress is one.

Failure mechanisms are generally classed as mechanical, chemical, or both. For cycling operations, fatigue cracking is perhaps the most sinister and costly mechanical threat. And it has little or nothing to do with age.

Microscopic fatigue cracking occurs when material is stressed repeatedly beyond its yield point. It begins below the rated tensile strength of the material and is progressive. Perhaps most important is low-cycle fatigue, which can occur in fewer than 1000 cycles. Superheaters, reheaters, and economizers are the most likely HRSG components affected, although the mechanism can attack thick drums and nozzles as well.

Most superheater and reheater failures caused by thermal stress result from water entering some of the tubes, headers, or piping, causing large temperature differences within the materials or between adjacent tubes. Thus, temperature conflict between adjacent parts or areas is important. Fatigue cracking can occur in neighboring tubes operating at contrasting temperatures, thick walled-nozzles (in high-pressure drums) heating unevenly, and portions of a superheated steam pipe becoming wet.

An important point for inspectors is that fatigue can initiate on both the inside and outside of the surface, and these microscopic cracks become the stress.

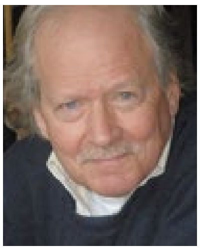
Some specifics. In economizers, fatigue cracking generally is caused by startup thermal shock (the introduction of cold water, defined as about 90F), buoyancy instability, or steaming. Thermal shock occurs when a relatively small number of tubes are cooled far below the temperature of the surrounding tubes (when feeding cold water into an economizer after a shutdown, for example).

Both buoyancy instability and steaming are common cycling issues. Buoyancy instability occurs during periods of poor circulation, especially at low-load operation. Steaming is common in economizers during warm startup when water flow is low and exhaust heat is relatively high.

For evaporators, the HP drum is at elevated risk when pressure changes too quickly. Consider the pressure/temperature gradient through a drum wall. The inside of the drum tracks the saturation temperature quickly. The outside of the drum lags as heat slowly "bleeds" through the shell. If the temperature differential gets too large, resulting stresses can start cracks at discontinuities—like large nozzles. (This is less likely in evaporator tubes because they operate at saturation temperature.)

One early indicator of temperature stress is cracking of the belly pan within the drum, an inspector's only nondestructive waterside entry point.

Consequences. The forces imposed by cycling (and two-shifting) must be understood and managed. And this goes beyond just recognizing the OEM-specified up and down ramp rates. Events like the Academy give site operations, maintenance, and engineering personnel useful information from hands-on professionals who are willing to share specifics about their experiences.



HRST reminds us that "for the most part, these failures are preventable through good maintenance and operation, along with proper instrumentation and controls." And enduring landmarks like the Alamo remind us that change is not always easy.

Steven C Stultz, Consulting Editor

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Editorial Staff

Robert G Schwieger Sr
Editor and Publisher
702-869-4739, bob@ccj-online.com

Kiyo Komoda
Creative Director

Scott G Schwieger
Director of Electronic Products
702-612-9406, scott@ccj-online.com

Patricia Irwin, PE
Steven C Stultz
Ed Sundheim
Consulting Editors

Clark G Schwieger
Special Projects Manager

Business Staff*

Susie Carahalios
Advertising Sales Manager
susie@carahaliosmedia.com
303-697-5009

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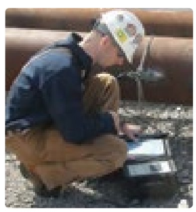

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1. Osborne Power Station, a 180-MW 1 × 1 combined cycle, was Australia's largest cogeneration plant when commissioned in 1998. Its steam host has since closed

Deep dive on HRSG and cycle chemistry make this meeting special

Steven C Stultz, Consulting Editor

Owner/operators attending the Fifth Annual Meeting of the Australasian HRSG Users Group (AHUG) held in Sydney, New South Wales, Dec 8-10, 2015, reported experiencing many of the same problems facing gas-turbine users the world over—some exacerbated by the relatively small size of the electric-generation industry in Australia/New Zealand.

In evidence this year was an underlying concern brought on by the "the export value of gas." Many plants no longer operate as designed. As operations changed, so did the demands on equipment, systems, chemistry, and plant personnel. New risks appeared. But new lessons learned were brought here, and discussed energetically.

Below is a summary report on the event, including discussion points and selected participant questions and comments.

AHUG participants don't hold back. They can't. Interaction is encouraged and vigorous. Each discussion quickly becomes a dynamic blend of tested knowledge and creative ideas, and in the words of David Addison, a member of the steering committee, "The only bad question is the one you don't ask! If you show up with a question you'll get it answered, or you'll be a lot further down the path of getting an answer."

The 2015 event included specifics on plant operations, maintenance, cycle chemistry, and storage. It featured interaction among presenters, equipment specialists, and users. Final-day workshops focused on HRSG inspection planning, life assessment, and advanced alloys. Sponsors and exhibitors included ALS Power Services, Conco Systems, Duff and Macintosh, Flexim Instruments, HMA Group, IAPWS, and PowerPlant Chemistry magazine.

This year, the principal takeaway was the taxing trend toward cycling and, eventually, short- or long-term layup. That means new demands on equipment, and new demands on operators. It means new demands on cycle chemistry and monitoring, a greater need for clear policies and procedures, and the ability to manage with reduced staffing and training.

For Australasia, the driving force is gas supply, which was discussed throughout the conference. But such operational change is also a growing global concern as power generators wrestle with changes in demand and the impacts of renewables on their systems.

Fourteen presentations set the foundation and followed a general agenda from fuel impact to operations to layup to inspection strategies. Underlying all was the need for proper cycle chemistry, a need becoming more apparent to owners and operators globally.

Operation modes dictated by gas prices

In Australia, inexpensive long-term domestic gas contracts sheltered from the world stage, are gone. Colin Gwynne of Aurecon, a consulting and services firm operating globally, focused on this shift and its largely unexpected impact on daily and long-term plant operations.

Since 2013, the Eastern Australian gas market has moved from domestic power generation supply to export LNG. The driving force: International LNG prices to support gas-fired projects outside Australia. Domestic power demand also has decreased.

Therefore, local gas suppliers are reluctant to sign long-term domestic supply contracts with their traditional power customers. And even though LNG plants in the Middle East have reduced production by about 30%

since 2013, new LNG facilities are coming on line in Eastern Australia. Most are capitalizing on an abundant Australian coal-seam gas supply.

The result: Established gas-fired plants now face an uncertain future, and need to change their modes of operation. Most base-load units are moving into a progression of cycling, two-shifting, peaking, and ultimately layup and storage. Cycle chemistry must now take a lead role in these modified operations and in any short- or long-term layup activities.

As Gwynne would stress, all of this is new for many power generators. Gone are the days of historically low and stable gas prices. Australia is pioneering large-scale coal-seam gas development, exposing its power producers more to the world stage. And planning for uncertainty is the new mode for these overlooked long-term customers.

Government forecasts show increasing LNG exports through 2020, with no domestic gas-fired power generation additions until 2025. More extreme predictions include a long-term (potential) return to coal-fired generation—the traditional Australian power bedrock. Although this seems unlikely, nothing is certain.

Thus layup and system chemistry were significant topics at this fifth meeting of the user group, which began with three case studies that follow.

1. **Osborne Cogen.** Commissioned for cogeneration service at the end of 1998, ATCO/Origin Energy Ltd's Osborne Power Station, located near Adelaide, South Australia, had been in 180-MW baseload operation (120 MW of gas turbine power, 60 MW of steam) until recently (Fig 1).

   Chemistry had been optimized towards the recommended IAPWS (International Association for the Properties of Water and Steam) program consistent with its operating profile. But recently Osborne has gone through a further change to more flexible operation and more startups. This has required even more chemistry changes. Current plans call for dehumidifiers and a nitrogen generator for layup and storage. A gas bypass stack also is being considered for long-term flexibility.
2. **Tallawarra Power Station.** Designed for cycling, EnergyAustralia's Tallawarra station in New South Wales (260 MW gas, 160 MW steam), commissioned in January 2009, has experienced blowdown and carryover issues. The three-pressure HRSG has been operating on trisodium phosphate (TSP) treatment; feedwater is AVT(O), all-volatile treatment with a few parts-per-million (ppm) of oxygen present.

   The unit has experienced low dissolved oxygen and high iron transport. Although some of these issues have been resolved, Tallawarra also is facing an uncertain future.

   A new operating philosophy is being considered. Modifications include nitrogen capping of the feedwater tank for wet layup, degassed cation conductivity to improve steam-turbine startup, and water-treatment plant modifications to permit continuous reliable operation when HRSG demand is zero.
3. **Darling Downs.** Originally designed for baseload (3 × 120 MW gas, 270 MW steam with bypass stacks), Origin Energy's Darling Downs Power Station in Queensland had many operating issues after commissioning in July 2010. These included LP drum feedforward stripping ammonia and oxygen from the HP drum, poor-quality recycled blowdown condensate (corrosion products), and superheater exfoliation. Air-cooled-condenser corrosion control was difficult because of high pH (about 10).

   Plant operation is now two-shifting, with one or two GTs taken out of service. Layup and storage systems are under review. Considerations include nitrogen capping, dehumidified air, chemical dosing before layup, and drainage system changes. Operators predict more steam/water-cycle corrosion and know that more shutdowns will provoke more exfoliation.

The three case studies showed, to varying degrees, the impact of modified operations. Comments and discussions on correct oxygen levels followed, including specific drum-level control experiences and the need for proper testing (IAPWS). This set the stage for the presentations that followed.

Maintenance for long-term storage

Stanwell's 375-MW Swanbank E Power Station in Queensland (Fig 2) had the largest gas turbine in Australia (Alstom GT26) when commissioned in 2002. It set a world record (unofficial) of 254.8 days of continuous operation.

But the station was removed from service in December 2014 and is not scheduled to return until 2017. In a public statement, Stanwell explained: "Analysis of the electricity and gas trading markets concluded that greater value could be achieved from Stanwell's gas entitlements by selling the gas rather than using it to generate electricity."

A comprehensive cold-storage and preservation program for all systems began; site labor was reduced to a caretaker team. Ongoing lessons learned, covered in detail by Stanwell's John Blake, could be helpful to other owners and operators.

To prepare for storage, a full baseline inspection documented component and system conditions. Major storage

2. Stanwell's Swanbank E claims a world record for its gas turbine's 255-day continuous run

3. Long-term layup of Swanbank's HRSGs relies on dehumidifiers for the water/steam circuit and gas path

4. Otahuhu's at-risk P22 headers were replaced with ones made of P91

risks predicted are outlined below.

1. Pitting and general corrosion:
   - Steam/water side—HRSG, steam turbine, piping.
   - Gas side—gas turbine and HRSG hot gas path.
   - Under-lagging corrosion—steam, gas, and feedwater lines.
2. Corrosion fatigue:
   - Steam/water side—HRSG and steam turbine.
3. Acid dew-point corrosion:
   - HRSG gas side.

This storage process began with Australia's AS3788, "Pressure Equipment: In-service Inspection" and Clause 4.6, preservation-plan requirements and return-to-service procedures.

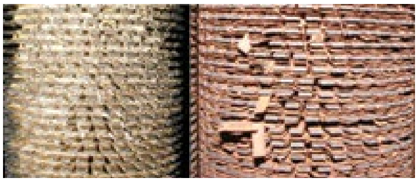
Blake outlined specific steps taken and lessons learned for both inspecting and preparing the HRSG and its associated steam/water and gas path, gas turbine, steam turbine, and generator. Balance of plant discussions included gas yard, plant air, control systems, and pumps.

Relative-humidity monitoring details also were given, showing equipment and locations (with ongoing lessons-learned updates). Cold storage monitoring trends were then presented for all major equipment.

Blake stressed vigilance to every detail, such as valve tagging to identify those modified for air circulation. He listed areas easily overlooked, such as draining the flash box on the side of the condenser.

Perhaps most beneficial were the cold-storage lessons learned:

1. New equipment is needed (dehumidifiers, for example). This should include critical spares (Fig 3).
2. Plant staff must understand the impact of every change (for example, valve position) made during layup.
3. The entire process (including changes) must be clearly recorded and traceable.
4. "Don't just set and forget." Staff should always look for improvements. This means reviewing all ongoing strategies, not just the original plan.
5. Ongoing strategy reviews should include all site personnel.



5. Long layup for repairs contributed to fouling of finned tubes—salt deposits at left, rust at right

During comments and discussions, Barry Dooley, Structural Integrity Associates Inc and chairman of the AHUG steering committee, stressed the LP turbine as a critical risk location for any lay-up beyond three days. Dooley also cited continuing IAPWS work on film-forming amines for protection, a topic that would be discussed again later in the meeting.

Sampling strategies for cycling plants

If you can't measure a process, you can't control it. And although good sampling systems are critical for any plant, they become more critical during flexible operation. This was the summary message from John Powalisz of Sentry Equipment Corp. His presentation focused on sampling techniques to protect assets, maintain output, predict failure, and prepare systems for startup and potential layup.

Steam and water sampling were covered first. As EPRI tells it in Report CS-5164, "Fossil Plant Cycle Chemistry Instrumentation and Control—State-of-Knowledge Assessment," "The primary objective of any sampling system is to transport and condition a sample without altering the characteristics of interest. The system parameters which need to be controlled are velocity, pressure, and temperature."

If the integrated steam and water sampling system fails to control flow, pressure, or temperature (secondary cooling); if it fails to give consistent online flows during startup or low load (night shift); or if it doesn't help mitigate high iron transport during startup or load changes, impacts will be negative. In general, if flow is too high (startup), system components could be stressed and some readings might be inconsistent. If too low, data errors and air ingress are common.

Powalisz emphasized the most controllable areas: procedures, training, and technology. These become even more critical when cycling. The question: What is the best approach for each particular plant?

Attention turned to a series of manual-panel best practices requiring no capital investment. For example:

- Monitor blowdown samples containing high levels of particulates for safety issues.
- At startup, establish sample flow at minimum level to feed analyzers.
- Close valved rotameters as soon as possible after a shutdown/cycle off to hold liquid in the flow cells and to keep probes wet.
- Set VREL® valves (high-pressure sample flow-control valves) to the fully closed position during shutdown.

Simple low-cost upgrades can also improve sampling consistency:

- Increase the size of primary sample coolers to allow more "forgiveness" (for improper settings).
- If missing, add total flow indicators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so that total sample flows can be set properly.

- Use preset combination back-pressure regulator/relief valves to improve flow consistency to analyzers and eliminate lost flow through pressure-relief valves/lines.
- Add ability to valve-in flush water to keep probes wet during shutdowns.
- Add a degassed cation-conductivity panel to discern air from contamination during low-load operation.
- Add a large-surface-area high-pressure magnetic trap or similar device to capture magnetite as far upstream as possible in lines with high particulate counts.

Alternative and supplemental-action discussions followed. The presentation then concluded with these recommendations:

- To address insufficient staff, automate critical sample points.
- To improve instrument reliability for limited staff, consider outsourcing instrument maintenance.
- To address high iron transport/plugging, add a high-pressure magnetite trap or put in place automated blowdown practices—or do both.

Good sample conditioning systems should increase safety for both personnel and instruments, provide rep-

6. Origin's Darling Downs personnel found valve damage caused by cycling

7. Stop-valve stem damage was attributed to plastic deformation, erosion, and/or corrosion

8. Bypass-valve disc-stack damage occurred on all three units at Darling Downs resentative samples to the analyzers, be easy to set up and use, be intuitive, and have low maintenance costs.

Available standards and guidance documents were then listed for ASTM, ASME, EPRI, IAPWS, and VGB.

The bottom line was this: You might not be able to control operational modes or numbers of employees, but you can control procedures, training, and choice of technology.

Significant maintenance events

Inspection of Otahuhu B's triple-pressure HRSG revealed safety issues outside the casing; reliability issues inside. The Siemens single-shaft combined cycle, powered by a V94.3A gas turbine, had a complex history, with several consultants and engineering contractors onsite since its commissioning in 2000.

Steering Committee Member Mark Utley of Contact Energy Ltd (CEL), owner/operator of the Auckland (New Zealand) facility explained that the as-supplied HRSG was of paramount concern. CEL assumed responsibility for the boiler soon after installation to address non-compliant welds and long-term risks. Operations were acceptable until 2008; further boiler defects and lingering construction faults surfaced at that time.

The first major tube failure was in 2008, specifically creep damage where a T91 superheater tube was connected to a P22 header. CEL replaced all at-risk headers with P91 (Fig 4). That same year, the owner called for EPRI chemistry benchmarking and launched a significant steam-cycle chemistry upgrade. Gas-turbine firing temperature was increased to recover lost capacity and HRSG safety valves were resized.

Before this outage, the plant had half of Structural Integrity's 19 recommended cycle-chemistry instruments. This was brought to 100% by 2009. Benchmarking improved from "average" to "above average."

But for the next four operating years, disturbing HRSG events and findings continued. These included faulty welds and cracks in lugs supporting headers, among others. A long layup for repairs caused fin and tube fouling (Fig 5) and backpressure limitations on the gas turbine attributed to gas-side corrosion. There was corrosion under insulation as well. The plant entered permanent shutdown in 2015.

Specific HRSG defects were shown to meeting participants—including the lack of penetration on tube-to-header welds, tube-to-header misalignments, and general poor weld quality. Acceptance criteria also were clearly defined.

The primary Otahuhu message: Challenging risks can be managed over time with an active and flexible approach. A wait-and-see attitude will not work. This put emphasis on Steering Committee Member John Blake's "Don't just set and forget" caution earlier in the day.

Steam valve damage

Operational changes also can lead to hardware issues deep inside system components. At Darling Downs, explained Origin's Pieter Wessels, valve damage seems to have occurred in the first 60 seconds of operation below the saturation line, with water going through the valve. The 630-MW power station (Fig 6) in Queensland was commissioned in 2010 with three GE Frame 9E turbines, three HRSGs, a 270-MW GE steamer, and an air-cooled condenser.

First inspection of the main steam valve was in May 2014, five months before the first steam-turbine minor. The unit's two main-steam stop valves, configured as combined stop and control valves with a common seat, were arranged in parallel. The inspection revealed damage to both stop-valve stems. Important to note is that Darling Downs had converted to cycling operation.

Stem damage (Fig 7) was attributed to plastic deformation, erosion, and/or corrosion.

HP-bypass DRAG® valves were inspected in October 2014. Inconel 718 disk stacks had significant damage on all units (Fig 8).

Repairs and actions were both short- and long-term.

For the stop valves, both stems were replaced and the plant increased its stock level from one stem to two. Operational actions included daily on-load valve-gear testing. Control-valve throttling was avoided by increasing minimum station load by approximately 10 MW and by continuous monitoring.

For the long term, control-valve throttling avoidance continued. Additional inspections at 12,000 to 15,000 hours determined the need to install a modified seat and install a modified control-valve head assembly.

For the bypass valves, short-term repair included turning all disc stacks 90 degrees, purchase of replacement disc stacks, and a review of HRSG startup procedures. For the longer term, stacks would be replaced at 12,000 to 15,000 operating hours and a design change would enhance HRSG superheater manual drainage. This would improve blowdown at shutdown (removing magnetite) and improve drainage at startup (removing water).

Phased-array inspection of complex components

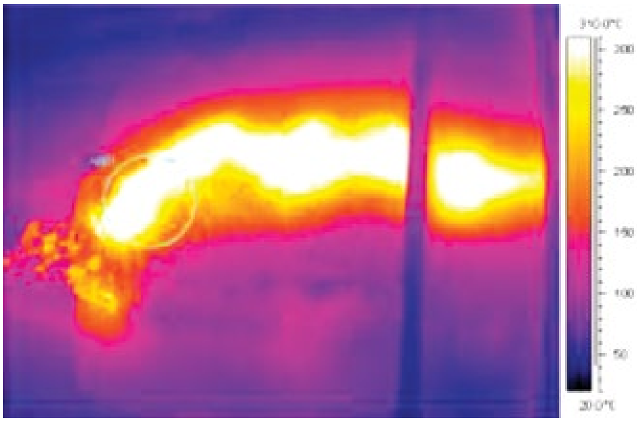
Chris Charlesworth, ALS Australia, offered insights into ultrasonic inspection techniques for complex shapes, such as root serrations of turbine blades. The phased-array inspection of complex components, he explained, can be enhanced through validation reports, procedure development, and other methods based on CAD models. The speaker said parametric CAD models speed up the inspection development (and approval) process.

Samples with known defects also can be developed to test the methodologies and tools. Rapid prototyping was beneficial in the examples described.

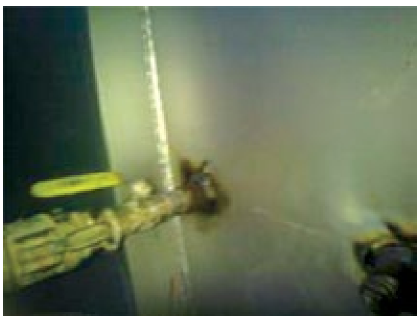
Time span for development, from scope definition to final inspection launch, can be as little as two to three weeks. Dooley suggested that linking this inspection technique with site chemistry would help to understand the root cause of the defect.

Expansion joints also must adjust to change

Consistent with other presentations, expansion joints are affected by a change in operations. For gas-turbine outlet fabric joints, as an example, cycling can increase thermal stress and cause cracks, hotspots, and fabric failure.



9. Thermal surveys quickly pinpoint hot spots caused by insulation failure or movement



10. Pumped insulation can be removed and injection ports reused

Dekomte's Jon Terrant addressed fabric expansion-joint technology for HRSG inlets and outlets, penetration seals, air intakes, and gas-turbine exhaust applications. These joints, the speaker said, reduce gas leakage, air ingress, and a host of related short- and long-term concerns.

Two-shifting and cycling have perhaps the largest destructive impact on expansion joints and require review of equipment in these new modes of operation. Results can include duct-temperature gradients, duct fatigue and stress caused by these gradients, irregular stresses caused by movement, and both acid and water dew-point condensation.

In just one example, the inlet joint on a hot casing will be impacted by inside dimension, gas velocity and pressure, axial and lateral movement, thermal transients, stress, and cycles (normal starts). Short-term solutions could include weld repairs to frame and duct, regular replacement of fabric, and external insulation. Long-term solutions are more complex:

- New steel part arrangement.
- Improved duct interface.
- New external insulation.
- New fabric and bolster design.
- New fixing and convector design.

Material options were also given, particularly for HRSG outlets. These included double-coated PTFE fabric, a single layer of EPDM/Viton, and multi-layer joints with a Viton gasket sealing the flange. Related component designs were then reviewed.

Penetration seals attracted strong attention, along with the pros and cons of both OEM and retrofit designs. The most common OEM offerings are metal bellows, packed gland seals, mechanical seals, and fabric seals. Retrofits include metal bellows, mechanical seals, and fabric.

This session ended with an interesting discussion on pumpable insulation. This is a viable fix when thermal surveys reveal casing hotspots (Fig 9). The cause normally is movement or decay of internal insulation materials.

Pumpable insulation can be injected online and monitored through thermal imaging as it spreads. This is a low-risk option to insulation replacement. The selected material, Isofrax®, has low thermal conductivity, good strength and vibration resistance, and can withstand temperatures up to 2300F. The material can be removed, and injection ports (Fig 10) can be reused.

Chemistry to support flexible operation

Flexible plant operation impacts HRSG chemistry. New Zealand-based David Addison, principal, Thermal Chemistry, began Day Two with optimized cycle chemistry, stating: "If baseload HRSG (cycle) chemistry is not optimized, it will never be optimized for flexible operation." The theme of operational change would continue from Day One, so Addison set clear definitions:

Base load

- Almost always online, steady load, high load factor.

- Infrequent starts, mainly cold starts.

Two-shifting/cycling

- Frequent stops and starts.
- Large load changes (load following) during operation.

Flexible/fast start

- Plants able to have accelerated hot, warm, and cold starts.
- Used with both once-through and drum-type HRSGs.
- Appropriate for two-shifting/cycling operation.

As discussed on Day One, flexibility is critical in today's power generation market. This includes the new world of fossil generation impacted by solar and wind generation, and in Australasia geothermal to some degree.

Addison further set the stage for cycle chemistry's challenges:

Startup chemistry

- Sampling and analysis systems must produce a quality sample within the flows and pressures required.
- Dosing systems must establish control and set points.
- Blowdown and water demand will strain the water treatment plant.
- Risk of condenser tube leaks will rise with cooling-water pump starts and bypass operations.
- Availability of plant personnel will be stretched; everyone will be busy.

Large load swings

- There will be pressure and flow issues, phosphate hideout, and carryover.

A good starting point, stated Addison, is the IAPWS optimized program and readily available (and free) IAPWS Technical Guidance Documents (TGD).

Standard base parameters were then listed:

- Feedwater, AVT(O) or OT (oxygenated treatment).
- LP evaporator drum (feedforward), AVT(O) or OT.
- LP/IP/HP evaporator (once-through), OT.
- LP/IP evaporator drum (standalone), phosphate treatment (PT) or caustic treatment (CT).
- HP evaporator drum, AVT(O) or PT/CT.
- Instrumentation (refer to IAPWS TGD, available at www.iapws.org).
- Carryover testing (refer to IAPWS TGD).
- Corrosion-product sampling and analysis (refer to IAPWS TGD).

For dosing, the standard is AVT(O) or OT feedwater chemistry with no oxygen scavenger used at any time. AVT(O) should provide 5 to 10 ppb dissolved oxygen.

Feedwater pH control is critical, and the fully automatic control loop should maintain a 9.8 control point under all startup and operating conditions.

Evaporator pH control also is critical. Automatic phosphate or caustic control ensures stable evaporator pH and minimizes over- or under-dosing issues.

pH control is critical, too, for controlling single- and two-phase flow-accelerated corrosion (FAC) control and to minimize the risk of contaminates in the system.

With phosphate treatment, hideout can be a challenge, particularly above 1450 to 1520 psig. Fast starts and load changes can aggravate the situation in some HRSG designs. If using trisodium phosphate only, no corrosion issues are caused by hideout. But with mono- or di-sodium phosphate there is major acid phosphate corrosion risk. Therefore, the standard recommendation is TSP only.

Phosphate should be maintained above 0.3 ppm for minimum protection, along with proper pH for FAC protection. If there is a need to go lower (phosphate) then NaOH can be added. Sometimes, a conversion to caustic treatment (with no hideout issues) is needed. The IAPWS TGD provides clear guidance on this in Section 6.4.

11. Carryover can cause significant damage to the steam turbine

Once-through HRSGs are suited to flexible operation with AVT/OT chemistry. They do, however, require proper condensate polishing for correct feedwater quality.

Sampling and analysis. Addison then turned to sampling and analysis. Minimum instrumentation should be in line with the IAPWS TGD (2015 revision) which includes fast-start and flexible HRSG advice in Section 4.7:

- Automatic analyzer water flushing.
- Short sample lines/local sample conditions.
- Degassed conductivity (CACE) on condensate and superheated steam.

Corrosion products. It is critical to know total iron levels, a key chemistry parameter. IAPWS is currently working on more guidance for flexible operating regimes.

Carryover. Perhaps the most robust discussion centered on carryover (Fig 11). For HRSGs with drums, flexible operation leads to high carryover risk, which is conducive to superheater and steam-turbine damage. This risk increases during startups and rapid changes in load. Thus drum level control is critical and should be fully validated against saturated-steam analysis and carryover testing (in line with IAPWS TGD). Continuous online saturated-steam sampling, and CACE and sodium analysis, are strongly recommended.

In general, carryover increases with HRSG operating pressure. Simple steam-drum designs have higher carryover limits, but offer poorer steam purity. Lower drum pressures reduce the carryover risk, but risks escalate with fast starts and flexible operation.

Consistent with others, Addison stressed the importance of proper layup and storage procedures and equipment. In summary, short-term wet layup of an HRSG requires nitrogen capping; long-term wet layup requires nitrogen capping, HRSG circulation, mechanical dissolved oxygen control, and pH control. Dry storage for both the HRSG and steam turbine requires automatic dehumidification systems.

IAPWS

Seventy percent of combined-cycle plant damage can be traced to poor chemistry, which contributes to tube failures via FAC, under-deposit corrosion, corrosion fatigue, stress corrosion cracking, and pitting. Corrosion-product transport leads to deposits in HP evaporators and steam turbines, and in air-cooled condensers. Steam-turbine damage in the phase-transition zone results from pitting, stress corrosion, and corrosion-fatigue cracking. Damage also results from deposition in the HP, IP, and LP sections.

Traditional searches for cause looked at HRSG design, turbine design, and feedwater system design. But it is now apparent that other causal elements were missing. Plants can be at fault by:

- Not addressing cycle chemistry basics.
- Not installing a fundamental level of instrumentation.
- Not using the international standards of cycle chemistry.
- Not using total iron as an indicator.
- Not having an integrated management program to prevent repeat cycle-chemistry situations.

Identification of repeat cycle-chemistry situations is a powerful (yet still overlooked) tool. Dooley then reviewed plant assessments using repeat cycle-

chemistry analysis, leading to categories within these recurring situations. Tied for first position are corrosion products and instrumentation. Next was drum carryover, followed by failure to challenge the system chemistry status quo, then HP evaporator deposits.

An alarming fact: 37% of HRSGs worldwide are using reducing agents, at very high risk.

Thermal assessments

Bob Anderson, principal, Competitive Power Resources Corp, Palmetto, Fla, recognized globally for his HRSG expertise, offered a thermal-transient assessment update. Common issues included small drain pipes, blowdown vessels located above headers, and drainage control not based on condensate detection. Anderson noted that only a few plants have a robust root-cause process for failures related to thermal transients.

Many questions and discussions followed as meeting attendees wrestled with data presented by the speaker and its implications for their plants. Interesting points were made about OEM ramp rates, drum and header thicknesses, numbers of tubes, thermocouples, and other specifics, showing the complexity of thermal transients and the assessments.

High energy piping

Chris Jones of Quest Integrity Group stressed three critical stages for a proper piping analysis process: pre-outage, outage, and post-outage. Jones presented a case study of high-energy pipe weld defects with changes over time, and a fitness for service assessment using finite-element analysis.

A key modeling parameter is content: Does it include adjacent defects, or is each defect treated separately? The case presented showed how analysis helped determine fitness for service, centering on creep damage. Local repair was possible.

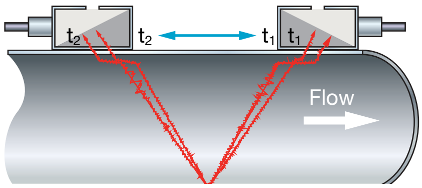
Discussions followed specific to finite-element analysis.

