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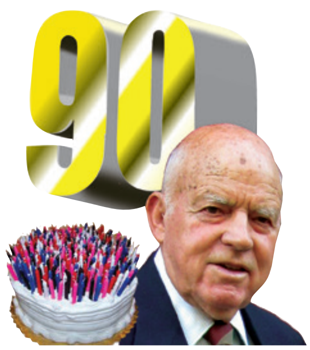

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Clyde Maughan, industry icon, generator advocate, turns 90

This is turning out to be a banner year for nonagenarians. Queen Elizabeth celebrated her 90th birthday April 21; Clyde Maughan hits the Big Nine-O on July 5, Tony Bennett has to wait until August 3. While the Queen and Bennett are recognized globally, it's unlikely many outside the electric power industry and the greater Maughan family could pick The Clyde out of a crowd.

To be fair, the Queen needs no introduction, having been in the public view her entire life, and Lady Gaga has given Bennett's image a big boost among those younger than about 60. The only PR Maughan really gets is an introduction from a virtually unknown industry-meeting chairperson and possibly a photograph in CCJ—this aside from being on stage once or twice a year to toot his French horn with a group of local musicians in the Schenectady (NY) area.

What Maughan means to the industry is, perhaps, best described by Tom Freeman, an executive at GE Power Services well known to owner/operators of generation equipment:

"Every so often, you meet someone you know to be an industry giant. Clyde Maughan has had two complete storied careers in our industry—one at my company and another serving the industry as a whole. I think the esteem that GE and the industry hold for Clyde can be summed up by something I witnessed at the first annual meeting of the Generator Users Group in 2015.

"In a room full of, dare I say, seasoned engineers wearing progressive lenses and sporting a fair amount of gray hair, I watched various people stand when Clyde entered the room, go silent when he spoke, and generally seek his counsel throughout the conference. Maybe I'm simply old enough to appreciate that, but I would say that it is the high honor that has been well deserved through decades of engineering excellence.

"Happy 90th Clyde, from the generations that seek to follow in your footsteps."

The Clyde was born into a large, self-sufficient Idaho farm family at the mercy of weather, insects, and anything else that could impede the growing of food necessary to sustain life. His first association with the "power industry" came as the family member responsible for fueling the small gasoline engine/generator used to charge the batteries supplying power to the farm's microgrid. These were the long-ago days before the Rural Electrification Administration provided the wherewithal to deliver power by wire direct from federal dams in the state.

Maughan spent the first 36 years of his career after graduation from the Univ of Idaho (BSEE, 1950) at the General Electric Co as an engineer and manager in generator and turbine engineering design/service/development/manufacturing and a variety of other positions. Since retiring from GE, Maughan has been in private practice.

Along the way, he has been directly involved in 250 or so repair projects on generators from 2 to 1400 MW supplied by virtually all of the world's major manufacturers. This work has included several dozen root-cause investigations of complex failures on stator and field components.

Plus, Maughan has served on several IEEE and IEC committees and working groups; managed a couple of major projects for EPRI; written or coauthored more than two-score major technical papers; published a handbook of more than 200 pages on generator repair and conducted nearly three dozen seminars (total of more than 1000 attendees) worldwide based on that work; and still had time to get an MS in Mechanical Engineering. Along the way, he earned his Professional Engineer's certification (since retired voluntarily) and was named an IEEE Fellow.

In recent years, Maughan has focused on disseminating to engineers worldwide the volumes of information he has compiled during his career. Much of this effort has been facilitated by the International Generator Technical Community™, an online forum that he helped to create. The IGTC library contains most of his technical documents. CCJ-online.com hosts the articles Maughan has published in the Combined Cycle Journal, as well as a series of webinars he conducted for CCJ ONscreen.

Although The Clyde has dialed back his activities in recent years, he remains quite active. Last year, for example, he was the driving force behind the formation

Continues on p 98

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Pipe-repair odyssey

Griffith Energy, like many combined cycles built at the end of the 1990s and in the early 2000s, clearly illustrates the commitment, persistence, and capital demanded to ensure the levels of reliability and performance required to succeed in the highly competitive electric generation business (Sidebar 1).

A good starting point for this article is 2010 when Tetra Engineering was hired by plant management to develop inspection plans for P91 high-energy piping (HEP) components, flow-accelerated corrosion (FAC), and attemperators (Sidebar 2).

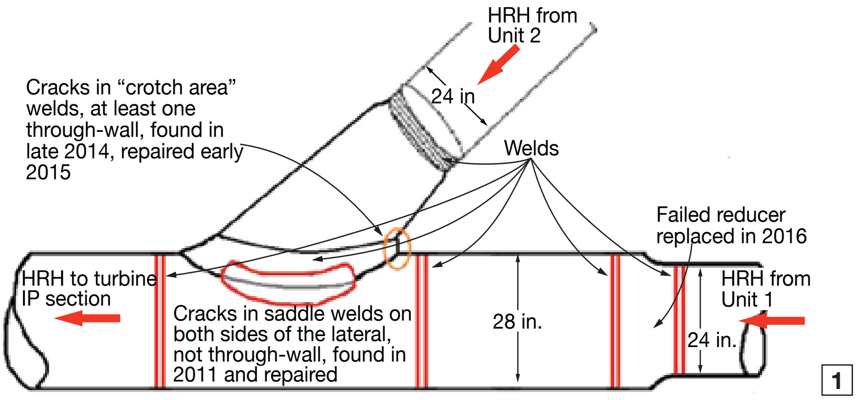
Tetra's approach, the company's Peter S Jackson, PE, told the editors, was to identify the highest-risk locations based on industry experience and conduct inspections in priority order. The weld-on lateral fitting in the hot-reheat system (trademark Latrolet) used to blend HRH steam from the two HRSGs into a single pipe, was a high priority based on experience at plants designed by Black & Veatch (B&V, Sidebar 3).

Jackson said a team of Tetra engineers, including Robert Hookway, PE, a member of the ANSI B31.1 committee, performed hot-condition walkdowns and baseline visual inspections in summer 2010. One outcome: Hangers needing attention were identified and corrected as needed.

The Tetra team returned in spring 2011 (during the plant's scheduled outage) to follow-up on the baseline work performed the previous summer. During the inspections of P91 piping and weld joints, the team noted damage to pipe supports in the area of the laterolet (generic term) and focused its interest there.

After discussion with management it was determined that the pipe supports in question were most likely related to start-up issues some 15 years earlier. The team later acknowledged that the supports were not likely related to the current findings.

Baker Testing Services, Rockland, Mass, brought in by Tetra, was onsite performing the ultrasonic (UT) nondestructive examinations (NDE). Baker's inspectors found non-through-wall cracks on both sides of the 28-in.-diam laterolet. At the laterolet junction, normal operating parameters were 570 psig/1050F feeding the HRH line supplying the IP section of the steam turbine (Figs 1, 2). The cracks were approximately 16-in. long and within a few thousandths of being through-wall.



1, 2. Griffith, as designed, relied on a weld-on lateral fitting to merge the 24-in. hot-reheat (HRH) lines from each HRSG into the 28-in. line delivering steam to the IP section of the Toshiba turbine. According to an advisory issued by Black & Veatch early in 2008, premature cracking had been associated with use of the subject fittings in main-steam and HRH applications. The drawing calls attention to saddle-weld cracking on both sides of the Griffith lateral found and repaired in 2011 plus cracks in the crotch area found and repaired about four years later. The companion photo provides the perspective needed to appreciate the magnitude of the job described in the text

A comprehensive inspection of the crack areas was conducted by Tetra and an independent welding contractor. A complete re-evaluation of the piping system was done using Bentley Systems Inc's AutoPIPE, replicating the original analysis by B&V. There was no indication of ultra-high stress under any operating condition; no cases run exceeded B31.1 stress limits. However, this assumes all materials

1. Griffith Energy

Griffith Energy is a nominal 570-MW 2 × 1 combined cycle owned by Houston-based Star West Generation LLC and managed by Mike Hartsig. The facility is located 14 miles west of Kingman, Ariz. Construction start was September 1999, COD January 2002—the heart of the five-year rapid expansion when about 200,000 MW of gas-turbine simple- and combined-cycle assets were installed nationwide.

Resources were strained during this period: Many power producers were lined up in the queue waiting impatiently for equipment; plus, experienced construction/startup personnel were difficult to find. Regarding the first point, gas-only Griffith Energy was assembled with principal equipment from multiple sources. The gas turbines, equipped with inlet chillers, are US-made GE 7F.03s, the supplementary-fired heat-recovery steam generators are triple-pressure boilers from Europe's NEM, and the condensing steam turbine/generator was manufactured by Asia's Toshiba. Heat rejection is by way of a wet cooling tower.

The availability of experienced project-management teams and tradespeople, and of heat-treating companies with deep knowledge of P91 and its idiosyncrasies, may have been a contributor to the plant's problems with respect to the lateral cracks. This is exemplified by P91 issues surfacing at plants across the industry.

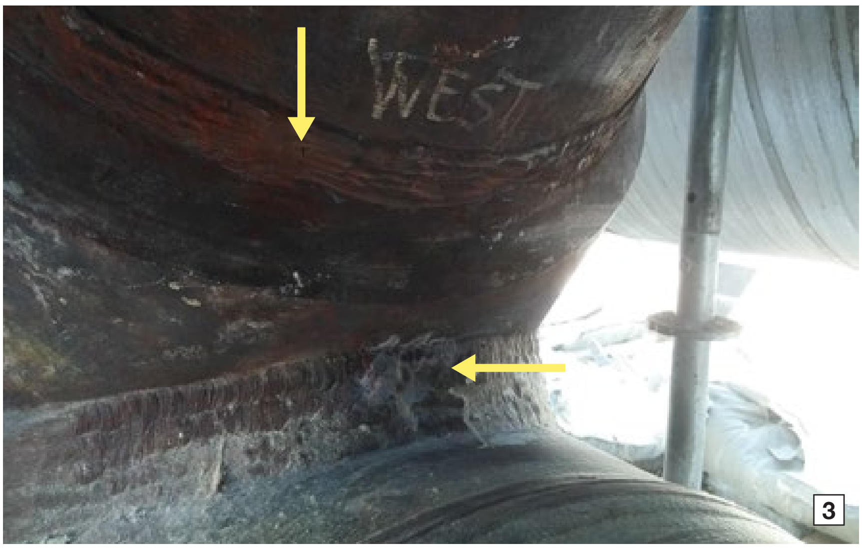
According to a Black & Veatch document, P91 was approved for use by ASME in 1983 and only gained widespread acceptance for main-steam and hot-reheat (HRH) piping, as well as for boiler and HRSG applications, in the mid-1990s.

Griffith Energy was built by BV Power Partners, which combined the capabilities of Black & Veatch and Zachry Construction Corp,

for the original 50/50 owners PP&L Global and Duke Energy North America. LS Power became the sole owner in May 2006. Star West was established in 2011 and purchased both Griffith and the nearby Arlington Valley Energy Facility from LS Power.

Griffith, designed to run as a base- or intermediate-load generator, is connected to the Western Area Power Administration's transmission system, via the Mead trading hub.

Hartsig came to Griffith as plant manager in 2010, after a period as plant manager at the 3 × 1 Frame-6B-powered Morris Cogen facility in Illinois. His power-industry career began in the early 1970s and includes experience at nuclear and coal-fired plants. Hartsig is proactive in the sharing of information with colleagues; he served as vice chair of the GE F-class Roundtable at CTOTF™ for a three-year term.



3. The "crotch area" had multiple cracks. One vertical crack in the crotch was through-wall. Plus, a long horizontal crack was found in the weld joining the HRH pipe from Unit 2 to the laterolet

2. Key contractors for HRH retrofit project

Tetra Engineering Group Inc, Weatogue, Ct (engineering and NDE)
Durus Industrial, Chandler, Ariz (welding)
US Metals, Houston, Tex (piping)
TEAM Industrial Services, Phoenix, Ariz (post-weld heat treatment)
Argus Contracting, Tempe, Ariz (insulation)
DP Scaffolding Inc, Las Vegas, Nev (scaffolding)
Sky High Crane & Rigging Inc, Lake Havasu City, Ariz (crane)

and installation work were perfect, which they were not.

After Tetra informed plant management they could not be onsite for the repair, Structural Integrity Associates Inc, San Jose, Calif, was engaged to meet with Tetra and plant management to review repair procedures. Plant management chose SIA as the technical advisor (TA) to work with the welding contractor.

Both Tetra and SIA were charged with determining the root cause of the cracks. Lab testing of material removed from the crack areas revealed a combination of stress and creep typically associated with P91. Prior to and following the repair, stringent pre- and post-weld heat treatment procedures were required to meet current standards for working with P91.

After grinding and weld prep, 9018-B9 rod was used to weld the joints, meeting all requirements and expectations. Management worked closely with Tetra to develop a comprehensive program for checking welds in the lateral and associated piping, within the heat- affected zone, annually from that time forward.

The lateral was performing as expected until one day in October 2014 when roving operators noticed water dripping from blanket insulation that had been placed on the laterolet following the 2011 repair. First thought was the blanket insulation might have been saturated with rainwater.

After inspection of upstream piping and other possible water-ingress points, plant management concen-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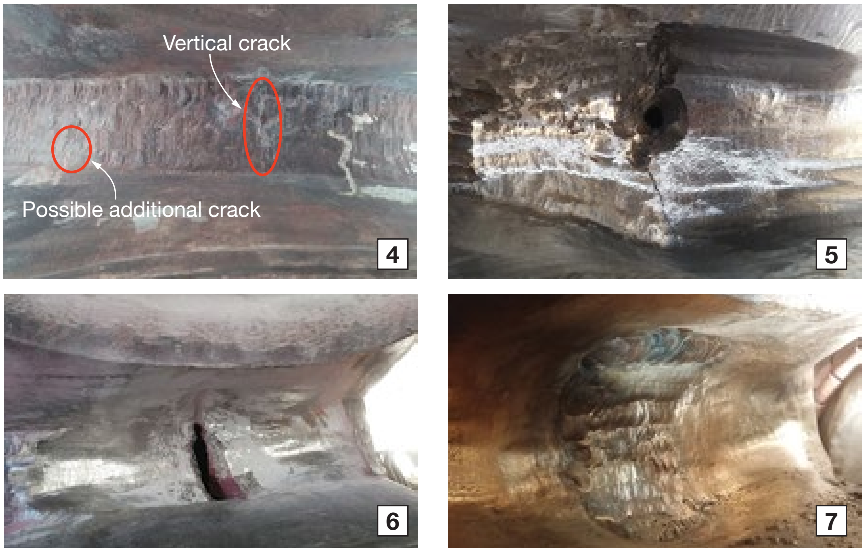


4-7. Close-up of the "crotch" section shows the vertical through-wall crack in Fig 4, that crack after 1 in. of material was removed (Fig 5), after completion of crack excavation (before mag-particle inspection) in Fig 6, and following the root pass and several passes of filler weld on top of the root in Fig 7

trated on all weld areas of the lateral. Isolating the leaking area in the insulation, management identified welds in the crotch as the likely area.

After consultation with Tetra and corporate management, consideration of operating conditions at the time, and the nature of the dripping, suggested an immediate shutdown was not necessary. Access to the area was restricted to protect personnel.

The plan was to monitor the leak closely by infrared thermography and should the volume rate of drip flow increase, Griffith would be taken out of service immediately for a thorough assessment. Infrared was effective because the blanket insulation was saturated and heat was conducted outward.

In February 2015, with the plant offline for the first time since the leak was noticed (Griffith was running continuously either 1 × 1 or 2 × 1 at the time, not cycling), Tetra returned to the Arizona facility. NDE inspections of the lateral and associated piping verified cracks in the "crotch area" of the laterolet. At least one was through-wall, more likely two. These cracks were not related to the work done in 2011. Phased-array and mag-particle techniques were used to identify and characterize the cracks.

The major cracks were evident to the naked eye. Figs 3 and 4 show a nominal 3-in.-long vertical through-wall crack in the 28-in. lateral deep in the crotch, and a 10-in.-long horizontal crack (OD)—5 in. of which was through-wall—at the bottom toe of the weld above the crotch.

This section joined the 24-in. Unit 2 HRH pipe to the laterolet. The vertical crack, which exhibited small horizontal fissures coming off the bottom of the weld (removed by grinding),

3. The Latrolet®: A special case in a cornucopia of P91 issues

Problems arising from the use of inappropriate methods for fabricating, installing, and repairing piping and other high-temperature steam-system components made of P91 (9Cr-1Mo steel) caught the industry by surprise in the early 2000s.

HRSG expert Bob Anderson, a plant manager before retiring to consulting and a member of the CCJ Editorial Advisory Board, chaired what may have been the first user-focused workshop on the subject in 2005. It provided owner/operators of gas-turbine-powered cogeneration and combined-cycle plants much-needed guidance on how to weld and repair P91.

There were many presentations on P91 issues later in the first decade of the new millennium, creating a steady stream of advisories and articles highlighting inspection procedures for verifying the quality of both the base material and the welding process, and on how to correct off-spec findings. Some advisories were highly focused. One of these was a notice from Black & Veatch (B&V) regarding the possibility of premature cracking of weld-on lateral fittings.

The background section of the B&V advisory reminds that creep causes pipe material operating at high temperature to permanently elongate and deform over time. Failure occurs when the accumulated strain exceeds design limits. Grade 91 and other martensitic materials also are more susceptible to cracking in a region near welds sandwiched between the base material and the heat-affected zone (HAZ).

This phenomenon, the advisory goes on to say, is called Type IV cracking and is associated with an enhanced rate of creep in the fine-grained and inter-critically annealed HAZ. Accumulation of local creep damage in the Type IV region is associated with premature failure.

B&V issued its advisory based on reports from two plants indicating cracking (later determined to be Type IV) of weld-on lateral fittings. Further investigation, including finite-element analysis (FEA), indicated high stresses exist and that cracking eventually will occur in the crotch area and on the sides of the fitting at the interface between the weld and pipe.

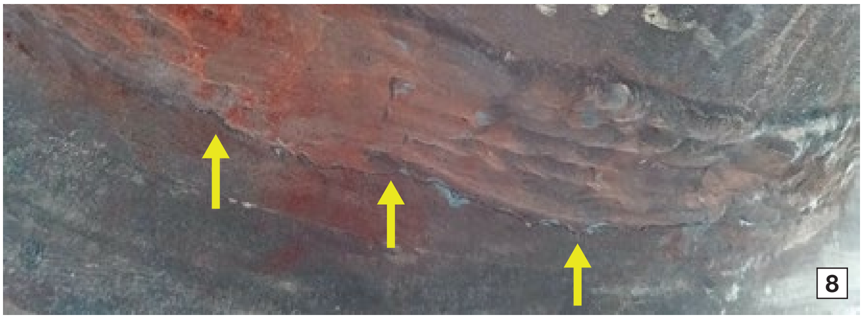
The local stresses at these locations are not high enough to cause immediate failure; rather, they are conducive to accelerated creep and premature cracking—and eventually premature failure. B&V engineers concluded failure is likely to occur in approximately five years of base-load operation. Creep cavities and cracking can be found prior to ultimate failure by NDE in areas of high stress.

Recommendation: Initiate a program to inspect weld-on lateral fittings and replace with a forged fitting of equivalent design when findings support such action.

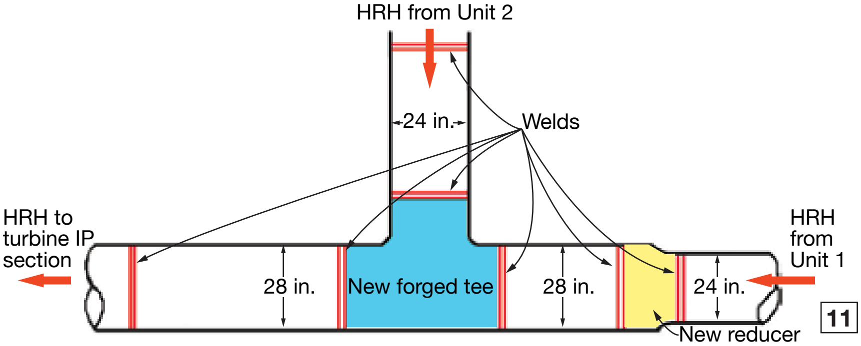
extended 0.25 in. into the lateral and 0.75 in. into the 28-in. pipe; however, the crack was through-wall only in the weld area.

This crack propagated from the inside out, originating from the pipe bore or a buried defect acting as a stress riser within the weld. Close inspection suggested craftsmanship issues, such as the possible use of incorrect welding rods.

Scott Snoddy, the project manager



8-10. As found crack in the base of the weld connecting the Unit 2 HRH line to the laterolet is nearly a foot long (Fig 8). The horizontal crack after excavation and before mag-particle examination is shown in Fig 9. The next photo presents the crack area after the root was laid and several passes of filler weld were applied on top of the root



11, 12. New arrangement used to merge the 24-in. Unit 1 and 2 HRH lines into the 28-in. IP supply line to the steam turbine incorporates a forged tee rather than a laterolet. The accompanying photo provides perspective

4. HRH laterolet repair plan

The weld repair plan developed by Durus Industrial is summarized below. President Bill Long stressed to the editors a proper process and filler materials are critical to success. It's not the piping, he said, it's about good welding and the heat-affected zone.

1. Wrap pipe for preheat. Once welding starts, maintain pipe temperature at or above 400F.
2. Apply Solar Flux® to weld joint as pipe is coming up to preheat temperature. It creates a chemical reaction to produce an inert environment, taking the place of backing gas.
3. Use the TIG/GTAW (ER-90S B-9) process for all root and hot passes. After root pass, MT the weld to ensure no cracking has occurred and the work meets applicable standards. If any indications are found they must be fixed and retested until results are acceptable.
4. Use the electrode/SMAW (9018 B-9) process for depositing all filler material. Between all passes, allow weld to cool below 600F before starting the next pass. Remove slag after each pass by grinding. Repeat steps until achieving the proper amount of reinforcement.
5. Bring pipe up to 600F and hydrogen bake-out for four hours. Cool according to the procedure used for P-15E material.
6. Wrap and post-weld heat treat to 1400F +0/-10 deg F. Soak at a rate of one hour per inch of thickness; the laterolet is about 3 in. thick.
7. Allow to cool and perform final MT and UT. Treat this as a Section I job. Take hardness measurements as well.

for Durus Industrial, and the lead on the previous weld repair collaborated with Jackson and the Tetra team on the current weld repair. This repair would be much more difficult than the 2011 work because a new process was required to avoid the need for argon dams in the pipe to run a root pass. The process was required to avoid further

13. Reducer, 28 × 24 in., buckled in service and was replaced

cuts in the piping.

The repair was designed to conform to ANSI B31.1; the weld procedure and welders were qualified to ASME Section IX. A third-party Level III inspector from Phoenix National Laboratories Inc was retained to verify conformance with the procedure and to inspect the work.

Welders practiced with stainless-steel plate in the shop for about 40 hours before making the field repairs. Test welds were heat-treated and checked by radiography, then sent for bending and tensile testing. Technicians were qualified for out-of-position welding using a 2-in. super coupon at 45 deg.

For the vertical weld, about 10 in. of material was removed and a gap in the wall of about ⅜ in. was created to access sound material (Figs 5, 6). Preheat to 400F for the excavation was provided by a non-carbonizing flame. Proper preheat was confirmed using temperature sticks. A borescope verified a proper root pass from inside the pipe. The completed weld is shown in Fig 7. Mag-particle testing prior to welding confirmed that all cracks had been removed. Phased-array UT also was conducted at several locations to assure no subsurface cracks existed.

The steps to eliminate the crack in the horizontal weld are illustrated in the photo array Figs 8-10.

A post-repair review of the laterolet failures and of P91 properties gave plant management no confidence that the fitting would not fail again. Further, metallurgists recommended that P91 not be heat treated more than three times to avoid compromising its structural properties and creating an end-of-life condition.

Plant management was aware of varying opinions about heat treating P91 but choose a conservative route. Another compelling reason to replace the laterolet with a forged tee as suggested by Tetra, B&V, and others was that the type of damage Griffith found at 50,000 hours of service other plants had experienced at 25,000 hours.

Final step. Griffith Energy's goal in replacing the fabricated laterolet with a forged tee was based on the need for a reliable fix that would be problem-free for the remainder of the plant's life. While the project might look simple given the simple sketch in Fig 11, and the neat completed job in Fig 12, it was challenging. Timewise, the retrofit took nine 24-hr days.

The forged tee was not available off-the-shelf. It had to be custom-made, in Italy. Houston-based US Metals handled the procurement and also supplied the required sections of 24- and 28-in. pipe, plus a 28 × 24 in. reducer to replace the original found to be questionable, while removing insulation for the repair (Fig 13).

Then there were fit-up challenges, because the pipe diameter of some parts being welded together differed slightly. Welding was challenging because purge dams had to be installed and moved from weld to weld as work was completed. All final work had to be done in the air off scaffolding which had to be reinforced to accommodate the weight of the pieces.

The next challenge was accessibility given the location of structural members which required the new and old pieces to be rigged in such a manner has to "snake" through the members. Project coordination, the plant's responsibility, also had its moments given number of participants identified in Sidebar 2.

The tee and pipe sections required were shipped to Durus' shop where approximate cuts were made for the pup pieces before moving them to Griffith where final cuts and weld prep were done. The job involved seven welds, one in the shop (the Unit 2 pup-piece-to-tee weld) and the remainder in the field. For the field welds, MT was performed after the root pass, phased array after filler weld was deposited over the root, and phased array again after post-weld heat treatment.

The maximum weight handled by the crane maneuvering components among structural members was about 3800 lb. Scaffolding was designed for 5000 lb. Scaffolders were at the plant on standby for the project to minimize the delay time in making any platform changes required.

After a little over 48 months, the previous repairs, the addition of the forged lateral, Star West and plant management had a long-term fix for a here-to-fore troublesome component. All in all the project was a success bringing together several contractors, sophisticated welding and rigging procedures, and most important, a safe job—no injuries or near misses. CCJ

How many turbine stages?

By Brent A Gregory, Creative Power Solutions

Turbine blades all come in the same usual shape with the only seeming variations being size and the presence of a rotating shroud or not. However, for gas turbines (GTs) of similar ratings, sometimes there are quite dramatic (if not subtle) differences. A good example—one that affects the owner/operator directly—is the number of stages in the hot section.

Some units offered have three turbine stages (generally speaking, GE), some four (Siemens, for example), at least one five (Alstom). This may be a cost concern when considering hot-gas-path replacement or performance-related issues.

The $64 question: What determines the designer's choice in selecting the number of turbine stages for a given GT design? Next, who, how, or what decides the number of blades in a particular row.

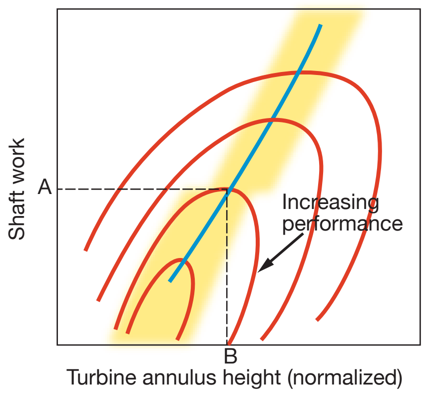
Looking at Fig 1, the vertical axis, shaft work, is akin to the "loading" or work performed; the horizontal axis, annulus height, depends on the height of the turbine blades. The illustration represents the relationship between the amount of work extracted from the hot gas and the blade height (as expressed in terms of mass flow through the annulus). The relationship is important for determining many factors related to performance, maintenance, and the first cost of the gas turbine itself.

This article considers only the cost implications associated with the number of turbine stages; performance implications are for another discussion. The Fig 1 chart, developed in the 1950s by Rolls-Royce, shows that the fundamental variables strongly correlate with turbine performance as the independent variable.