Australian legislation

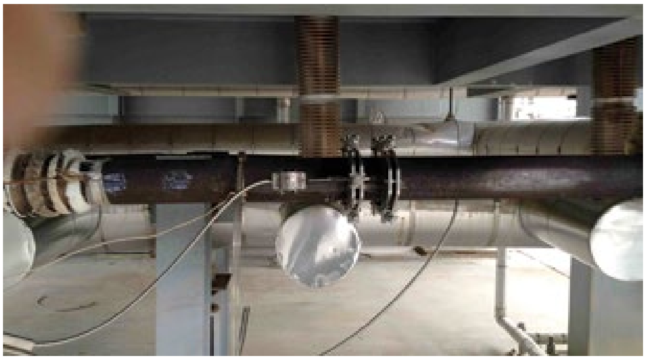
Legislative and standards updates were given for HRSG owners and operators throughout Australia and New Zealand. Pressure equipment regulations vary state by state, and a complex layer of codes is in force. Standards are being updated, reviewed, and drafted. The move to greater penetration of international standards, in some cases, is being held back by the slowdown in domestic manufacturing.

Darren Sullivan, an ALS plant inspection manager, offered the review, concentrating on pressure parts and safety management systems. For conference attendees, there seemed to be an opportunity to input directly into this process or seek clarification related to HRSGs.

Newly revised pressure equipment standards were listed for conformity assessment (AS 3920:2015), for hazard levels (AS 4343:2014), and for welding and brazing qualification (AS/NZS 3992:2015). ASME and selected international standards were also discussed.



12. Ultrasonic detection of water in drain pipe relies on transit-time technique



13. Prototype drain control system, on a superheater here, has been installed on three HRSGs to date

In summary, Sullivan encouraged attendees to participate, through the AHUG Forum, to ensure proper HRSG presence.

Control of SH/RH drains

Anderson, a member of the steering committee, then addressed the industry's ongoing issues with superheater and reheater drains and how ultrasonic flowmeters and good design and procedures can help mitigate them. Here's what he suggested:

For startups from 0 psig (simple).

- Drain pipes must be large enough (gravity head only).
- Discharge must be below point of origin.
- All drains must be open before purge to ensure the superheater is empty.
- Drains should remain open during purge.
- Drains should be closed when pipe temperature downstream of control valve exceeds Tsat + ~80 deg F for 30 seconds.
- Time is available for draining before steam flow begins.
- A limited quantity of condensate is generated at 0 psig.

Pressurized startup (complex).

- More condensate is generated.
- Very little time is allowed from gas turbine fire to initial steam flow.
- Drain flow varies greatly with pressure.
- Opening drains for long periods can result in excessive drum pressure decrease and blowdown system temperature/flow changes.
- Water detection is critical to minimize steam release during purge. Bear in mind that thermocouples cannot detect water.

Various methods for detecting water were reviewed, including an ultrasonic system using the transit-time technique (Fig 12). An EPRI prototype drain control system, installed on three HRSGs to date, was then examined (Fig 13).

Current installations cover several pipe sizes and materials plus different configurations. The Flexim Americas Corp fluid detector described in Fig 12 calculates signals to correlate the noise ratio of ultrasonic sound waves passing between transducers. DCS logic then controls the drain valves. Development and testing of this system continues.

IAPWS updates

Dooley, executive secretary of IAPWS, and Gary Joy, chairman of the Australian national committee for IAPWS, ended Day Two with an update of that organization's activities and by reminding participants of the value of its Technical Guidance Documents. Updates of greatest interest to readers were the following:

- A TGD on film-forming amines will be released in 2016 and will include specifics on their safe and effective use.
- The TGDs on instrumentation and treatment for fast-start and frequently started HRSGs, published June 2015, are being updated.
- The TGD "HRSG HP Evaporator Sampling for Internal Deposit Determination" will be published in 2016. CCJ

Unique 'flex' unit design takes on the tough California market

In the abstract, most everyone knows California is a tough place for power generators to do business. Up close, it's even tougher, as a visit to NRG Energy's 560-MW El Segundo Energy Center (Fig 1) revealed. What was also evident is how the business of generating power continues to change, with implications for how combined cycles are designed to respond to grid requirements.

In a nutshell, the value of operating flexibility continues to grow. In California, however, flexibility has to be juxtaposed to the equally important objective of avoiding every ppm of air emissions and every droplet of discharge possible.

Opportunities in the market and restrictions in emissions led NRG to a unique plant design, the Siemens' Flex Plant 10 in a two-unit 1 × 1 configuration. The cycle design (sidebar) received broad exposure in 2010 when it was selected by NRG, and again in 2013 when the plant was commissioned (August 1 of that year). Less has been reported on operating experience.

Ken Riesz, general manager, noted that the plant meets its flexibility performance requirements "with no problem." El Segundo is obligated to deliver 150 MW from each unit to the California ISO within 10 minutes, to meet (and get paid for) the requirement for "non-spin reserve."

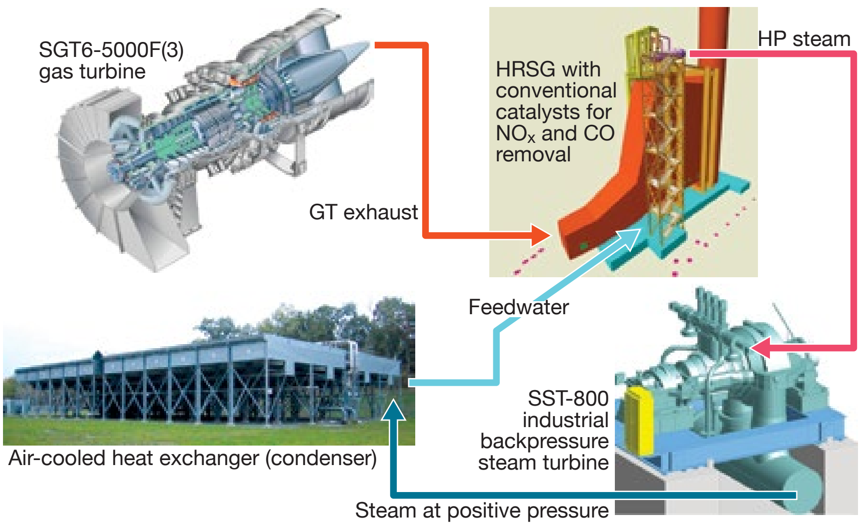
Each gas turbine, rated at 192 MW (without steam power augmentation), takes five minutes to synchronize with the grid and another five minutes to get to 150 MW. "We only have about 90 seconds of margin within this start window," Riesz said. Start reliability for both units combined is 99%.

The plant has met this obligation about 10 times since commissioning. Twice since commissioning, the plant has started up *twice* in one day. Most of the time, however, the plant operates in the CAISO day-ahead market, the exception being summer months when the units have functioned more as baseload capacity. Siemens originally described its Flex series of combined cycles as something between peak- and intermediate-load plants. At El Segundo, it appears to be living up to that billing.

Riesz reports that it takes a total of 45 minutes to achieve full steam-cycle output from a warm start condition, the plant's normal protocol.

Keep in mind that the plant also has only one hour after the start signal to be in compliance with its 2-ppm stack NO_x limit (10 ppm in the GT exhaust). The facility also is regulated by an

1. El Segundo's two new 1 × 1 gas-fired combined cycles (circle) are installed where an oil/gas-fired thermal unit once stood. Two more old units slated for removal are to the left of the new ones. The access drive from the coastal highway snakes around the substation; a massive petrochemical complex is on the other side of the highway (foreground). Diagram illustrates arrangement of key components in El Segundo's single-pressure non-reheat steam cycle



aggregate annual limit for pounds of NO_x discharged.

In the scheme of contemporary combined-cycle designs, the Flex 10's 49% cycle efficiency (8900 Btu/kWh heat rate) is not that high. But El Segundo wasn't designed for baseload-like efficiency, but instead for robust cycling and dispatch while meeting the state's onerous emissions limits. For example, the stack temperature is higher than for the latest combined cycles, which makes for a less efficient cycle, but this lessens back-end corrosion and minimizes issues with the selective catalytic reduction (SCR) unit.

Steam-cycle lessons

Much of the 1% start unreliability is attributed to steam-cycle challenges. "It's easy to make a mistake on startup with a small single-pressure drum," Riesz said, "and then hot water flashes to steam, and you trip the steam turbine and the gas turbine." He cautioned that you have to be careful controlling drum level (Fig 2) and even more careful during a hot restart.

Steve Petenbrink, maintenance manager, noted one maintenance issue the plant had to solve was failing baffle plates in the area where the GT exhaust rises to meet the first panel of HRSG tubes. "We conduct annual weld repairs of baffles which maintain the mixing and reduce bypass flow past the tubes."

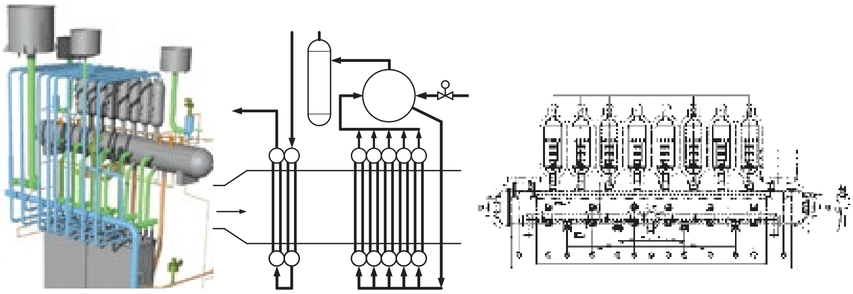
Water-chemistry control also is different for the El Segundo boilers compared to most HRSGs. Example: Conductivity is higher. Plant staff installed "little degas scrubbers" to remove CO_2 and attain a conductivity level that would meet spec. On the other hand, this boiler does not require a condensate polishing unit.

Raw water source for the plant is the West Basin Municipal Water District, which provides grey water via a four-mile pipeline.

In this boiler, supplied by NEM, a Siemens company, far more water resides in the tubes than in the drum—but the drum has a much thinner wall than a conventional HRSG so it can heat quickly. Thermal growth is rapid initially, but then stops, consistent with the need for fast steam-cycle starts and full steam-cycle output (70 MW) in 45 minutes. The HRSG design makes one ask whether differential thermal expansion among the bottles, drum, tubes, risers, and downcomers would be an issue, but Riesz and Petenbrink have observed no evidence of this.

Another area to watch with this HRSG design is the steam bypass system. The plant has a condensate receiver tank but no conventional hot well separate from the deaerator. Because of the positive-pressure steam-turbine exhaust (it's a backpressure unit, not condensing), the condensate temperature is higher than one might expect and, if not managed properly, can trip the condensate pump.

"We have to maintain suitable pressure in the deaerator to get proper pressure to the condensate/feedwater pump," Petenbrink said, "and this can be more of an issue on hot restart because the pressure tends to die off."



2. NEM DrumPlus™ HRSG (above) combines once-through and drum-type boiler features. "Bottles" above the drum are external steam/water separators. Overall, the design allows unrestricted startup of the gas turbine and rapid response to qualify for non-spin reserve in the California market. The HRSG reaches full load six minutes after the gas turbines, although the full steam-cycle output requires a total of 45 minutes

3. Four inlet valves directing steam into the once-through, single-casing backpressure turbine are said to be a little tricky to balance and sequence during starts, stops, and ramps (left)

4. Fan blades for the air-cooled heat exchanger (looking up from below) collect much debris from the ocean air. Wash water must be collected and treated (above)

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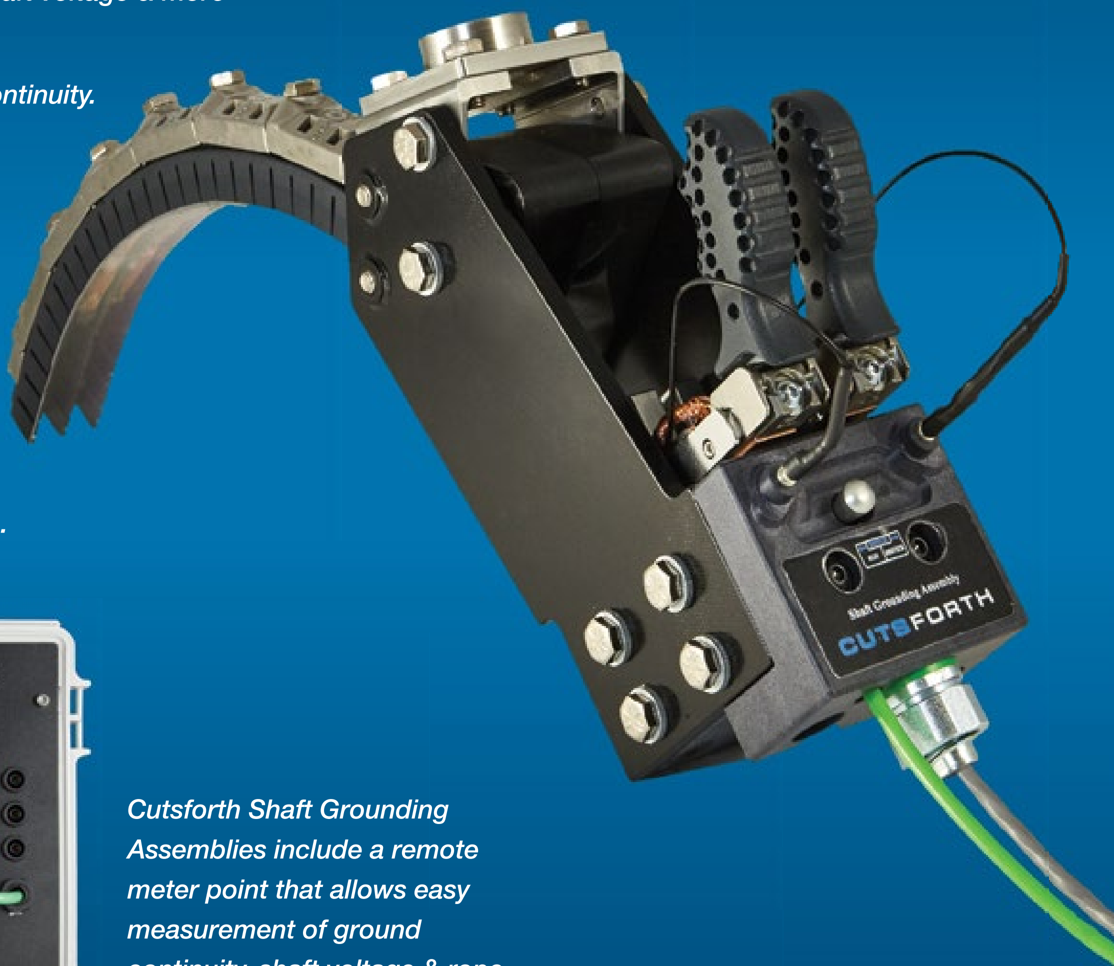

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Flex 10 comprises a 501FD3, unique HRSG design, workhorse steam turbine

Except for the gas turbine, you're not likely to see El Segundo's principal components at another US combined-cycle plant. The heat-recovery steam generator (HRSG) is a hybrid of once-through and drum boiler designs, the steam turbine is a design largely used for robust mechanical-drive requirements at process facilities, and the backpressure turbine and unique site required an air-cooled heat exchanger (ACHE) rather than an air-cooled or surface condenser.

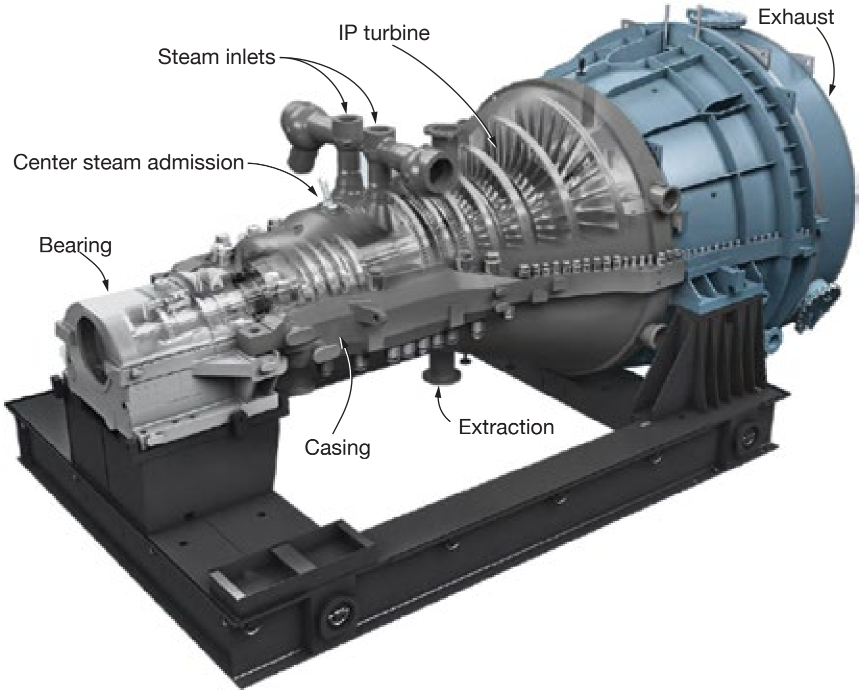
In other words, it's not only the breathtaking seaside setting (and beach just over the retaining wall), the shoehorned plot between a major coastal highway and the ocean, or the quaint beach front town just south of the plant which make El Segundo an atypical generating station.

The SGT6-5000F(3) GT, an upgraded version of the Westinghouse 501F introduced in 1993 (at that time with 150-MW nominal output), features a 13-stage compressor and four-stage turbine, 16 annular combustor cans, single-digit NO_x emissions, and 192-MW output at El Segundo without power augmentation, 210 MW output with it.

Features important to the flex operation and reduced emissions include the following:

- Dry low-NO_x combustor (DLN) with four stages, each of which comes online independently, with continuous fuel injection through the pilot burners and swirler fuel injection.
- Static frequency converter instead of a mechanical starter motor.
- Turning gear speed of from 3 to 120 rpm, which allows the generator rotor wedges to lock up faster during starts and the unit to cool down faster during shutdowns.
- Supplemental cooling air bypassed around the combustor to reduce CO emissions (less than 10 ppm down to 40% load).
- Turbine outlet temperature control based on compressor inlet temperature, rather than combustor shell pressure.

Thus far, experience at El Segundo confirms that the unit meets expectations for longer intervals between hot-gas-path inspections than the originally planned 12,500 equivalent operating hours/900 equivalent starts. El Segundo is permitted for a maximum of 400 starts annually, 200 for each GT. Both units together have seen 10,000 hours of operating duty and over 500 starts.



Details pertinent to combined-cycle application of the Siemens SST-800 steam turbine, normally used in mechanical-drive applications, were not shared by the OEM beyond that information available on the company website

The SST-800 steam turbine (figure) is actually one of a family of turbines which can be built up from modules for outputs from less than 50 MW to 250 MW (with dual-casing design). It is described by the OEM as a single-pressure, non-reheat unit with single casing, center steam admission, and reverse-steam-flow inner casing. A combination of impulse and reaction blading is used; all blades are fixed in blade carriers (that is, they are not free-standing). Nominal steam inlet conditions are 1450 psig/940F; steam flow is around 620,000 lb/hr.

Blades in the inner casing are structured to enable steam to flow in the opposite direction towards the middle zone. The middle zone is configured for direct flow towards the exhaust (as in El Segundo's case) or up to seven controlled or uncontrolled extractions, which may be common in mechanical-drive service.

The turbine's base is fixed at the exhaust end. At the high-pressure end, the rotor is supported by independently accessible bearings. This alignment allows a wide degree of thermal and mechanical flexibility. At El Segundo, the four steam inlet valves can be throttled for additional flexibility.

HRSG. The single-pressure, non-reheat HRSGs, branded DrumPlus™ by OEM NEM, were first described in CCJ (1Q/2014) as part of its coverage of a Combined Cycle Users Group meeting. Summary: A conventional steam drum is replaced by a knock-out vessel, external separator bottles, and a much smaller drum. The best way to think about the design is that the drum provides primary water/steam separation while the bottles accomplish secondary water/steam separation.

Because it carries more water than a conventional unit, this NEM boiler is said to provide added thermal stability while the system undergoes temperature transients during starts, stops, and ramps. On the other hand, the holdup time of water in the drum is less than normal. This means that the system is more sensitive to, say, a trip of the feedwater pump, and, in general, less forgiving during startup and transient conditions. The large attemperator for startup is rated at 25% of the steam flow. Full steam bypass is allowed by design.

El Segundo employs an ACHE rather than a conventional condenser because the "footprint" and profile of the ACHE is smaller. Steam at a few pounds pressure takes up much less volume than steam under vacuum. The ACHE is quieter, too.

5. Plastic hood covers the boiler-feed-pump motor to protect against ingress of moisture and sea salt

6. Several platforms and access doors were added to facilitate inspection and maintenance of the GT exhaust duct

Riesz added "we just needed the right procedures." No issues were reported with the attemperators on the bypass and main steam lines. The plant features a large attemperator for use during startup and a smaller unit to control peak steam temperatures.

Another interesting operating nuance is sequencing the four steam turbine inlet valves (Fig 3) regulating flow into the steam chest. Valves inside the steam chest regulate flow to different areas of the turbine. Steam enters at the middle of the unit and is split between the high-pressure turbine and the intermediate/low-pressure turbines, both running on one shaft with the generator.

During plant startup, water level in the HRSG drum is maintained relatively low to accommodate the pending swell that occurs as the water is heated. As pressure builds in the drum, the steam bypass valve opens to maintain pressure by allowing steam to bypass the turbine and flow directly to the air-cooled heat exchanger (ACHE) while the steam turbine is warmed up.

Once the ACHE is properly vented and conditions have reached saturation, ACHE fans are started to control pressure in the exhaust steam duct. Condensate is collected in the condensate return tank, where it is stored until being pumped back to the HRSG via the condensate and/or boiler-feed pumps. As the steam turbine comes up to temperature, the bypass valve is closed and the unit is slowly brought to its valves-wide-open load point.

Water everywhere but. . .

A quick tour of the facility with Petenbrink revealed other O&M nuances.

7. El Segundo has only one condensate pump (left), and one boiler-feed pump, unlike most combined cycles designed for baseload and intermediate-load operation. This requires focused maintenance procedures, full spares, and predictive-maintenance capabilities

Standing underneath the air-cooled heat exchanger, he said, "by permit, not a drop of wash water is allowed to spill to the ground; when we wash these fan blades (Fig 4) to remove salt buildup, we have to collect every drop in plastic containers, treat it, and recycle it." Apparently, the same stuff that's in the air and must fall to the ground when it rains isn't allowed to touch the grounds of a power station. This is what zero discharge means at this location.

The oceanside location also makes for interesting tradeoffs in gas-turbine air filters—with financial consequences. The plant has fine HEPA-grade particulate filters preceded by coarse filters. The former cost five times as much to replace. "We've learned to financially optimize how and when we replace each type," Petenbrink said.

The plant did observe salt deposits on compressor blades the first time one of the GTs was opened. To avoid problems with deposition, the plant conducts online water washes every other day and an offline wash with soap and water monthly. The coarse pre-filters are generally replaced semi-annually (online), the fine filters (replaced offline) annually.

Finally, Petenbrink pointed to the protective cover installed over the boiler-feed-pump motor to prevent moisture and salt intrusion (Fig 5) and he indicated where platforms and maintenance doors were added or modified to facilitate maintenance access (Fig 6).

Conduct of operations

Riesz has high praise for NRG's formal operations program, called "Conduct of Operations." He thinks it's "the best ops model out there." Since inception of the program, brought to the company by Fran Sullivan, NRG's senior VP of operations, NRG's aggregate plant reliability is up, human error by operators has been reduced, and pride of ownership is evident.

Complementing the ops model at El Segundo is a full simulator for training, which uses the current control configuration in the T3000 automation software. "The simulator wasn't cheap," Riesz said, "but it allows us to test control modifications and new strategies 'virtually' before we apply them to the physical units."

He also lauds the safety culture at El Segundo. The plant (recall that oil/gas-fired thermal units operated at the site before the combined cycles replaced them) has had no lost-time reportable accidents in 10 years, and that includes the construction of the combined cycles and the dismantling/retirement of the old units.

Every operator is empowered to shut down equipment over safety concerns. Safety comes first. "For that matter, environmental compliance comes before ops, too," Riesz added.

To the extent possible, the plant staff tries to find problems before they occur. Conventional predictive maintenance techniques are used, like vibration and oil analysis. The plant is currently experimenting with real-time data analytics. They "trend lots of stuff in PI."

Internally driven excellence is even more paramount at El Segundo. "We're the only site which has deployed the Flex 10, so there aren't many lessons learned we can bring from the outside." Plus, because the plant isn't a baseload-type facility, there's only one boiler-feed pump and one condensate pump for each combined cycle (Fig 7).

The plant keeps full spares on site for swap-outs. "We plan our outage time well, nighttime and weekends, to minimize any impact on availability." During longer planned outages, the goal is to restore the equipment to the most reliable state possible.

To support the 47-person staff, El Segundo has full LTSAs with Siemens—one for the T3000 control system, and one for the gas turbines, which are monitored 24/7/365 by the OEM. Plant staff describes the T3000 as "a lot easier to use than the Bailey Infi 90 serving the old plant," but that it is graphics intensive, and they struggled with the "not-so-user-friendly" alarm configuration out of the box.

On tap. . .

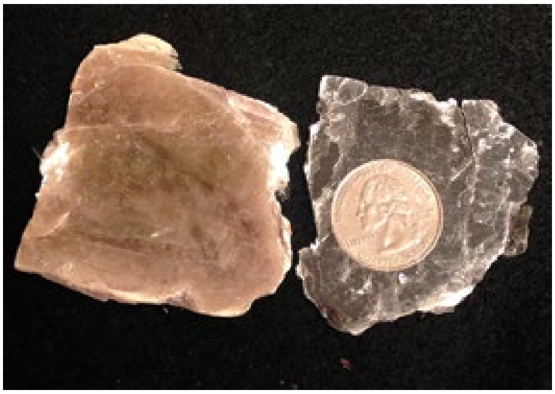
At some point, the plant has to relocate the control room. Originally, it was easiest to put it in the space of the existing control room serving two of the three original units which have yet to be dismantled. "We have lots of decisions to make regarding replacing servers, what kind of architecture we want, and so on," Petenbrink said.

Riesz noted the plant is also considering modifications to significantly turn down the gas turbines below 150 MW without violating the site's CO emissions limits. "It's a Siemens proprietary approach to air/fuel mixture control in the combustors," he added. CCJ

Understanding insulation basics helps promote long service life

By **Dr Nancy Frost,** Gerome Technologies

Various insulation materials are used in rotating machines, each with specific performance requirements. Understanding how each type of insulation works is critical for the proper construction, operation, and maintenance of generators (and motors). The trend in rotating-machine design and manufacture is to continually require more from insulation because customers want smaller generators with higher outputs. This means insulation systems experience higher electrical stresses and must have a higher thermal conductivity.



1. Raw mica is processed, and applied to tape or paper with resin, for use as an insulator

Insulation

There are three critical aspects to electrical insulation: design, material, and processing. The material must be suitable for the application, conducive to use in a manufacturing environment, and satisfy the machine's performance specifications. Many times the requirements for these three areas are at odds with one another, so trade-offs often are made in the selection of insulation materials.

Mica is one of the most important insulating materials. This naturally occurring mineral has a platelet struc-

History lesson on generator insulation and associated failures

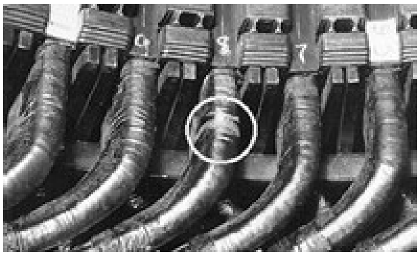
About the turn of the 20th century, mica flake was discovered to have remarkable electrical and thermal properties. Insulation systems rely on mica because of its resistance to partial discharge (PD); no manmade product can compare in this regard.

But with shellac, cotton, and other relatively primitive materials incorporated in early generator insulation systems, troubles persisted. By the mid-teen years of the last century, it was discovered that by using a vacuum-pressure cycle, mica/cotton tapes could be impregnated with a hot asphalt compound to obtain a major improvement in electrical duty. But in the late 1920s a tape-migration phenomenon had surfaced (Fig A, circle) and, by the mid-1940s, most stator windings on large Westinghouse generators were experiencing fatal migration.

Excerpted from "A Brief History of Turbine-Driven Generators" by Clyde V Maughan. Paper is available in the online Resource Center managed by the International Generator Technical Community at http://www.generatortechnicalforum.org.

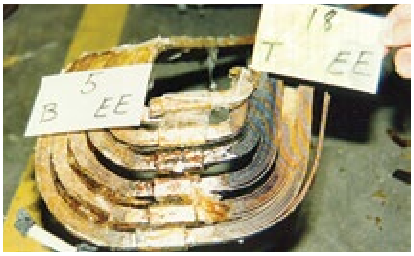
Thermalastic™, said to be the first modern synthetic groundwall insulation system (1950) was developed by Westinghouse in response to the failures experienced. The epoxy-like polyester material provided the incentive for development of improved groundwall systems by all OEMs—such as GE's Micapal I™, Micapal II™, and others; Siemens' Micalastic™; ABB's Micadur™, etc.

Stress on the groundwall has a dramatically important impact on electrically related problems associated with stator windings. The predominant issue is the phenomenon referred to as partial discharge (PD), sometimes incorrectly called "corona." The stress gradient within the groundwall results in electrical breakdown in the inevitable, tiny voids in the groundwall. These mini-arcs tend to eat through any insulation system that does not have the PD resistance of mica.



A. Tape separation of 0.75 in. (circle) was caused by migration of groundwall insulation

B. Significant surface partial discharge is in evidence in the slot



C. Major winding failure occurred from shorted strand groupings ture that gives it a high dielectric strength, excellent long-term resistance to electrical stress, and a resistance to partial discharge (PD, Fig 1).

For modern insulation systems, mica is processed into small pieces and made into mica paper to facilitate its use in a manufacturing setting. In this form, mica has little mechanical strength; therefore, it is applied to a carrier—such as glass cloth, Dacron®, or film. A binder holds the mica and carrier together.

The binder—polyester, epoxy, or silicone—can be fully cured or b-staged. The latter means the resin, or glue, is only partially cured; it is in a tacky state that is not gooey or flowing at room temperature. Depending on the type of resin, addition of a catalyst also may be necessary.

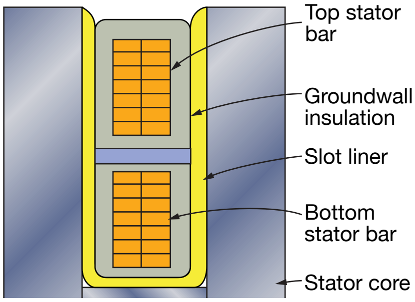
The small mica flakes form overlapping layers in the insulation, making it harder for a critical electrical failure path to form through the insulation, because it has to weave back and forth between flakes.

Stator

Mica tape is one of the main components in the stator insulation system, which isolates the current-carrying copper from the magnetic steel of the stator core (Fig 2). The design can be simple or complex depending on the physical size and output of the machine.