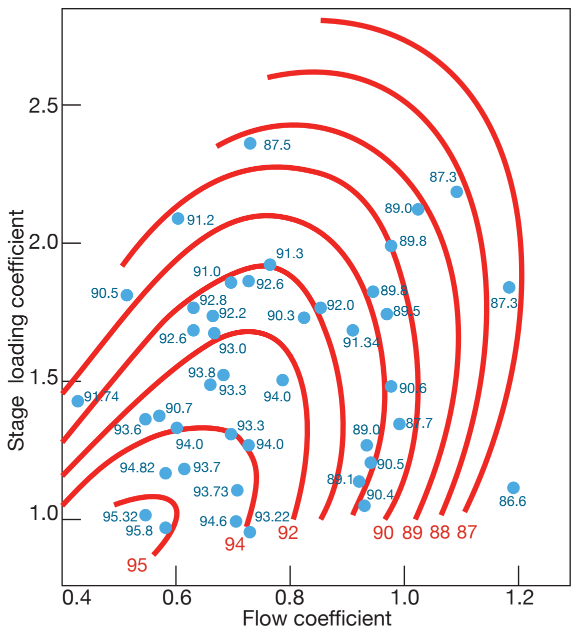
This is reflected by the red contours in the figure, which are lines of constant efficiency. The highest performance is for turbines defined by lower work requirements and lower velocities in the gas path. Engineer Ron Pearson realized early in the development history of GTs that the number of fundamental factors determining performance might only be the following:

- Demand on the turbine (work output).
- Surface area of gas-path components, expressed (or normalized by algorithmic manipulation) as the axial velocity of the hot gas.

Pearson's work was later published by a colleague, S F Smith, and the figure came to be known as the "Smith Chart," a/k/a the "Pearson Chart." The red contours (derived tests and field data) represent lines of constant efficiency, where turbine efficiency increases towards the lower left of the chart. The blue line (drawn somewhat arbitrarily) represents the peak efficiency for any given design of turbine. The yellow shaded area defines the margins of where the blue line may be drawn.



1. Chart represents the relationship of the amount of work extracted from the hot gas to the blade height



2. Smith/Pearson chart reflects the design and optimization strategies of each OEM over many years and development cycles

The significance of the chart: Given that work (the demand of the compressor and generator), for land-based turbines) and wheel speed (most often 3000 or 3600 rpm for generator drivers) are fixed, the only remaining variables are the mass flow required to achieve that work and the temperature drop across the turbine, according to the following equation:

Work = Mass flow × ΔT × Cp,

where Cp is the specific heat of the gas flowing through the turbine.

This means there is only one real solution that maximizes performance of a given turbine designed to meet certain requirements, and that is given by the blue line drawn through the peak points of each red curve.

That leaves as the only variable the axial "through-flow" velocity. From the physics of flow (continuity equation), this depends on the turbine annulus height. Increasing the annulus area reduces flow velocity; decreasing the area speeds up the flow. Thus the designer may have few options with which to manipulate a turbine gas path. It also follows, indirectly, that deviations away from the blue line have an effect on blade shape and on the number of blades.

To help explain, consider the following example: Assume the point on the ordinate in Fig 1 ("A") denotes the work required by the turbine. Using a simple straight edge, the highest performing turbine is found at point "B" on the abscissa.

This illustrates there are few options open to the engineer to complete the optimum design of the turbine. Given the annulus area is fixed at point B, the designer can set the maximum diameter, and the annulus area (a function of the tip and hub diameters) is deduced from simple math.

However, the maximum diameter usually chosen at a point where the mechanical designer is comfortable with the maximum stresses on the turbine attachments and the blade length—typically the last-stage blade. The aerodynamic designer, who shares responsibility for the final layout of the turbine, is even more challenged in terms of available avenues to optimize all the design constraints.

But he or she can choose to divide the required shaft work into several parts—each representing a turbine stage. Referring back to Fig 1, if the work "A" is divided between two or more stages, then the corresponding point on the ordinate is lower and the blue optimum performance curve describes a new annulus area.

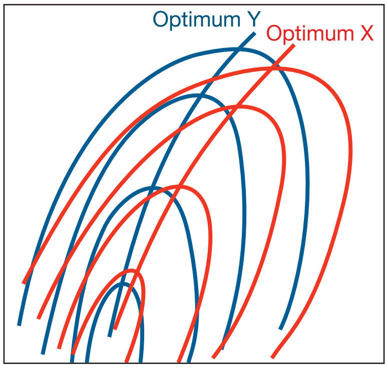
Note that as the designer invokes this option, the performance of each turbine stage increases. The result: Turbine performance is better than the single point described by the original "AB" point. When it comes to adding turbine stages, there is a law of diminishing returns to consider. For mid- to large-size (40 to 400 MW) gas turbines, that limit is three to four turbine stages.

What are the key factors that drive the designer's choice among two, three, four, or even five turbine stages? The author's career at Rolls-Royce, GE, Honeywell, and Alstom suggests that the historical progress of an OEM's product allows the designer to generate a Smith/Pearson Chart for a given product range.

Generations of turbine designers have walked in their predecessors' footsteps, meaning that new designs largely reflect previous designs with only very cautious introduction of new technologies. The Smith/Pearson Chart reflects the design and optimization strategies of the OEM over many years and development cycles.

In the original paper by Pearson and Smith, approximately 70 turbines were examined to make up the first chart (Fig 2). Efficiencies are corrected for the variables important to chart development. Important to remember: While the chart is accurate for the turbines represented, it may not be accurate for another OEM's equipment because of varying design methodologies and a different design tool chest. The reasons for this are complex and well understood, but beyond the objective of this article.

The fact that one OEM's Smith/Pearson Chart will almost certainly not overlay with that of another OEM's is illustrated in Fig 3, where the different colors differentiate the OEMs.



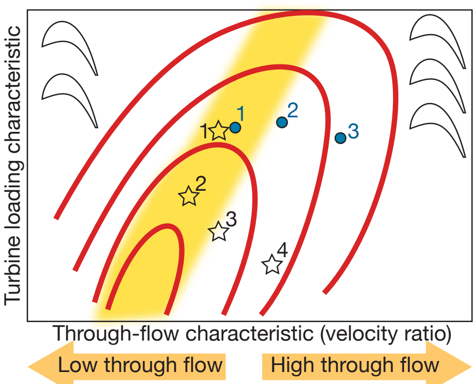
3. One OEM's Smith/Pearson chart (red) almost certainly will not overlay with the chart of another OEM (blue) because turbine designs are inherently different

Each OEM has a unique optimum X or Y and the efficiency curves do not line up with one another.

These "brand" characteristics are determined by such things as empiricism derived from previous designs and the results of performance criteria derived from specific tests based on years of research in the academic world, and by emerging technologies such as Computational Fluid Dynamics (CFD).

OEMs typically producing heavy-frame gas turbines (HFGT) in addition to aircraft engines have a significant advantage when it comes to making technology decisions regarding frame-engine components. For instance, when comparing a three-stage turbine to an equivalent-output unit with a four-stage turbine, be aware that the latter may well have had the advantage of a significantly better performance prediction model which gave distinct advantages for higher efficiencies for a given shaft work.

Aircraft engines also are required to be lightweight. So the number of stages must be low. Fuel burn is very important, too, and the optimum of these variables is difficult to identify. Advanced design techniques are increasingly using artificial intelligence (AI) to optimize the variables because there are many of them to consider.



4. Smith/Pearson chart reflects a paradigm shift, such as a transition from a historical three-stage design plotted on a per-stage basis to a more modern four-stage design

The complex reasons for OEM variability are intriguing and may well lie in the history of that early chart produced by Pearson. Efficiency numbers which help define a given design are only as good as the ability to predict it accurately The early designs of gas turbines were steered by performance models which penalized turbines with high turning in the blade rows. Later performance predictions were steered more by loss models that emphasized friction losses and less about the degree of turning in the blade row.

For producers of HFGTs that make a broad range of turbines (including aircraft engines) it is even more apparent why the Smith/Pearson Chart varies among OEMs. Manufacturers of both HFGTs and aircraft engines (such as GE) enjoy a distinct advantage because the fundamental philosophy underlying the resultant efficiency curves are optimized along lines of cost, performance, and weight.

Regarding the last, aircraft-engine designers will develop turbines with fewer blades and vanes than the heavy-frame designer, who is impacted little by weight issues. In Fig 3, efficiency curves ("Optimum X") for turbines having lower blade counts are driven to the right. The fundamental philosophies of design are of great importance when considering a turbine layout. That philosophy affects strategic business decisions such as first cost and lifetime costs.

It is doubtful a three-stage design could ever trump the four-stage design in terms of performance. Other factors driving the decision will determine the rational for choosing a design, but producers of a wide range of turbines will have many choices at their disposal.

Several factors prevent the turbine stages from falling on the "optimum" line but it is always, during a strategic design review, the chief engineer's prerogative to ask the designer why it is so, and to determine what compromises the designer can/should make.

Wrapping up this section of the article, more probably should be said about the history of industrial three-stage turbines, which are incorporated in thousands of GE machines worldwide. Examples include all Frame 6Bs and Frame 7s through the Model FA.

The three-stage GT turbine evolved from steam turbines which were largely developed along high-through-flow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Takumi: a person who has vast experience and knowledge in a specific field.
Omotenashi: customer-specific hospitality catering to each customer's unique needs.
IHI doubled maintenance shop area
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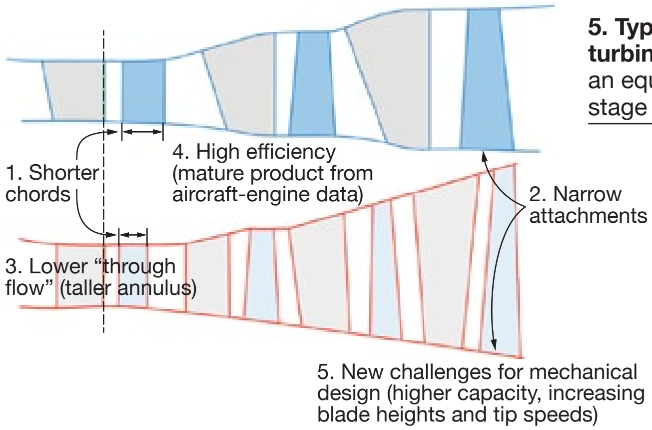
3909 West 5th Street, Cheyenne WY 82007 TEL 307-638-8983 Email: atsunori_ikejiri@ihi.co.jp



5. Typical three-stage turbine is shown above an equivalent-duty four-stage machine

designs because of their inherent low-pressure-ratio (lighter duty) stages. As OEMs transitioned their products from steam to gas turbines they turned to new technologies available to them from research developed for aircraft engines.

Aircraft-engine technologies drove new initiatives because of the need to increase firing temperature and the need to dramatically increase efficiency while reducing weight. In this work, the expansion across each stage determined the annulus area, so the optimums implied by the Smith/Pearson chart were largely ignored. Aircraft-engine developments have forced HFGT OEMs to rethink many historical paradigms.

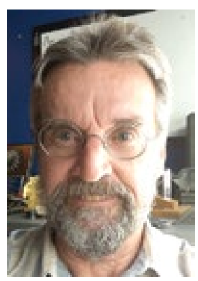
Fig 4 illustrates the paradigm shift from the mature three-stage design, plotted on a per-stage basis, to a modern four-stage design. At least one OEM has transitioned to a four-stage turbine for its latest large frames from the three-stage design used in earlier models. The change was motivated by performance.

Even if the extra stage drives up first cost, the performance increase reflected in a lower fuel burn easily pays for the enhancement in less than a year. OEMs also have considerable advantage in using highly loaded technology in the first stage or two to allow less aggressive (read expensive) technology downstream.

If an OEM was thinking modern design, or even a retrofit, here's what a four-stage design would look like relative to an equivalent-duty three-stage turbine (Fig 5):

- Shorter chords as a result of highly loaded airfoil technology (more work per blade). Higher loading reduces airfoil count and/or reduces the width of the blade.
- The blade shape and count are significant variables when designing turbines to the left or right of the optimum.
- Attachment areas are refined based on aircraft-engine technology or an evolution of a known "good" design practice within the OEM's experience.
- Lower "through flow" allows the expansion of each stage to be incorporated in the same diameter as a three-stage machine, allowing the retrofit of a four-stage unit into a similar area. The casing can remain and the turbine inner flow path (hangers) can be reshaped to accommodate the new gas-path profile.
- Lower "through flow" enables efficiency optimization. Historically, the stage optimum efficiency implied by Smith/Pearson was largely ignored; a more modern design would tend to follow the optimum.
- The retrofit challenge will be to maintain the very high mechanical loads on a new last stage. Four-stage designs allow for increased performance with larger capacity flows, increasing output by as much as 20% for a given frame design. If designers can retrofit new technologies, such as those afforded by adding extra stages in the available design space, it opens up a new era for turbomachinery currently anchored in their existing facilities by 100 of tons of concrete.

However, it is highly unlikely that an OEM would seriously consider retrofitting an existing frame with more turbine stages (though it is often done in a compressor) because of the high mechanical demand placed on the rotor. Some OEMs with a long tradition of three stages can make a significant technology leap by adding a fourth stage to what traditionally would have been a three-stage machine and make a dramatic technology leap in quoted performance over the competition. CCJ



Brent Gregory has a demonstrable track record of leadership in gas-turbine new product introduction, technology innovation, and design retrofit. He has contributed 50 years of professional service with major gas-turbine OEMs—including Rolls-Royce, GE Aircraft Engines, GE Power Systems, Honeywell Engines, and Alstom.

Gas-side tube fouling: performance thief

By Patrick Walker, HRST Inc

In the electric-power industry, natural gas is considered a clean-burning fuel. But gas-side fouling of heat-transfer surfaces within an HRSG isn't just related to the fuel. Other fouling factors can include geographic location, operational profile, component failure history and trends, and /or emissions control equipment. All can contribute to overall fouling and fouling rates.

Several types of foulants are common to operating HRSGs—including rust, insulation, ammonia salts, and sulfur compounds. Here are some background facts on each:

Rust is the prevalent type of fouling (Fig 1). Most tubes and fins are carbon steel and subject to oxidation (rust scale formation). The oxidation rate increases as water or water-vapor levels increase, either during operation or while offline.

During operation, water can be introduced by upstream tube leaks or from SCRs using aqueous ammonia in their injection systems. Offline, leaking roof doors and penetration seals, open or missing dampers, casing cracks, and failed insulation lagging can allow moisture to enter the unit slowly. HRSGs in geographic areas characterized by high relative humidity are subject to higher oxidation rates.

Insulation fouling of heat-transfer surfaces is common, but mostly observed as a few small localized patches stuck to the finned tubes throughout the access lanes. A major insulation fouling issue usually appears when a plant has experienced a liner failure, or has significant liner gaps present, and the insulation has been sucked out and deposited downstream (Fig 2).

Insulation from a catastrophic liner failure usually deposits on the first three rows of tubes, which catch most of the liberated material. However, small fibers migrate downstream and plate out on other panels or on catalyst for emissions control. The SCR and/or CO catalysts act as large filters for airborne insulation, increasing the pressure drop across the catalyst. If fouling is severe, it can force a unit to trip offline or to run at partial load until the issue has been corrected.

Ammonia salts typically are found in units with SCRs. Salt formation is believed limited by the amount of sulfur in the exhaust gas and its reaction with excess ammonia (so-called ammonia slip). Salt precipitates on cooler metal surfaces downstream in the unit (Fig 3). The salt buildup can vary from a light powdery deposit to a dense solid coating.

These types of salts usually are difficult to remove once well-established on the heat-transfer surfaces. Many plants have switched from a reactive to a proactive cleaning approach to keep

1. Loosely adhered rust flakes bridge gaps between fins

3. Early stages of salt accumulation on finned tubes

2. Insulation from an upstream liner failure is wiped away exposing fins underneath

4. Sticky sulfur deposits, the consistency of peanut butter, have plugged finned tubes

fouling rates under control, as well as to prevent the foulant from bridging the gaps between fins.

Sulfur compounds. Heavy sulfur buildup is common in units operating primarily on fuel oil (Fig 4). Lighter fouling can occur in HRSGs at plants burning high-sulfur natural gas in the gas turbine or duct burners. Trace amounts of the odorant mercaptan (added to some natural gas to facilitate leak detection) will add to the overall sulfur content in the fuel.

Wetted sulfur deposits are very corrosive and can cause tube failures fairly quickly if conditions are "favorable." Many times the sulfur deposits are sticky in nature and the foulant will "jump" from the tube that you are cleaning and stick to neighboring tubes.

Thermal performance of the HRSG is diminished because the foulant can act as a thermal shield, reducing the transfer of energy from the turbine exhaust gas to the working fluid. As sections of the HRSG become fouled and no longer absorb the intended energy from the exhaust, downstream components can become exposed to elevated exhaust-gas temperatures which can cause them to over-perform compared to original design. Such over-performance can cause steaming and downflow instability issues with economizers, as well as increased flow-acceleration corrosion (FAC) risks in certain areas (CCJ 4Q/2015, p 83).

Foulants also contribute to reduced efficiency of the gas turbine because they increase backpressure through the HRSG. Assuming an additional 4 in. H_2O of backpressure caused by gas-side fouling, a 7EA or 7FA gas turbine could experience a power output loss of 0.42% to 0.56%, or a heat-rate increase of 0.42% to 0.56%, and experience an increase in exhaust gas temperature of from 1.9 to 3 deg F. Even a slight increase in exhaust-gas temperature could prove problematic for metals near design temperature limits.

While it may seem that a higher gas temperature would benefit boiler thermal performance, the reduction in heat-transfer performance attributed to the fouling typically is sufficient to negate any performance improvement from higher HRSG inlet temperature. As the foulant continues to build over time and the backpressure approaches the upper-limit set point for the gas turbine, the unit will become more susceptible to trips or run-backs, especially in the colder times of the year.

OEMs often look to promote and sell gas-turbine upgrades that can reduce the current low-load range, increase overall output, and reduce fuel cost and emissions—among other benefits. But these upgrades also can increase the mass flow of exhaust gas through the HRSG, which can compound the backpressure limits on combined cycles already approaching the upper ΔP limits for turbine trips and run-backs.

Imagine spending several million dollars for turbine upgrades only to find out that full-load operation may not always be possible because of backpressure limitations. It has happened.

It's important to recognize that complete HRSG debris removal and a full return to first-fire backpressure conditions are both unrealistic. The amount of heat-transfer surface in a given module can be staggering.

Perspective: A 36-ft-wide harp having 16 rows of 61-ft-tall × 2-in.-diam tubes with 0.75-in.-long fins spaced at six fins per inch has more than 750,000 ft² of surface area to clean. That translates to an area of about 17.2 acres, or roughly the equivalent of 13 professional football fields (including the end zones). Cleaning that much surface using only tube lanes for access is challenging.

With traditional CO_2 surface blasting effective for only the first two to four tube rows of the module (depending on tube geometry), that leaves more than half of the tubes virtually untouched when the harp is cleaned from both the upstream and downstream sides.

The deeper the bundles, the less effective traditional CO_2 surface blasting alone will be at removing debris. In some cases, surface blasting can drive the debris deeper into the bundle, where it is out of sight and difficult to reach. If the foulant is sticky in nature a flow-path dam can be created deep in the bundle with significant impact on backpressure.

Tube spreading. HRST Inc has designed and patented tube-spreading equipment and a cleaning process for accessing the deeper portions of tube bundles generally inaccessible by traditional surface blasting techniques. The tube spreading process is the most critical component of this deep cleaning approach and should be handled with caution.

Damage can result from tube spreading when improper tools are used, stress calculations are not performed for each of the individual panels being cleaned and/or the company performing the tube spreading does not have a good understanding of all potential limitations. Pre-existing conditions like stress-corrosion cracking (SCC), significantly bowed tubes, and rolled tube joints must be considered when developing a tube spreading plan.

There is no perfect solution to gas-side cleaning. This is evident by the various methods that have been developed and used—including sootblowers, acoustic horns, sand/grit blasting (CO_2 blasting is a derivative), water washing, compressed-air blasting—even explosives.

Preparation. When considering the need for gas-side cleaning, it is important to know which sections are contributing the most to the excessive backpressure. At most plants, backpressure monitors are located at the GT outlet and on either side of the catalyst (if present).

Planning for a cleaning often will require installation of some type of data collection device in multiple access lanes throughout the HRSG. These devices do not have to be elaborate or expensive (think of U-tube manometers), or though they can be (think of wireless ΔP transmitters linked to the DCS historian).

Once data are collected, bundles can be rated in terms of excess ΔP over design conditions by referencing OEM manuals. This information then can be used to direct cleaning efforts, combined with visual inspections from the access lanes and borescope inspections into the tube banks.

Before selecting a company to perform gas-side cleaning, do your due diligence and research all potential vendors. A few hours spent vetting candidates can save time and money in the long run. Don't hesitate to ask for the following information:

- Experience modification rate (EMR), OSHA 200 logbook, or equivalent.
- An explanation of how the cleaning contractor plans to remove the foulant present at your site, plus contingency plans. Remember that different types of fouling can require different cleaning approaches. Example: If the foulant is mainly rust and lightly adhered, then compressed air alone often is sufficient to remove the debris. But if the foulant is sticky, or concrete-like, more aggressive forms of cleaning will be required.
- How the contractor determines what is "clean." Agreeing on criteria beforehand will save time during final inspections and sign-offs for work performed.
- The type of equipment to be used, and processes to be followed, during the cleaning work. If any tube spreading is involved, make sure the proper stress calculations are performed on the sections to be cleaned.
- References from previous clients, especially those with equipment and fouling similar to yours. CCJ

Custom repair techniques match complexity of original design

It's not a secret that many Row 1 (R1) vanes serving in 501F gas turbines are deemed scrap (or near scrap) after the second repair cycle. Perhaps less well known is the variety of repair techniques and modifications available to salvage more operating time from these expensive components.

According to Matt Lau and Jason Field of ACT Independent Turbo Services Inc, Houston and La Porte, Tex, the company's objective is not just to repair the vanes but also to understand failures. With this information it can adapt and improve parts, when possible. CCJ editors visited ACT to dig deeper into recent presentations on hot-parts repairs made by senior staff at user-group meetings. At the time, the company was finishing a major expansion and consolidation of its facilities.

1. Priority one is wall-thickness restoration on thin R1 vane airfoils. Accurate measurements (in inches in the photo) of existing condition are critical

Distortion and airfoil thinness

The interview began with ACT personnel explaining the fundamentals of evaluating component condition. Lau stated that with any cooled industrial-gas-turbine (IGT) component, metallurgical condition, wall thickness (Fig 1), and crack evaluation are the critical starting points for making sound repair recommendations.

For 501F R1 vanes, it sometimes is observed that repairs are performed without restoring the vanes to adequate thickness first. Priority one is thickness restoration on these thin airfoils.

Leading-edge airfoil. Lau and Field say a critical evaluation during an incoming inspection is the condition of the airfoil. If the leading edges have experienced severe damage (Fig 2), further inspection of the core cavities is warranted (Fig 3). The leading-edge core cavity has two thin strips, often thought of as guide rails for the core insert (Fig 4).

ACT believes these guide strips are very important for pressurizing the leading edge with critical cooling air and directing cooling air to the leading-edge cooling holes. Company experts say there is a direct correlation with failed or missing core rails and burn-through of leading edges on repaired vanes.

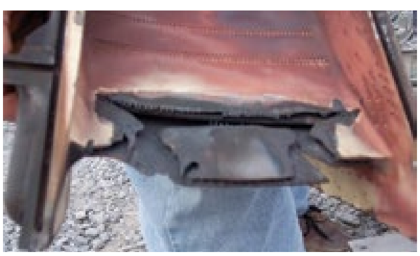
For R1 vanes in fair condition, ACT incorporates replacement of core rails to assure proper core insert fit-up and correct cooling. For vanes with severe damage, the entire leading edge of the airfoil is replaced with one having rails cast into the component. New cooling holes then are CNC EDM-machined post repair in accordance with the cooling configuration program for that specific vane type.

Trailing-edge airfoil. Company experts further explain that trailing-edge airfoil damage can be approached in a manner similar to that for the leading edge by correlating trailing-edge damage (Fig 5) to the associated cooling flow. In the case of the trailing

2. Severe damage to the leading edge of R1 vane

3. Inspection of inner cavity shows wear and tear

4. Leading-edge core cavity has two thin strips, often thought of as guide rails for the core insert



5. Trailing-edge damage in photo is severe

6. Damaged "bathtub" requires replacement

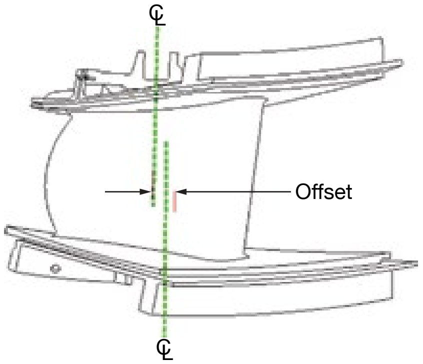
7. Vane with new bathtub is more robust than original design

edge, ACT says that issues with the inner-wall covers (sometimes called the "bathtub," Fig 6) are associated with severe trailing-edge airfoil damage.

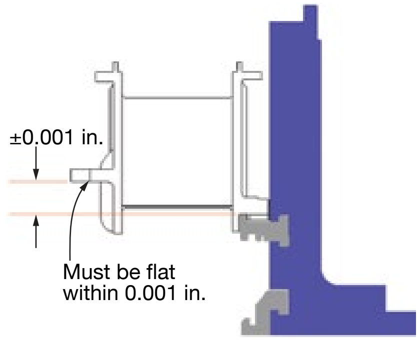
Oftentimes the bathtubs are overlooked during the repair process; tubs either are shortened during removal or thinned by oxidation. If replaced, sometimes subpar tubs are installed using inadequate weld processes.

ACT recommends replacement and installation of new tubs at every repair visit (Fig 7). New tubs should be slightly thicker than nominal, of correct form-geometry, and "double welded" to assure good weld penetration. Lau explains that the upgraded bathtub replacement, with improved weldment, is "cheap insurance" when compared to the alternative of losing trailing-edge cooling efficiency and a tub.

Field explains that the bathtub can be thought of as a reservoir for cooling air with a specific metered volume. When there are issues with the tub, they will affect other areas of the vane cooling. Tub position and height also are critical. If too tall or too short, the amount of cooling air in the reservoir may increase or decrease. Tub deviation is detected via sonic-nozzle flow testing. Additionally, if the tub is positioned incorrectly, it can interfere with the inter-vane joint gaps.



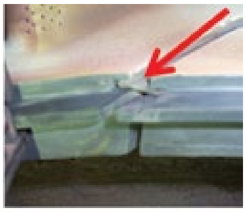
8. Radial offset relationship



9. Axial datum relationship

10. Torque-block dimensions are critical

11. Seal/sidewall misalignment cannot be tolerated



12. Seal groove misalignment in operation can be avoided by assuring proper fit-up with actual seals in an accurate fixture

Dimensional checks

When asked about vane installation, Lau and Field explain repairs are ineffective if the vanes do not fit properly in the machine. They say the 501F R1 vanes are relatively thin, move easily, and the result is usually severe post-operation distortion.

The best way to approach distortion correction is to first mock-up the machine with a solid, tight-tolerance fixture that simulates the R1 blade ring. The second portion of the approach is to have "master segments" that are within ±1 mil of nominal specification. The tighter the tolerances of master segments, the better the end product.

With the correct tooling, the next approach is to clearly understand the datum planes, both radial and axial (Figs 8 and 9).

After correcting the distortion and performing weld repairs, joint gaps and the torque-block lug must be addressed for proper installation and fit-up. Field explains that the torque-block dimensions are critical (Fig 10), but often are overlooked by repair shops where fit-up and component relationships are not fully understood.

The evidence: W501F vanes often sent to ACT for repair do not have blade rings. One reason may be is that repair shops not associated with outage groups rarely get to assemble the vanes to see how they really work. Lau further explains that uniformity is critical to avoiding issues onsite. Example: Torque-block lugs must be held to a very tight tolerance (+0.002/-0.000 in.). Lugs must be machined, not hand-blended.

Another critical area is the joint seals and seal grooves (Figs 11 and 12). Joint seal grooves should be addressed after all other repairs and distortions are corrected. In cases where severe distortion correction was performed, all seal grooves should be welded solid and re-machined. All seal grooves should be test fit with actual seals and in an accurate fixture using master segments.

ACT's goal is to make the joints so uniform that it does not matter where they go in the assembly. The result will be the same dimensional tolerances within all segments. Caution: If the grooves are done prior to correction, compounding errors will occur, causing incorrect engagement and sidewall misalignment.

Seal engagement, while maintaining correct sidewall alignment, is

13. One version of an OEM cooling configuration

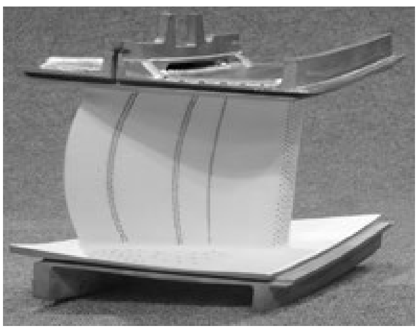
14. Cooling configuration shown was engineered by a third-party supplier of vanes tough even for the most contentious repair shop—but it is critical. Lau says this is much easier to achieve if all of the distortion is addressed during repairs. ACT cuts the typical allowable tolerance in half to assure uniformity.