Recall that stator bars have three main components: copper, mica, and resin. The copper carries the current, the mica provides primary electrical stress protection, the resin fills voids and serves as a glue to hold everything together.

Challenges: Keeping the stator-bar insulation intact during installation into the stator slot is critical to success. The groundwall insulation must be sufficiently robust to withstand the mechanical stresses during installation and remain electrically sound for a long service life. Other components



2. Key stator components— core, coils, and groundwall insulation—are shown in cross section

If the outside surface of the groundwall is not adequately grounded, there will be discharges of much more energy. This, in turn, can result in surface PD (Fig B).

In the 1950s, the stress level on the asphalt insulation systems was about 45 volts/mil (vpm). With the advent of hard (polyester-type) systems, the stress level increased to around 54 vpm. By the mid-1960s, improved (epoxy) systems were being used, and the stress levels increased to vpms in the low 60s, creating problems for designers under pressure to produce larger indirectly cooled generators.

In these machines, where the copper thermal losses had to transmit through the groundwall, thinner groundwall insulation became highly valuable. From this pressure, and in recognition that root-cause electrical failures of the groundwall insulation were rare, evolution toward much higher stress levels occurred—today exceeding 90 vpm.

Problems associated with bar windings. Because eddy-current losses would immediately melt a stator bar of solid copper, a stranded design always has been required. Very early (in 1915) a Swiss engineer, Louis Roebel, invented an elegantly simple way to address the problem by transposing the bars.

The standard Roebel transposition effectively compensates for the radial flux density gradient in the slot portion of the winding. However, on large generators of non-coil design, the radial flux gradient in the endwindings becomes sufficiently large to cause problems.

Another approach for endwinding radial flux compensation has been to sub-group the bar strands into bundles of strands; bundles may range from as few as one strand to as many as 14 or more. These "bundles" are maintained throughout the entire phase belt. The bundle design greatly complicates the winding manufacturing process and has been accompanied by numerous service problems (Fig C).

The evolution of large-generator winding insulation and support systems has presented many difficult challenges to generator design engineers and to manufacturing personnel who make these machines. Progress will continue, but with continuing increases in machine ratings and continuing cost pressures, old problems will recur, present problems will continue, and new problems inevitably will develop.

3. Proper application of mica tape is important to protect against partial discharge

in the stator groundwall insulation system include end-basket support materials—such as felts and tie cords to hold the stator windings in place.

Magnet wire. The current-carrying component of the stator, the magnet wire, must be electrically insulated from the adjoining turns and from the stator core itself.

Each coil design has a unique electrical stress on the groundwall and magnet wire components within the coil. Example: A machine can have a two-turn coil with small copper cross-section, which facilitates manufacturing of the insulation system; or it can have a higher-aspect-ratio magnet wire in a four-turn coil, which leads to higher electrical stress on the insulation.

Magnet wire material can be enameled or covered (also called "served") copper, or both. Enameled magnet wire may be single, heavy, or quad build, which refers to the thickness of the enamel applied to the copper. Materials for served magnet wire include Daglas®, mica, and Kapton® (polyimide); all can be put over bare or enameled copper. Served wire typically is used in high stress systems requiring extra protection.

Challenges: Magnet wire insulation must withstand the flexing and manipulation required to insert the stator bar into the slot. This often can be minimized by using stack consolidation to create a coil or bar that will hold its shape during the winding operation.

The consolidation material can consist of a separate tape on the outside of the wire stack in a barber-pole layup or an adhesive layer on the outside of individual wire strands. Another method uses a rigid b-staged material in the center of the stack. The magnet wire coil stack then is formed and squeezed in a heated press to cure the consolidation tape and hold all the copper strands in the desired coil structure.

Groundwall insulation. The

design choices for stator construction must be evaluated for the electrical stress each puts on the groundwall insulation. Engineers can vary the number of coil slots, the number of turns in a coil, and the number of conductors per turn to achieve the desired outcome.

Mica and resin are the components of groundwall insulation, which covers the copper magnet wire. Discrete layers of mica tape can be applied to build up sufficient electrical insulation for the groundwall package. Resin holds the layers together and fills any voids. Mica works well in this application because it resists PD, one of the known failure modes of groundwall insulation in high-voltage (HV) applications.

Challenges: The groundwall insulation must be flexible and strong enough to hold together during manufacturing and while the machine is in service. If the mica tape is not applied properly it is easier for a conductive path to form, leading to PD. Proper application begins with consistent lapping and indexing—terms describing the overlapping of the mica tape on itself over the length of the coil—to avoid the formation of voids and possible ground paths between the copper and steel (Fig 3).

Also, it is critical to get the right amount of resin saturation in the tape to prevent faults and premature aging. In general, there are two ways to do this: Push in the resin (VPI process), or squeeze out extra resin after taping (RR process).

Stator slot. As the rotor spins, the stator coils experience large electromagnetic forces that make them want to fly apart. The stator winding kit provides components that hold everything in place when properly installed. Slot insulation materials typically are composites—including a slot liner, bottom filler, mid stick, top packing, and wedging system. The slot liner often is a laminate of Nomex® and films, while the rest of the system usually is glass laminate or composites.

Challenges: Slot insulation materials keep the stator coils in place during operation, and their long-term mechanical strength, plus their electrical performance, are critical. There are established methods for the installation of side and top packing, as well as ripple springs. Where wedges are used to hold the coils in place, they must be installed carefully to avoid damaging the groundwall insulation.

Side and top packing, wedges, and top ripple springs (if used) must fill the slot area without over-stressing the material or damaging the stator ground-wall. Ripple springs, both side and top, are designed for installation to a proscribed compression level—not completely flat.

Rotor

The rotor body typically is machined from a single forging, with slots for the rotor copper cut into the steel. The key concerns for the insulation materials in the rotor are mechanical, because of the high radial centrifugal forces experienced when the rotor spins.

In addition, thermal damage/degradation of the insulation system is a concern because the currents in the copper can lead to high heating losses (I^2R losses). Since the coefficients of thermal expansion of the copper and the insulation are not the same, movement during heating/cooling can occur and abrade the insulation.

The design of a rotor must balance the need for cooling with that of sufficient copper cross section to carry the current. More copper carries a higher current, which means more power (energy transfer). But it also generates more heat and, therefore, needs more cooling. Venting provides cooling, but it reduces the amount of copper, so there is less power output. This is the push/pull the design engineer must accommodate.

Insulation. There are a variety of materials and designs for rotor insulation that have performed successfully in the field. These are comprised of composite materials in a special layered construction. This includes primary insulation to electrically isolate the copper from the steel (slot liners). Insulation between individual copper turns can be vented and can be comprised of a variety of materials—such as glass-based composites (with or without film layers)—to improve the dielectric breakdown strength. Fillers also are used in rotors, as in stators, to completely fill the slot—such as top and bottom fillers, as well as creepage blocks and sub-slot covers.

Challenges: Expertise in the fabrication of rotor components is critical because these materials experience high mechanical forces and strong thermal cycling throughout their service lifetimes. CCJ

Dr Nancy Frost is a dielectrics engineer working as business development manager for Gerome Technologies, an insulation fabricator. She has more than two decades of experience as a materials supplier, academic, HV laboratory manager, and developmental engineer for GE and Kodak. Frost has given over 50 presentations and short courses on insulation materials; she is active in IEEE and other professional organizations.

CMCs debut this year in GE aero engines, 7F gas turbines next

By Lee S Langston, professor emeritus, UConn

General Electric Co is developing hot-section ceramic components for future versions of its popular 7F gas turbines. Among the first will be a ceramic matrix composite (CMC) shroud for the first stage on new 7F.04 and 7F.05 machines; it also is an option on full Advanced Gas Path upgrades to the earlier 7F.01, .02, and .03 models.

CMCs, at about one-third the weight of conventionally used hot-section nickel/cobalt alloys they replace, are more heat resistant and require less cooling air. These properties promise enhanced engine durability, life, fuel economy, and performance.

Ceramics have many favorable characteristics. Compared to metals now used in gas turbines, they often can have superior corrosion resistance, hardness, lower density, and high-temperature capability. Their main drawbacks are comparatively low toughness and the possibility to fracture in a catastrophic brittle mode.

Toughness is a measure of load or stress needed to drive a crack through a material. A china dinner plate is not easy to break in half, but if it has a slight crack, fragmentation is easy, compared to, say, an identical ductile metal plate.

Ceramics subjected to compressive stresses, where crack defects are made smaller, are very strong. Ceramics subject to tensile or bending stresses (such as in rotating turbine blades), where crack defects are made larger, can cause sudden failure. CMCs have been developed to alleviate this characteristic ceramic brittle behavior.

Graceful failure

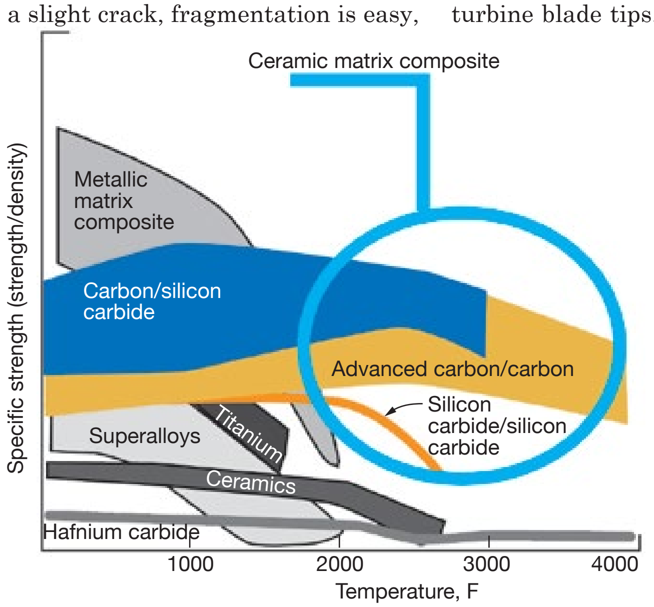
GE is introducing CMCs both in its 7F gas turbines and latest jet engine for single-aisle commercial aircraft—such as the Boeing 737 and the Airbus A320. Called LEAP (Leading Edge Aviation Propulsion), it is scheduled to enter into service this year (2016). Since the LEAP CMC program is further along than that for the 7F, let's review it.

CMC first use in LEAP is as the shroud for the first-stage high-pressure turbine (HPT). Note that the shroud is the segmented inner structure of the engine casing and the closest stationary surface to the rotating first-stage turbine blade tips. There are 18 segments in the LEAP engine casing's inner structure.

GE will expand its application of CMC use in the company's 100,000-lb-thrust GE9X engine, now under development for Boeing's 777X airframe and scheduled to enter service in 2020. It will feature CMC combustion liners, HPT stators, and first-stage shrouds. Early in 2015, GE ran tests on a turbine rotor with CMC blades—the ultimate structural test of this new material. One can speculate that GE's use of CFMs in its 7F gas turbine will follow a similar path taken for the GE9X.

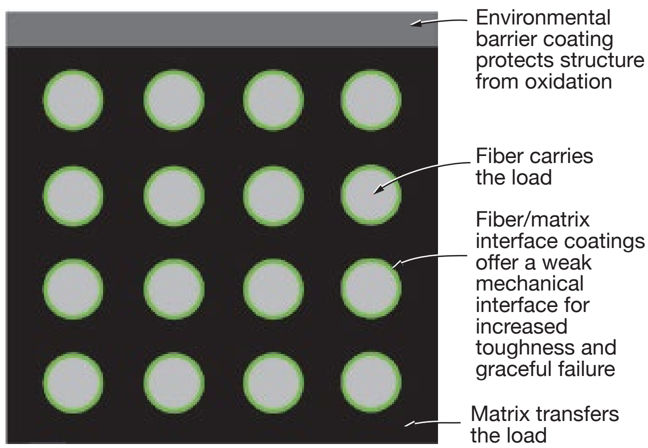
The LEAP CMC first-stage turbine shroud is a composite consisting of fine intertwined ceramic silicon carbide (SiC) fiber, embedded in, and reinforcing, a continuous silicon carbide-carbon (SiC-C) ceramic matrix. The shroud also has an environmental barrier coating to protect the CMC from chemical reactions with the turbine gases.

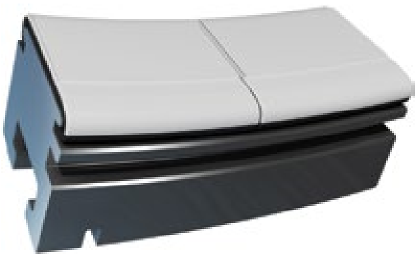
The CMC SiC fibers are continuous (greater than about 2 in. long), a fraction of a human hair in diameter, and relatively free of oxygen (which can degrade its high-temperature properties). The resulting intertwined fiber



1. How the strength of advanced ceramics compares to that of metallic alternatives (left)

2. CMC with fibers embedded in a matrix (below)





3. CMC shroud for 7F fleet helps increase GT output, reduce heat rate

reinforcers are covered with a multi-layer coating based on boron nitride.

The fiber-reinforced CMC has a unique failure mechanism, dubbed a "graceful failure" mode. As the SiC-C matrix cracks develop under imposed thermal or mechanical stresses, the load is transferred to the reinforcing SiC fibers. Their multi-layer boron nitride coating then permits the fibers to slide in the matrix, allowing load transfer and energy absorption. Thus multiple micro-cracks build up, prior to actual fracture, resulting in increased toughness, and imitating the ductile behavior of a metal.

This crack-mitigation tolerance, which resists the classic brittle failure of a pure ceramic, should also yield gas-turbine parts that are not highly sensitive to manufacturing flaws.

In sum, GE's use of CMC gas-path parts looks very promising. CMC's graceful-failure mechanism will allow the use of this promising composite ceramic, with its light-weight and high- temperature characteristics. GE estimates an advantage of at least 180 to 360 deg F compared to metals currently in use.

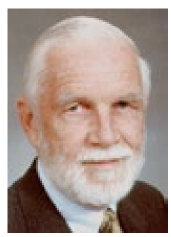
This means CMC parts could operate at about 2400F, well into and above the softening/melting point of superalloys. (Pratt & Whitney estimates a CMC operating temperature at 2700F.) Currently, CMCs are very expensive—hundreds to thousands of dollars per kilogram. GE is counting on cost reduction by process scale-up, automation, and improved machining.

The CMC future

All-in-all, GE has been working on CMCs for two decades, has spent over \$1 billion on CMC technology, and recently opened a \$125-million plant in Asheville, NC, to mass-produce CMC gas-turbine components. Just last October, the company announced an investment of over \$200 million to create factories in Huntsville, Ala, to mass produce silicon carbide materials and manufacture CMCs for both aviation and land-based GTs.

The brief account given here to describe the management of tensile cracking does not do justice to the research, analysis, and testing GE and others have done to develop CMCs for gas turbines. Trying to manufacture a ceramic material structure which imitates what nature provides in a ductile metal is a challenge.

However, success does not always favor the pioneer. For instance, in the late 1960s, Rolls-Royce attempted to be the first to use a composite ducted fan on its then new RB211 engines, for the Lockheed L-1011 airframe. The fan, using a carbon-fiber composite Hyfil, failed final testing, contributing to the 1971 bankruptcy of the company. The jet engine industry has since developed successful composite fans, but the inaugurating company got off to a rocky start. CCJ



Lee S Langston, professor emeritus of mechanical engineering, University of Connecticut, joined Pratt & Whitney Aircraft as a research engineer after receiving his PhD from Stanford University in 1964. A Life Fellow of ASME, he has served the society as editor of its Journal of Engineering for Gas Turbines and Power and as a director of the ASME International Gas Turbine Institute.

Seek 'peak' performance for multiple owners, multiple grids

The phrase, matrix organization, was popular a decade or two ago in management circles. It refers to an org chart where a staff worker or middle manager reports to multiple bosses and stakeholders, rather than a traditional binary "one worker, one boss" hierarchy.

One of the largest combined-cycle facilities in the country is a "matrixed" powerplant.

It has multiple 2 × 1 power blocks equipped with GE 7FA gas turbine/generators (GT) and D11 steam turbine/generators (ST). Each 550-MW block is not only owned separately, but functions to serve each owner's separate objectives. More specifically, one block is governed by a tolling agreement with a solar-rich utility and primarily serves a large metro area. Another block is owned by a utility. Two more blocks are owned by a merchant power company.

Three separate operating budgets and operating schedules govern the facility. The common infrastructure—such as water treatment, fuel supply and delivery, fire and safety systems, control rooms, etc—are paid for equally by the three owners, regardless of output, operating hours, or other metric which might be used to apportion expenses. The operating staff is common to all three owners, too.

Like so many other combined cycles nationwide, performance objectives have changed considerably since the facility was commissioned in 2003.

It's all about the peak

The common performance objective across the owners and power blocks is similar: It's all about meeting peak demand. The GTs, all told, can experience more than 1200 starts annually.

For example, the solar rich utility buys 230 MW of solar thermal, greatest between 10 am and 3 pm each day. On a typical sunny day, the associated power block will shut down during those hours, and the unit will experience a start/stop in the morning and another in the evening.

In other words, the block "follows the sun" much like a peaking gas turbine in terms of starts. On the other hand, a peaking GT would, in earlier times anyway, operate during the day to satisfy peak AC demand of the utility's customers, and then shut down at night.

By contrast, the power block devoted to the other utility operates less like a peaking GT and more like an intermediate-duty machine. Last year, for example, the unit remained online all of September and October.

The merchant power blocks are experiencing few calls to start these days. As of the first week in January (2016), those blocks were expected to be in layup until April.

Flexibility toolkit

Water is at a premium at this site and the emissions envelope for different operating modes is tight. Thus, the plant has assembled the familiar toolkit to meet peak demand, minimize emissions during starts and stops, minimize raw water sourced from an aquifer, maintain combustion stability under dynamic conditions, and prevent as much wear and tear on the GTs as possible (none of the blocks are governed by an LTSA with a vendor). The toolkit includes:

- Software system to monitor and optimize loading of the turbines while keeping emissions in check.
- Enhanced startup procedures through a plant-built startup sequence calculator.
- Supplemental firing of the HRSGs for power augmentation.
- GT inlet fogging systems for power augmentation during appropriate ambient conditions.

In addition, the plant extensively modified its water treatment systems to accommodate the growing need for flexibility, changes in operating profile, and a restrictive permit that prohibits

1. Existing pad for the retrofit fogger has plenty of space for the more compact, precise, and reliable pump/VFD drive unit (left), compared to the original belt-driven pump/motor system (right)

2. Idyllic desert setting can go from what you see at left to that at the right in a matter of minutes when rain and dust storms flare up

the discharge of process water from the site.

Simplified ZLD

Source water typically contains 25 ppm silica and has a conductivity of 2000-2200 µS/m.

Core problems with the original zero liquid discharge (ZLD) water system were the following:

- The plant was discharging too much wastewater to the evaporation ponds.
- The brine concentrators (BC), the heart of a ZLD system, were troublesome and required frequent servicing and offline cleaning. Average run time between BC unit cleanings was 3-4 months.

The permit at the time did not allow pumping water somewhere else under any circumstances. When the "freeboard" elevation in the pond got below 4.5 ft. the plant risked a forced shutdown.

The first solution attempted was to eliminate the clarifiers, holding tanks, and other "front-end" equipment (such as multi-media filters), and install a third BC unit. That wasn't enough.

Later, the facility was able to get the air permit modified to allow spray evaporators in the ponds and the water permit modified to allow floating pumps to return pond water to the ZLD for treatment. Permit mods, plus the following process changes, allowed the plant to streamline the ZLD:

- Add spray evaporators and floating pumps to the ponds (three of them).
- Replace original single-pass reverse osmosis (RO) *rental* units, used when the ZLD system is offline, with a permanent dual pass RO unit for processing raw makeup from the aquifer.
- Minimize cooling-tower blowdown by increasing cycles of concentration (from 150 ppm to 180 ppm) together with added monitoring capability.
- Improve BC performance by use of anti-scalant and anti-foaming additives.

One important consequence of the mods is that the plant is no longer dependent on expensive rental RO "bottles" and/or solely on the brine concentrator for HRSG boiler makeup. The revamped ZLD system has been operating well and saving hundreds of thousands of dollars annually, according to an account at a user event.

One lingering issue is corrosion at the top of the brine-concentrator tubesheets. Generally, brine-laden wastewater flows through the inside of the tubes in a BC, while steam condensing on the outside transfers heat across the tubes. Nozzles at the top distribute the brine through the tubes.

The primary cause of corrosion isn't known but the thought is that brine "wicks" underneath and between the nozzle and titanium alloy tubes. Better control of chlorides is thought to be part of the solution.

Climbing the peak

HRSG duct burners add up to 25 MW additional capacity, the foggers up to 20 MW from each GT at full blast. Normally, the blocks run on an automatic generation control (AGC) signal from grid dispatch, but not during power augmentation. During these hours, the goal is to deliver as much capacity as possible, not cycle to meet fluctuating demand.

Variable-frequency drives (VFD) on the fogger water pumps help control flow to the GTs as ambient humidity fluctuates. Foggers typically run in the summer months when temperatures are above about 70F.

The plant has endured a prolonged learning curve with various fogging systems (Fig 1). All GTs came equipped with foggers supplied by the OEM, but they proved unreliable and also contributed to erosion of compressor blades. After attempts at correcting issues with the original foggers failed, a replacement system from Mee Industries was installed on one block. It apparently operated well and fogging water droplet size was controlled well enough to avoid blade erosion.

However, early in 2014, the facility contracted with Caldwell Energy to retrofit the remaining GE units with its equipment, using as much of the original equipment as possible. According to Caldwell's Rodney Kohler, the original foggers relied on belt-driven plunger pumps. Not only were they prone to failure at this site, pieces of the pump seals would clog spray nozzles and other downstream components, especially during summer when they are frequently online.

The Caldwell foggers avoid belt-driven pumps, gearboxes, and lube oil systems, and instead incorporate high-pressure, positive-displacement pumps with VFD-equipped motors supplied by Danfoss. Kohler said these pumps more accurately deliver the right amount of water to the nozzles, while minimizing valves and piping. They also require less frequent inspections, typically after 10,000 operating hours.

Foggers are critical at this site to meet contractual output obligations when dispatched during peak demand periods. At a facility where every drop of water has value, precise control over water delivery to the fogger nozzles is important. Plant personnel reported no significant issues with the new foggers, although Kohler noted that some teething problems had to be worked out with thermal management in the VFD power electronics package.

Beat the fuel burn

Because of the high number of starts, one of the facility's primary key performance indicators (KPI) is to minimize fuel consumption during startups. To this end, the plant developed a six-mode startup sequence automation package, which runs in the Ovation control system.

Examples of the modes are:

- Post-startup of the GTs and until steam conditions are met for the steam cycle.
- The "dirty" mode: Used when the GTs are operating well below their optimum output versus emissions range and CO emissions are elevated.

- "Extended turndown" mode: Used when the required output from each GT is well below 100 MW and the plant wants to avoid a shutdown/restart step. To enable this mode, the 170-MW GTs were re-tuned to further minimize CO emissions at part loads, down to 70 MW. Extended-turndown capability has significantly improved the economics of overnight operation and start performance by avoiding starts in the first place.
- Full output.

In addition, there are automated procedures for hot, warm, and cold starts based on aggregated temperature decays from previous starts.

Essentially, the software benchmarks each start on megawatts, emissions, fuel burn, dispatch times, turbine ramp rates, etc, by comparing the current start sequence to an "expected" start based on actual operating conditions—such as ambient air conditions, equipment temperatures (for example, hot, warm, or cold start), and steam-temperature profiles. All the required data are collected in the DCS; the plant just puts it to good use in a convenient way that enhances operations.

Automation is important for reducing human error and making starts consistent, but also to give operators performance targets. The goal is to reduce the fuel burn and meet or exceed the dispatch times. Automating startup routines also adds flexibility. When the GTs are in extended turndown, the operating mode used to avoid a restart, a power block can be brought to full load in 17 minutes.

Another benefit of consistent startup sequences and predictable fuel burns is they help plant management arrange for more cost-efficient gas deliveries.

Desert storms

Severe thunderstorms and wind/dust events occasionally have tripped the steam turbine/generators at this site (Fig 2). To protect the equipment and remain online, the plant installed "doghouses" over the collector ends of the steam turbine/generators to prevent water intrusion. Other improvements made to the steamers and their auxiliaries include:

- Added platforms for better access to the lube oil/hydraulic skids.
- Improved the sample panel indicators and housing.
- Converted the high-pressure electrohydraulic control (EHC) system fluid from Fyrquel to EcoSafe 46, which is said to be more stable and less toxic to personnel and the environment. CCJ

Consider the STUG conference *must attend*

The Steam Turbine Users Group's (STUG) 2015 meeting, August 24-27, in Orlando, offered the most comprehensive program for steam-turbine owner/operators in recent memory. The user group has earned a sterling reputation in just its third year of existence, hosting the only industry meeting dedicated to the specific information needs of O&M personnel responsible for steam turbines at combined-cycle plants.

STUG 2015 was conducted in parallel with the Combined Cycle Users Group's annual conference. Both STUG and CCUG are sister organizations under the Power Users Group umbrella (ad, p 52). Crossover was permitted between the two meetings.

In 2016 STUG and CCUG will again share the same venue, this year joined by the Generator Users Group (GUG). All three meetings will be held August 22-25 at the La Cantera Hill Country Resort in San Antonio. Access details at www.powerusers.org.

The STUG 2015 agenda featured these three key elements:

- Presentations by more than a half dozen users on projects offering valuable learning experiences for colleagues—including lessons learned and best practices.
- Six-hour workshops conducted by each of the three principal OEMs: Siemens Energy, MD&A/Mitsubishi Hitachi Power Systems, and GE. They enabled users to "visit," via well-illustrated slides, modern shops and their capabilities, equipment and service offerings, and recent projects of interest involving inspection, overhaul, repair, and upgrade of steam turbines and generators.
- Presentations by third-party equipment and services providers on a dozen topics selected by the steering committee for their high level of interest to attendees.

Discussion periods following the presentations, most of them vibrant, allowed attendees to tap into the knowledge of all participants and take away information critical to making their plants safer, more productive facilities. As you read through this report, keep in mind that *users* wanting more information can access the complete, well-illustrated presentations in the conference archives section of the Power Users Group website at www.powerusers.org

STUG
STEAM TURBINE USERS GROUP

2016 Conference and Vendor Fair
August 22-25
La Cantera Hill Country Resort
San Antonio, Tex

Steering Committee

2015 Chair: Jake English, *Duke Energy*
2015 Vice Chair: Bert Norfleet, *Dominion*
Jess Bills, *Salt River Project*
Gary Crisp, *NV Energy*
Eddie Argo, *Southern Company*
Jay Hoffman, *Tenaska Inc*
John McQuerry, *Calpine Corp*
Lonny Simon, *OxyChem*
John Walsh, *Sundevil Power*

Meeting overview. The STUG conference started easy enough Monday afternoon (August 24) at 2 p.m. with a four-hour workshop on heat-recovery steam generators (HRSGs) conducted by HRST Inc's Lester Stanley, PE, Bryan Craig, PE, and Bryan Grant. The well-attended, highly interactive session featured three presentations jammed with technology, best practices, and lessons learned to help owner/operators extract world-class performance from their steam supply systems:

- Maintaining HRSG economizer and evaporator performance and reliability.
- Superheater and reheater performance and reliability.
- HRSG operations and component failures impacting steam turbines.

A two-hour welcome reception and dinner followed the HRSG workshop, enabling attendees to renew old acquaintances and make new ones, and glimpse the content-rich program planned for the next three days.

STUG and CCUG pooled attendees for half an hour of introductory remarks, housekeeping items, hotel safety procedures, etc, early Tuesday morning and then split—the STUG registrants headed for a highly regarded day of user presentations and open discussion while and the CCUG attendees focused on safety management, maintenance best practices, and combined-cycle optimization.

The two groups reconnected for third-party vendor presentations following the afternoon break. There were two 45-minute sessions, each having three concurrent presentations. A three-hour vendor fair closed out the Tuesday program. It was a full day with a great deal of material to absorb.

Wednesday was challenging for STUG participants who had to choose between tracks developed by Siemens and MD&A/Mitsubishi Hitachi Power Systems Americas (MHPSA), each running nearly six hours—divided into three segments with breaks in between.

There were six additional vendor presentations in the afternoon, following the same format as on Tuesday. A three-hour open house sponsored by GE at an offsite location closed out the day, which started at 8 a.m. and ended at 9 p.m. Thursday was not much easier with a full day of formal presentations and roundtable breakouts by GE from 8 a.m. to 5 p.m.

User presentations

O&M issues associated with one model of air-cooled generator

Stator phase-connection conductor fatigue was one of several significant O&M issues mentioned by a central engineering staff engineer from a large owner/operator with seven copies of the affected air-cooled generator in its fleet. All of the units are coupled to steam turbines and are rated 21 kV, 313 MVA. The OEM did not participate in the STUG meeting.

Plant became aware of the problem in August 2010 following a stator-winding in-service failure. A root-cause investigation pointed to phase-bar resonance. The generator was repaired and returned to service, and an aggressive plan was implemented to inspect and repair all at-risk units in the fleet.

Solution was to repair damaged strands, where necessary, and improve the support-blocking arrangement for phase bars. The blocking mod has "evolved," the speaker said, and periodic maintenance is expected. Periodic assessments of generator condition now include natural-frequency testing. Plus, the company's M&D center has a program in place to warn of conditions that might lead to another failure of this type.

A review of operating data indicated a correlation between conductor fatigue and temperature. The OEM installed an RTD in six phase-lead slots (both top and bottom phase bars) on this model of generator. The RTDs installed in the slots closest to the first and last of the top phase bars revealed a temperature rise higher than that indicated by the other RTDs prior to cracked-strand repair.

Data recorded following repairs showed the temperature rise reported by each RTD returned to values consistent with the average of all 12 stator RTDs. The bottom line: There was a definitive correlation between loss of conductor cross-section and temperature rise under load.

Slides posted on the Power Users website describing the findings and work above contain well-labeled high-quality images of value to anyone considering a similar project.

Locating, correcting a generator stator ground

Another user reported on his 3 × 1 F-class plant's experience troubleshooting a stator ground on the steamer's generator and the corrective action taken. The steam turbine, with nearly 45,000 operating hours and 950 starts, tripped when the generator field flashed at 94% speed. Gas turbines were shut down and troubleshooting began about an hour after the incident. Generator lock-out/tag-out and visual inspection of principal components—exciter, power potential transformer (PPT), isophase bus (IPB)—were among the first actions.

Next, megger readings were taken on the generator, IPB, and step-up transformer (GSU). The PPT was disconnected from the IPB and assessed as "fine." The unsealed IPB was checked for water; it was dry and there was no sign of a ground. The generator-to-IPB flex coupling was disconnected, but the generator voltage couldn't be raised to check for a ground.

GE was called in and its technician verified a ground in the generator. The neutral bus bar was disconnected and all three phases meggered individually. Personnel found the A phase grounded; B and C were fine. The top and bottom bushings then were disconnected and they were fine; the ground was in the bars. The three sets of A phase bars were disconnected; two revealed grounds. Upper end shields then were removed.