Cooling holes and configuration

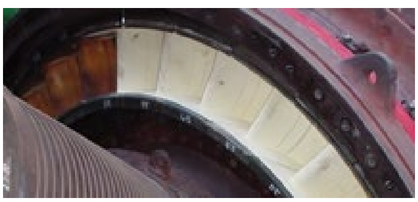
Only when all of the above vane repairs are completed can a repair shop address the cooling holes. Field says it is ACT procedure to perform 100% weld repairs near and around any cooling holes to remove all cracks—even it means the cooling hole will be lost. Many times cooling holes need to be remade to assure the proper diameter for flow consistency.

Field states that cooling-air pressure and the flow of cooling air is critical to vane life. Re-machining the holes using CNC EDM processes re-establishes the correct cooling holes, position, and vector.

Lau says it is challenging for repair shops to program the often complex 3D geometry of the cooling holes and locations (Figs 13 and 14). Shops also have to identify and understand the multiple cooling-hole configurations and patterns. Not all OEM and aftermarket vanes have the same hole configurations, and a mistake there may cause issues with flow and cooling that can limit component life or result in failure.



15. High-bond-strength coating is needed to achieve the demanding intervals users specify



16. Group like segments (new/old) together when installing partial sets

Coatings

Lau says that he has always believed the 501F R1 vane required a robust coating upgrade when compared to typical specifications (Fig 15). With today's advances in coating technology, there is no reason that F-class vanes should not get the coating they require for optimal life. For the 501F R1 vanes, Lau and Field prefer a high-aluminum-content CoNirAlY bond coat with an 8- to 14-mil-thick thermal barrier top coat. Robotically applied coatings with high bond strength are crucial for the demanding intervals that users are trying to achieve.

Field tips

Wrapping up, Lau offers the following tips for users involved in field reassembly:

- Check for isolation-block/segment wear. Damage will result in vane assembly dimensional deviation.
- Blade-ring roundness can affect vane segment joint gaps; check 45-deg areas for "kinks."
- Group like segments (new/old) together when installing partial sets (Fig 16). This helps with segment-to-segment alignment and tracking.
- Segments should be equally loaded in the downstream position when joint seals are installed/fit-up.
- Recheck diamond and T-slot joint seal engagement before final locking of torque blocks. Pull and reinstall vane if there is doubt of full seal engagement. CCJ

Turbine blades: Good, better, best

By Lee S Langston, professor emeritus, UConn

About 60 years ago, a small group of industrial researchers specializing in gas turbines set out to eliminate grain boundaries in superalloy turbine blades. The result: A class of single-crystal blades that has increased both gas-turbine thermal efficiency and component service life, while providing unmatched resistance to high-temperature creep and fatigue. The article below traces the road taken.

Gas turbine (GT) thermal efficiency increases with higher temperatures of the gas flow exiting the combustor and entering the work-producing component—the turbine. Turbine inlet temperatures in the gas path of modern high-performance jet engines can exceed 3000F, while non-aviation gas turbines typically operate at 2700F or lower.

In the highest-temperature regions of the turbine, special high-melting-point nickel-base alloy blades and vanes are used because of their ability to retain strength and resist hot corrosion at extreme temperatures. These so-called *superalloys,* when conventionally vacuum cast, soften and melt at temperatures between 2200F and 2500F.

This means blades and vanes closest to the combustor may be operating in gas-path temperatures far exceeding their melting point and must be cooled to acceptable service temperature (typically eight-to-nine-tenths of the melting temperature) to maintain integrity.

Thus, turbine airfoils subjected to the hottest gas flows take the form of elaborate superalloy investment castings to accommodate the intricate internal passages and surface hole patterns necessary to channel and direct cooling air (bled from the compressor) within and over exterior surfaces of the superalloy airfoil structure.

To eliminate the deleterious effects of impurities, investment casting is carried out in vacuum chambers. After casting, the working surfaces of these cooled turbine airfoils are coated with ceramic thermal-barrier coatings to increase life and act as an insulator—allowing inlet temperatures 100 to 300 deg F higher.

Howmet

1. Ceramic mold for multiple directionally solidified turbine blades is placed in a vacuum furnace at Howmet's foundry in Terai, Japan. Molten superalloy will be poured into the mold

Grain-boundary problems. Conventionally cast turbine airfoils are polycrystalline, consisting of a three-dimensional mosaic of small metallic equiaxed crystals, or "grains," formed during solidification in the casting mold. Each equiaxed grain has a different orientation of its crystal lattice from its neighbors'. Resulting crystal-lattice misalignments form interfaces called grain boundaries.

Life-limiting events happen at grain boundaries—such as intergranular cavitation, void formation, increased chemical activity, and slippage under stress loading. These conditions can lead to creep, shorten cyclic strain life, and decrease overall ductility. Recall that creep, an insidious life-limiter, is the tendency of blade material to deform at a temperature-dependent rate under stresses well below the material's yield strength.

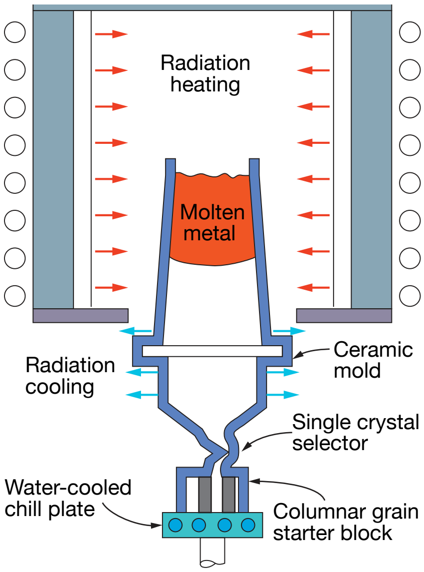
Corrosion and cracks also start at grain boundaries. In short, physical activities initiated at superalloy grain boundaries greatly shorten the lives of turbine vanes and blades, and dictate lower-than-optimal turbine temperatures with a concurrent decrease in engine performance.

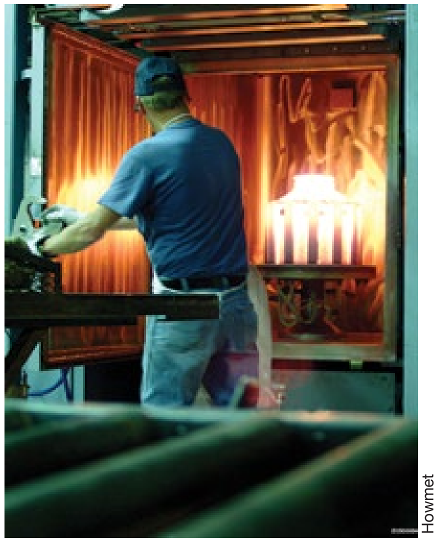
One can try to gain sufficient understanding of grain-boundary phenomena so as to control them. However, in the early 1960s, researchers at Pratt & Whitney Aircraft (now Pratt & Whitney, P&W, owned by United Technologies Corp) set out to deal with the problem through elimination of grain boundaries from turbine airfoils, by inventing techniques to cast single-crystal (SX) turbine blades and vanes.

One-dimensional crystals. P&W's first step in the development of SX blades was directional solidification (DS). Carried out in vacuum furnace, DS is accomplished by pouring molten superalloy metal into a vertically mounted, ceramic mold heated to metal melt temperatures, and filling the turbine airfoil mold cavity from root to tip (Fig 1).

The bottom of the mold is formed by a water-cooled copper chill plate having a knurled surface exposed to the molten metal. At the knurled chill plate surface, crystals form from the liquid superalloy and the solid interface advances, from root to tip.

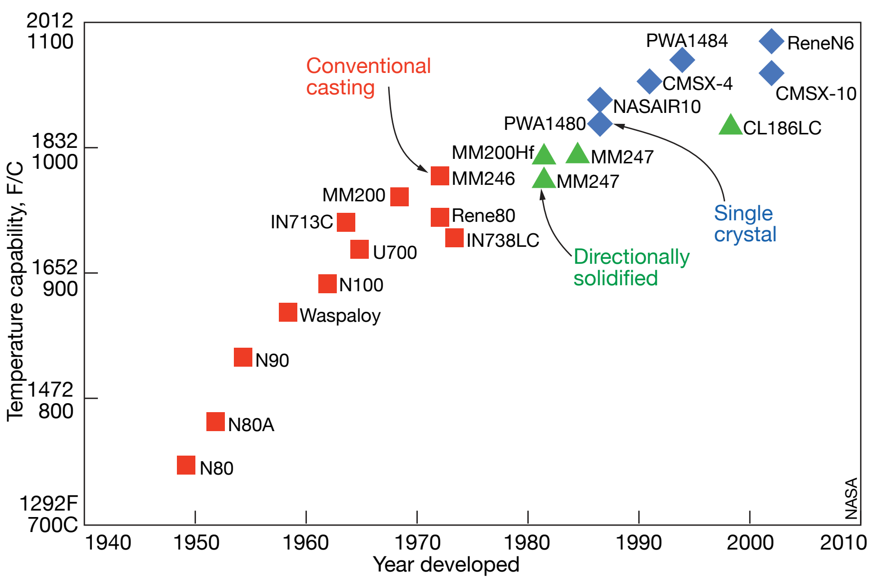
The mold is surrounded by a temperature-controlled enclosure, which maintains a temperature distribution on the lateral surfaces of the mold so that latent heat of solidification is removed by one-dimensional transient heat conduction through the solidified superalloy to the chill plate. As





2, 3. Single-crystal blade is made by a process like that shown in the simplified sketch at left. Vacuum furnace is opened after casting a cluster of single-crystal gas-turbine blades in a ceramic mold (right). Note the chill plate beneath the mold

4. Turbine blades (first stage, short; second or third stage, taller) are acid-etched to show grain structure. Pair at left is single crystal; center, directionally solidified; right, equiaxed



5. Development of alloys for turbine blades, traced in timeline, shows superiority of single-crystal structure. Note that the temperature capability is the temperature for creep life posed as the time (1000 hours) the alloy reaches a certain elongation/strain (1%) under a given stress (20,000 psi)

the solidification front advances from root to tip, the mold is slowly lowered out of the temperature-controlled enclosure.

The final result is a turbine airfoil composed of columnar crystals or grains running in a span-wise direction. For the case of a rotating turbine blade, where span-wise centrifugal forces set up along the blade are on the order of 20,000 g, the columnar grains are now aligned along the major stress axis. Their alignment strengthens the blade and effectively eliminates destructive intergranular crack initiation in directions normal to blade span.

In gas-turbine operation, DS turbine blades and vanes have much improved ductility and thermal fatigue life. They also provide a greater tolerance to localized strains (such as at blade roots), and have allowed small increases in turbine temperature (and, hence, performance).

Their first use by P&W in a production engine was in 1969, to power the SR-71 Blackbird supersonic reconnaissance aircraft. Commercial jet engine use of these airfoils followed, starting in 1974.

One crystal, one turbine blade. Building upon directional solidification, P&W reached its goal of eliminating turbine airfoil grain boundaries in the late 1960s.

The making of a single-crystal turbine airfoil starts in the same manner as a directional solidification airfoil, with carefully controlled mold temperature distributions to ensure transient heat transfer in one dimension only, to a water-cooled chill plate (Figs 2, 3). Columnar crystals form at the knurled chill plate surface in a mold chamber called the "starter." The upper surface of the starter narrows to the opening of a vertically mounted helical channel called the "pigtail," which ends at the blade root. The pigtail admits only a few columnar crystals from the starter.

Crystal orientations grow at different rates into the liquid metal in the pigtail, with one orientation growing the fastest. Thus, with ample coils, only one crystal emerges from the pigtail into the blade root, to start the single crystal structure of the airfoil itself.

In the 1970s, after SX production techniques developed, SX turbine airfoils were installed in P&W's F100 production engines, to power the F-15 and F-16 jet fighters. The first commercial aviation use was in the JT9D-7R4 jet engine, which received flight certification in 1982, powering the Boeing 767 and Airbus A310.

The first use of SX turbine airfoils

in land-based GTs was for corrosion resistance in a 163-MW machine, the Siemens V94.3A (now SGT5-4000F), introduced to market in 1995. In recent years, electric-power GT inlet temperatures have increased to aviation levels, so the SX airfoils with higher temperature capacity are now needed for long life. The SX turbine blades and vanes in GE and Siemens H-class machines are huge, with lengths of from about 1 to 1.5 ft, with each finished casting weighing more than 30 lb.

The result. In gas-turbine use, single-crystal turbine airfoils have proven to have as much as nine times more relative life in terms of creep strength and thermal fatigue resistance and over three times more relative life for corrosion resistance, when compared to equiaxed-crystal counterparts.

By eliminating grain boundaries, SX airfoils have longer thermal and fatigue life, are more corrosion-resistant, can be cast with thinner walls—meaning less material and less weight—and have a higher melting-point temperature. These improvements all contribute to higher thermal efficiency.

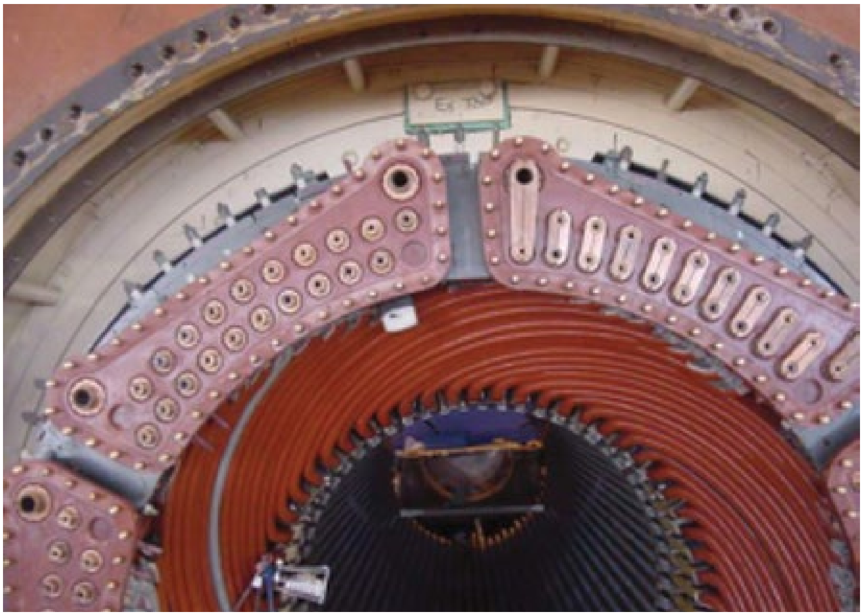
Cost-wise, a turbine designer can choose from among the airfoils shown in Fig 4: equiaxed (less expensive), DS (expensive), SX (more expensive), plus SX with exact lattice orientation specified (most expensive). Because single-crystal properties, such as elastic modulus (the tendency of the material to deform along a specific axis), vary with lattice angular orientation, the optimization of this property can improve specific problem areas of blade design—such as creep life or critical vibration modes.