Next, the field was removed and an El Cid test performed on the stator core. An acrid smell from an undetermined location was revealed. GE recommended a full rewind after finding grounded-bar insulation cut at the end windings; this was attributed to inward migration of the outside space block (OSSB).

The speaker continued by outlining the steps to replace the OSSBs, which included loosening the belly bands, removing the compression ring, replacing the OSSBs one at a time, reassembly, etc. To mitigate a recurrence of the failure, the following OSSB actions were implemented:

- Increase torque on compression nuts from 2000 to 2500 lb-ft.
- Specify a finer finish on the OSSBs.
- Add dovetail retaining devices in previously unused dovetails.
- Add a punching with master bond adhesive.
- Put a rounded edge on the compression ring.

Final segment of the presentation was a detailed account of the generator rewind using a series of about 20 photos; view them on the Power Users website. One suggestion for projects of this type is to be sure there's sufficient deck space before you begin. At this plant, every bit of space on a generously sized turbine deck (built out after commissioning), plus additional scaffolding, was required to do the job.

Another recommendation: Take care of your field by storing it out of the weather; keep it warm and dry using heaters and dehumidifier and a burlap cover. Megger weekly.

Switch from Fyrquel to EcoSafe® 46 reduces maintenance, benefits safety

A plant manager responsible for multiple 2 × 1 combined cycles in a desert location subject to periodic heavy rains and winds presented on several steam-turbine (ST) improvements. Most of his podium time focused on the installation of doghouses on the collector ends of the ST generators, and conversion from Fyrquel hydraulic fluid to EcoSafe® 46. New platforms for lube-oil/hydraulic skids to facilitate equipment access, plus sample-panel improvements, also were discussed.

Water intrusion at the collector end of one unit initiated a field ground which triggered the field ground detector causing the field excitation breaker to open. Low-cost remedies were tried first, but tape and other barriers installed to prevent water intrusion were not successful and a doghouse was installed over the collector end to achieve the desired outcome.

Experience with the original Fyrquel phosphate ester electrohydraulic control (EHC) fluid was not satisfactory. It has poor hydrolytic stability and reacts with water in the oil to reduce the fluid's effective lifetime.

The hydrolysis reaction, the speaker said, is not rapid at "normal" ambient conditions but accelerates as temperature increases (recall that this is a desert location) and is catalyzed by the presence of strong acids. Given a hydrolysis byproduct is phosphoric acid, the reaction is said to be autocatalytic (self-sustaining) and the reason for the neutralization filter loop installed in EHC systems.

EcoSafe EHC was said to be relatively stable and not subject to the degredation problems affecting phosphate ester fluid. In addition, the reaction products of EcoSafe EHC are weak organic acids, which are less aggressive than the acids formed during hydrolysis of phosphate ester. EcoSafe also contains beneficial corrosion inhibitors.

In addition, the speaker reminded that Fyrquel is a known carcinogen and removal from the site has a safety benefit. Also, he cited EcoSafe as being less expensive than Fryquel.

How to reduce steam-turbine outage time

The competitive nature of the generation business today demands relentless cost-cutting. One area power producers focus on is reducing outage time for inspection and overhaul. A user offered attendees several ideas on how to shorten a D11 outage based on his company's experience on three comparable outages involving a base scope of work with the following elements:

- Replace N2 packing box.
- Fix dished diaphragms.
- Inspect and repair steam-turbine valves.
- Conduct a steam-path audit.
- Re-align the steam path.
- Inspect and replace steam-path seals.
- Inspect and repair bearings and lube-oil pumps and motors.

The first of the three outages was conducted at a regulated plant in fall 2011 and lasted 60 days; the second at a deregulated plant in fall 2014 took 40 days (and this also included replacing one row of bucket covers); the third at a deregulated plant in spring 2015 took 30 days. Such progress piqued the interest of attendees.

Experience and better and more rigorous planning played a major role in the company's achievement. To begin, the same, highly experienced steam-turbine (ST) outage manager oversaw all three outages. Planning was conducted in great detail and involved experienced participants from both the owner and the OEM. This gave the owner a leg up on getting a commitment for outage support by one of GE's most highly regarded site technical teams.

Details, details, details: In one planning meeting involving the owner and GE, the speaker said the outage schedule was reviewed on an hour-by-hour basis.

An aggressive, confident plan in hand for the second outage, the owner purchased diaphragms in advance of the plant shutdown for ST stages having a high risk of dishing. Diaphragms removed were sent to a third-party vendor for restoration and stored pending re-use in the turbine serviced during the third outage.

A third-party services provider, equipped with a portable machine shop, was selected to supply and install gland and inter-stage packing and spill strips as needed. An alternative provider also was selected for tops-off laser alignment of steam-path components. Yet another third party provided a vertical boring mill to cut the radial root seals to the correct diameter and the steam-seal face to the proper thickness based on as-found condition.

The ST audit focused on performance losses attributed to both the thermal and structural condition of steam-path components—such as losses caused by damage to rotating and stationary blades, tip seals, packing seals, erosion, deposits, excessive clearances, etc. Recoverable losses include excessive seal wear, trailing-edge erosion of blades, and foreign-object damage. For each recoverable loss identified an estimated repair cost was calculated and an economic evaluation identified which repairs were cost-effective.

The speaker noted the value of diaphragm storage racks which the company had custom-built to facilitate NDE work and grit blast cleaning, optimize floor space, and minimize the need for cranes to move around diaphragms during inspection, cleaning, and repair tasks.

Installation of a temporary freight elevator from outside the ST building to the turbine deck reduced labor man-hours and provided a safety benefit over the use of stairs. Plus, spares were provided for critical valve assemblies to eliminate the need for conducting valve inspections and rebuilds during the outage.

Not following the normal practice of flipping over the HP shell also saved time. All diaphragm removal, stud extraction, NDE, and casing repairs were performed with the casing top side up. GE used a robotic tool to remove the diaphragms in the upper half; it offered both time and safety benefits.

Bonus/penalty arrangements are beneficial in most cases. The speaker suggested bonus payments be contingent on having no OSHA recordable violations, and no startup issues—including steam and oil leaks—as a result of poor workmanship.

Get quality intel before planning your next outage

An engineer representing a non-utility generator operating eleven D11s with CODs extending from 2000 to 2013 told the group that two of the units have completed second majors; four more STs are expected to have their second majors in the next few years. General fleet-wide experience was presented first: Water induction reported at a few sites has been attributed to failed attemperators, drains, and instrumentation. Plus, piping-system stress resulting from balance-of-plant ageing issues has caused D11 vibration problems, particularly during hot restarts.

Specifics regarding the two units with the most operating hours: Site 1 has no record of water induction ever occurring, but piping hang-ups during expansion/contraction were cited as the cause of high ST vibration. Greasing of slides reduced vibration from 8 to 3.5 mils.

At Site 2, plant personnel reported an increase in vibration in the high-/intermediate-pressure (HIP) section of their D11 during a startup in 2012, then reported they had experienced issues in the previous month or so which translated to two step changes in vibration level. A data dive was initiated and assumptions made based on unit history and experience to guide inspection planning. Some assumptions were correct, the speaker said; some were "educational."

Decisions made during the planning process included the following:

- Purchase buckets for HP stages 1-3 and have them on-hand before opening the unit.
- Have on-hand an N2 packing box of the latest design, plus IP stages 12 and 13.
- Make arrangements for bucket replacement, possible straightening, and balance.
- Expect major diaphragm repairs will be required for five stages.
- Prepare for a 60-day outage.

Inspection findings displayed in several photos reveal severe wear and tear of internal components.

Lessons learned and experience gained during the second major at Site 2 included the following:

- HP stages 1-5 had to be replaced, not just 1-3 (access the photos on the Power Users website and you'll see why).
- Major diaphragm repairs were required on Stages 1-13. Hindsight: It would have been less expensive to purchase new components before the outage, indicating the value of planning based on quality intel.
- All piping to the HIP case was disconnected, realigned, and rewelded.
- The actual outage ran 62 days.
- Vibrations started to increase when the 2 × 1 unit was put back into operation and cycled in a 1 × 1 configuration. The pipe hanger system is being evaluated for additional corrections.

Finding the source of valve issues can challenge experienced turbine engineers

An engineer responsible for the owner/operator's steamer fleet discussed experience regarding the failure of a main-stop-valve (MSV) pressure-seal-head (PSH) gasket.

The background: Unit was commissioned in 2004 and an issue-free valve minor was conducted five years later. Several months after that, the right PSH was found leaking. A major in spring 2012 revealed PSH gasket damage and the left and right gaskets were replaced. A month later, the unit experienced a stop-valve nut failure and gaskets were replaced.

Less than a year later, the right PSH was leaking again and the drain

GRiD TODAY

Editorial Staff
Bob Schwieger, *Editor*
bob@grid-today.com
Kiyo Komoda, *Creative Director*
Scott Schwieger, *Director, Electronic Products*
scott@grid-today.com

Business Staff
Susie Carahalios, Sales Director
susie@carahaliosmedia.com, 303-697-5009

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Telephone: 702-869-4739; fax, 702-869-6867

To cancel or change your subscription, write scott@grid-today.com

Serving the electricity

The electricity industry has reached a tipping point at which the distributed/transactional/no- or low-carbon electricity grid model begins to outrun the traditional bilateral centralized paradigm. The electricity "grid" is no longer a transmission and distribution system built so that monolithic regulated utilities can produce and distribute power to customers on a bilateral basis.

Technological advances and incentives (especially in solar PV, demand-side management, and distributed energy resources) at the distribution end, as well as "behind the meter," are driving utility customers towards onsite generation, microgrids, and net metering, leaving fewer traditional customers over which to spread the costs of grid upkeep. The promise of affordable distributed storage only aggravates the threats, or magnifies the opportunities.

The need for grid resilience is complementing the utility goal of reliability and quality of service. Businesses cannot afford to have their data networks, wireless communications, and digital service platforms disabled even for a few minutes. We have truly become a digital economy and electricity service has to accommodate the need to be "always on."

The emergence of commercially viable, scalable, and potentially cost-effective energy storage systems (beyond traditional pumped hydroelectric storage, PHS) changes the very nature of the grid, once considered the most sophisticated "just-in-time" industrial complex ever. Storage is like grain silos, underground natural gas storage, coal piles at powerplants, and Amazon warehouses. It allows electricity to be held as inventory. Storage also offers orders of magnitude faster response for grid disturbances.

Inventory and response means protection. Every business, in theory, can now protect itself against grid outages and transact with the grid in real time.

Energy storage is also changing the nature of the grid by forcing existing generating assets and options to get more flexible, too. The manager of a large Midwestern cogeneration facility told the editors his goal is to get at least part of this combined-cycle plant to function like a battery. The owners, he said, have made investments in new add-on equipment to do that and carve out a new revenue stream.

industry's next century

New peaking gas turbines are being designed to start and achieve full load in seven minutes, or less; new combined cycles have cut start times dramatically. The threat from storage to the gas-turbine world is real. Nothing changes overnight in the electricity business, but most everyone agrees that storage has become a new asset class, a force to be reckoned with.

Meanwhile, the independent system operators (ISOs) and regional transmission organizations (RTOs), created in response to FERC initiatives to deregulate electricity, are becoming platforms for wholesale and retail electricity transactions. Inventory, whether as batteries, PHS, compressed-air storage underground, or flywheels, or as natural gas sitting in the pipeline, is what makes transactions more fluid. Customers as small as homeowners selling their PV back to the grid, and as large as industrial complexes making good use of huge volumes of available fuel, now use the grid as a platform for buying and selling.

All this additional flexibility and responsiveness is critical because intermittent renewable energy (solar PV and wind primarily) keeps getting less expensive, carbon from fossil fuels keeps getting more annoying, existing coal plants are getting regulated into retirement, and new coal is a non-starter at least until carbon capture and sequestration (CCS) becomes commercial and economic, which is not expected for at least another decade.

The same companies that provide you stationary and mobile platforms for phone, email, Internet, and social media are driving a new portfolio of home energy management devices. Established solar PV suppliers are combining their offerings with storage, leasing systems, and shared savings in the incentives and rates with residential and commercial customers. They seek to get in between the utility and its customers.

GRiD recognizes the electricity business is becoming a network business. Our content goal is to provide news coverage, industry analysis, and, perhaps most importantly, owner/operator experience with these new systems, dynamic markets, and techniques for adapting traditional assets so they don't become irrelevant or replaced by the emerging asset class.

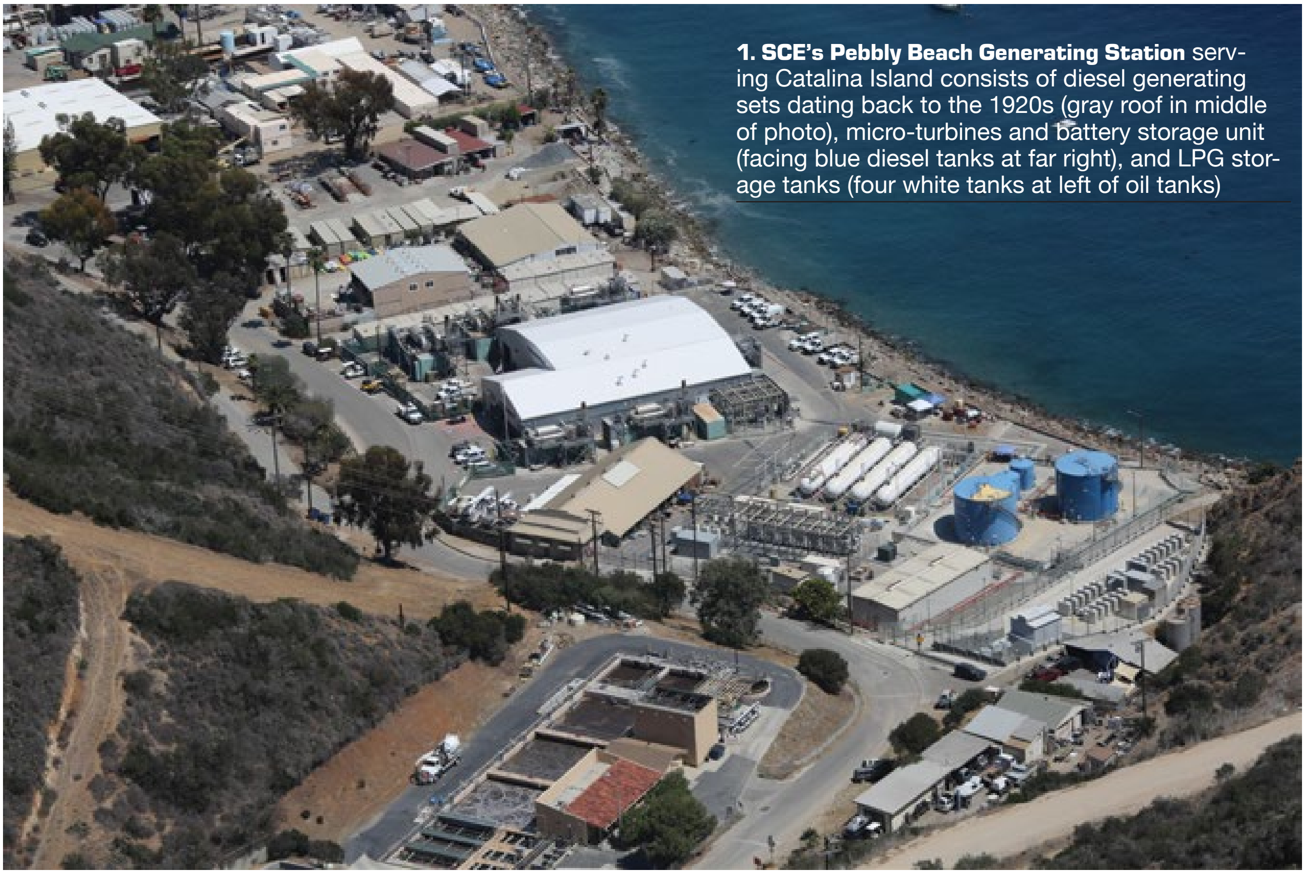
We will build on the legacy of the COMBINED CYCLE Journal, which recognized the dramatic displacement of traditional generating assets (coal, hydro, and gas/oil thermal plants) by the substantially more efficient advanced gas turbines. CCJ became the content provider trusted by users to the degree that most GT user groups allow only CCJ into their meetings to collect and disseminate the experience to the community.

Unlike other publications serving niche markets, **GRiD** is agnostic with respect to technologies and customers. We will cover the impacts of cycling supercritical coal-fired plants to "fill in" around wind equally with adding new storage assets for the same function.

Our content philosophy begins with the asset owner/operator who lives and dies with the equipment and the grid owner/operator which has to manage a resilient network and transactional platform while assuring the traditional "obligation to serve" is not lost.

We will bring our audience the latest in microgrid design and operations as well as experience with the fastest starting gas turbine/generators available on the market. We will cover the early experiences with the plethora of energy storage facilities now beginning to dot the most liquid electricity markets. In all cases, we will do so from an owner/operator perspective.

Welcome to the world of **GRiD**.



1. SCE's Pebbly Beach Generating Station serving Catalina Island consists of diesel generating sets dating back to the 1920s (gray roof in middle of photo), micro-turbines and battery storage unit (facing blue diesel tanks at far right), and LPG storage tanks (four white tanks at left of oil tanks)

Microgrid balances variable load, NO_x emissions by 'sculpting' supply

Southern California Edison Co's (SCE) Pebbly Beach Generating Station serving Catalina Island (22 miles off the coastal area south of Los Angeles) was a "microgrid" decades before the term became a fixture of power-industry lexicon. That is, it is an isolated small grid serving an island community (Fig 1), distinguished from the more modern definition of a microgrid which interfaces in real time with a larger interconnected grid.

As the South Coast Air Quality Management District (SCAQMD) progressively tightened regulations, complying with NO_x emissions levels, while meeting the extreme variable loads of the island's largely tourism-based economy, became at odds with operating a group of diesel engine/generator sets dating back to the 1920s.

With the addition of a set of propane-fueled micro-turbine/generators totaling almost 1.5 MW and a 1-MW battery facility (Figs 2, 3), SCE is now able to "sculpt" supply to meet the twin objectives of an onerous one-hour rolling average NO_x constraint across the diesel units and a load demand profile which can fluctuate from a 6-MW peak to under 2 MW as the island's population shrinks and swells from one to three times the permanent population of approximately 4000 residents.

In test work prior to the full installation, SCE proved that the Capstone Turbine Corp (Chatsworth, Calif) C65 engine favored for deployment could be successfully and reliably adapted to fire liquid propane gas (LPG).

Pebbly Beach is also a microcosm of the changing objectives of today's powerplants. If reliability has always been jobs one, two, and three, flexibility is quickly become jobs four, five, and six. The micro-turbines and the battery add new dimensions of responsiveness, especially now that the entire facility is being automated with an Ovation™ control system from Emerson Process Management Power and Water Solutions (Pittsburgh).

History

SCE added diesel sets as population—and popularity—of the island grew. The current fleet stretches back to the 1950s and consists of six units (Fig 4). The first installed is 1 MW, then came 1.125-, 1.4-, 1.5-, and 1.575-MW units, and finally a 2.8-MW engine/generator installed in 1995. Diesel fuel is stored in two 125,000-gal tanks, liquid propane gas (LPG) in four 80,000-gal tanks.

As a side note, LPG is vaporized and used directly in the micro-turbines; plus, SCE also supplies propane to island customers via an underground distribution system. LPG vaporized for customers is "cut" with air to better match the characteristics of natural gas.

The engines could ramp comfortably between 5% and 100% of their maximum continuous ratings (MCR), allowing a great degree of flexibility for meeting demand. Then selective catalytic reduction (SCR) had to be added in 2004. The SCR units require a minimum exhaust temperature, which constrained output above 80% of MCR. This made it particularly difficult to control the frequency and voltage of an island grid and still meet NO_x emissions limits.

Calling all units

Meanwhile, a little serendipity never hurts. SCAQMD had acquired and warehoused C65 micro-turbine units manufactured by Capstone and the agency was looking for places to use them. They suggested that SCE take 10 to offset emissions from the diesels when they had to cycle.

SCE's Ron Hite, facility manager, said they were willing to consider the offer but the reliability of the unit first had to be proven on LPG.

SCE agreed to take one unit and run it for two years. One concern: LPG burns significantly hotter than natural gas, which could shorten life from higher wear rates. Independent analysis, conducted by Regatta Solutions, San Juan Capistrano, Calif, confirmed at the end of the long-term test program, that the wear rate was no different than when firing natural gas.

"One component in the combustion chamber burned up," recalled Hite, "but the supplier was able to successfully redesign and replace the part."

I'll take twenty. SCE went back to SCAQMD and asked for as many units as the agency could spare. Ten would offset emissions, 20 would significantly reduce NO_x emissions.

So, SCE got twenty-three 65-kW units.

Unlike the diesels, they function as on/off devices. The diesels always stay within 80% to 100% of full load and the C65s meet demand or grid fluctuations in 65-kW increments. Think of a bicycle drive chain (well, most modern day bikes). The diesels are the big sprockets (usually two or three) in front, the C65s are the smaller ones in the back (usually six or seven).

"We run the heck out of them," Hite said, referring to the micro-turbines. The only unusual maintenance required is associated with the seaside location.

2, 3. Twenty-three 65-kW micro-turbine/generators (at left in enclosed area at center of photo) are located adjacent to the 1-MW NaS battery and power conditioning system (right). Close-up of battery and PCS is below. They allow SCE to optimize diesel operation to minimize emissions and more precisely respond to wide fluctuations in demand

"They are literally sitting in the salt spray of the ocean," Hite stated. "Electronic circuit boards for the controls can collect salt," he said, "and short out and subsequently we learned they have to be coated with a protective gel." Other than that, it's a pretty temperate climate so there's little concern about output deviations resulting from ambient-temperature changes.

There is a peculiar characteristic of these precise little units. They are lightweight and sensitive (see sidebar) to even the slightest excursion in grid voltage and frequency. Island demand fluctuates daily from 2 to 6 MW and there's a 300-kW load from a rock quarry and other industrial customers on the island. Thus, the C65s can easily trip offline and that's where the battery comes in.

Battery as fine chisel

The sodium-sulfur chemistry (NaS) battery supplied by Japanese firm NGK Insulators Ltd, Nagoya, Japan, together with a 1-MW Purewave™ power conditioning system (PCS, supplied by S&C Electric Co, Chicago), was installed in 2011 and offers another dimension for grid management.

A battery can function as load or supply. Kilowatts can be injected into the island grid at even smaller increments than the C65s for shaving peaks. The battery can discharge its *full load* within milliseconds. At other times, the battery can reverse and take load off the grid.

For example, noted Hite, late at night the island's demand can drop to 2 MW, the ragged end of the largest diesel's operating range. When this

Tech specs on the micro-turbine, storage units

Micro-turbine. Major components of the Capstone C65 (Fig A) are a compressor, recuperator (which recovers exhaust heat recycled to the turbine inlet), combustor, turbine, generator, and solid-state power conditioning system. The last converts the high-frequency AC engine output (spinning at close to 100,000 rpm) to standard 3-phase, 60-Hz AC for the grid.

As the illustration shows, the C65 has a single-stage turbine wheel with three air-lubricated bearings and an electronic gearbox. The shaft is the only moving part. Specifications for the low-NO_x turbine used in California include the following:

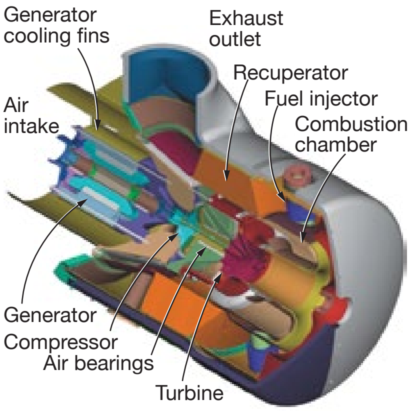
- Net power output, 65 kW.
- Net efficiency (LHV), 12,200 Btu/kWh.
- Net power quoted is available up to 70F ambient temperature. Output drops linearly to below 50 kW between 70F and 120F.
- NO_x emissions are less than 4 ppm at 15% O_2 (volume basis).
- Firing temperature, 1750F.
- Weight, 2400 lb (grid-connected version).
- Height, 103 in.
- Width, 30 in.
- Depth, 87 in.
- Recuperator materials of construction, stainless steel.
- Shaft (turbine, compressor, generator) speed, 96,000 rpm.

Battery. The roots of the NaS battery chemistry date back to the late 1960s when it was developed by Ford Motor Co. The version used in today's grid-scale systems has been supplied by NGK (although other sodium-based chemistries are available). Essentially, electrons flow between a sulfur cathode and a molten sodium anode through a beta alumina solid electrolyte (Fig B).

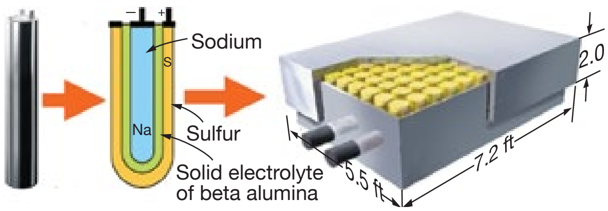
The general advantages of this chemistry are the high energy density (one of the highest of commercially available systems), low-cost materials, and relatively high cycle efficiency (Fig C). NGK claims approximately 85% DC-to-DC efficiency and 75% AC-to-AC efficiency. Performance is insensitive to ambient temperature in the range of -4F to 104F; 300 charge/discharge cycles per year at rated capacity should be expected, or 4500 over the life of the unit.

However, the sacrifices include operating temperatures typically much higher than competing systems to keep the sodium in a molten state. And as most former high-school chemistry enthusiasts recall, sodium reacts spontaneously and violently when exposed to water so the cell must be protected from any moisture intrusion.

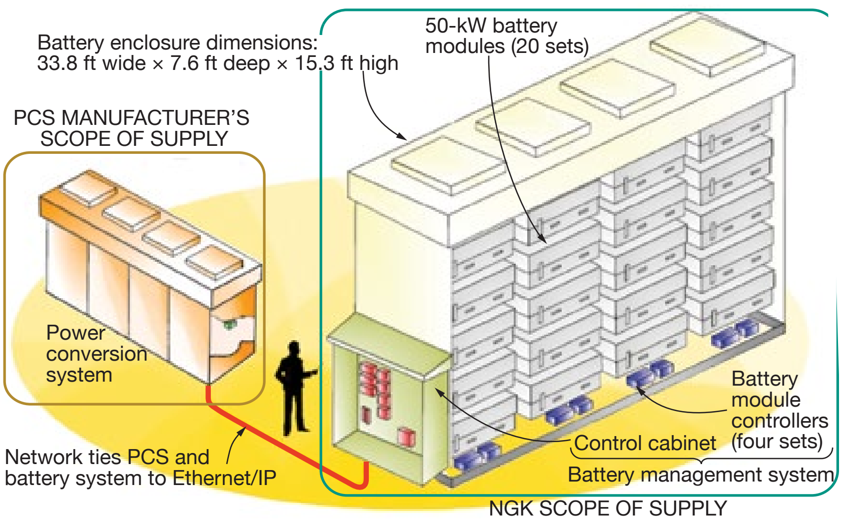
Like other battery chemistries, unwanted side products of the chemical reactions can build up and cause problems with corrosion and deterioration in efficiency. Others have reported that NGK solved the root cause of the catastrophic fire by adding fuses between cells, insulation boards between blocks in the modules, and anti-fire boards above and below the battery modules.



A. C65 micro-turbine has one moving part—the rotor. The design essentially mimics a single-stage jet engine



B. A single cell, the basic element of an NGK Insulator battery, is at left; a 50-kW module comprised of these cells is at right



C. Individual batteries in the NGK NaS storage system are arranged in modules of 50 kW each (Fig B); modules are slotted into an enclosure with controller boxes at the bottom. Diagram is of a 1-MW, 6-MWh system

engine drops below 1.95 MW, the urea pump for the SCR will cut out.

The battery allows for almost instantaneous incremental moves to push or pull power in these "dicey" operating moments—especially considering the NO_x-emissions rolling average. The same sequence occurs with the other diesels when they drop below 80% of their respective output curves. The battery adds emissions-free kilowatts during such disruptions and allows the engines to always operate within the optimum NO_x emission profile, even when charging the battery.

Pebbly Beach did get caught in the downdraft of NGK's catastrophic fire and recall of all its operating modules in 2011. "We had maybe the fourth or fifth NaS installation in the US," said Hite. "We were instructed by NGK to shut down the unit and keep it down until NGK could investigate the root cause."

They fixed the problem, re-engineered the system, and replaced all the modules at no cost. "The system has performed extremely well since," Hite stressed. Excellent performance

4. Diesel/generators, spanning unit sizes from 1 to 2.8 MW, were subject to ramp restrictions after SCR was added in 2004 for NO_x control

5. Substation delivers power to the island through three 12-kV circuits

is supported by 24/7/365 monitoring and troubleshooting provided remotely by NGK.

One characteristic of the NaS type battery (sidebar) is its high power density and long cycle time. At Pebbly Beach, the battery can deliver 1 MW for six hours, making it 6 MWh capacity.

Better control coming

Today the diesels are completely manually controlled. For that matter, so is the frequency of the grid, consisting of three 12-kV circuits (Fig 5). Historically, SCE has used the time error correction (TEC) technique dating back to the 1920s using a synchronous clock that runs off the island's AC power. Several times per shift, the clock is re-synchronized when the reading is compared to a far more accurate time reading from another clock tied to satellites.

The new Ovation system will integrate all the assets and provide full automation and information for grid management. Construction is expected to be completed in April (2016), with four months slotted for commissioning.

In considering best practices and lessons learned, Hite mentioned that microgrid owner/operators need to carefully consider inertia. Diesels are "big iron" and provide excellent rotating mass for frequency control. The microturbines are not so much, although Hite added that Capstone now sells a 1-MW machine. The other suggestion from Hite is to "thoroughly evaluate storage technologies for your specific application." Doing so may help avoid the knee-jerk decision to go with lithium ion, the option which lately has been sucking the oxygen out of the grid-scale storage sector. **GRiD**

pipe below the valve seat had ruptured. Mechanics found that both the left and right gaskets had failed and replaced them. Only weeks later, the right PSH was leaking yet again. In February 2015 an outage was taken to replace valve internals and modify stem leak-off piping. There have been no further issues to date.

A root-cause investigation revealed the pressure setpoint for the HRSG IP section was too high, causing the MSV to throttle to less than 20% open. Result: Severe turbulence in the valve.

In addition, the stem leak-off piping was routed to the drain tank rather than the steam seal header as the OEM's design handbook specified. Failure mechanism: During startup, the drain tank would overfill and condensate would back up to the valve through the leak-off piping causing the soft-iron PSH gasket to fracture.

D11 issues take center stage as users share O&M experiences

Issues with the GE D11 steam turbine, a popular machine with combined-cycle operators, took up a good portion of the air time at STUG. There was meaningful discussion among users throughout the meeting, enabled by way of an "audience polling" system.

While it may seem gimmicky, audience polling actually is a lightning-fast way to crowd-source responses among peers. If you had a burning issue with, or question about, your machine, attending the STUG and getting 50-100 users to address your specific concern in real time is probably in itself worth the time and expense of attending.

What follows are a few snippets from the discussion to illustrate the value of the user exchange at STUG and other user group conferences as well. Most D11 owners likely are familiar with N2 packing problems across the fleet. An attendee said that QA/QC procedures at the vendor's manufacturing facility were deficient during the height of the combined-cycle sales and installation bubble (1999-2004) and that the root cause was poor castings from Japan.

Another user talked about N2 packing head cracking and HP and IP shell cracking in a 1995 vintage machine. Regarding the former, the surprise was discovering cracks in locations different from those mentioned in the vendor's Technical Information Letter (TIL)-1627 R1—cracks visible to the naked eye.

Polling break: *50% of the attendees reported having experienced HP/IP shell cracking.*

Several users said they manage the N2 packing issues by having a spare or two handy. Depending on the types and location of cracks, repair can be two times the cost of replacement said one user who found cracks around the bowl in addition to the seat. GE's policy is that they will grind the cracks out but will not weld-repair them, with the possible exception, as noted by one user in the audience, of an excavated pressure tap crack.

Other users have done weld repairs, however, so the solution is anything but straightforward. But more frequent monitoring and inspection are necessary after repair. In one case, GE requires the heads to be inspected every year. Restrictions on performance are also possible.

Later in the day, the audience was treated to a visceral video of what happens when a D11 stop-valve head gasket fails. This presenter noted that there are lots of problems with these valves and lots of troubleshooting required.

In this instance, however, minor issues were precursors to the major gasket failure—including steam leak-off piping modified during a recent outage and incorrectly routed to the drain tank (rather than the steam-seal header). Also, IP pressure set point was too high, causing valves to throttle. Plus, the drain tank overfilled during startup and backed up to the stop valve. Pertinent as well is this 2 × 1 plant cycles twice daily.

The speaker added that there were several D11s in his fleet but apparently all of them are different enough that there is no interchangeability of components.

Another user with several D11 steam turbines in his company's portfolio discovered one rotor with a 17-mil bow in it six months after its second major outage. Apparent cause: Piping stresses from pipe-hanger issues. Other findings were both expected and surprising, he said. He also reported on water-induction-induced vibration damage to HP and IP turbine stages and dozens of major cracks found in a valve chest caused by water induction and aggressive day/night on/off cycling.

In a general session on HP and IP rotors, another user reported on a 21-mil rub-induced rotor bow which was subsequently spot heat-treated to get the bow under 3 mil. A snapped N2 packing box was the cause. Still another reported on a 14-mil rotor bow, which was mostly corrected with heating lathes.

Polling break: *23% of the users conduct a steam-turbine major inspection at six years or less, 26% between six and eight years, and 30% at eight years or more.*

During a discussion on turbine bearing failures resulting from lube-oil cooler leaks, a user stressed what a nightmare it is trying to rid LO piping of water. He lamented eight months of heartache from excessive amounts of water in the lube-oil system. An audience member warned that LO tanks sitting at low levels accumulate water, more so in high-humidity climates. One 10,000-gal tank holding 2000 gal of lube oil was said to have accumulated 1000 gal of water in only two years.

Other audience members offered these cautions:

- Always assume the worst of tanker trucks.
- Gasket areas and metal dips and joints are sources of gunk.
- Varnish can accumulate on the tank sidewalls.
- Lube-oil coolers can and will leak and the integral-fin variety are difficult to check through eddy-current testing.
- Rental chillers, especially if workers are unfamiliar with how they operate, used to maintain temperature while flushing, can shock a lube-oil system and knock gunk off the equipment.

Polling break: *43% of steam-turbine users perform main-stop-valve freedom testing daily, 38% weekly.*

One audience member asked about after-seat drain-line overheating following its mention in a presentation. In response, the organizers engaged their polling mechanism:

Polling break: *Only 13% had experienced this issue; 66% responded "no."*

Finally, there was an item of note from the session, "Future Outage, Maintenance, and Operational Challenges." One user highlighted her company's first use of a submarine drone to inspect cooling-water pumps. These have become critical reliability components as one user claimed the lead time for a replacement is six to nine months and the motor alone costs a quarter

of a million dollars. Plus, spares have special storage requirements. As one user put it, "it's not easy to store a 30-ft vertical pump."

Polling break: *55% of users apply condition-based evidence to the inspection interval for their vertical circulating-water pumps, while 34% base the interval on calendar time or operating hours, and 12% run them to failure.*

OEM presentations

STUG is a relatively homogeneous group and you might think an OEM should have no problem developing a technical program that would hold the interest of steam-turbine users for six hours. Not true, not by a long shot. First, and perhaps most importantly, plant personnel are not used to sitting for a couple of hours at a time, let alone six. And for many, "formal coursework" is under-appreciated. Then, too, every individual has specific interests given their position in the plant; information outside those interest areas will not get the attention it might deserve.

The STUG steering committee and the three turbine OEMs put considerable effort into compiling information for the 2015 meeting that collectively amounts to what you might get in a college course over a semester. If you were at the conference, perhaps you missed portions of presentations of value to you. If you were unable to attend the meeting you're probably unaware of what was presented.

Below are thumbnail sketches of the presentations—with some "nuggets" inserted here and there—so you can locate content specific to your information needs without clicking through hundreds of slides; speakers' names are in italics. There's a lot to gain by spending some time on the Power Users website reviewing presentations of interest.

Siemens

Steam-turbine maintenance and upgrade technology, *Jim Auman*

Slides illustrating stationary and rotating components—including details on integral shrouds, several airfoil shapes, different types of roots, control-stage technology, blade locking screws, seals (brush, abradable coatings, retractable), etc—would be of particular value to employees not having intimate knowledge of steam turbines.

Several slides familiarize users with mods and upgrades and their value. Capacity increases—as much as 6% in some cases—can be achieved via technology and flow upgrades, typically possible during an outage of from four to six weeks. Inspection recommendations and service bulletins addressing side-entry integral shroud looseness and the migration of free-standing L-1R were included.

Steam-turbine upgrade technology and recent project experience, *Mike Smiarowski*

Siemens has responded to grid demands for increased cycling and load-following with new components offering upwards of a 25-year lifetime, higher reliability, major inspection intervals for retrofits of 100,000 equivalent operating hours, partial-arc design for HP retrofits, etc.

The speaker reviewed some design features conducive to higher output—including improved inter-stage shaft sealing, twisted three-dimensional shaped drum blades, improved blade profiles, and changes to the shape and size of the last stage. Also mentioned were upgraded replacement steam chests and valve parts made of improved materials. Mods recommended for LP turbines include upgraded blade carriers, single-piece inner casing, optimized exhaust flow guide, integrally shrouded L-2R, and freestanding L-0R and ILB L-1R blades.

Benefits of ST and condenser upgrades for units rated between 200 and 900 MW are these, with the expected heat-rate benefit (typical) in parentheses: HP turbine (1.5%-2.5%); HP/IP (1.5%-3.0%); IP (0.2%-0.5%); LP (0.5%-2.0%); condenser (0.2%-1.0%).

The speaker also presented thumbnails of several rotor overhauls and the performance benefits gained, closing by stressing that advanced planning is critical to success.

Generator Footprint™ replacement, *Greg Palubin*

Generators can suffer all manner of wear and tear over their lifetimes. For units owners want to keep in service, but would require serious work to assure long-term reliable service, a total generator replacement may make best sense. Siemens offers a program whereby it will drop in a machine from any manufacturer provided its footprint is compatible with the foundation for the generator being removed. The company has experience in this regard, reporting success in more than 35 plants.

Here's how the process works:

1. Siemens engineers perform a site walk-down to collect electrical, mechanical, and foundation information.
2. The OEM's engineers analyze the data collected in the first step—that is, axis height, turbine thrust, foundation interfaces, etc.
3. Siemens collaborates with the customer to optimize its machine for future operation.
4. Siemens can support the project with service, project management, and parts from proposal to end-of-life.

Other presentation highlights included details on the company's Micalastic® insulation system, which is characterized as having high thermal stability and other benefits; global vacuum pressure impregnation (GVPI); rotor cooling scheme contributing to uniform temperature distribution and higher efficiency, etc. Basics of excitation systems, and cooling systems relying on direct/open air, totally enclosed water-to-air, and totally enclosed air-to-air heat transfer, were presented in a few slides.

Siemens Flex-Plants™, *Jacki Engel*

If you want to learn about the advantages of Siemens' fast-start/fast-ramp offerings for new combined cycles, this presentation satisfies that need.

Steam-turbine field service capabilities, *Gene Morgan*

More than half of Morgan's presentation discusses the company's processes to maximize safety, quality, productivity, and human performance; reviews its district office network; how Siemens works with owners as a partner; personnel capabilities and craft labor resources; and foreign-material exclusion program. Remainder offers one-slide service summaries for generators, valve refurbishment, fluid systems, NDE activities, lifetime assessments, and steam turbine and generator inspection, followed by similar capsules of capabilities in training, tooling, supply of critical parts, etc.

Steam-turbine factory service

This summary of shop capabilities focuses on the company's Charlotte facility, offering snapshots of products and services, lean manufacturing, workforce development (apprenticeship program, training, etc), tooling, and centers of competence for stationary parts, valves, rotors. About 30% of the presentation discussed factory service for gas turbines.

Combined-cycle generator fleet topics, *Scott Robinson*

If generators are among your responsibilities, this presentation is worth reviewing. Robinson stressed in his opening remarks that generators are designed to be very reliable; however, regular maintenance is required.

He reviewed industry-wide generator issues, including these:

Stators: End-winding looseness, cracks in copper bars caused by vibration, core looseness, damaged wall insulation in windings, hot spots in stator core.

Rotors: Damaged inter-turn and core slot insulation, cracked turns in end windings, rotor tooth top cracking, cracks in rotor wedges, J-straps, and poll crossover.

Next, Robinson showed users how to optimize outage intervals to achieve lowest maintenance expenses. Packaged in this section of the presentation were the work-scopes for minor, medium, and major inspections and sample schedules for integrating gas-turbine and generator outages.

What may be of particular interest to users experienced in generator overhauls is that Siemens has updated some of the maintenance recommendations they have been following for years. For example, wedge tightness testing has been removed from the minor-inspection scope, as have some electrical tests; a bearing insulation test has been added. For the medium inspection, bearing condition exams have been added and the bump test removed.

Siemens' Generator Lifetime Assessment was introduced to the group and described as a proactive outage planning partnership between the customer and OEM. Two important benefits are a reduction in the risk of experiencing an unplanned outage and optimization of technical and customer needs.

The focus of Robinson's discussion of top NDE solutions for combined-cycle generators was the company's FAST Gen℠ program involving high-resolution visual/video inspection; stator-slot wedge tightness test; and Siemens multi-frequency core assessment service.

An advantage of FAST Gen is its use of robotic inspection for proactive planning of generator maintenance and the gathering of inspection data for assessments, trending, predictions, and recommendations. Robots were said to reduce inspection time by up to 50% because disassembly is minimal. Retaining-ring inspections also can be performed in-situ with robotic tooling provided there is sufficient access space.

Robinson closed out his presentation with an overview of online monitoring and diagnostics capabilities—including such standalone instruments as a fiberoptic vibration monitor for end windings (now on nearly 200 units), radio-frequency monitor to warn of electrical arcing (now on over 300 units), and an active shaft grounding system (on 21 units). The company's power diagnostics center provides remote monitoring and daily analysis of any deviations.

MHPSA

It seems fair to say most owner/operators attending the 2015 STUG meeting knew more about GE and Siemens steam-turbine (ST) products and services than those offered by Mitsubishi Hitachi Power Systems Americas.

Mitsubishi has increased its presence in the Americas dramatically since the millennium. Organic growth was first. Market traction achieved, next steps included acquisitions (MD&A, Pratt & Whitney Power Systems); a merger with Hitachi involving the energy equipment businesses of both companies; and heavy investment in facilities, such as the sprawling Savannah Machinery Works, opened in 2011, which recently shipped the first US manufactured M501J gas turbine.

So it made good sense to start the MHPS track with an overview of the company's activities, and that was done quickly and efficiently in four slides. The opening presentation also got into technology, with an update on the company's 40-in. L-0 issue. Most ST users are aware that erosion is a common issue for all last-stage blades (LSBs), but some MHPS units with 40-in. LSBs observed higher erosion rates than others (not believed a fleet-wide issue). A few experienced shroud damage, which was attributed to the high erosion observed under the shroud on the leading-edge side of the airfoil.

The OEM's engineers were said to be working actively with individual users to monitor turbine-blade erosion. The latest design of the 40-in. blade (so called Type 3), provided to users experiencing unexpectedly high erosion rates, has Stellite welded to the shrouds. Periodic inspections are scheduled to verify expectations.

A quick update on generators in combined-cycle plants closed out the opening presentation. The company's 23 VPI air-cooled and TEWAC (totally enclosed water-to-air cooled) units generally were operating without issues, the speaker said. There have been no rotor rewinds, full or partial. However, two sites, each operating for about a dozen years, have required stator repairs because of partial-discharge damage.

Nearly three dozen hydrogen-cooled generators in service for more than three years were said to be operating without major issues. There have been no reports of core looseness, and no rotor rewinds (full or partial) have been necessary.

MD&A overview, *Chris Elmore*

If you're unfamiliar with MD&A, access this short (12 slides) presentation and quickly come up to speed. Elmore spoke from a bullet-point list of services and shop capabilities, including: generator services and stator and field repair capabilities, turbine repair facility, steam-path services, high-speed balance facility (located in St. Louis), field machining, valve repair, parts restoration, etc. He also introduced the group to Turbo Parts LLC, a unit of MD&A and a supplier of steam- and gas-turbine stationary parts and components—such as packing rings and spill strips.

Hardware, upgrades, and capabilities, *Mark Passino*

Chris Elmore introduced Turbo Parts and Passino, the next speaker, provided details on the company's expanded capabilities and improved lead times, thanks to a new facility in Danvers, Mass. The lead engineer for parts talked about upgrades for main-steam stop/control and other high-pressure valves, explained the company's packing wear assessment process, and custom bolting.

Valve repairs and capabilities, *Jason Wheeler*

Inspection and repairs—both in the shop and onsite—were the focal point of this presentation. Wheeler said the company's 2014 activities included servicing more than 220 valves from 40 units—mostly GE and Siemens (Westinghouse) bypass and main stop valves, but also ones from other manufacturers. Repair of large butterfly valves is another core competency.

Wheeler had separate slides with details on the inspection of stems, discs, and seats, as well as on the repair or replacement of stems and discs. He presented case histories on the re-machining of seating surfaces and determination of Flexitallic gasket crush, both in the shop and in the field, to correct leakage issues. Several slides on replacement parts/material analysis/weld repairs closed out the presentation.

Alignment methodologies and applications, *Peter Oehman*

The speaker began with a question, "Why align?" and then answered it:

- To correct bearing loading, thereby

reducing vibration and the chance of bearing failure.
- To correct misalignment caused by turbine foundation settlement.
- To minimize rotor stresses caused by improper bearing position.
- To prevent new seals from rubbing.

Oehman went on to describe the methods of alignment—a good primer for in-plant training. The methods he discussed were alignment bar, optical, tight-wire, lead wire, electronic radial alignment gauge/concentricity alignment tool (ERAG/CAT), and laser.

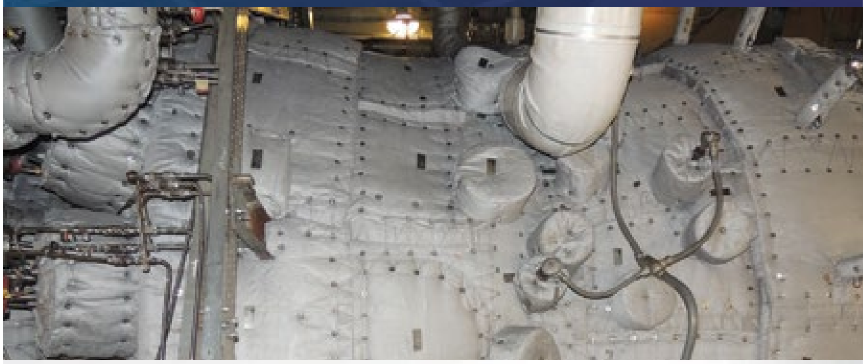
Next, the speaker talked about the importance of understanding shell distortion and how it affects alignment. As you might have known, proper alignment of stationary components with respect to the rotor is essential for efficient sealing of steam. Improperly aligned steam-path components reduce efficiency and increase the likelihood of vibration caused by rubbing. Be sure to consider the effects of piping forces as well; they can contribute to shell distortion.

Oehman closed by describing traditional types of alignments—tops-off and tops-on/tops-off—as well as MD&A's Topless Alignment®. The last was described this way:
- Centerline measurements are made tops-off.
- Shell horizontal joint distortion is measured and used to determine centerline component tops-on to tops-off movements.
- Calculated movements are used as offsets when aligning in the tops-off condition.

Turbine/generator vibrations, *Dr Michael Hine*

Hine began by listing the causes of unbalance: erosion, lost blade, bowed rotor, balance correction. He then presented a short primer that covered limits for pedestal and shaft vibrations, rotor position measurements, sub-synchronous vibrations, harmonics, and bowed-rotor correction.

This presentation probably would be of greatest value to someone familiar with turbine vibrations and looking for a refresher. Example: Oil whirl was one phenomenon mentioned. The speaker said it develops as a sub-synchronous vibration typically at 0.47 multiplied by the run speed; orbit diameter increases over time, tracking rotor speed (whirl). When it locks on to the system frequency (whip) the situation can become dangerous. One way to minimize sub-synchronous vibrations, Hine said, is to reduce fluid circulation in the bearing; changing the bearing design may be necessary.



D11R-HIP retrofit

Presentation began with a list of D11 issues that could compromise unit reliability—including shell and head cracking, rotor bowing, diaphragm dishing. One suggestion for avoiding these problems: Retrofit the high-/intermediate-pressure turbine with one using advanced technologies for the airfoils, rotor, diaphragms, etc, available from MHPSA. The speaker said benefits include a performance increase and reduced O&M costs. He closed by saying LP cylinder retrofits were available as well.

Generators, *Andrew Adam*

Adam identified the following issues with generators in combined-cycle plants that the GM of Generator Services said MD&A could repair easily—the first using a patented fix:
- 7FH2 spring migration. This problem affects the 7FH2 fleet with LCI start capability and is believed caused by heating and cooling cycles.
- 7FH2 and GE 324 dry ties.
- Alstom/ABB pole crossover cracking.

MD&A St. Louis shop overview, *David Rasmussen, PE*

Rasmussen covered much of the same territory as Chris Elmore (see above).

MD&A repairs, *David Rasmussen, PE*

Rotor bowing was the first topic introduced by the speaker. Bowing is created from surface stresses above the yield strength of the rotor material, Rasmussen said. Residual stresses must be relaxed, he continued, and if surface areas are rubbed and hardened, the excess hardness must be removed along with any surface cracks. Failure to remove excess hardness is conducive to rotor cracking and failure. The group was told MD&A's St. Louis facility is equipped to straighten bowed rotors.

Next topic: Defects in stationary parts for A13, D10, and D11 steam turbines—specifically N-2 packing casing (1) male and female fits and (2) distortion (out of round), and diaphragm dishing-deflection downstream. Each of these generic weaknesses (speaker's words) was described in detail with good photography. Then Rasmussen offered details on repairs the company uses to correct the issues; alternatively, it can supply new parts.

Last-stage-blade overview, *David Rasmussen, PE*

Challenges abound for designers of last-stage blades (LSBs), which are particularly important because they provide about 10% of the steamer's output. Consider the following:

- LSBs are the longest and most massive blades in the turbine.
- Natural frequencies must be dampened.
- They operate in a wet-steam environment.
- High-strength materials are required.
- They are subject to high- and low-cycle fatigue.

As a result, LSB's are expensive and delivery times are long.

Rasmussen identified the following design philosophies to provide frequency damping and discussed the generic weaknesses associated with each:

- Free standing vanes.
- Lashing lugs part way up the vanes.
- Grouped blade tips, up to continuous coupling.

He included in the presentation the generic weaknesses associated with finger-tip roots used on some long blades.

To accommodate the wet steam environment, designers consider such materials as titanium alloy, Jethete (a martensitic stainless steel), and 400 series stainless steels; plus, leading-edge erosion protection.

Remaining life assessment, *David Rasmussen, PE*

The speaker provided several summary slides identifying the data required to perform the necessary engineering and metallurgical analyses associated with a remaining-life assessment (RLA), and several more slides outlining both the specific analyses and tests recommended and the computational methods used to make the necessary calculations. For anyone contemplating an RLA, reviewing the dozen slides Rasmussen prepared is a good place to start.

General Electric

Helping achieve your desired outcomes, *Jamesetta Strickland*

General Electric packed a great deal of information into the nearly six hours the STUG steering committee allowed the company for its steam-turbine presentations. Sounds overwhelming, but the GE team divided the subject matter for each session into "bite-size" packages of technical information with hard starts and stops. This way anyone who needed a time-out would not come back into the room and be lost for half an hour or more. There was almost sure to be a new topic within 10 minutes or so.

The opening presentation was short and general enough so you didn't miss anything important while getting settled. Several slides outlined the important material to come—upgrades (enhanced steam path, HP/IP section replacement, OpFlex™ steam turbine agility, shell warming system), repair network, repair solutions, field force automation, etc.

Steam turbine maintenance, *Bill Girzone, Steve Walcott, Nick Giannakopoulos*

The thumbnails of GE Technical Information Letters (TILs) compiled by the trio of experts is of high value to (1) new plant employees trying to come up to speed on turbine issues they may have heard about, (2) those responsible for planning outages, and (3) experienced hands, as a refresher. The lineup of TILs discussed is below. If this information is insufficient for your needs, contact the plant's GE service representative for the complete document.

TIL 1943: LP rotor pin and cross-key staking. Applies to assembled rotors shipped during the 2005-2014 period. Issue: Inadequate staking of LP finger dovetail pins and cross-keys have shown potential for axial migration of pins/keys during operation which could lead to reduced overspeed capability.

TIL 1927-R1: Drain-line overheating. Addresses solutions to overheating events that have occurred in after-seat drain lines installed in some turbines with 9-in. main stop control valves (MSCVs). R1 of this TIL provides three new/modified recommendations of importance to users.

Lifting-beam modification TILs. Safety concerns impacting certain lifting-beam configurations are addressed in a series of advisories. A change in assumptions and calculations for some lifting beams in use resulted in lower safety factors than originally calculated. An existing TIL was revised and three new ones, plus a Product Service Safety Bulletin (PSSB), were issued to assure the safety factors desired. The documents of interest are the following:

- TIL 1926 R1, Lifting-beam mods for axial-flow machines with combined casing lifts.
- TIL 1956, Lifting-beam inspection for medium and large steam turbines.
- TIL 1957, Lifting-beam modification requirements for medium and large steam turbines.
- TIL 1959, Lifting-beam advisory for medium and large steam turbines.
- PSSB, Lifting-beam precautions for axial and down-flow medium and large steam turbines with combined casing lifts.

TIL 1940: N1 steam-seal packing axial clearances. HP steam-seal packing (typically R3 and R4) in some units has suffered axial rub damage during shutdown or warm/hot-restart. Bear in mind that severe rubbing is conducive to bearing vibration. Recommendation: Follow temperature-matching guidelines presented in GEK 110856.

TIL 1739: Main-stop-valve stem erosion. MSV stem erosion can lead to binding, failure, or interference with valve operation. Condition is attributed to impingement of iron-oxide particles on the MSV stem during valve throttling; exfoliation of HRSG tubing is the source of the particulates. Guidelines are presented for stem inspection, erosion mitigation, and stem replacement if necessary.

TIL 1629-R1: Combined stop and control valve seat liberation. Failure of the Stellite seat inlay in some main control valves has resulted in steam-path damage and, potentially, the loss of turbine speed control. Water induction/steam quenching and poor bonding between the Stellite and base seat material are the causes cited.

TIL 1531-R1: Disc cracks on 7-, 9-, and 11-in. main control valves. Cause is attributed to alternating stresses during specific valve throttling conditions. Recommendations regarding testing, replacement, etc, are presented.

TIL 1950: Valve operability, testing, and health. Important that turbine valves operate properly to prevent an overspeed event. Periodic testing and maintenance are recommended. However, it may not be possible to test valves on some units; many of those are in combined-cycle plants. Guidance is provided by the TIL.

Vibration, *Tim Maker*

Virtually everyone on the deck plates is aware that high vibration can trip their steam turbine, something no one wants to happen. Vibration has many causes and relatively few plant personnel have a strong background in its analysis to determine why it measures x in./sec today when it was fine yesterday. There's a gremlin at work in the minds of many. How many times have you experienced, or heard colleagues complain of, increases in vibration levels following an outage—even, perhaps, after a low- or high-speed balance?

Maker's presentation focuses on sub-synchronous vibration attributed to oil-wedge instability (whip/whirl) offering typical causes and corrective actions, and including a case history. The speaker's goal obviously was awareness and appreciation of vibration, not to teach the subject (there were only eight slides). Attendees at a general meeting like STUG tend to disengage from the speaker when the person at the front of the room believes he or she is presenting a "course."

Perhaps the most valuable part of the presentation, in addition to the practical review of oil-wedge instability, were the follow-on references suggested:

- GEK 100468 for journals 10 in. and smaller.
- GEK 100469 for journals larger than 10 in.
- GEK 111107 for rotors operating at 1500 or 1800 rpm.

Steam turbine lifing, *David Welch*

The life remaining in principal equipment—such as steam and gas turbines and generators—is a major concern of generation executives. How many years will my turbine last if we continue to operate the way we are today? What are our contractual obligations going forward? Can we meet them by changing operating procedures rather than investing in costly upgrades? If not, what upgrades do we perform and what will they buy us in terms of life extension? Questions such as these can adversely affect soundness of sleep.

Welch's presentation hit the highlights regarding lifetimes you can expect from principal components. It is compact, like the previous presentation by Maker, with only a dozen slides. But it is well organized and easy to navigate, enabling you to begin a checklist of things to do going forward to maximize the return on your assets.

The first section on stationary structures covers HP/IP shell casing lifing and distortion, HP/IP diaphragms, D11 N2 packing head repair verses replace, and MSCV castings. The second section focuses on rotating components, HP/IP blades and rotors, and last-stage-blade finger dovetail cracking. Field observations were presented and recommendations offered.

D11 HP/IP advanced steam-path retrofit, *Randy Tadros*

Siemens and Mitsubishi presented their retrofit/replacement solutions for the D11 on Wednesday (see above). Thursday was GE's time to review with attendees upgrades for its equipment. Once again, information was divided into digestible packages, enabling attendees to focus on what alternatives to consider at their plants. If any of the solutions described below are new to you, access the GE presentations on the Power Users website as a starting point.

Dense Pack™ retrofit, an HP or HP/IP solution, offered since 2000 and installed in more than 80 units, is said to resist degradation based on fleet-wide inspection results. It incorporates advanced aerodynamic buckets and nozzles, advanced sealing technologies and optimized clearances, and a rugged mechanical design. Benefits: Improves the efficiency of mature steam turbines, boosts profitability, and extends asset life.

HEAT™ steam-path retrofit replaces existing HP/IP sections on 60-Hz D11s, delivering up to a 2% increase in output via technology advancements using the same bottoming cycle. The "drop-in" turbine requires no modifications to the existing foundation. An example presented, involving a HEAT retrofit on a 255-MW unit (1800 psig/1000F/1000F/3 in. HgA) delivered a 5% increase in output, improved HP-section efficiency of close to nine percentage points, and improved IP-section efficiency by more than three percentage points.

LP upgrades discussed included section replacement with one delivering higher output, lower heat rate, reduced exhaust losses (longer last-stage blades).

Heating blanket, *David Welch;* OpFlex AGILITY™ combined-cycle startup enhancement, *N Piccirillo*

Most of the D11 solutions offered by competitors presenting on Wednesday, and those described by Tadros immediately above, involved major commitments in terms of schedule and cost. Welch's second presentation, together with Piccirillo's offered practical and affordable solutions for users wanting to start their steam turbines faster, and ramp up and down faster, all without adverse metallurgical and mechanical impacts. Benefits can be many, including less fuel burned, emissions reduction, increased revenue from participation in the ancillary services market.

Welch described heating blankets for faster starting/ramping, reducing the rate of cooling during shutdown/cooldown periods, and controlling top to bottom temperatures during shutdowns to minimize shell deflection.

Piccirillo explained to attendees how OpFlex AGILITY can be used to reduce the time for starts by optimizing the process and starting automatically (just a push of the "start" button). Best of both worlds: Combine blankets and OpFlex. A 2 × 1 plant manager in the Northeast recently told the editors he had both and was able to eliminate all cold and warm starts. Hot starts enabled the facility to start reliably in less than 40 minutes on a consistent basis.

D11 major best practices, *Merv Joseph and Ben Kazirskis*

The speakers focused on best practices for reducing the time required for a D11 major inspection—typically 45 to 50 days. They offered a checklist for better organization, and preplanning for non-standard scope, which reduced the MI outage to 29 days at one Latin American plant.

Repair technology, *John Sassatelli and Donald Blais*

In doubt as to what GE brings to the table regarding repair technology in the shop and onsite, and the outage support it can provide? Access this presentation. It was the longest in the GE program in terms of number of slides (plenty of photos on how specific jobs are done), covering the specifics of rotor-bow correction, typical rotor weld repairs, steam-path repairs, diaphragm cleaning and inspection, stress relief of welded bucket tenons in the field, stud hole restoration, coupling alignment, seal repair, etc. Special tooling was part of the presentation—including N2 packing head separation tool, shell key puller/snout pipe puller, and turning-gear drive as a backup for when the installed TG is out of service.

ST performance: Degradation mechanisms and quantifying losses, *Brian Marriner*

Good presentation for an in-plant lunch and learn. Buy a couple of pizzas and set up a projector in the break room. First part of the presentation covers the common causes of steam-turbine performance degradation—leakage, friction, and aerodynamic losses—and where to look for them. There are especially good photos showing how steam leaks by nozzles and buckets, across joints and seal faces, through excessive butt-gap clearances, etc.

Other slides will help your team differentiate among airfoil profile changes caused by small-particle impingement, foreign-object damage, deposits, erosion, corrosion pitting, and poor repairs. Such surface discontinuities contribute to performance-robbing friction and aerodynamic losses. An informed, motivated staff can provide specific information critical to maintenance planning, and for achieving performance excellence, that is difficult or impossible to get from PI data or the corporate M&D center.