Fig 5 shows creep-life progress in turbine-blade alloys. In the plot, the abscissa gives the year of alloy development and the ordinate presents the temperature capability for a variety of turbine-blade superalloys. As shown, single-crystal blades are clearly superior. 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.

Busy major inspection: Three failures identified, corrected

By Relu Ilie, Israel Electric Corp



1. Water box provides direct cooling of the stator winding

2, 3. Broken bar is in the upper right corner of water box (left), broken-bar end and attached nozzle is at right

Generator problems can be challenging to solve given the complexities of equipment design, difficulties in identifying the true root causes of failures, proper evaluation of alternative corrective actions and of alternative contractors, etc.

The following case history describes three significant issues found and addressed during the major inspection of a 35-year-old, 2-pole, 269-MVA generator. This outage was conducted five years ago and the repairs described here have prevented a recurrence of these failures since that time.

The generator is a hydrogen-cooled unit with a directly cooled stator winding using the water-box design shown in Fig 1. Each water-box segment supplies the nozzles serving several winding bars as well as the series bar-to-bar electrical connectors.

Stator bar failure. For a couple of months before the major inspection, plant personnel recognized hydrogen was leaking into the cooling water at a continuously increasing rate. During the outage, the leak was located inside one of the water boxes at the turbine end.

After dismantling the water box and bar insulation, a broken bottom bar was found. Most of the 18 subconductors were found broken; only two or three strands kept the water nozzle in place (Figs 2 and 3). The bar still was able to carry current and the broken strands were still closed enough to allow some cooling-water flow.

It did not appear that there was any significant leakage of water out of the broken strands into the stator-bar insulation, which is why a ground fault did not occur. Note that while hydrogen pressure is higher than water pressure, water still can leak out of the strands by capillary action.

Israel Electric Corp (IEC) engineers were well aware that replacement of a bottom bar would entail the removal and replacement of approximately 28 top conductor bars—an outage-duration concern. The OEM proposed an interim possible repair: Cut out the damaged section of the conductor bar and braze on its end an extended nozzle—about 3 inches—to revert the conductor bar back to its design length, in-situ.

IEC accepted this repair plan. After its implementation, the individual bar and the complete stator winding were fully leak-tested (pressure and vacuum) before the machine was returned to service.

Loose rotor-wedge locking screws. The rotor was rewound eight years before this major outage by a highly regarded non-OEM supplier. In the center of the rewound rotor there are 28 1-in.-long screws, each located at the longitudinal midpoint of the tooth adjacent to every active slot.

Inspection of the screws revealed the following: One was found partially unscrewed, another could be unscrewed by hand, and three were completely missing (Fig 4). Fragments of broken screws were found in the blower housing at the turbine end.

IEC personnel identified thousands

4. Wedge locking screw has backed out part way

5, 6. Impact damage on rotor body (overall view) is at left, example of area damage is at right

7-9. Stator damage (overall view) is at left, example of severe shorted laminations in the center, stator-core damage at right

of points of impact damage on the rotor surface along its full length. This was attributed to rotor-wedge locking screws that came loose and rattled around the stator bore (Figs 5 and 6). A positive: The retaining rings were not damaged—the loose screws probably stopped by the gas baffles or held by the magnetic field.

After the fault, it became clear that the rewind contractor probably applied its standard design of full-length wedge locking against axial movement, by use of central screws located at wedge side. This method is intended, in an axial-cooled generator design, to address the potential issue of ventilation-hole blockage, and also to avoid wedge-to-retaining ring contact and associated arcing.

However, the IEC machine was designed originally for rotor radial cooling with wedges allowed to move (slightly) axially, independent of the windings or rotor body. Slot-wedge screws were not used by the OEM because of the risk of fatigue cracks either in the wedge or rotor tooth.

Fortunately, damage to the rotor forging and wedges was minimal and inconsequential. Evidently, the rewind contractor didn't pay enough attention to securing the screws. As corrective action, mechanical locking by staking was employed, in addition to suitable Loctite bond.

Stator core damage. The stator also was damaged seriously by the screws that liberated from the rotor. Hundreds of points of significant damage were found along the entire length of iron core surface and on wedges. Additionally, tens of core areas were found smooth/polished, meaning a huge number of severely shorted laminations, including excessive heating and core iron melting on the tooth tips in some areas (Figs 7-9).

A stator-core replacement was out of the question, because of the time and cost involved. When the bottom-bar damage described earlier was repaired, stator-core damage locations were ground, using a high-speed grinding wheel, and electro-etched. This required several weeks of difficult work done with patience.

The repairs were tested and confirmed by EL-CID tests and high-flux (loop) tests with infrared scan. In some locations, follow-up grinding and electro-etching were necessary and the tests had to be repeated several times.

Failure root cause. Two strong and relatively long short-circuit events occurred three and four years before the inspection. These events were close to the generator: One on the HV bus of the neighboring substation and the second on main transformer HV terminals.

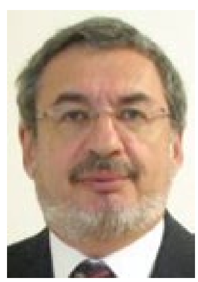
IEC engineers suspected there was significant cumulative effect of the end-winding movement that caused crack initiation in the copper strands. After that, vibration in operation likely fatigued the copper and caused the rest of the damage.

A main conclusion. From the failures described above concerns are raised relative to the use of OEM versus non-OEM shops to perform critical refurbishment work—such as rewinds.

The described events illustrate one worthwhile and creative solution performed for the stator-bar failure by the OEM, and, on the other hand, a deficient rotor rewind done by an alternative service provider. Of course, in other cases, the results from using the OEM versus an alternative supplier may be completely different.

A second conclusion: Major refurbishments which are supposed to eliminate existing problems, may also introduce new weaknesses and lead to other types of failures. Further maintenance difficulties may result when main generator components (rotor and stator, for example) are made/rebuilt by different suppliers.

Using supplier qualification process for reverse engineering work may help; however, it cannot solve problems related to a lack of deep understanding of the OEM's design. Another possible help may come from supervising the entire process by knowledgeable in-house specialists or independent highly-qualified consultants. CCJ



Relu Ilie is in charge of powerplant electrical equipment for Israel Electric Corp. He has 33 years of experience in generation and transmission, mostly dedicated to issues with electrical machines. Areas of expertise include failure analysis, inspection, monitoring, and testing. Ilie has authored several technical papers/presentations; he is involved in IEEE standards activities.

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

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Best Practices Awards

The **CCJ** Best Practices Awards program, now in its 12th year, has as its primary objective recognition of the valuable contributions made by plant staffs, and headquarters engineering and asset-management 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—such as fast starts, performance improvements, workforce development, NERC CIP, compliance, etc.

There are two levels of awards to recognize the achievements at individual plants: Best Practices and The Best of the Best. This year, these five plants were recognized with Best of the Best awards, four for performance improvements, one for operation and maintenance:

- Brandywine Power Facility, for developing and implementing two sets of comprehensive preventive-maintenance procedures that have reduced the number of unplanned outages and extended the service lives of combustion hardware. One assures fuel-system preparedness when switching from natural gas to distillate in the winter, the other proper testing and maintenance of fuel-system components in the off season.
- Dogwood Energy Facility, for improvements to the facility's historical archive system, enabling plant personnel to analyze more than half a million data points from four different control systems at any computer in the plant.
- Doswell Energy Center, for identifying solutions from US-based manufacturers for the upgrade and retrofit of critical components to maintain the facility's early frame engines in top condition. The decision to source equipment made in America has dramatically improved availability and reliability, and reduced costs.
- Pleasant Valley Station, for procedures and methods for the handling and storage of distillate fuel and lube oil to mitigate fluid degradation and the cost of waste disposal.
- Tuaspring Power Plant, recognizing the efforts of plant staff in fine-tuning the enterprise asset management system for this integrated combined-cycle/desalination project and for automating business processes to promote safe, efficient, and reliable plant operations while minimizing manpower costs and maximizing profitability.

See the following pages for details on each of these best practices.

Plants recognized for their best practices in 2016

AES Amman East Power Plant
AES Levant
AL Sandersville
Armstrong Power
Athens Generating Plant
Brandywine Power Facility
Brooklyn Navy Yard Cogeneration Plant
Colusa Generating Station
H L Culbreath Bayside Power Station
Dogwood Energy Facility
Doswell Energy Center
Effingham County Power
Faribault Energy Park
Fremont Energy Center
Granite Ridge Energy
Green Country Energy
Harquahala Valley Generating Station
Lawrence Generating Station
Lea Power Partners
MEAG Wansley Unit 9
Millennium Power Plant
MPC Generating
Paris Energy Center
Pleasant Valley Station
PSE Ferndale Generating Station
Rathdrum Power
Rokeby Generating Station
T A Smith Energy Facility
Tuaspring Power Plant
Waterside Power
Worthington Generating Station

Dogwood

Server upgrades, migration of historical data

At Dogwood Energy Facility, a 2 × 1 combined cycle in Pleasant Hill, Mo, powered by 501FD2 gas turbines, historical data provide Plant Manager Steve Hilger and his team valuable insights and often are used to troubleshoot existing issues as well as to identify new ones. The facility is owned by Dogwood Energy Management and operated by NAES Corp.

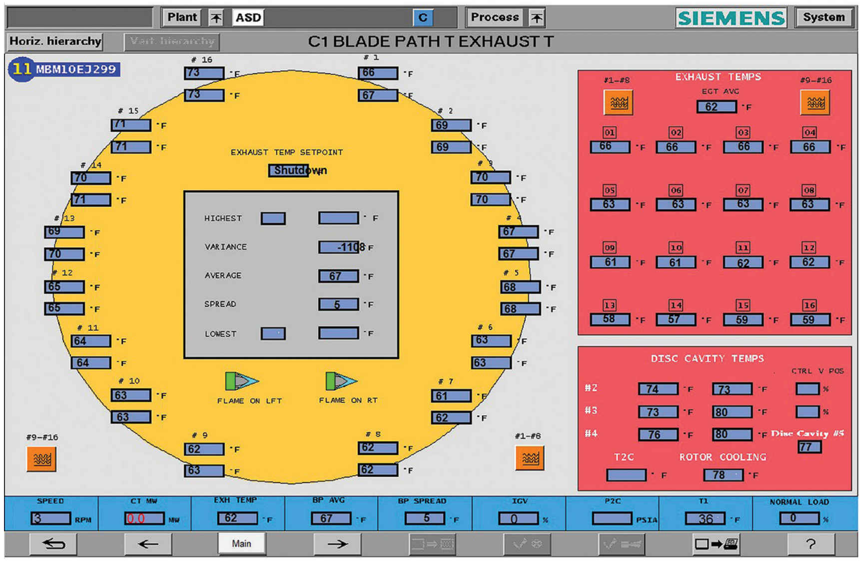
While historians store a massive amount of data, some of that information may be left behind when systems are replaced with new technology. As plants upgrade, add equipment, and change configurations, historical data can be forgotten, easily—until needed.

One of Dogwood Energy's challenges was how to extract archived data from four different control systems into a secondary historian to allow evaluation of that information. Installing a new control system offered an additional challenge as personnel looked for the best way to identify and resolve communications issues with the third-party controls. Plants often experience a loss of data transfer to the historians—sometimes even a complete loss of data from those third-party systems.

Dogwood's OSI PI historian was commissioned after the plant was completed in 2001. At that time, the active control systems were WDPF/Ovation, Teleperm, Tosmap, and Allen Bradley. PI's flexible architecture and OSIsoft LLC's willingness to work with users to improve its product enabled the plant to capture historical data from all four systems up to 50,000 exceptions per second.

Since 2001, Dogwood Energy has upgraded PI three times. With the historical data transfer, the plant has used only half the available archive space. In addition to capturing data, PI also provides interfaces—such as PI ProcessBook and Excel PI DataLink—that allow data extraction and trending. These capabilities are readily available to both plant staff and offsite owners.

Having a secondary plant historian is nothing new; it pays dividends when installing a new control system/historian. Dogwood completed a total DCS change-over in fall 2013, moving to a single T3000 platform for plant controls. To maintain continuity of



1. **Historical data** provide valuable insights and often are used to identify impending problems

data through the plant sale and DCS change-out, staff maintained the PI historian and lost no data.

The impact on end-users was minimized by remapping all historical points to the new control system and to PI. Plant personnel pulled the hard drives and native tape back-ups of obsolete systems and kept them on hand—just in case.

Dogwood currently is working to alleviate third-party interface issues by moving non-critical interfaces out of the plant's control system and directly into the PI historian through multiple OPC and separate Modbus interfaces. These changes have improved the reliability of the Allen Bradley interface and allowed staff to gather additional data points. The plant continues to migrate and expand the interfaces into the PI server. The PI hard drives were upgraded to solid-state drives and switches from 10/100 to a gigabit Ethernet.

Results. Improvements to the historical operating-data archive system provide the opportunity to sample and perform analyses on over 500,000 data points in less than 30 seconds and give plant personnel access to all available data, while enabling them to create pages in ProcessBook that provide read-only, real-time data displays from any computer in the plant (Fig 1). The fact that PI supports all versions of OSI's software and is backwards compatible only sweetens the value of the system.

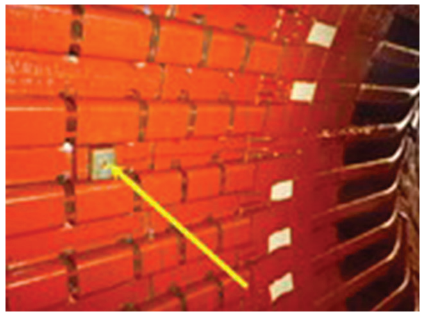
Flux probes enable predictive maintenance

Monitoring the condition of in-service electric generators is a challenge for the plant O&M staff. Based on some known issues with partial discharge (PD) and spark erosion (SE) in the generators married to Dogwood Energy's gas turbines, the plant embraced online PD technology and offline borescope inspection over the last several years to assess stator condition.