A series of five slides provides perspective on the impact of bucket and nozzle surface roughness on efficiency loss in the HP and IP turbines, and on the loss of nozzle efficiency as airfoil trailing-edge thickness is reduced.

The third section on estimating the impact of performance losses was only a few slides long. The highlight is an equation for estimating output loss caused by stage efficiency loss. The actual kilowatt loss for a given stage, the speaker said, depends on the combined impact of the stage efficiency losses, the energy produced in that stage, and the location of the stage within the steam path.

The final section discussed recoverable versus unrecoverable losses. The former are losses recovered as a result of repairs/cleaning—such as replacement of worn/rubbed packing and or spill strips; the latter, losses remaining after repairs/cleaning are performed—such as inner casing distortion.

Generator maintenance, *Carlo Yon and Sherwyn Applewhaite*

Topics covered included were connection-ring tie systems, oil intrusion into hydrogen scavenging and purity systems, rotor removal during major inspections, ripple-spring wear into stator bars, and generator wedge tightness inspections.

GE has employed three connection-ring tie systems over the years. From 1970 to 2004, dry ties were used on model 7FH2 and 324 generators. From 2005 to 2012 it was consolidated dry ties for 7FH2, 324, and 330H generators. Use of this alternative was initiated as an improved bonding system by concentrating resin at the tie. In 2010, the wet-tie era began. Wet ties are used today on all 7FH2, 324, 330H, and 390H/450H generators. Tie system should be maintained in accordance with intervals prescribed in GEK103566 Rev J.

The practical section on hydrogen seal-oil ingress and system experience discusses issues such as seal-oil coking and contamination and recommendations for resolving issues.

The speaker stressed there is no fixed set of rules for rotor removal. Each unit and case is unique. The basis for a rotor removal involves consideration of rotor history and thorough visual inspection of stator and field. A slide likely of particular interest to most users presents the top five reasons for removing the field—such as operating with high vibration that worsens with load—and the top five reasons for leaving it in—including robotic inspection is capable of capturing all inspection points.

The importance of wedge tightness was covered in the last segment of the

PROFESSIONAL SERVICES

Plus new/used equipment, tools, parts

generator session. Stator wedges hold down stator bars in the slot to keep them secure and control vibration and greasing. Bear in mind that if vibration is not checked, insulation wear could lead to a short to ground. The speaker referred attendees to GEK 103566, which recommends wedge inspections during majors.

Vendor presentations

The success of a user group meeting depends on the steering committee's ability to attract meaningful participation by owner/operators, OEMs, and third-party equipment and services providers. For third-party participants, user groups generally are the most efficient way to reach customers. Most of these vendors are small, with a single salesperson (sometimes the business owner) and may not offer more than a couple of products and services.

For owner/operators, the evening vendor fair conducted at virtually all user-group meetings is the most efficient way to for them to touch hardware and learn about products and services of value that they might not hear about otherwise. Most groups also allocate time for presentations by third-party providers, which often provide more details than OEMs might. Obviously, that's because not-well-known companies must do so to pique your interest.

At STUG 2015, six vendors presented Tuesday, six Wednesday. Presentations were organized in two back-to-back 45-min sessions, each with three break-out rooms. The editors profiled six of the presentations below.

Extending generator service life, *Paul Heikkinen, TGM*

Heikkinen's presentation Tuesday afternoon was a welcome relief from the mind-numbing detail on shop equipment and workplace practices presented by some representatives of turbine OEMs earlier in the day. He knows the kind of information owner/operators need to grow in their jobs and delivered it without commercial interruption.

Heikkinen has been around gen-

erators and motors since he was a child, working in his father's electrical shop while others his age were out playing ball. The logical place to begin given attendee experience ranging from a year to decades is with exploded views of a generator rotor and stator so everyone was on the same page regarding nomenclature and how these critical components were constructed.

Logic also suggests that knowing what components can have the most significant impacts on generator life is a good place to begin your assessment of current condition and life expectancy. Heikkinen started with the rotor and showed that insulation deterioration is likely to drive its ageing. He quoted experts who said, "Insulation in service is exposed to high temperature, high voltage, vibration and other mechanical forces, as well as environmental conditions. These various factors act together and individually to wear out or age the insulation."

One of Heikkinen's slides identifies the Top 10 failure modes for generators. Missing from the material posted to the Power Users website is a supporting slide for each failure mode that digs into the details on how to identify that problem and mitigate it. Time constraints prevented the speaker from covering such details at the STUG meeting; it would have required a couple of hours.

Here's a snapshot of the information Heikkinen has compiled: The leading failure mode on the summary slide, thermal ageing of stator core, stator windings, and/or rotor windings, is caused by inadequate cooling. The supporting slide asks the following:

- *Why do I have this problem?* Possible answers include (1) heat-exchanger failure, malfunction and/or improper operation, (2) clogged air filters, (3) inadequate hydrogen pressure, etc.
- *How do I know I have this problem?* Possible answers include (1) elevated stator slot RTD temperatures, (2) smell of hot or burning insulation in air-cooled generators, etc.
- *How do I test for this problem?* Possible online alternatives include PDA, flux probe, ac impedance; offline alternatives include insulation resistance, polarization index, El CID, etc.
- *How do I prevent this and extend generator service life?* Possible courses of action: operate generator within design parameters, adjust operating parameters to compensate, etc.

Obviously, the support slides provide valuable checklists for finding the source, in this case, of inadequate cooling, for problem verification and for issue correction.

Access to Heikkinen's material can help you recognize emerging issues and extend generator service life through proper operation, routine maintenance, and quality repairs. For more information, email the speaker at paulh@turbinegenerator.com.

Roadmap to Mark IV/V control system survival, *Abel Rochwarger, GTC*

Rochwarger, Gas Turbine Controls' chief engineer, walked attendees through the company's program for keeping Mark IV and V control systems in service without compromising the availability and reliability of critical generating assets. He also discussed GTC's support network for the Mark IV, V, VI, and VIe.

A highlight of the presentation was the speaker's simple approach for determining how many spares of specific control cards to have on hand. His thinking: In a forced-outage situation, fixed costs apply, gas costs may apply (take or pay), and power may have to be purchased at a higher (spot) price to fulfill commitments. Easy to see how you might have a negative margin. The challenge: How to mitigate exposure.

Rochwarger showed users his ABC curve to help decide what is cheap to have and can save the day. You can plot the curve easily using the following information: Vertical axis is value, in percent; horizontal axis is items to procure as a percentage of the total number of items. Starting at 0%/0% extend a line through the following points: 70% value/20% items, 90/50, and 100/100. This defines the ABC curve. What you find is that 50% of the items you might ordinarily stock only have a 10% value for outage recovery.

Another consideration, Rochwarger said, is how many parts should the plant stock to be "safe?" He noted that a simplified statistical deviation based on a binomial distribution suggests as a rule of thumb the square root of the number of units in operation, "n." Correct application of the square root of "n" rule requires consideration of the costs of the forced outage and storage space, and projected inventory costs based on ABC curve results. Other variables come into play as well—such as the shelf life and warranty of critical spares. And, he reminded, don't forget common sense.

At that point in the presentation, Rochwarger tooted the GTC horn suggesting users evaluate supply-chain reliability as part of their analysis. He said GTC has an unparalleled inventory of Mark IV and V cards, cores, and parts ready to ship within 24 hours or sooner with circuit integrity confirmed by live panel test (purchaser gets a Certificate of Conformance). Emergency courier service is available, he continued, and field engineering service can be provided within 24 hours. Card repair and exchange services are available as well.

Rochwarger recommended a periodic health check for Mark V, VI, and VIe control systems. The typical exam takes two days per turbine, he said. Here's a short list of procedures carried out:

- Alarm troubleshooting and clearing.
- Verify control constants to specifications.
- DC power supply health check.
- File cleanup.
- Battery health check.
- Cleanliness/cooling,
- Junction box and terminal-board tightness check.

Among the benefits: long-standing issues are resolved, sequencing modifications are made, and a full report of the proceedings is presented.

New generators, old problems, *Jamie Clark, AGTServices Inc*

The title of this presentation was right on: The equipment problems of yesterday do recur in new plants. You can ask why, but not get satisfactory answers. The ageless generator consultant, Clyde Maughan, who began his career with GE, tells the story of being asked for his opinion on a particular generator problem and giving a quick—and correct—answer that left some very knowledgeable people stunned. The obvious question, "How do you know that?" The reply, "We solved that design problem in the late 1950s."

The point, of course, is that companies change direction and a lot can be lost in the process. In this instance, GE furloughed many hundreds of engineers to cut cost. The boss got to keep his job, but the product line suffered. Happens as well among plant owners, some of whom buy and sell generating assets willy-nilly; personnel get discouraged, the continuity of decision-making is compromised, and old problems are recreated.

Clark began with an overview of stator issues in the winding, core, end-winding support system, wedge system, etc. For the stator winding he covered the causes and effects of contamination, loose ties, broken ties, loose blocking, corona activity, and movement. Stator core issues discussed included contamination, loose through bolts, loose (or absent) belly bands, mechanical damage, and movement. Obvious is that contamination has negative impacts on all components. Clark had it at the top of his list of discussion items for the field, too. Others included blocked cooling circuits, turn shorts, field grounds, and loose blocking.

You can access a wealth of information on all the areas discussed by Clark with a keyword search at www.ccj-online.com. It's impossible to cover all that material here. But you certainly want to encourage plant personnel to access the speaker's presentation on the Power Users website. The six dozen photographs and illustrations presented are among the best ever seen by the editors. Their value in training new hires and for refreshing the recollections of O&M personnel before a generator inspection cannot be over-estimated.

Electromagnetic signature analysis testing, *James Timperley, PE, Doble Engineering Co*

The speaker, an IEEE Fellow, is recognized by colleagues as the "father" of the current approaches to EMI (electromagnetic interference) testing. Timperley spent the first 38 years of his career with American Electric Power, the last nine with Doble, which to date has applied EMI Diagnostics to more than 1150 generators, about 900 transformers, more than 600 bus systems, and well over 1000 motors.

The NDE technique has been used to support the need for condition-based maintenance of high-voltage (2400 V and above) equipment since 1980. It monitors radio-frequency (RF) energy from electrical activity at defects to detect and identify many types of system and equipment-related problems. Trending data over weeks or months is not required for accurate condition assessment. Non-intrusive data collection, in real time, while equipment remains in service offers economic and safety benefits to all powerplants.

Timperley reported that almost 80% of the components tested have revealed no problems requiring attention at the time of the test. This is good news because the test method allows users to avoid allocating maintenance resources for healthy equipment. EMI Diagnostics is efficient, providing maintenance recommendations with the first test.

The speaker reviewed some of the conditions identified via EMI Diagnostics—such as stator-bar slot discharges, loose stator wedging, winding contamination, exciter issues, etc. He then ran through 11 case studies attesting to the value of the technique—excellent material for an in-plant training program.

Here's one example Timperley presented: An inspection of connections in the grounding cabinet and at the generator neutral were recommended during the next outage. Operation without a grounded neutral is not advised. The old shaft ground was not working and a new copper braid was installed, eliminating shaft currents through the gearbox and inboard bearing. The carbon-shaft ground had not been maintained and no longer prevented shaft currents. The copper braid retrofit solution prevented additional bearing and gearbox damage.

Isolated phase bus inspection and maintenance best practices, *Gary Whitehead, Electrical Builders Inc*

High-voltage electrical gear has emerged as a top interest area among gas-turbine users. Whitehead called to the group's attention that the failure to inspect and maintain isophase bus duct (IPB) can lead to problems no plant manager wants. His presentation begins with the basics—a primer of sorts—to familiarize attendees having no experience beyond the generator with equipment that's important to know. This included an overview on the two basic types of IPB—continuous and non-continuous.

Whitehead then got into the causes of IPB failures and how to avoid them, the starting and ending points being a robust inspection and maintenance program. Safety is stressed; no one wants to make a mistake around live bus duct. Readers can access the complete presentation on the Power Users website.

Improving reliability, operator consistency, and efficiency for cycling CCGT plants, *David Davis and Ray Boucher, Real Time Power Inc*

A highlight of Davis' presentation was the company's automated software solution for computing the optimal run schedule for thermal energy storage (TES) systems in both day-ahead and real-time markets. The idea is to increase profitability by exploiting daily pricing patterns to chill water in off-peak hours and then provide turbine inlet-air cooling in peak demand periods to boost output and improve heat rate.

Davis said TES systems often are operated using default running schedules based on vendor design calculations, which do not account for the actual prices of electricity and natural gas, or weather conditions, or the thermodynamic state of the plant. The high variability in external and internal conditions during plant operation, he continued, implies that a fixed operating policy is sub-optimal in real-world situations. CCJ

Best Practices Awards

One of the biggest challenges facing owners and operators of generating assets in deregulated markets is the need to continually improve the performance of their facilities—to increase revenues and decrease expenses. One component of this goal of "continual improvement" is best practices. These are the methods and procedures plants rely on to assure top performance on a predictable and repeatable basis.

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, along with Waterside Power (TM2500), Ripon Cogen (LM5000), and Lincoln Electric System's Terry Bundy (LM6000) and Rokeby (GT11N1 and GT11NM) Generating Stations. **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).

The 3Q/2015 issue featured best practices from 11 more plants: two with 501G engines (Athens Generating Plant and Granite Ridge Energy); four with 7FAs (Faribault Energy Park, Washington County Power, Colusa Generating Station, and Essential Power Newington), and five with 501Fs (AMP Fremont Energy Center, Klamath Cogeneration and Peakers, Monroe Power, Lea Power Partners, and Hawk Road Energy Facility). Profiles of 2015 best practices concludes in this issue.

In this section:

Mid-Georgia Cogen

Logic upgrades improve emissions control during transients

Challenge. This 2 × 1 combined cycle, powered by Siemens 501D5A gas turbines, relies on Nooter/Eriksen HRSGs equipped with SCRs to limit NO_x emissions. The reagent is aqueous ammonia.

When the plant was commissioned, the control logic implemented relied on ammonia flow transmitters to hold NO_x emissions within the facility's Title V permit limits. The control-valve logic worked well when the plant was at full load; however, during transients it was unable to maintain emissions at prescribed levels.

Also, control-valve tuning problems often resulted in inefficient use of ammonia. The corrosive nature of aqueous ammonia was conducive to fouling of transmitter sensing lines, causing inaccurate flow readings.

Both conditions required personnel to manually operate the ammonia control valve to hold NO_x emissions in compliance. There were several instances when the failure of an ammonia flow transmitter nearly caused the plant to exceed permit limits.

Solution. Plant staff implemented tuning changes to control NO_x emissions using the analog output of the CEMS NO_x analyzer. Control-valve demand was tuned to account for the time delay that it takes the hot gas to travel through the HRSG to the NO_x analyzer probe in the stack and down the sample line to the CEMS analyzer. This tied the emissions control system to the monitoring system, creating a more reliable method for controlling stack discharges.

Results. Since implementing the logic changes, the ammonia control valves have operated in "Auto" with no operator intervention required to deal with logic-related equipment failures. Mid Georgia Cogen also has realized more efficient use of aqueous ammonia by maintaining the control valve NO_x set point closer to the Title V permit limit.

Project participant: Timothy Brooks Waddle Jr

Boiler-feed-pump seal-water mods

Challenge. The site relies on two Ingersoll-Dresser boiler-feed pumps (BFP) to supply water to the HRSGs' HP drums. The pumps depend on cooling water from the condensate system to lubricate and cool their mechanical seals. By original design, the BFP seal water was supplied via a manually operated valve.

Because operators have many duties during shutdown, the seal-water supply was not always isolated as soon as the BFP was secured. With seal water continuing to flow to a secured BFP, the mechanical seal would experience premature failure.

Solution. Plant staff replaced the manually operated seal-water isolation valve with an automated valve equipped with open and closed limit switches. DCS logic was developed for the automated valve to open with a BFP start and close with a BFP stop.

To provide confirmation beyond valve position, a downstream pressure switch was installed with feedback to the DCS. A manual bypass valve also was installed to increase reliability in the event the automated valve failed to open.

Results. By automating the seal-water isolation valves, plant personnel have eliminated premature mechanical seal failures. Plus, BFP reliability has increased because the control room operator has indication of seal-water valve position and confirmation of seal-water supply pressure.

Project participant: Keith Charles

Mid-Georgia Cogen

Owned by Southeast PowerGen LLC

Operated by Consolidated Asset Management Services

300-MW, dual-fuel, 2 × 1 combined-cycle cogeneration facility located in Kathleen, Ga

Plant manager: Keith Charles

Ferndale

Milestone: 1-million work hours without a lost-time injury

Challenge. Establish a safety program at Ferndale Generating Station (FGS) that goes beyond mere compliance and nurtures a culture conducive to eliminating at-risk behaviors and ensuring the safety of all personnel.

Solution. The FGS staff historically has maintained plant-specific procedures with the intent of going beyond basic compliance and including best practices where practical. Safety procedures are frequently reviewed against regulatory requirements and industry best practices to maintain a high standard. While holding to high standards, the plant has endeavored to keep the procedures and processes user-friendly to facilitate success at all levels.

Over the years, several safety practices implemented have contributed to enhanced plant safety, including the following:

- Development of a comprehensive confined-space procedures database.
- Development of an electronic LOTO-permit master database.
- Switching procedures to reduce/eliminate arc-flash hazards.
- Contractor EHS surveys to ensure safe contractors onsite.
- Contractor orientation program.
- Noise areas delineated for increased hearing conservation requirements: single protection (85 dBA) and double protection (100 dBA).

Ferndale Generating Station

Owned by Puget Sound Energy

Operated by NAES Corp

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

Plant manager: Tim Miller

- Use of SharePoint intracompany to share best practices and lessons learned.
- Plant-wide management-of-change procedures to include hazard assessment of significant changes, new processes, and non-routine tasks.
- Annual self-evaluations.
- Safety observation program.

With the goal of continuously improving its safety programs, the plant brought in the Washington State Div of Safety and Health (DOSH) for a voluntary compliance program in late 2006. The several items for improvement identified in the inspection were quickly addressed by the plant. An unexpected conclusion of the review was a recommendation by DOSH to apply for its VPP Star designation, as they believed the plant's thorough safety procedures and performance warranted it.

When DOSH's VPP team completed a formal assessment of the plant safety program, FGS was certified as one of about 30 VPP Star sites statewide. The Washington State program is considered more rigorous than the federal OSHA program based on its additional requirements.

The VPP team cited Ferndale's "employee involvement" as a "best-of-the-best safety practice." When DOSH completed a three-year on-site assessment in 2011, the plant was recertified as a VPP Star for the maximum interval of five years.

1. Ferndale plant staff is all smiles celebrating 1-million work hours without a lost-time injury

Results. Site safety best practices were identified by DOSH, leading to Ferndale's designation as a VPP Star in 2008. The VPP Star designation has been readily maintained to date. In 2014, the plant staff of 20 passed a milestone of 1,000,000 work hours (21 years) without an OSHA lost-time injury.

Project participants: The entire plant staff (Fig 1)

New operating practices improve superheater reliability

Challenge. Plant personnel had to find a way to manage the high-pressure (HP) superheater outlet temperature during a gas-turbine (GT) startup to avoid exceeding the HP steam temperature to steam-turbine metal temperature differential startup limitation without quenching and risking damage to the HP high-temperature (HT) superheater.

Since commissioning in 1994, the facility had experienced several HP/HT superheater tube-to-header joint failures (Fig 2). These were attributed to inadequate welding of tube-to-header joints.

More recently, while assessing data from accelerated plant startup testing, operators noted that the HP desuperheater control-valve outlet temperature was near saturation for the operating pressure. Review of plant-historian data revealed that the HP steam temperature downstream of the attemperator would commonly dip to saturation temperature during startup.

Further investigation revealed that there was no overspray protection in the HP desuperheater spray-valve control logic, which allowed operators to unknowingly overspray the steam beyond saturation. This design oversight in the original control logic potentially allowed exposure of the HP/HT superheater tubes to severe stress cycles from overspray quenching.

2. Tube-to-header joint failures in the HP/HT superheater were caused by desuperheater overspray

Solution. FGS staff developed and implemented desuperheater spray-protection logic to protect the HP/HT superheater from the risks of overspray. However, the constraints imposed by this new protection logic made it increasingly difficult for operators to meet the HP steam-to-metal temperature limitation required to start the steam turbine.

The solution to better control HP steam temperature was to limit GT exhaust temperature by maintaining a lower output—about 25% load—until the steam-turbine permissives were met and the machine could be started.

Results. Since the addition of overspray protection logic, there have been no further instances of HP/HT tube-to-header joint failures. Operators are able to control superheater outlet temperature with minimal (if any) desuperheater spray during steam-turbine startups by modulating GT load, thereby reducing cycling stresses on the equipment.

Project participants included Operations Manager Bryan Alexander

Drain-valve automation improves safety, reliability

Walton County Power LLC

Owned by Southeast PowerGen LLC

Operated by Consolidated Asset Management Services

440-MW, gas fired, three-unit, simple-cycle peaking facility located in Monroe, Ga

Plant manager: Mike Spranger

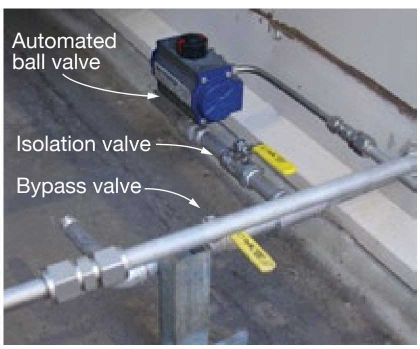
Challenge. During shutdown, Walton County Power's V84.3A2 gas turbines would trip when fuel gas transitioned into "diffusion" mode. During full-load operation, the units rely on the primary "premix" fuel supply, leaving the diffusion header, used only during startup and shutdown, with no flow.

Plant personnel learned that condensation accumulates in the gas piping and subsequently blows out the flame when the diffusion valve opens during shutdown. Heat tracing was installed on all the fuel-gas headers to reduce the accumulation of condensate. This helped to reduce trips during transition from premix to diffusion but did not completely solve the problem.

Operations staff improved results by blowing down the diffusion header. This was accomplished by opening the manual blowdown valve for a minimum of five minutes prior to the transition. The procedure proved effective in minimizing unit trips. Safety, however, was a concern: To access the valve (circled in Fig 1), operators had to crawl on their hands and knees under the running turbine and be exposed to very high noise levels, potential hot gases, and trip hazards.

Additional hazards included risks associated with hot piping, poor lighting, and potential eye injury from debris blowing under high pressure. In addition, the failure of an operator to close this valve prior to gas transition could result in high-pressure fuel gas being dumped into the turbine enclosure through the ½-in. valve.

1. Manual drain valve shown after new piping was installed. Original configuration blew high-pressure combustion air into enclosure and exposed operator to numerous hazards



2. New automated ball valve shown expels gases outside turbine enclosure and is controlled from DCS. Manual bypass valve and root isolation enable failsafe operation

Solution. The solution was established in two steps. First step was to immediately address the safety concern by installing piping to the outside of the turbine compartment and placing a manual blowdown valve outside the package for ease of access. The drain was put in a location away from heat sources, such as the turbine itself, and in a well-ventilated area so any gas that might be released would dissipate quickly.

The second step (Fig 2) was to install an air-operated ball valve and solenoid (normally spring closed). The DCS was configured with automatic control logic to cycle the valve at approximately 10 minutes prior to transition for a duration of five minutes.

The control room operator (CRO) also was given manual control of the valve via the HMI if the duration had to change because of ambient conditions. As a safety backup, DCS logic fails the valve closed at 100 MW under all conditions, providing a safe margin before diffusion gas enters the header.

Results. This approach allowed an immediate safe atmosphere for all personnel during the blowdown procedure. It produced a standard blowdown time which further reduced unit trips attributed to flame out. The CRO can now monitor the operation from the control room and release the outside operator to perform the numerous other duties required during unit shutdown.

Unit trips have been reduced dramatically, decreasing thermal and mechanical stresses on the gas turbines and thereby reducing equivalent operating hours and extending the time between major maintenance intervals. The total installation cost of this solution was \$228 per unit for a total of \$684 for the plant.

Project participants: Wes McMillian, Michael Gilbert, Charles Gibson, Scott Hobbs, Chris Harris

Jack County

Uninsulated valve cover is typical of the freeze-protection steps taken to assure high availability in wintertime

Winter weather readiness—Texas style

Challenge. Increased visibility of generating asset reliability in the Electric Reliability Council of Texas (ERCOT) system following a February 2013 severe weather event forced owners/operators to implement measures to improve winter operating reliability.

Preparing a generating plant for extremely cold temperatures, especially for the Texas plants that aren't built under shelters, requires extensive organization and preparation—weeks if not months in advance—and must account for permanent and temporary pipe insulation, shelters, heat tracing, heaters, and windbreaks. The sheer size of Jack County Generating Facility (1240 MW), and its significance to the overall ERCOT load, created many challenges to ensure all systems were "winter ready." Note that this plant's first 2 × 1 power block began commercial operation in 2006 (photo, above), the second in 2011.

Solution. Organization and division of responsibilities were necessary to ensure maximum achievability and reliability. A winter weather readiness procedure (sidebar) was authored and implemented to outline planning, readiness, reporting, and record-keeping responsibilities. A winter-weather readiness coordinator was identified and given responsibility as the single point of contact for the facility.

The planning phase is detailed through a winter-readiness planning schedule that lists specific actions, target dates, and department/supervisor responsibilities. All winter-weather planning and preparation is completed by November 10, followed by the submission of an annual "Declaration of Completion of Generation Resource Weatherization Preparations" as required by ERCOT by November 20.

Jack County Generation Facility

Brazos Electric Power Cooperative

1240-MW, gas-fired, two-unit 2 ×1 combined cycle, Bridgeport, Tex

Plant manager: Jeff Nottingham

Based on previous cold-weather events, a list of typical problem areas that have impacted operational reliability are identified below:

- Heat-trace systems failed or inadequate.
- Wind breaks missing or inadequate.
- Insulation removed, damaged, or inadequate.
- Instrument-cabinet or enclosure heating elements failed or inadequate.
- Freeze-protection support equipment or material not available.
- Pressure, level, and flow sensing lines not protected or inadequate.
- Instrument air system not properly draining and drying.
- Motor-operated valves, positioners, and solenoid valves impacted by ice buildup.
- Small-diameter water lines inadequately protected or drained.
- Ice accumulation at the entrance to the gas-turbine air inlet house.

Freeze-protection kits are stocked, inventoried, and sealed and stored in a location that allows easy access in emergencies. The kits contain heat-trace strips of various lengths, pipe-wrap insulation, extension cords, nylon tape, canvas tarps, receptacle box with GFCI outlets, propane bottles, a torch head, and triple flint spark lighter. The kits are designated for emergency use only and labeled accordingly.

Temporary wind breaks are constructed in areas that are prone to high winds. Temporary shelters are constructed around critical equipment to provide added protection. Portable heaters are staged at strategic locations and available for extended freezing conditions.

Freeze protection checklists and observational checks are initiated when ambient conditions fall below 40F and they are repeated every two hours. Additional staffing considerations are made when ambient conditions are projected to fall below 30F and high winds and freezing rain are likely. The DCS is configured to alarm at 40F to prompt further actions.

Graphical trends are configured in advance with critical instrumentation displayed to identify instruments that might freeze. Weather news and local radars are accessed through the Internet and displayed in the control room on overhead displays.

Additionally, the company broadcasts a live risk-level gauge that establishes maintenance and operational restrictions based on ambient conditions (specifically, green – no restrictions, yellow – some restrictions, and red – heavy restrictions). Challenging ambient weather conditions result in a higher risk potential, thereby eliminating any non-essential work activity.

A key component of the winter-weather readiness system is installing temporary protective covers on critical valves and instruments (photo). These covers prevent freezing rain and cooling-tower drift from accumulating on moving components to ensure continued proper operation.

The covers are made of uninsulated

Jack County's winter-readiness planning schedule

Action item	Responsible party
September 15	
Winter-readiness planning meeting (internal)	Maintenance supt
October 1	
Freeze-protection-kit inventory	Admin dept
October 15	
Portable gas-heater (torpedo) maintenance	Maintenance dept
Inventory warehouse freeze-protection consumables	Admin dept
Inventory winter personal protective equipment	Admin dept
Inventory freeze-protection fuel supplies	Maintenance dept
November 1	
Employee training on winter-weather readiness procedure	Supervisors
Install temporary heat tracing	Maintenance dept
Thermography of heat-trace panels and circuitry	Maintenance dept
Inspect transmitter-box heating elements	Maintenance dept
Stage freeze-protection kits in designated areas	Admin dept
Install valve and component insulating covers	Operations dept
Survey heat-trace panels and alarms	Maintenance dept
Facility winter readiness review	Supervisors
November 10	
All winter-readiness deficiencies corrected	All
November 15	
Install temporary wind breaks and canopies	Maintenance dept
Air-dryer preventive maintenance	Maintenance dept
Winter-weather readiness evaluation	Maintenance supt
Facility winter-readiness meeting (external)	Maintenance supt
November 20	
Submit ERCOT "Declaration of Completion of Generation Resource Weatherization Preparations (Winter)"	Plant manager
Weekly	
Inspect freeze-protection kits	Admin dept
Inventory fuel levels	Maintenance dept
Ambient below 40F	
Conduct freeze-protection checks	Operations dept
Severe-weather events	
Evaluate additional staffing needs for severe weather	All

silicon cloth containing a draw string for closure and access to gauges and labeled for identification and costs are minimal. The covers have proven to be highly effective in areas where heat trace and temporary enclosures are not practical.

Another important area of winterization is the gas-turbine inlet-air cooling system and auxiliary systems. While chillers aren't used in winter, proper layup is crucial to their summer readiness.

At the close of the winter season, temporary wind breaks, shelters, and equipment covers are removed and stored. Additionally, the winter readiness coordinator maintains a lessons-learned log listing winter readiness deficiencies and subsequent corrective actions taken. This information supplements the existing action plans and aids in staff training and further preparedness.

Results. Departmental assigned responsibilities, a well-defined procedure, and a collaborative group effort have resulted in a high degree of system protection, increased employee awareness, and program ownership, resulting in no freeze-related incidents since February 2013 and ultimately 100% winter reliability.

While the annual cost of ensuring winter readiness is substantial, the expenditures far outweigh the cost of non-conformance or unnecessary forced-outage time. The winter weather readiness program's success has significantly improved the reliability of the facility as well as the ERCOT system.

Project participants:

Troy Cannon, operations superintendent
Carl Raines, operations supervisor
Rod Irion, shift supervisor
Brian Ash, maintenance superintendent
Greg Peterson, maintenance planner
Lori Roberts, office supervisor

Hartwell

1. Making the workplace safer by facilitating access to equipment. Generator terminal enclosure before stairs were added is above; after, right

Improve access to generator terminal enclosure

Challenge. Critical gas turbine and generator systems were difficult to access as the plant was designed (Fig 1, left). It also was challenging to safely carry tools and other equipment necessary for troubleshooting. Delays in repairs had been experienced because of the need to mobilize additional equipment and resources to allow for safe hand off and retrieval of tools. These delays contributed to an increase in forced-outage time and adversely impacted availability. Also, on more than one occasion, a safety near-miss had been realized during this evolution.

Hartwell Energy Facility

Oglethorpe Power Corp

300-MW, gas-fired, two-unit simple-cycle peaking facility located near Hartwell, Ga

Plant manager: Mike McCollum

Solution. Remove old ladder arrangement and replace with new 4-ft-wide stair design (Fig 1, right).

Results. Results have included safer

2. Rusty Donald, Debra McKee, Mike McCollum, Rich Wallen, and Kenn Pittman display Hartwell's Best Practices Award

Fleet-wide initiatives at OPC: Continual training, knowledge transfer

Challenge. An ageing workforce, together with changing technologies in new and upgraded control systems, have helped Oglethorpe Power Corp (OPC) identify opportunities to ensure that the expertise and capabilities of plant personnel continue at the levels the company requires. Oglethorpe's pursuit of operational excellence demands collaboration and creative and innovate techniques to assure the leveraging of all opportunities to provide value-added training, retention, and knowledge transfer.

Solution. Develop scenario-based simulator training with the OEM's help; conduct week-long drill exercises for associates yearly. Training incorporates lessons learned from the industry and prior site-specific events, as well as other purposely designed scenarios to challenge operators in a controlled learning environment. This also provides the platform for engaging discussions of the teams involved and further encourages knowledge transfer among associates.

Results. Results have included reduction in unit trips, runbacks, and equipment challenges. Level of knowledge and retention among associates continues to grow, together with teambuilding and passage for daily checks in the generator terminal enclosure. This has also been realized in repair time on generator gas detection systems, turning-gear operations, and generator purging activities. Another unexpected result has been in outage time/resource/manpower reduction as this system has allowed for a decrease in person hours for maintenance activities because no lift is needed for tool and equipment loading and offloading.

Project participants: Plant Manager Mike McCollum and Technicians Andy Wiltshire, Brad Jordan, Greg Gillespie, Rusty Donald, and Kenn Pittman

Jim Messersmith, senior VP plant operations, and Rich Wallen, CT fleet manager, accept Best Practices Award for Oglethorpe Power Corp

cohesiveness. Many intangibles which cannot be quantified definitively by communications and knowledge-sharing also have improved dramatically.

Project participant: CT Fleet Manager Rich Wallen

Oglethorpe CT Fleet

Oglethorpe Power Corp

Chattahoochee: 458-MW, gas-fired, 2 × 1 combined cycle (Franklin, Ga)

Doyle: 487-MW, gas-fired, five simple-cycle units (Monroe, Ga)

Hartwell: 300-MW, gas-fired, two-unit simple cycle (Hartwell, Ga)

Hawk Road: 487-MW, gas-fired, three-unit simple cycle (Franklin, Ga)

Talbot: 668-MW, gas-fired, six-unit simple cycle (Box Springs, Ga)

Thomas A Smith: 1250-MW, gas-fired, two 2 × 1 combined-cycle units (Dalton, Ga)

Michigan Power

Inspect HRSG boiler drums to prevent failures

Michigan Power

Owned by ArcLight Captial

Operated by Consolidated Asset Management Services

154-MW, gas-fired, 1 × 1 combined-cycle cogeneration facility located in Ludington, Mich

Plant manager: Ken Tomaski

Challenge. Michigan Power LP (MPLP) is a baseload cogeneration facility. During a major inspection in September 2013, the HP boiler was inspected for flow-accelerated corrosion (FAC) by HRST Inc. Inspectors noticed a rust bloom indication on the lower part of the HP drum head-to-shell weld.

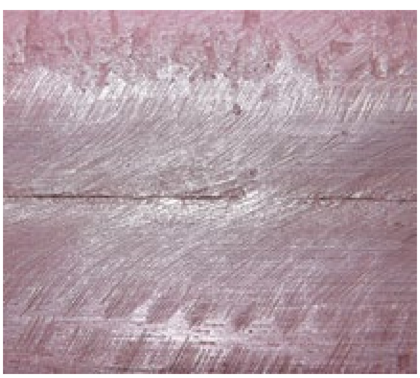
Further investigation revealed multiple circumferential cracks or linear indications running along the head-to-shell weld on the internal surface of the drum. HRST recommended performing NDE on the indications and to consider checking the lower portion of both head welds plus the full circumference of both downcomer nozzles.

The plant hired JANX to mag-particle test the area of interest. It found a linear indication on the lower half of the HP drum, from about the 3 to 7 o'clock position (photo). This area then was inspected ultrasonically. Results: The indication was approximately 1.1 in. deep (the parent metal is 4-in. nominal) and 104 in. long. Inspectors also found a smaller linear indication approximately 3 in. long from the 8 to 9 o'clock position.

Solution. A boat sample was taken from the HP drum linear indication. It contained a portion of shell base metal, weld metal, and head base metal. Next, Stress Engineering Services Inc and GE Water Technologies performed a metallographic analysis of the boat sample to identify the damage mechanisms that caused the cracking.

Both companies said the drum cracking likely was caused by corrosion fatigue—the combined effect of cyclic stresses and corrosion. There was no evidence of high-temperature damage, such as creep.

MPLP doesn't believe that the indications were the result of cyclic stresses. Data indicated cool-down and warming conditions were well within the manufacturer's recommendations and the water chemistry for the unit has been exceptional. Cracks in these areas are not common for baseload plants and are more common in cycling plants. The HP-drum linear indication seemed to be a linear crack along the head-to-shell weld.



Crack-like indication was revealed by wire-brushing

The linear indication was properly ground out to parent metal, x-rayed, heat treated at 400F as suggested by Deltak, the HRSG manufacturer. The unit was welded by a boiler and mechanical contract company, using an applicable ASME weld procedure and x-rayed to complete the weld process.

Results. JANX x-rayed all head-to-shell welds in the drum; no other indications were identified. After finding the linear indication along the head-to-shell weld in the HP drum, both the HP and LP drums were completely checked with mag particle to make sure there were no indications with either drum.

A hydro test was successfully performed on the HP drum before returning the boiler to service. A preventive maintenance (PM) plan was created to mag particle the HP and LP drums during upcoming minor and major outages.

Recommendation to others: Check all boiler drums with mag particle or dye penetrant during your plant's first outage and create a PM to check drum welds during future outages—this no matter what the operating regime and pre-commissioning inspection results.

Project participants:
Anthony Peplinski, plant engineer
Dan Cox, EHS specialist

Digital rounds offer quick problem identification, one-click historical trending

Challenge. Many devices and systems around the powerplant do not have instrumentation and it is essential for operators to take readings and check equipment at least once per shift to identify possible issues. Rounds were previously taken on sheets of paper attached to a clipboard, making it difficult to research the historical data for a particular piece of equipment.

The plant had been using a PI historian which could view historical information for all instrumented field devices. The main challenge was to manually collect data from field devices that did not include instrumentation, archive and be able to trend these data, then determine trigger points where action would be taken for corrections.

Solution. A handheld, ruggedized, weather-resistant Microsoft Windows device was deployed as a solution. The software called PI Manual Logger was installed on the mobile device and on a desktop computer in the control room. A stylus is included, but one-handed operation can be used for entering field-device readings.

The handheld device includes a docking station and an extra battery; the docking station is connected to the desktop via a USB cable. The PI manual logger software is configured to connect and archive data to the corporate PI server. Operators carry the handheld device when they make rounds and after returning to the control room dock the device and download data to the PI server.

A specialized Microsoft Excel workbook was developed and includes the PI datalink add-in software to import the logged points from the server. High and low tolerances were developed for each point being logged and when the point is outside of the tolerance the conditional formatting colors the cell to indicate an abnormal condition (Fig 1).

A pre-made trend file is written for each data point and a hyperlink in the Excel file opens the trend with one click. The previous 300 days of logged data is instantly displayed in the trend (Fig 2) and additional analysis can identify if a deficiency is present. If a deficiency is identified, a work order can be logged in the CMMS for maintenance actions to be taken.

Management and engineering also have the ability to open the specialized Excel workbook to perform their own analysis of the rounds data collected.

Results. The digital rounds recorder was quickly adopted by plant operators at the Nueces Bay Energy Center. Although the old paper recording method is available in the event the digital rounds recorder fails, a failure has not occurred in over a year.

The baseline normal operation for the recorded field devices has been identified and operations and management staff appreciate the ability to quickly record, trend, and analyze data from equipment without field instrumentation.

Future enhancements of this technology may include instant update via wireless connection and the ability to take pictures, mark them up, and send them to the control room to report potential issues.

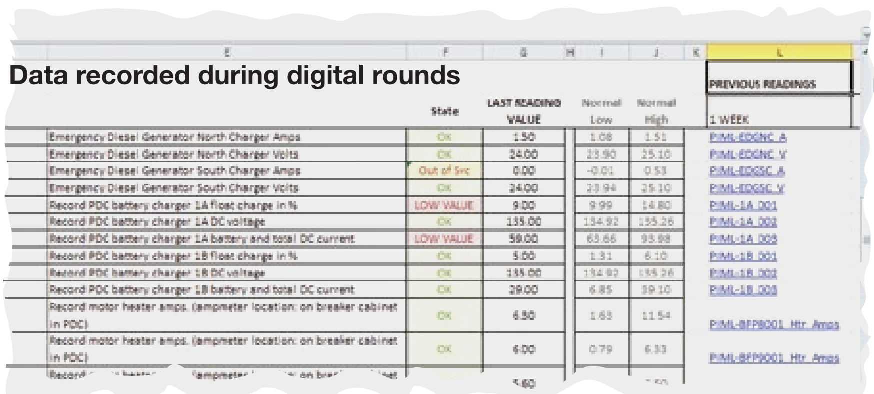
Project participants:
Eric Mui, senior ICE tech
Vanessa Garcia, plant engineer

Nueces Bay Energy Center

Topaz Power Group

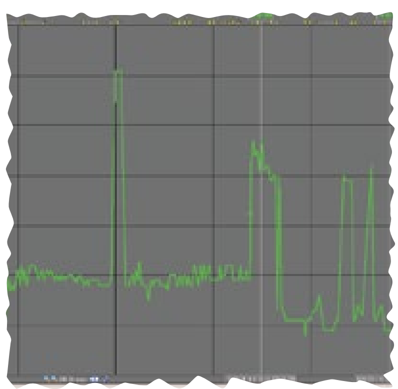
648-MW, gas-fired, 2 × 1 combined cycle located in Corpus Christi, Tex

Plant manager: Norm Dupperon



Data recorded during digital rounds

E	F State	G LAST READING VALUE	I Normal Low	J Normal High	L PREVIOUS READINGS 1 WEEK
Emergency Diesel Generator North Charger Amps	OK	1.50	1.08	1.51	PIML-EDGNC_A
Emergency Diesel Generator North Charger Volts	OK	24.00	23.90	25.10	PIML-EDGNC_V
Emergency Diesel Generator South Charger Amps	Out of Svc	0.00	-0.01	0.53	PIML-EDGSC_A
Emergency Diesel Generator South Charger Volts	OK	24.00	23.94	25.10	PIML-EDGSC_V
Record PDC battery charger 1A float charge in %	LOW VALUE	9.00	9.99	14.80	PIML-1A_001
Record PDC battery charger 1A DC voltage	OK	135.00	134.92	135.26	PIML-1A_002
Record PDC battery charger 1A battery and total DC current	LOW VALUE	59.00	63.66	93.98	PIML-1A_003
Record PDC battery charger 1B float charge in %	OK	5.00	1.31	6.10	PIML-1B_001
Record PDC battery charger 1B DC voltage	OK	135.00	134.92	135.26	PIML-1B_002
Record PDC battery charger 1B battery and total DC current	OK	29.00	6.85	39.10	PIML-1B_003
Record motor heater amps. (ampmeter location: on breaker cabinet in PDC)	OK	6.50	1.63	11.54	PIML-BFP8001_Htr_Amps
Record motor heater amps. (ampmeter location: on breaker cabinet in PDC)	OK	6.00	0.79	6.33	PIML-BFP9001_Htr_Amps
Record [illegible] heater [illegible] (ampmeter [illegible] on bre[illegible]	[illegible]	5.60	[illegible]	[illegible]	



1, 2. Excel workbook reveals imported data points recorded in the field (left). The state of the alarm can be shown to indicate a value outside the normal tolerance. A trend file was created for each collected data point. A hyperlink in the spreadsheet file can be clicked and the trend for the previously recorded values can be analyzed quickly (right)

Paris Energy Center

Paris Energy Center
Owned by Viva Alamo
Operated by NAES Corp
260-MW, gas-fired, 2 × 1 combined cycle located in Paris, Tex
Plant manager: Mark Vest

Warehouse inventory control

Challenge. Paris Energy Center's annual inventory counts were taking two to three days to complete. Plant personnel wanted to simplify the process and reduce the amount of time to complete the count while considerably reducing the variance in the overall inventory.

Solution. To simplify the process, bar codes were added on all asset containers. Each bin of small items, such as specialized bolts and nuts, were counted and placed in a sealed bag and the counts noted on the bags' exteriors. This enabled the procurement specialist to process inventory by simply walking down each aisle monthly looking for open bags, indicating a recount was necessary. By year's end, all inventory had been counted at least once and was ready for the overall annual count.

Results. Total annual inventory counting time has been reduced to half a day; variance reduced to zero. This approach also ensures that parts are always available when needed.

Project participant: Gayle Foster

Noise reduction in steam-turbine area

Challenge. Plant was experiencing significant noise. It interfered with operations and was a safety hazard. When on or around the steam turbine deck, personnel noticed that multiple exit points of pressure during startup caused serious vibration and generated a noise level that was hazardous to hearing and made radio communications all but impossible.

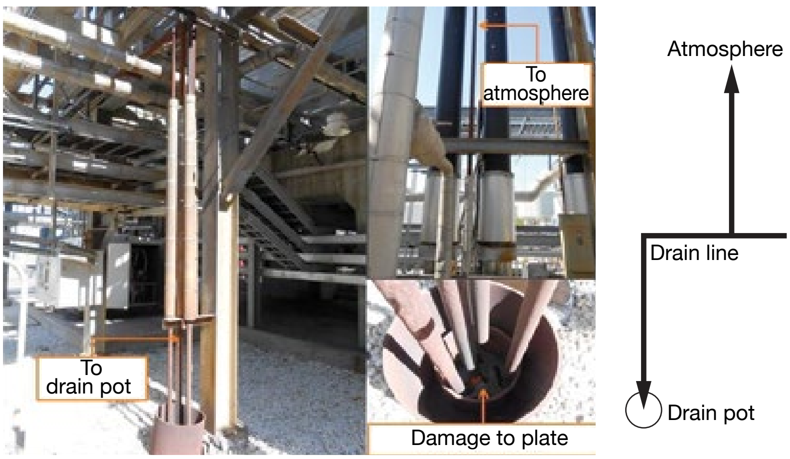
Safety concerns:
- Calculated unsilenced noise was 161.3dB, significantly above the safe-hearing threshold.
- Double hearing protection was ineffective in reducing noise to a safe level.
- Heavy vibration was experienced on the steam-turbine deck.

Operational concerns:
- Communication via radio in the area was affected dramatically.
- Noise had warranted complaints from surrounding facilities.

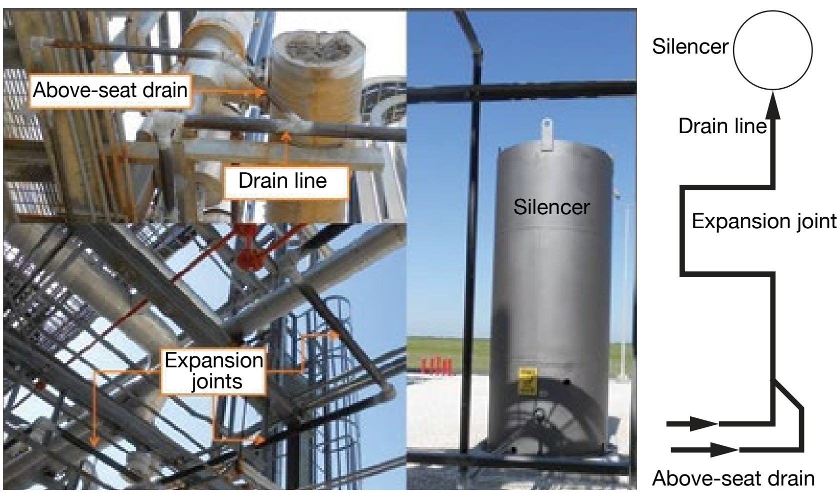
Solution. In order to reduce noise and vibration in the area, a silencer was installed on the ground level that was large enough to address all targeted pressure exit points. Piping was rerouted from these points to the silencer (figures).

Results. After the silencer was installed and targeted piping was rerouted, the following improvements were noted:
- Noise reading was reduced to 97.7dB.
- Double hearing protection was no longer required.
- Vibration on steamer deck was reduced significantly.
- Radio communication with plant personnel operating on or around the steam-turbine deck was no longer affected.

Project participant: Casey Johnson



Redesign of drains system (before, above) and addition of a silencer (after, below) dramatically reduced noise in the steam-turbine area



MEAG Wansley Unit 9

Owned by Municipal Electric Authority of Georgia

Operated by NAES Corp

503-MW, gas-fired, 2 × 1 combined cycle located in Franklin, Ga

Plant manager: Tim Williams

Simple solution to prevent air accumulation in LO pump discharge line

Challenge. MEAG Wansley had to implement GE Technical Information Letters 1919 (Gas turbine lube- and seal-oil pump discharge check-valve modification) and 1903-R1 (Steam turbine lube-oil system emergency standby pump outlet check-valve modification) without pulling the pumps or drilling holes in the check valves as suggested by the OEM to remove air that could accumulate in the pump casings and discharge lines and impede operation—while still meeting the design intent of the recommended mods.

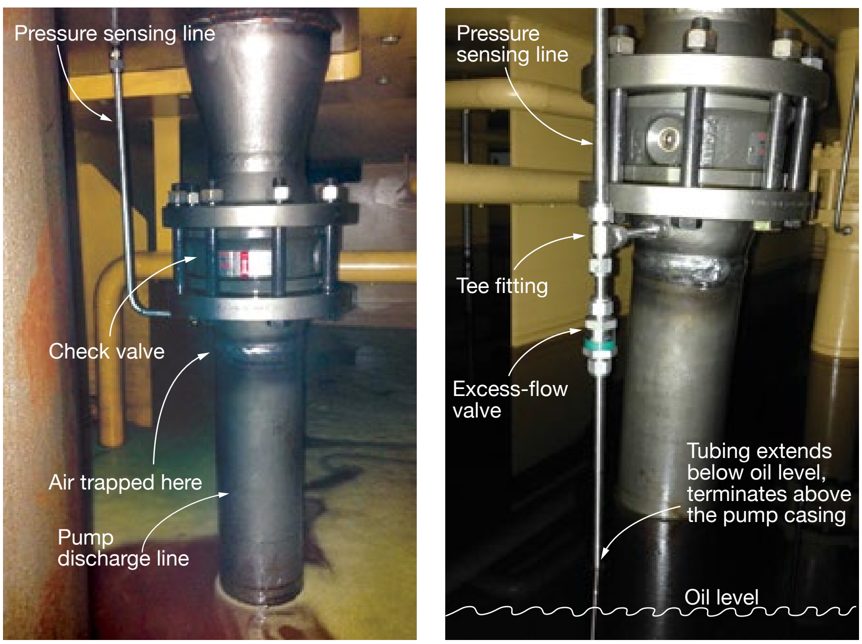
Access to the lube-oil pumps is limited at Wansley by an air-cooled heat exchanger located directly behind the accessory module. Removing the pumps to perform this mod would require a crane to lift them over the heat-exchanger module. The cost of implementing this TIL by removing the pumps and drilling holes in the check valves was estimated at about 100 man-hours plus $2500 crane rental.

Solution. Plant personnel opted to use the existing tap on the pump just upstream of the check valve to remove any air trapped inside pump discharge line (Fig 1 left). This tap was installed as a sensing line for pressure instruments.

Without removing the pump, plant personnel accessed the existing tap and sensing line through the explosion relief door on the side of the lube-oil reservoir. They then installed a tee in this line and connected the open port of the tee to an excess-flow valve that discharges below the lube-oil level but above the level of the pump casing (Fig 1 right).

Note that an excess-flow valve is basically a self-resetting circuit breaker for a fluid line. It will allow a certain amount of flow, but once that amount is reached, the valve closes. After the system shuts down and the pressure equalizes, the valve reopens.

The excess-flow valve allows air to escape from the pump while not running—thereby preventing the pump from becoming air-bound—but closes when the pump starts, restoring the normal function of the sensing line.



1. Before and after photos show the original arrangement of the lube-oil discharge piping at left and the simple mod at the right to protect against air-binding of the pump

Results. Staff was able to install the modification through the explosion-relief door on the side of the accessory module/lube-oil skid. The pump was started and stopped several times to verify proper operation of the sensing-line instruments and excess-flow valve.

Personnel are confident the pump will not become air-bound while on standby.

Using this approach, the entire job from start to finish took approximately four man-hours and cost less than $300 in parts—a saving of 96 man-hours and $2200 over the alternative solution using the crane.

Project participants: Matt Engelbert and James Jensen

Larger mixed-bed bottles reduce ergonomic risks

Challenge. MEAG Wansley's water treatment system, as designed, incorporated sixteen 3.6-ft^3 mixed-bed bottles, which typically required offsite

2. Original arrangement of 16 mixed-bed bottles jammed in a stationary truck trailer (left)

3. New arrangement has two easily accessible mixed-bed cylinders (right)

regeneration every two months. The 50-in.-high × 14-in.-diam cylinders, located inside a stationary truck trailer, were difficult to handle safely. Employees were exposed to multiple ergonomic risks—including strains, slips, trips, and pinch points.

The physical arrangement (Fig 2) required plant personnel to disconnect the 270-lb bottles and move them manually 10 to 15 ft for forklift access. From this point, operators would boom the forklift over piping to lift the bottles to ground level. The procedure was reversed to install regenerated bottles—essentially doubling the work time and hazards.

Solution. Staff research suggested a switch to 34-ft³ mixed-bed tanks. Two such tanks provide the same capacity as the 16 original mixed-bed bottles. Plus, installation of the larger tanks in an adjacent building removed the hazards associated with lifting the bottles from the trailer (Fig 3). Inexpensive PVC piping connects the two locations; an array of valves and quick-connect hoses facilitate installing the tanks for service.

Results. The new mixed-bed tanks are accessed by way of a roll-up garage door. This allows forklift access for replacement, thereby removing ergonomic risks associated with the manual handling of mixed-bed bottles.

A large saving in man-hours was also realized; the new mixed-bed tanks can be exchanged by one employee in 30 minutes. Previously, two employees required six hours to exchange the 16 bottles. Technicians appreciate the reduced exposure to ergonomic and safety hazards. System capacity and regeneration cost remained the same.

Project participants: Dana French, Ryan Haas, Dennis Flecker, and Matt Engelbert

Measuring emergency eye wash and shower pressure

Challenge. All industrial facilities are required to conduct weekly inspections of eye wash and shower stations in accordance with OSHA 29 CFR 1910.15 and ANSI Z358.1. Does your equipment meet the standards established by these regulations? Is the flow at least 20 gpm at 30-90 psig? Can this pressure/flow be sustained for 15 minutes with both the eye wash and shower operating simultaneously?

Like many multi-tenant facilities, MEAG shares with others a common utility service, potable water supply, etc. During a recent inspection, a local operator noted that shower pressure "appeared" to be low after approximately one minute of run time. Testing confirmed that suspicion. On a side note, the site routinely loses potable water when repairs are underway or a power failure occurs.

Solution. A simple but reliable method was devised to test the flow rate. Four 55-gal drums were secured to a pallet for ease of movement, and a lightweight aluminum sheet was used to direct the flow of water into the drums. Using a stopwatch and tape measure, depth in the barrel was measured at the end of each minute over the duration of the 15-min test.

Dimensions of the container and simple calculations provided total gallons-per-inch and flow rate. Tests were conducted at multiple stations around the site, and the results were surprising. Flow was less than 9 gpm (half the requirement), and water pressure at the inlet point dropped from 113 to 19 psig when the shower/eye wash station was activated.

4. Flow test is conducted on emergency shower

Results. When appropriate notifications were made to the host facility's engineering department, a follow-up investigation revealed a similar problem at another combined-cycle unit immediately adjacent to the MEAG site. Piping repairs restored full pressure and flow of potable water, but this alone does not guarantee availability of water during maintenance or power outages.

Because of this, the site's chemical unloading procedure was also updated, instructing site personnel to verify proper flow and operation of the eye wash and shower before any work involving hazardous or caustic chemicals commences.

Lessons learned indicate that when

testing emergency equipment, subjective procedures should be reviewed and checked periodically—not only to assure compliance but to protect personnel.

Project participants:
Danny Fowler, EHS manager
Matt Engelbert, plant engineer
Ryan Haas, operator

Plant lighting upgrades

Challenge. Plant lighting usually is taken for granted, except by the individuals who have to service the fixtures. Some are located in hard-to-reach places that require a ladder or man-lift. Repair of high-pressure sodium (HPS) fixtures in difficult locations can expose technicians to multiple hazards—elevated work height, weight of the component, risk of electrical shock, among others.

The hinged cover for one of MEAG Wansley's original HPS fixtures weighed 29 lb and had to be raised vertically to access internal components for repair. Since no support was provided for the raised cover, the technician had to remove it completely to perform repairs. Staff decided to investigate ways to minimize safety and ergonomic hazards and, at the same time, increase reliability and cost-effectiveness of plant lighting.

Solution. Research identified outdoor LED lighting as a promising solution. The LED fixture that best satisfied plant needs weighed less than 15 lb and featured a horizontally hinged cover requiring no support when open.

Not only would this eliminate lifting and holding a 29-lb hinged cover, but the LED fixture considered reportedly would outlast the HPS lights by more than 2:1—50,000 service hours versus 20,000—and consume 85% less power for equivalent output.

Results. Technicians appreciate the reduced exposure to ergonomic and safety hazards afforded by the new LED fixtures. In addition, their longer lifetime, lower power consumption, and less frequent maintenance requirement offset the cost of replacing the fixtures in the near term and reduce annual operating costs for the remainder of the plant's service life.

Project participants: Tim Williams and Bert Wright

How poor gas baffling affects HRSG performance

By Anand Gopa Kumar, HRST Inc

Editor's note: Gas-baffle failures are common yet often overlooked during HRSG inspections and maintenance programs. Most failures are from operational wear, particularly coil-to-coil baffles in the middle of the unit. Failures in evaporators and economizers have the largest negative impact on performance.

Although cycling adds to thermal stress throughout the combined-cycle system, other equipment issues can contribute to thermal stress and decrease performance regardless of the operating mode. One category is gas-pass baffling within the HRSG.

To make a distinction, the gas-turbine exhaust first encounters flow distribution devices, such as perforated plates or guide vanes, within the HRSG inlet duct. They direct the gas flow primarily for optimal performance of duct burners and emissions control equipment.

Properly designed gas-pass baffles are arranged to prevent gas flow from bypassing the tube bundles (superheater and reheater, for example) and to maximize heat transfer.

Baffles are simple yet effective devices. They must also be sturdy and properly arranged to accommodate thermal expansion.

Even small gaps impact performance

Small gaps allowing bypass of turbine exhaust gas are sometimes overlooked in HRSG inspection and maintenance programs, or perhaps in the original design. Properly placed baffles redirect the gas into the intended path thereby allowing the heat-transfer surfaces to absorb the maximum amount of thermal energy from the gas flow (Fig 1). Improper gas baffling can cause bypass around the tube bundle and create damage that decreases performance (Fig 2).

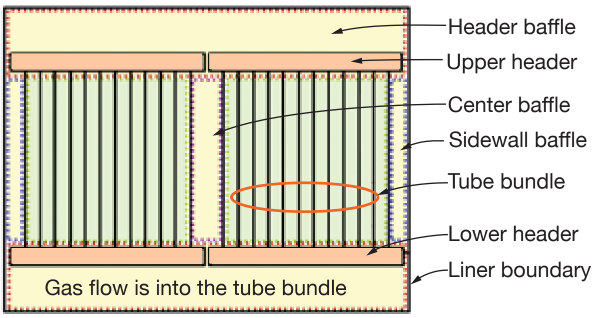
The lack of gas baffles can leave gaps between the tube bundle and the casing wall or between the left and right hand side of the tube bundles (coil to coil). The lack of resistance allows the gas to flow faster through the openings and reduce heat transfer.

The panels with heat-transfer performance most affected by gas bypass are evaporators and economizers. Additionally the thermal energy not absorbed by the evaporators is absorbed by the economizers thereby increasing the potential of economizer steaming and other damage, including flow-accelerated corrosion (FAC) and wall thinning.

Case studies

The table compares the performance characteristics of an unfired HRSG operating behind a GE 7FA gas turbine in a 1 × 1 baseload combined cycle, both with and without baffling in the gas path. The results were obtained with HRST's in-house HRSG performance modeling software Performance Pro™.

The performance model was set up for an ideal case where an HRSG with



1. Proper gas-path baffling for HRSG tube bank pays dividends in performance

2. Missing or poorly designed gas baffles are show in the top row, solutions in the second row

Impact of gas-side baffles on HRSG performance

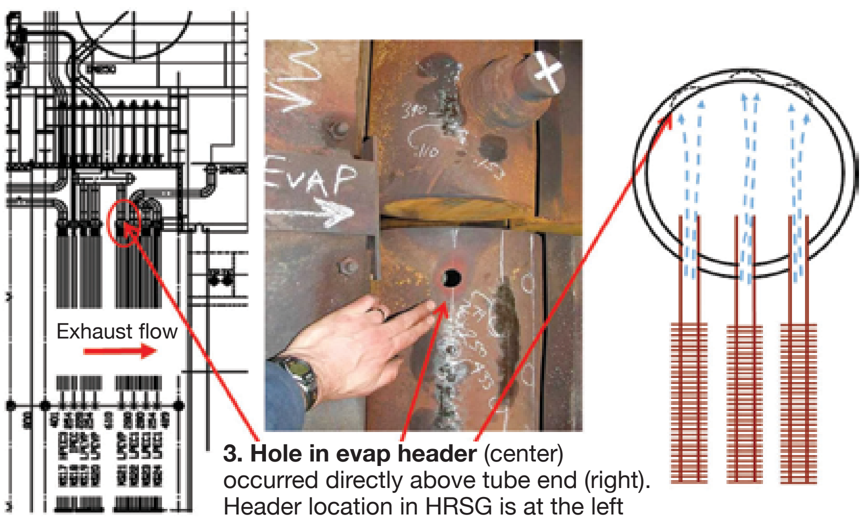
	HPSH	HP evap	HP econ	RH	LPSH	LP evap	Total HRSG	HP	RH	LP	Output
	Thermal duty, million Btu/hr							Steam flow, 1000 lb/hr			MW
With baffling	148.3	241.2	123.7	95.1	4.9	45.0	829.0	415.1	481.7	49.8	91.5
No baffling	145.7	236.0	125.6	93.6	5.0	43.9	821.4	409.6	478.8	48.4	90.5
Loss without baffling	-2.6	-5.2	1.8	-1.5	0.1	-1.1	-7.6	-5.5	-2.8	-1.4	-1.0
Increase with baffling, %	1.78	2.16	-1.50	1.57	-2.05	2.51	0.92	1.32	0.59	2.74	1.08

proper gas baffling was compared to the same HRSG with a two-inch gas bypass between the panel and casing wall, and a four-inch gap between the coils throughout the HRSG.