This helps plant personnel predict when maintenance is required to mitigate the effects of PD and SE, and to protect against a ground fault. An unplanned outage to repair such a fault would be very costly and highly undesirable.

The lack of predictive-maintenance tools to evaluate generator rotor health raised these questions:

- What were the most cost-effective tools Dogwood could use to predict when generator rotor maintenance is required—without taking units offline.
- How could these tools help provide early identification of potential rotor problems and reduce the risk of "surprise" events?



2. Air-gap magnetic-flux technology is a cost-effective tool for monitoring the condition of rotor windings

Based on this investigation—and considering that Dogwood historically has been a cycling facility—staff determined that air-gap magnetic flux probe technology was a cost-effective tool for monitoring the condition of rotor windings, without impacting availability.

Analysis of air-gap flux probe data can pinpoint the number and location (pole and coil) of rotor-winding shorted turns with the unit online. The effects of shorted turns in rotor windings can cause operating conditions that may limit net plant output—or in severe cases, an extended forced outage. While PD detection technology historically has provided a level of predictive monitoring, it doesn't come close to providing this level of precision.

During a stator rewind in 2014, Dogwood elected to install a flux probe in the generator air gap (Fig 2). The flux-probe cable is routed from the stator core, through the stator end-windings, and out to the generator casing. A gland that provides a gas-tight penetration for the flux-probe cable, is welded to the outside of the generator casing. The analysis system is connected to the casing gland using coaxial cable, allowing the collection outside the generator while the unit is running.

Assessment. The flux-probe supplier collected the first data from this system in summer 2015 to establish a baseline on rotor shorted turns. The flux-probe waveforms were strong, noise-free, and repeatable, with excellent rotor coil slot-peak definition. This indicated proper operation of the flux probe.

Personnel varied the load during testing from minimum to 90% of the rated generator load, providing an acceptable data set for detecting single-turn shorts in all rotor coils.

Analysis of the information showed no indication of turn shorts in any of the eight rotor coils.

Based on the information provided by this first test and the predictive-maintenance value confirmed by the test results, management decided to install flux probes on the remaining generators at the site.

Engineering Manager Chuck Berg said the information gathered and analyzed with these tools allows staff to provide stakeholders with timely, well-informed recommendations on when to perform generator maintenance, while minimizing the risk of "surprise" events that could reduce plant performance and availability.

3. LOTO cabinet is moved outside of the control room. This location provides access to all permits, can handle all contractor flow during big outages, reduces control-room traffic

New cabinet streamlines LOTO system

Dogwood Energy Facility's lock-out/tag-out program continually meets requirements by use of LOTO forms, energy control isolation procedures, lock boxes, individually keyed locking devices, and a padlock board to account for the locks. While the LOTO program seemed to work well during small outages, plant personnel found it challenging to manage during outages with expanded work scopes.

Despite meeting LOTO requirements, the plant had no dedicated area to store lock boxes and associated paperwork. They were kept in a three-shelf multi-use cabinet in the control room, which also was used for the plant radios and their charging stations, handheld air monitors, etc.

Space restrictions created inefficiencies and LOTO boxes and associated paperwork would migrate to various places around the control room. The temporary solution was to bring in two folding tables to organize the LOTOs, but this arrangement took up more floor space than desired.

With NERC requirements restricting control-room access, plant management believed the LOTO work station should be mobile, allowing the safety program to be administered in the lobby or other designated areas, when necessary.

To streamline the process of getting contractors signed on and off LOTOs, Mike Davis, an O&M technician, took responsibility for working with a reputable local shop to design and build a mobile cabinet allowing better organization and providing separate cubbies for LOTO boxes and paperwork.

Cabinet design provided for 28 lock boxes; historical data indicated Dogwood typically had fewer than 30 active LOTOs at any given time. Each LOTO box sits on a shelf that slides out, allowing easy access to its contents (Fig 3). To mitigate the risk of tip-over caused by top-heaviness, the cabinetmaker installed 200 lb of ballast in the bottom. This also improves the center of gravity when moving the cabinet on its eight heavy-duty casters. The cabinet is 42 in. high, an ergonomic working height for most standing individuals.

While processing LOTOs during the first outage using the lock-box cubbies, operators found that adding a number to each lock box further improved organization of the process. Numbers enable employees and contractors to identify quickly the lock box requiring their attention.

Kudos. Dogwood used the new lock-box cabinet during its 2015 fall outage, and it was well-received by plant staff and contractors. Feedback from several contractors that previously had worked Dogwood outages: The new system flows better, reduces confusion, and allows workers to quickly return to work.

The ability to easily locate the desired lock box and associated paperwork has significantly improved time management and reduced frustrations that often arise during an outage.

Safety is of paramount importance at Dogwood. Plant management strives to minimize confusion for visiting contractors by streamlining processes and maintaining a top-notch safety program. Contractors recognize at the front gate that they are working in a facility which truly makes safety its top priority. The more user friendly a system is, the more likely employees and contractors alike will accept and adhere to it, contributing to an overall "NAES Safe" environment. CCJ

Doswell

Innovative actuator upgrade injects new life into legacy GTs

1. Silo combustors: If you're new to the industry you've probably never see one

2. New Beck IGV actuator, at right, sits alongside the Siemens actuator (above)

3. Fuel-gas ball-valve actuators: Assured Automation offering (white) is below the old-style Argus actuators (right)

Keeping up with repairs of major equipment at an ageing combined cycle often means finding alternative solutions to upgrade obsolete components. The 933-MW Doswell Energy Center, constructed in 1992 using Siemens V84.2 technology (Fig 1), is a case in point. Critical components—such as inlet-guide-vane (IGV) actuators, fuel-gas ball valves, and electrohydraulic fuel-gas actuators—became increasingly difficult to replace or even repair as the years passed because manufacturers either went out of business or no longer supported the components.

EthosEnergy Group is the O&M contractor for the LS Power facility in Ashland, Va, managed by industry veteran Merritt Brown. The plant was challenged to find affordable and reliable replacement hardware from US-based manufacturers that would do the same job as the original equipment and fit in the same space.

According to the OEM, IGV actuators had reached end-of-life and would no longer be supported for repair. Faced with a costly European upgrade option, Brown and his team—Bryan Frady, maintenance manager; Ken Schauer, maintenance specialist; and O&M Technicians Jimmy Fuerte and Tim Cook—reached out to Harold Beck & Sons, Newtown, Pa, a damper actuator manufacturer. It offered a

4. Hydraulic actuators on fuel-oil control valves will be replaced with electric actuators

robust solution that proved a perfect fit—one with many advantages over its Siemens counterpart.

The Beck actuator features analog control versus the pulsed reversing contactor control in the Siemens model, thereby providing smoother operation of the IGVs and translating to better temperature control (Fig 2). The Beck offering uses a 4-20-mA signal, eliminating the unreliable rotary-dial position indicator and providing more reliable position indication. The Beck actuator also uses no oil, eliminating the chance of leaks and reducing maintenance.

Doswell discovered in 2014 that the turbines' original belt-driven fuel-gas and fuel-oil ball-valve actuators were obsolete. Four actuators are installed on each of the V84.2 silo combustors (refer back to Fig 1), a total of 32 among Doswell's four units. The OEM offered a replacement option and also would refurbish the original valves, but the cost of both was staggering.

Site personnel investigated several alternatives and contacted manufacturers' rep PTLF Process LLC, Mt Laurel, NJ, to help them identify a suitable replacement actuator. PTLF and Doswell selected a model from New Jersey-based Assured Automation (Fig 3). It provides a simple direct-drive gear-style design offering better control, higher reliability, and instant fit-up to the existing valves. Best of all, the new actuators were priced at less than 10% of the cost for the OEM-offered actuator.

The plant isn't stopping here. Plans are underway in 2016 to complete the IGV and ball-valve actuator upgrades on all of Doswell's V84.2 units and begin a retrofit project to replace the original electrohydraulic fuel-gas and fuel-oil control valve actuators with electric-driven components (Fig 4). That upgrade would nearly eliminate the need for even having a hydraulic system on the V84.2, a system prone to leaks, chronic failures, costly repairs, and limited OEM support. CCJ

Readiness plan assures reliable transfer from gas to oil

Switching from natural gas to fuel oil during times of seasonal or contractual need brings with it a special set of risks. Plant Manager Mark Briggs and his O&M team at the NAES-operated Brandywine Cogen LP developed maintenance procedures to assure a reliable supply of liquid fuel to the 7EA-powered combined cycle during the critical winter run season. The plant, located in Brandywine, Md, near Washington, DC, is owned by KMC Thermo LLC.

One of the challenges to reliable fuel transfer is heat—in the combustion compartment from casing leakage, in the purge air, etc. These and other heat sources raise the temperature of oil as it is fed to the combustion system.

Plant personnel knew it was not possible to eliminate all sources of heat, but were able to mitigate its impact and keep dispatches reliable. They developed two preventive-maintenance (PM) procedures—one for the spring, one for the fall—to meet expectations.

The fall PM is particularly important. Maintenance Manager Chris Nevitt and David Trask, maintenance technician, came up with the following plan:

- Replace the duplex filters and clean strainer screens on the fuel-oil transfer skid.
- Replace the Moog filters on the bypass valve and 10-port actuator.
- Flush the tubes that run from the 10-port isolation valve to the fuel-oil check valves.
- Replace flex hoses.
- Replace check valves in the purge-air, water-injection, and primary and secondary fuel circuits.

In the spring, plant personnel rebuild the fuel-oil check valves, verify the integrity of tubing insulation, and look for leaks in the combustion air circuit, repairing any found. Tubing is not flushed in the spring unless operating data show an uptick in pressure during the winter run season. Fuel transfer exercises are conducted weekly during the spring and summer.

Additional steps taken:

- Protected fuel-oil tubing and flex hoses against excessive heat inside the combustion compartment by wrapping with Pyrojacket® (ADL Insulflex® Inc, Ont, Canada) insulation, as shown in Fig 1.
- Repositioned secondary fuel-oil check valves to minimize the risk of coking, which can inhibit proper valve operation. Fig 2 shows fuel now is supplied *above* the horizontal centerline of the secondary inlet. With fuel entering at this location, and purge air flowing horizontally, no fuel oil remains inside the check-valve ball area to be cooked by the hot purge air. While it is not possible to install secondary check valves in the most favorable positions on all cans, critical to success is positioning the secondary inlets above the centerlines so oil drains down rather than puddling.
- Replaced the OEM-supplied fuel-oil check valves with Parker-style valves to further protect against coking. They incorporate a Teflon-coated ball cage less prone to sticking from heat and coking. Repair kits used during the spring valve overhaul described earlier include new balls, springs, gaskets, and ball cages (Fig 3).

Another enhancement: Installation of screens at the primary check valves (Fig 4). Available from McMaster-Carr, Santa Fe Springs, Calif, Part No. 9230T514 typically catches liberated coke particles before they clog an injector orifice. When a screen clogs, you still see higher-than-normal pressures for that can, but replacing a clogged check valve is much easier, and less costly, than removing the primary fuel-oil tubes. When O&M personnel see higher pressures, they replace the check valve, flush the system and look for root causes of heat interference.

Clean-up. M-Pyrol®, a solvent made by Ashland Inc, was selected as an aggressive carbon cleaner that doesn't harm metal or leave a residue. It is corrosive, but works well if you keep it away from rubber, avoid skin contact to the degree possible, and replace the 55-gal drum every other season.

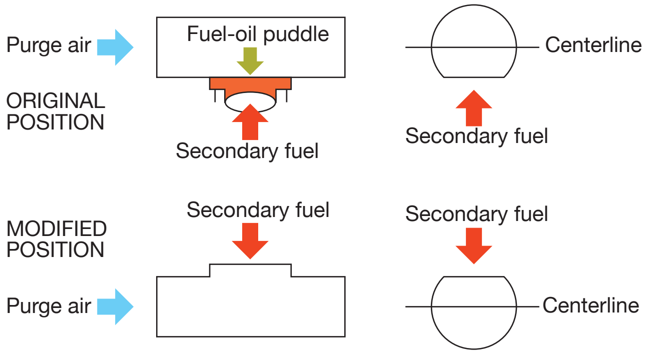
Conventional oven cleaner also does a quick, thorough job of cleaning metal check-valve components—provide you keep it contained and rinse the residue off your parts immediately.

Coking debris settles in the ribs of flexible hoses, so the flushing solution described in the sidebar doesn't remove all of it. Nevitt and his staff send the hoses to Fil-Clean LLC (Houston) for cleaning.

Results. A 100% reliable fuel-transfer process is a lofty goal. Brandywine has had consistent success with the approach described by keeping

1. Wrapping fuel hoses with Pyrojacket® protects the hose and mitigates coking (left)

2. Secondary check valves were repositioned to prevent puddling of liquid fuel (below)



PEACE OF MIND

Remotely Monitors And Reports Coolant Flow And Temperatures As Well As Piping System Integrity

A key component of JASC's back-up liquid fuel system reliability design is the Smart Fluid Monitor.

With cooling water piping infrastructure having a life expectancy of decades and turbine major maintenance intervals of every 4 to 5 years, the ability to remotely monitor the performance and integrity of the cooling system has become an important part of achieving improved liquid fuel system reliability.

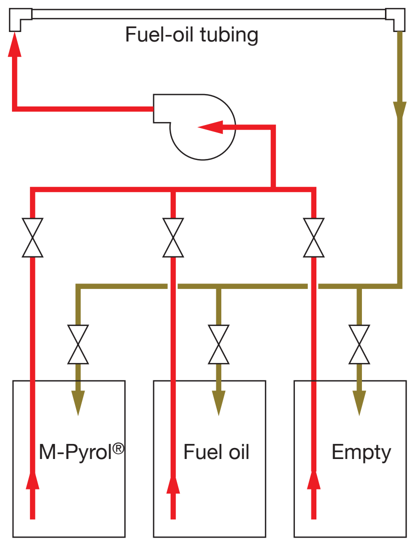
JASC's SFM, remotely monitors and reports coolant flow and temperatures as well as piping system integrity. This provides peace of mind that adequate coolant flow is available to critical system components such as JASC's superior actively cooled valve designs allowing for extended operational intervals.