Certain modules, such as the HP evaporators, experience a significant improvement in thermal duty with the addition of baffles to prevent gas bypass. Additionally, modules such as the HP economizer would extract more thermal duty without proper gas baffling as hotter exhaust gas bypassing from the upstream module has more energy available.

These higher gas temperatures could increase the risk of economizer steaming. However, the presence of gas baffles also could cause the superheaters to over-perform, thereby requiring increased attemperator spray for steam temperature control. Overall, the power output of the steam turbine will be increased by a factor of 1.08% or approximately 1 MW.

A similar comparative performance analysis was performed at a 1 × 1 combined cycle in Bangladesh powered by an MHI 701F. Visual inspection of the



3. Hole in evap header (center) occurred directly above tube end (right). Header location in HRSG is at the left

HRSG revealed significant gas bypass in many of the modules. A comparative performance model was built to determine the effects of adding gas baffles to the bypass areas.

A 1.2-MW increase in power output was predicted for the steam turbine using the performance model with the addition of gas baffles to access lanes near the evaporators. Upon installing the necessary baffles, the customer reported an increase in excess of 1 MW by ensuring proper heat transfer between the tubes and turbine exhaust gas without any bypass.

Potential flow-induced damage

Poor gas baffling in IP and LP evaporator tube banks can lead to an elevated risk of FAC wear in the upper headers of the evaporators. The gas bypass between the casing wall, tubes, and coil-to-coil gaps would lead to tubes in these locations experiencing a higher temperature.

This results in a higher amount of steam being produced in these tubes. The mass flow rates of the steam/water mixture in these tubes will be higher than those in the remainder of the tubes in the same row. A high-velocity steam/water mixture in the LP and IP evaporator will exponentially increase the wear-rate of carbon steel attributed to FAC.

Fig 3 shows a sidewall upper header that was subjected to increased mass flow in the tubes close to the end of the panel. The elevated mass flow of the steam/water mixture created a hole in the header because of FAC wear.

The risk of wear is further increased with the presence of a steam/water mixture discharging into the upper header. Operation at such instances can lead to unforeseen damage to the HRSG and potentially lead to a forced outage because of leakage in the evaporator. Preventive measures—such as proper gas baffling repair and ultrasonic testing readings at the end of upper-header panels—are recommended.

Offline inspection opportunities

Most common offline inspections begin with distribution plates and guide vanes, liner plates and components, tubes and fins, and tube ties. Baffles should be an equally important inspection target in all ducts, access lanes between tube bundles, and crawl spaces above and below headers.

Their condition should be documented and recorded through both photography and measurement. CCJ

On turning 30

Thirty years of unselfish service to owner/operators of Frame 6B gas turbines is quite an accomplishment. It takes a dedicated steering committee and conference manager (box) to plan and conduct a meeting with content of enduring value year after year. Just ask Geoff Kret of TOTAL, John F D Peterson of BASF, and Doug Starkey of Linn Energy when you attend the 30th Anniversary Dinner, June 13, at the PGA National Resort in Palm Beach Gardens, Fla: They've been participating since the group started and relish sharing their extensive knowledge with all those interested in learning.

The traditional two-and-a-half-day technical meeting has been expanded this year into Thursday afternoon to accommodate a *user-only* shop tour hosted by PSM. With all the changes in industry structure recently, your participation in this event likely will pay dividends.

The Tuesday program is dominated by interactive roundtables focusing on safety, auxiliaries, generators and exciters, I&C, compressors, and combustion section. A vendor fair from 5 to 8:30 p.m. closes out the day.

Wednesday, GE Day, features a series of formal presentations (all relatively short) in the morning and topical roundtables and kick-the-tires tabletops in the afternoon.

Thursday morning continues the interactive discussion program started Tuesday, plus a roundtable on the turbine section. Presentations by AAF on hydrophobic HEPA filters and by Turbine End-User Services on how to successfully deal with third-party parts repairs round out the 2016 program.

Frame 6 Users Group

2016 Conference

June 13-16

PGA National Resort

Palm Beach Gardens, Fla

Register today at:
www.frame-6-users-group.org

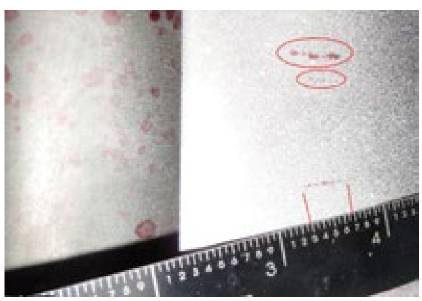
Steering Committee

Co-chair: Jeff Gillis, ExxonMobil Chemical
Co-chair: Sam Moots, Colorado Energy Management LLC
J C Rawls, BASF Corp (Geismar)
John Vermillion, Atlantic Power Corp
Brian Walker, Foster Wheeler Martinez Inc
Mike Wenschlag, Chevron Corp
Zahi Youwakim, Huntsman Corp
Wickey Elmo, Goose Creek Systems (conference manager)

Inspection results

Almost sure to work its way into the compressor discussion is the recent findings by inspectors from Advanced Turbine Support LLC of cracked S1 stator vanes and liberated S17 and exit guide vanes. The damage report from Director of Field Services Mike Hoogsteden was phoned into **CCJ's** offices on April Fools Day, so it took the pictures included here to convince the editors he wasn't kidding. Frame 6Bs rarely "make the news."

In the 48 hours prior to Hoogsteden's call, company inspectors had identified *mid-chord cracking* (Fig 1) on the suction side of three S1 stator vanes located in the lower half of one 6B compressor. Clashing damage, caused by contact between the leading edge of stationary vane tips with the trailing edges of rotor blades at the platform, also was in evidence.



1. Eddy-current inspection is critical for identifying mid-chord cracking, which can "hide" from dye-penetrant detection

BASF Geismar

Plant audit identifies major cost-saving opportunity

At the Frame 6 Users Group's 2015 conference, J C Rawls, utilities department technology engineer for BASF in Louisiana, accepted the **CCJ's** Best Practices Award recognizing the chemical company's Geismar facility for re-engineering and modifying its boiler feedwater system to reduce energy consumption and improve plant availability/reliability.

The Frame 6B is a popular gas turbine for industrial cogeneration facilities, on the Gulf Coast in particular, because of its durability and "right size." Process plants use GT/HRSG cogen units for their clean, efficient steam production; electricity is a beneficial byproduct for use onsite and/or sale.

Most engineers familiar with industrial-plant energy systems recognize that infrastructure expands as required by the installation of new process units. Expansions typically do not justify a re-engineering of the existing systems—feedwater, in this case—each time a "customer" is added. The important thing is to have sufficient steam and other utilities available when needed.

Periodic audits point to opportunities for improvements when ROIs are consistent with company financial goals. At Geismar, the installation of two simple piping runs and related valves to connect common infrastructure paid big dividends. Others may find similar benefits from a review of their plant utility systems.

Tom Yura, senior VP for the BASF-Geismar site, Derek Zambo, utilities production manager, and Rawls explained the feedwater-system challenge this way: Two separate sets of pumps were used to supply the boiler feedwater (BFW) header serving two cogen units and four boilers. One set of three pumps (A1, A2, and A3 at right in the drawing) pumped condensate returns into the header; the other set of five pumps (B1-B5 at left in the schematic) supplied demineralized makeup from the deaerator to the header.

Five pumps (A1, A2, A3, B4, B5) were kept in service to assure reliable supply of BFW for the site. In recent years, as a result of successful condensate-recovery strategies, the increased rate of condensate returns dictated operation of three condensate pumps, even though each was throttled back somewhat to match the typical condensate flow volume.

Two demin pumps supplied from the deaerator also were operated because of the inconsistency of condensate return flow at this very large chemical complex. Periodically, the required demin flow dictated operating the two pumps at their rated capacity.

2, 3. S17 stator-vane (left) and exit-guide-vane liberations (right) were easy to identify during borescope examinations

S17 stator-vane and exit-guide-vane liberations (Figs 2 and 3) were found in three different units. The liberated vanes resulted in significant collateral damage and forced the engines out of service. Lesson re-learned from the aft-compressor findings was the importance of regular borescope inspections to verify both the condition of airfoils and the existence of counterbore plugs in all Model 6581 units.

Recall that Advanced Turbine Support has been at the forefront of the industry's efforts to identify compressor issues for more than a decade. The company's technicians were the first to find and report clashing damage in the 7EA fleet (2006), the first to report locating stator-vane cracks in the "area of interest" described in the OEM's Technical Information Letter 1884, first to demonstrate the value of eddy-current inspections over dye penetrant for mid-chord crack identification, etc.

Hoogsteden and colleagues previously reported to owner/operators their findings of clashing in GE 7FAs, 6Bs, and Frame 5s, as well as in 7Es; however, this is its first report of mid-chord cracking in an engine other than a 7E. You can visit with the Advanced Turbine Support team at Booth 8 along the front wall adjacent to the bar.

Safety roundtable

Users who have not attended a Frame 6 conference, and are "on the fence" about coming to the 2016 meeting, can get a sense of the event's value from the following overview of the 2015 safety roundtable:

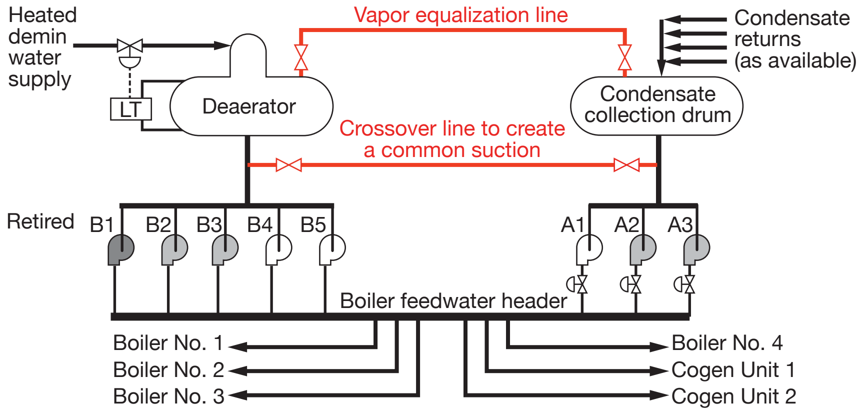
BASF's J C Rawls opened the session with a slide encouraging the

Typically, however, these pumps were operating at far less than full capacity.

Based on the normal operating scenario described above, this meant the plant operated:

- All three condensate pumps and had no spare, and
- Two of the five demin pumps, leaving three spares.

If one of the condensate pumps was taken out of service for maintenance, returns in excess of the capacity of the two operating pumps was discharged to the sewer, meaning expensive demin water provided the required makeup.



Site energy-system schematic shows locations of the vapor equalization line, and of the crossover line to create a common suction line for all pumps

Solution. Knowing the deaerator and condensate collection drum were located at the same elevation, and operated at nearly the same pressure and temperature, engineers proposed the installation of a connecting jumper pipe between the suction lines for the condensate pumps and for the demin pumps. This would create one common suction line for all eight pumps and reduce the number of pumps required in service. The proposed solution was approved. To ensure proper level control in the condensate collection tank, a second cross-connect line was installed between it and the deaerator, allowing the vapor pressures in both tanks to equalize.

Results exceeded expectations. With the demin pumps able to pump condensate, their excess capacity could be used for that purpose, thereby allowing one, or even two, of the condensate pumps to be shut down. Only three pumps total are required at typical loads, so the normal operating lineup now is the following:

- One or two condensate pumps in operation, leaving one or two spares, and
- One or two demin pumps in operation, leaving three or four spares.

Benefits of the modified BFW piping system are the following:

- Capital was saved because the spare condensate pump being considered was no longer needed.
- Significant power savings accrue from operating three pumps instead of five.
- Pump runtime is reduced because only three pumps are now required—not five. The load sharing now possible allows for "resting" some condensate pumps, which previously had operated 24/7.
- When one of the least-efficient pumps in the system was found damaged, it was retired rather than repaired because spare pumps were available.

Additionally, the following unanticipated benefit was realized after the crossover pump suction line was placed in service: Two condensate pumps were forced out of service simultaneously, at a time when demin production was limited because of other operational issues. The crossover line allowed the demin pumps to continue serving the plant by pumping condensate into the BFW header. Had the crossover line not been in place, the loss of condensate supply could not have been made up with the limited amount of demin water available. The result would have been a severe production curtailment, or site outage, in the worst case.

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group to provide perspective and ask questions on such topics as incidents, compartment entry/access, fire protection, maintenance issues/concerns/best practices, exciter/ground brush change-outs, fuel issues, heat, overspeed testing, instrumentation failures, and anything else of interest.

Frame 6 users don't need much encouragement to talk about their experiences or to offer meaningful opinions. Room size and attendance of 60 to 70 owner/operators are ideal for productive discussion based on the editors' experience. Plus, about a third of the attendees in any given year have been around Frame 6s for more than a decade and really do know the machine's idiosyncrasies. Add in a mixture of participants with several years of direct engine experience and new personnel eager to learn and it's relatively easy to ignite a discussion wildfire.

Interestingly, the safety discussion last year, and at the previous couple of meetings, reflected user concerns with package fire protection systems and entry safety. Regarding the former, it appears relatively little thought had been given to the lifetime of fire protection systems until recently. Sure, plants were conducting the prescribed tests over the years, but system controls and wiring at some installations have seen better days and should be upgraded or replaced.

Plus, some facilities are still using Halon, which is associated with environmental issues. Replacement of the remaining Halon systems could be termed a "work in progress." CO_2 and water mist are alternatives. But selecting the former raises safety questions regarding package entry when the gas turbine is operating. Regarding the latter, some users express reluctance at putting water into the package.

The first question in the session came from a user who asked how to drain the liquid CO_2 tank for inspection. This is a pressure vessel that at his plant hadn't been inspected for 20 years. It appeared that a few in attendance had not given this inspection much thought previously; others were not sure of the inspection interval.

A user cautioned that venting can be hazardous, especially when the tank is located in an enclosed space. If the vessel is outside, use tape to prevent access to the area near the tank prior to venting. Another caution offered was that rapid venting could cause freeze-up of the tank liquid.

You could gauge how far the religion of safety has progressed over the last several years by the long discussion on package entry. Someone mentioned "confined space" and the floodgates opened. An attendee cautioned about calling the package a confined space because that would cause problems during maintenance; even with the doors off, it still would be a confined space, he said. At his plant, the O&M team considered the package a confined space regarding procedures—permit included—without officially categorizing it as a confined space.

Next, compartment temperature was introduced as a discussion topic. A debate ensued on "how hot is too hot?" Consensus view was that anything more than a couple of hundred degrees can be problematic because controls wiring would be affected adversely. Adequate ventilation was stressed as a starting point.

Perhaps some re-engineering is in order, a user suggested; there are many viable ventilation arrangements, he said. One to avoid is locating one fan on the side of the engine. Reason: Uneven cooling could cause a unit trip. Another point made during this discussion was that European standards for compartment ventilation differ from US standards. US owner/operators with engines made in Belfort, France, might want to conduct a system review.

If ventilation is adequate and the package temperature still is too high, start looking for leaks. Check exhaust flex seals for cracking, an operator opined. Another recommended inspecting crossfire tubes for leakage. He said this was the cause of high package temperature at his plant.

Upgrading to bellows type crossfire tubes solved the problem.

There are many flanges that might be leaking hot air/gas, an attendee said. How do you identify the one or two that are? Simple, one of the more experienced users offered: Tie a rag on a stick and do it the old-fashioned way. You can't find a leak when the engine's not running, he said. This is tried and true.

However, it is counter to the thinking of corporate safety personnel, and the OEM, who frown on package entry when the unit is running. People seem at loggerheads over this issue. Many suggestions were offered, including the following:

- Install a thermal monitor to pinpoint a leak. That idea was nixed by someone who had tried it and found that a hot compartment adversely impacts accuracy and repeatability.
- Disable CO_2 or Halon fire protection systems prior to entry. Is this something the plant really wants to do? Would corporate safety personnel and insurance companies support such a procedure?
- Develop a safety protocol. One possible example: Keep the door wide open while someone is in the package for a *defined period of time* with one or more others standing by right outside the door in case assistance is required. Control-room personnel would be forewarned, of course.
- Check bolts/studs/nuts on flanged joints for proper torque during annual inspections. Engine vibration and thermal cycling can loosen fasteners over time. If joints are loose, you might want to replace gaskets before retorquing to minimize the possibility of leakage.
- Install acoustic emission sensors to alert when a leak occurs. Mistras Group has exhibited its equipment for flange leak detection in gas-turbine plants at several user group meetings.

New combustion system reduces emissions

O&M personnel responsible for Frame 6B gas turbines are a breed apart from their colleagues who manage F- and higher-class engines dedicated to electricity production—at least from an editor's perspective. The 6B, which often serves in chemical-plant and refinery cogeneration systems, is a durable machine well-appreciated by the hard-nosed engineers and technicians who care for it.

In the cogeneration business, the gas turbine can be viewed as a necessary evil, its primary purpose to make hot gas for steam generation; electricity is a byproduct. Budgets favor spending on the process side, with the powerplant staff typically getting subsistence funds to keep the GT shaft rotating and steam in the pipe.

But when critical parts approach end of useful life and production risks increase, meaningful investments are made in power generation equipment. Recently, a Frame 6B user explained how the need to replace liners on one of his plant's GTs morphed into a combustion system upgrade. This experience offers another reason to take the PSM shop tour Thursday afternoon.

The last set of spare Phase-4 combustion liners for one of the petrochemical facility's two 6Bs had reached end of life. By way of background, these engines were installed in 1992 and equipped with one of the earliest DLN combustion systems. The permit was for 25 ppm NO_x and CO (corrected to 15% O_2).

There are relatively few such DLN engines in existence—the speaker referred to them as DLN-0—because pressure from permitting authorities pushed emissions limits down to 15 ppm NO_x shortly after these GTs went into service. The more restrictive standards required use of the OEM's DLN-1, which today can achieve single-digit NO_x emissions.

Change is ongoing in the competitive world of gas-turbine design and one of the first things this user and his colleagues learned was that the current Phase-6 replacement cap and liner assemblies for the 6B were 6 in. longer than the original Phase 4s. With a simple replacement off the table, some serious thinking/planning was necessary. Engineers embraced the opportunity to upgrade the combustion system with the latest technology and achieve operational benefits for what hopefully would be another two decades of reliable service.

For example, an operating constraint with the old DLN system was the restrictive ambient-temperature range—nominally 59F to 95F—required to hold emissions below permit limits. The 59F floor was particularly onerous. When the ambient temperature dipped below that, plant personnel generally had to derate the engines to keep operating.

After reviewing available solutions, engineers settled on two possibilities: A DLN-1 Phase-6 conversion offered by the OEM, and PSM's LEC-III® combustion system.

The first option included new cans, flow sleeves, can cover with primary fuel nozzles, crossfire tubes (inner and outer), fuel hoses, and consumables. Conversion to Mark VIe controls was required as well; secondary fuel nozzles would be reused and the transfer system would remain.

The PSM option required similar new components, plus the company's primary flame scanner kit and low-emissions secondary fuel-nozzle kit. The latter enabled elimination of the transfer system and its associated piping. Enhanced operating flexibility was a significant benefit of the LEC-III: The ambient temperature window expanded to from 20F to 105F with turndown from 100% to 55% of rated power. The LEC-III was selected to replace the original DLN system.

Emissions were guaranteed at 15 ppm for both NO_x and CO (corrected to 15% O_2). Actual emissions achieved after tuning were less than 8 ppm NO_x and less than 1 ppm CO. The speaker said expectations were that annual NO_x emissions would be reduced by 85 tons, CO by 65 tons per year. The conversion was completed in about a week, meaning it could be done during a typical hot-gas-path inspection.

PSM's product manager for the LEC-III, Ian Summerside, followed the user to the podium. He spoke primarily about the capabilities, features, and benefits of the combustion system and the company's retrofit experience, which now encompasses more than five-dozen units (including well over a dozen 6Bs). Summerside said the LEC-III is a "simple" solution when ultra-low NO_x emissions are required. Combustion inspection intervals are 24,000 hours or 600 starts, whichever comes first. CCJ

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Products and services from over 100 companies support new unit construction, retrofit and maintenance activities at existing facilities, and plant operations. Solutions span gas and steam turbines, HRSGs, pumps, valves, piping, cooling towers, condensers, etc

AAF International

Global leader in the field of air filtration, meeting the most demanding conditions and the toughest environmental challenges. The company's filtration, noise abatement, and other turbine products are effective, durable, and crucial to greater efficiency and performance.

ABB

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

Advanced Filtration Concepts

Offers new and innovative filtration products for the GT/CC power industry. Invest to save with inlet air filters that are high efficiency, low 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 Indoor Air Quality Care

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

Advanced Turbine Support

Has delivered unbiased fleet experience and superior customer service for more than a decade. Company provides users high-resolution borescope inspections, cutting edge ultrasonic and eddy-current inspections, and magnetic-particle and liquid dye-penetrant inspections in accordance with OEM Technical Information Letters and Service Bulletins.

Aeroderivative Gas Turbine Support

AGTSI offers a full range of aeroderivative gas-turbine, off-engine, and package parts from the most basic to the most critical. An expansive inventory of spares and replacement parts is maintained at our warehouse for all models of GE LM2500, LM5000, LM6000, and LMS100, as well as P&W GG4/FT4.

AGTServices

Over 200 years of combined, proven OEM engineering, design, and hands-on experience; known in the industry for its schedule-conscious, cost-effective solutions with respect to generator testing and repairs.

American Chemical Technologies

Provides state-of-the-art synthetic lubricants to the power generation industry. Founded more than 30 years ago in the US, ACT has grown to become an international supplier of value-added lubricants that provide superior benefits to equipment, the environment, and are worker-friendly.

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

Committed to providing customers with cost-effective solutions to the most complex emissions control problems; company is constantly developing new catalyst technologies to meet ever-more stringent emissions requirements.

Bremco

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

C C Jensen Oil Maintenance

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

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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.

Combustion Parts Inc (CPI)

Leading new replacement parts provider for the combustion section of GE gas turbines specializing in transition piece, cap, and liner assemblies for Frame 6B, 7B, 7E/EA, 7FA, and 9E models.

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.

Donaldson Company

Leading worldwide provider of filtration systems that improve people's lives, enhance equipment performance, and protect the environment. Donaldson is committed to satisfying customer needs for filtration solutions through innovative research and development, application expertise, and global presence.

Dry Ice Blasting of Atlanta

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

EagleBurgmann Expansion Joint Solutions

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

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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.

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.

GP Strategies

Provides training, engineering, and performance improvement services specifically designed for the power industry: The EtaPRO™ Performance and Condition Monitoring System and GPiLEARN+™.

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.

Gulf Coast Filters & Supply

Keep your filter house and evap coolers operating at peak condition. GCF provides comprehensive, personalized filter-house products, field service, and maintenance, emphasizing safety, professionalism, efficiency, minimal job-site disruption, quality products, and thorough testing and inspections.

Haldor Topsoe

Our air pollution technology includes a series of unique catalysts for Selective Catalytic Reduction (SCR) systems for the control of nitrogen oxides (NO_x), and the reduction of carbon monoxide (CO) and volatile organic compounds (VOCs), from stationary and mobile sources.

Hilliard

The HILCO® Division cost-effectively brings fluid-contamination problems under control and engineers a full-range of filters, cartridges, vessels, vent mist eliminators, transfer valves, reclaimers, coolant recyclers and systems, and membrane filtration systems.

HPI

A leading provider of OEM alternatives for engineered turbine solutions. Founded in 2002, the company offers EPC services for turnkey powerplants; maintenance, repair, overhaul, and mechanical field services in addition to custom controls. Company also is a qualified provider of turbine refurbishment solutions for the nuclear and marine markets.

HRST

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

Hydro

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

Hy-Pro Filtration

Provides innovative products, support, and solutions to solve hydraulic, lubrication, and diesel contamination problems. Company's global distribution and technical-support networks enable customers to get the most out of their diesel, hydraulic, and lube-oil assets. ISO 9001 certified.

Indeck Keystone Energy

Designs and manufactures packaged boilers "A", "O", "D" Type, modular "D" type packaged and field-erected boilers, International Lamont line of high temperature hot water generators, and auxiliary equipment. Indeck has over 5,000 successful boiler installations in 45 countries.

Janus Fire Systems

Manufacturer of special hazard fire protection solutions. Designers of engineered clean agent and high- or low-pressure carbon dioxide systems composed of hardware and software tailored to the application.

JASC

Engineers and manufactures actuators and fluid-control components for power generation, aerospace, defense, and research applications to improve operational capability and performance.

KnechtionRepair Tools

Manufactures tools designed to make thread repairs to both the female and male ends of cross-threaded compression fittings. In most cases, the repair will be accomplished without removing the tube from the system. This saves the O&M tech time and avoids additional downtime.

Kobelco Compressors America

Provides robust, high-efficiency fuel-gas compressors for use with all major types of gas turbines—including GE, Mitsubishi, Alstom, Siemens, Rolls-Royce, and Solar. Over 300 of the company's screw-type compressors have been supplied for gas turbines.

Liburdi Turbine Services

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

M & M Engineering

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

Mechanical Dynamics & Analysis

One of the largest turbine/generator engineering and outage-services companies in the US. MD&A provides complete project management, overhaul, and reconditioning of heavy rotating equipment worldwide.

Membrana, a 3M company

Market-leading producer of microporous membranes and membrane devices used in healthcare and industrial degassing applications. The Industrial & Specialty Filtration Group manufactures Liqui-Flux® ultrafiltration and microfiltration modules as well as Liqui-Cel® membrane contactors.

Mitten Manufacturing

Leading fluid system packager for numerous OEMs, EPC firms, utilities, and plant operators all over the world offering a number of value-added designs, spare parts management, and field services.

NAES

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

National Electric Coil

Leading independent manufacturer of high-voltage generator stator windings with expertise in design and manufacturing of stator windings for any size, make, or type of generator. This includes diamond coils, Roebel bars—including direct cooled, inner-gas, and inner-liquid cooled bars—and wave windings.

NEM Energy

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.

NRG Energy Services

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.

Parker Balston

Develops and manufactures nitrogen generators for all your power generation needs including boiler layup, gas seals, purging gas lines prior to service, blanketing demin water tanks, and LNG terminals.

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.

Praxair Surface Technologies

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

Precision Iceblast

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

Proco Products

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

PSM—an Alstom company

Full-service provider to gas-turbine equipped generating plants, offering technologically advanced aftermarket turbine components and performance upgrades, parts reconditioning, field services, and flexible Long Term Agreements (LTAs) to the worldwide power generation industry.

PW Power Systems

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

Rentech Boiler Systems

International provider of high-quality, engineered industrial boiler systems. Rentech is a market leader in providing HRSGs for cogeneration and CHP plants. It is in its second decade of designing and manufacturing high-quality custom boilers—including HRSGs, waste-heat boilers, fired packaged boilers, specialty boilers, and emissions control systems.

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.

Siemens Energy

A leading global supplier for the generation, transmission, and distribution of power and for the extraction, conversion, and transport of oil and gas. Leadership in the increasingly complex energy business makes it a first-choice supplier for global customers. Known for innovation, excellence and responsibility, company has the answers to the sustainability, flexibility, reliability, and cost challenges facing customers today.

Sound Technologies

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.

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.

Structural Integrity Associates

Powered by talent and technology, SI is a global leader in providing innovative engineering solutions. Using a multidisciplinary approach, our experts bring a fresh perspective and proven solutions for structural evaluation and repair.

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.

Taylor's Industrial Coatings

Highly skilled staff is trained and equipped with the latest tools and equipment necessary to complete coating projects on time and in scope with a commitment to safety, technical support, and quality workmanship.

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

TectraPro produces state-of-the-art training materials for the utility industry which feature detailed 3D model images and videos. Our content can also include customization where site control screens, photos, piping and instrument drawings and documentation are presented.

TEi Services

Offers a full range of heat-transfer products and services and fully trained, certified maintenance personnel. Provides world-class emergency repair services, underpinned by a 75-yr history in the design and manufacture of condensers, feedwater heaters, and heat exchangers.

TesTex Inc

World leader in electromagnetic non-destructive testing (NDT). We continually define the state-of-the-art for the testing of ferrous and non-ferrous materials and structures through applied research and development.

Thor Precision

Value-added service center provides reverse-engineered rotor bolting for the gas-turbine aftermarket—specifically for Frame 3, 5-1, 5-2, 6B, 7E, 9E engines—including compressor, turbine, marriage, and load-coupling hardware.

Turbine Generator Maintenance

Provides turnkey field service maintenance for all turbine/generator components. TGM services the turbine, generator, exciter, control systems, and auxiliaries either individually or in any combination. Its service area includes the US, Caribbean, and South America.

Turbine Technology Services (TTS)

Wide range of expert engineering and consulting services, conversion, modification and upgrade services, GT installation and reapplication services, and design and implementation of complete turbine management systems.

Universal AET

Designs, procures, and manufactures OEM and retrofit inlet and exhaust systems including filter houses, inlet duct/silencers, enclosure doors, diffusers, plenums, expansion joints, transitions, exhaust ducts/stacks, exhaust baffle silencers, and stack dampers.

Universal Plant Services

Specializes in the maintenance, repair, and overhaul of gas and steam turbines, centrifugal and reciprocating compressors, as well as all rotating equipment, with qualified millwright and field machining specialists.

Victory Energy

Offers all types of industrial boilers: watertube, HRSG, firetube, and solar-powered units. Company provides unprecedented support with its rental boilers, spare parts, field service, and auxiliary equipment—including water-level devices, economizers, stacks, expansion joints, and ductwork.

Vogt Power International

Supplies custom-designed HRSGs for GTs from 25 to 375 MW and has extensive experience in supplementary-fired units. Scope of supply includes SCR and CO systems, stack dampers, silencers, shrouds, and exhaust bypass systems.

Young & Franklin

Premier fuel control supplier for combustion turbines for both long-term hydraulic solutions and, more recently, innovative all-electric controls solutions. Product scope supports natural gas, liquid, syngas, and alternative fuels as well as providing air controls to provide proper fuel to air mixtures.

Zeeco Inc

World leader in combustion and environmental systems including burners, flares, thermal oxidizers, vapor control systems, aftermarket parts and services, rental systems, scanners, and monitors.

Zokman Products

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

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