The SFM is sensitive enough to detect small flow discrepancy between the cooling water supply and return lines. The Smart Fluid Monitor is utilized for either basic water cooled check valve systems or can be used on more advanced future liquid fuel reliability systems such as water cooled 3-way purge valves and ZEE (Zero Emissions Equipment).

Best of all it is a simple retrofit for adding Monitoring, Protection and Notification on any previously installed water cooled valve piping infrastructure.

Fuel-oil flushing procedure

1. Disconnect selected can tubing from 10-port isolation tee.
2. Connect pump discharge tubing.
3. Disconnect selected can tubing from check valve at can in combustion compartment.
4. Connect flush tubing at check valve to discharge into "Empty" drum (see diagram).
5. Connect air supply to pump discharge tubing.
6. Blow out can tubing with 30-psig air for 30 seconds.
7. Disconnect air and connect tubing to pump discharge.
8. Line up valves to pump M-Pyrol® through selected tube and recirculate to the "M-Pyrol" drum.
9. Recirculate the cleaning solution for 30 minutes.
10. Shut off pump to allow M-Pyrol to soak in tube for another 30 minutes.
11. Recirculate M-Pyrol for an additional 30 minutes.
12. Disconnect M-Pyrol pump suction tube and vent to atmosphere.
13. Allow pump to continue running, to drain tubing of M-Pyrol.
14. Attach pump discharge tube to plant air and blow remaining M-Pyrol into its drum.
15. Disconnect plant air and connect pump discharge tube to pump.
16. Connect clean fuel-oil drum to pump suction tube.
17. Line up valves to pump clean fuel oil through selected tube and recirculate to the "Fuel oil" drum.
18. Flush with clean fuel oil for 30 minutes.
19. Flushing complete, reconnect all fittings.
20. Clean tubing for the remaining cans in the same manner.



Fuel-oil flush procedure is described by flow chart

3. Repair kit for fuel-oil check valve includes ball, spring, gaskets, and ball cage

4. **Installing screens** in the primary check valves typically catches coke particle before they clog injector orifices

the process simple and adapting it to the exigencies at hand. It has saved numerous man-hours and expense by avoiding unplanned outages and has extended the service life of the plant's combustion systems. Applying this regimen of preventive measures also spares personnel the tedium of more noxious tasks—such as disassembling the primary fuel-oil cans to remove and clean the oil tubes. CCJ

Pleasant Valley

Oil change, bypass plate mitigate varnish issues

Historically, most gas-turbine (GT) hydraulic-system varnish issues have been associated with GE units where lube and control oil share a common sump. However, the 501D5A installed at Pleasant Valley Generating Station, Dexter, Minn, owned and operated by Great River Energy, was plagued by sticking servo valves on its liquid-fuel-system Moog Inc actuators. This contributed to some forced outages and the need for expedited servo repairs, both of which can be costly.

By way of background, Pleasant Valley, managed by Tye Stuart, is a nominal 450-MW three-unit peaking facility which primarily operates on gas, but has oil backup. The 501D5A (Unit 13) was installed in 2002, about a year after two V84.3A2 GTs (Units 11 and 12) were commissioned.

Staff had been able to alleviate the sticking problem by cleaning out a 50-micron ruby orifice when it clogged with sludge and varnish—until one day when this "fix" didn't work. In this case, the failed actuator would not respond after both cleaning the orifice and changing the servo.

Varnish fouling was so bad the inoperable actuator was sent out for cleaning and repair. The shop report stated this was the worst case of varnish contamination it had seen in an actuator. Clearly, remedial action was necessary.

Interestingly, the plant had sent a sample of the offending oil to its lab only two months earlier for varnish-potential analysis. Tests specified included acid number, membrane patch, ultra-centrifuge, Ruler, and Fourier transform infrared spectroscopy (FTIR).

1. Pleasant Valley personnel realized they probably had lube-oil issues because of its dark color (right). Fresh oil is at left

2. "Stitching" on heating element is caused by overheating

The lab report came back with normal results and indicated a low level of degradation byproducts associated with varnishing, despite the fact that plant personnel noticed considerable darkening of the oil themselves (Fig 1).

Lesson learned: Plant personnel needed a better understanding of how varnish forms and how to conduct a thorough assessment of the hydraulic system. Staff involved included Mike Herman, Preston Walsh, Chuck Condon, Kevin Beske, Craig Birkett, Doug Goodale, and Stuart Crum.

Mind the heat. Because heat is a major factor in varnish formation, station personnel pulled the lube-oil sump heater and found it had failed. There was evidence of "stitching" on the element—a failure mode caused by overheating (Fig 2).

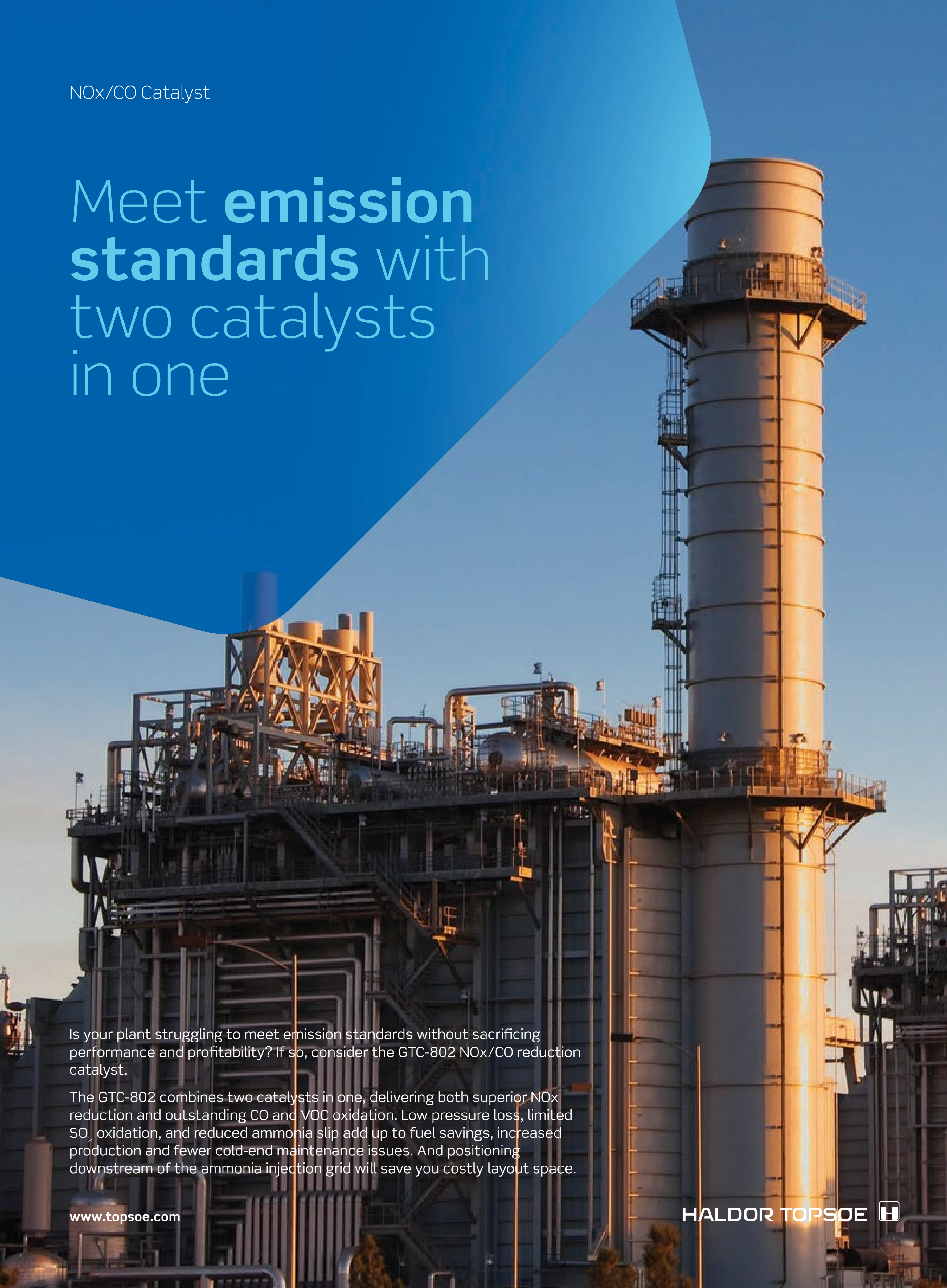
The sump was designed to have the heater in a thermowell, enabling its removal without draining the oil; however, the heater specified was designed for full immersion in the oil, a better heat-transfer medium than the air in a dry pipe. Plus, the heater rating, 22 W/ft², was too high for this application.

After talking to engineers at Chromalox Inc, the heater manufacturer, staff determined that a 10-W/ft² element would be more suitable for a dry-pipe application. It would both prevent overheating of the oil and prolong heater life.

In addition to use of a heater with a lower output, plant personnel wrapped about 90 ft of 8-W/ft² self-regulating heat tracing around the sump. It was equipped with a thermostat set to maintain 115F on the outside surface of the sump. Next, the sump was insulated.

Insulation also was added to the hydraulic power unit (HPU) shack, thereby reducing the amount of heat necessary to maintain the temperature set point and reducing the chances of thermal degradation.

Staff believed it had found the "smoking gun" in the heating system.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But after learning more about varnish, they identified additional improvements to mitigate the problem. While heat contributes to varnish formation, cool surfaces in stagnant flow areas are where it "plates out."

Keep LO moving. With liquid-fuel runs few and far between, there was a lack of circulation in the system, which facilitates varnish deposition. Staff learned that some GE users challenged with similar issues had good success by adding a small bypass plate; they believed it might work on the Siemens unit as well.

A nearby hydraulic repair facility was able to design and manufacture a cross-port relief manifold for Pleasant Valley. The CPRM is sandwiched between the actuator and the servo, providing 0.5 gpm flow through the actuator when it is not in service. This avoids stagnation and helps keep the varnish in solution. The 0.5-gpm flow setting was selected because staff believed it would have minimal impact on system operation.

The shop also refurbished and cleaned the remaining liquid-fuel valve actuators, and also replaced the 50-micron ruby orifice with a 100-micron orifice to minimize the likelihood of clogging. Finally, insulation was added to the access door adjacent to the actuator—to keep that area warmer in cold weather.

Another area explored was the hydraulic fluid itself. Plant management knew it was necessary to change the oil, not a big expense for a 150-gal sump. The lubricant supplier also recommended a flushing oil, which was added and circulated through the system for two days prior to the change-out.

Station personnel wanted to be sure Pleasant Valley had been using the best lubricant for the application before ordering fresh oil. Not! The original oil spec for this system called for an R&O ISO 100 (R&O for improved anti-rust and anti-oxidation properties) oil and that's what the plant had been using since COD.

A lubrication engineer was consulted, and staff polled other 501D5A owner/operators to see what oil they were using. The informal survey revealed most users in climates similar to Pleasant Valley's rely on a ISO 46 oil.

So the plant switched to Mobil DTE 10 Excel™ 46, believing the lower-viscosity oil would flow better, plus its anti-wear additive would protect the pump and reduce friction. The Mobil formulation also has a more favorable viscosity index and better thermal stability than the plant's original oil.

Since the menu of varnish-potential analyses specified previously did not detect any varnish precursors, station management decided to forego this comprehensive testing regimen in the future but stick to generic, routine lube-oil tests. However, personnel plan on monitoring for color and changing the oil every two years as a preventive measure.

Best practices for lube-oil storage, handling, use

To eliminate past issues, industry best practices were adopted and several changes made to the methods for storing, handling, and using lubricants and greases. These are highlighted in the bullet points below:

Oils

- After careful review of existing inventory, and consultation with a tribologist, plant consolidated its inventory of oils from 12 varieties to eight. This lowered inventory costs while reducing confusion and the chance of cross contamination.
- Transporting full 55-gal drums (Fig 3) with a forklift can be risky, especially over uneven terrain. A couple of near misses were an eye opener. For bulk oils, such as turbine and hydraulic, plant purchased 120-gal "forkable" cube-shaped totes, which have a low center of gravity and can be moved to point of use easily and safely.

  Desiccant breathers were added to the totes to protect against moisture ingress. Oil is manually pumped into the machinery sump as needed, using a dual-stage coalescing and 3-micron particulate filter cart to ensure a high level of cleanliness.
- For quantities of oil smaller than those described in the previous item, staff obtained color-coded dispensing jugs for each (Fig 4). Next, plant personnel applied color-coded labels on all lubricated equipment to identify the oil for each point of use.
- A color-coded "oil menu" is posted in the lube room to help identify the oils (Fig 5).
- Shelves were installed in the lube room to assist with organization and to maximize storage space.
- Established a more intensive oil analysis program to better indicate the quality of the lubricating fluid. Added tests include, but are not limited to FTIR spectroscopy, foam test, demulsibility, and the ASTM D2272 rotating pressure vessel oxidation test.

Greases

- Pleasant Valley occasionally experienced problems with "over-greasing" as evidenced by grease migration into motor windings and oil sumps. In addition to reducing the quantity of grease applied, plant eliminated the use of battery-powered grease guns, opting for manual only. Battery-powered guns can pump grease at up to 20,000 psig which can compromise grease seals and cause premature equipment failure.
- New hand-operated grease guns have a clear barrel for easy identification and inspection of product labeling; plus, color-coded end pieces.

3. Avoiding the handling of 55-gal drums reduces the likelihood of personnel injuries

4. Color-coded dispensing jugs guard against spills and selection of the wrong lube

5. Oil menu helps plant personnel pick the proper oil

6. Grease guns are color-coded and easy to locate

- New grease guns are located in the lube room (Fig 6) on labeled and color-coded caddies.
- Color-coded grease zerk caps were installed on all greased equipment. Their color corresponds to the applicator color code to reduce cross contamination and misapplication of lubes.

Proper storage protects against degradation of fuel oil

In summer 2014, Pleasant Valley personnel discovered a large amount of demulsified water, biogrowth, and degraded fuel at the bottom of the plant's 800,000-gal main fuel-oil tank. This "glop" was unusable and had to be disposed of in an environmentally safe manner. Corrosion also was found in several fuel-system components.

Pertinent facts: (1) The tank had been maintained about half-full since 2010; (2) in winter 2014, the centrifugal pumps began losing suction when the oil level fell below about the 300,000-gal mark; and (3) ultra-low-sulfur diesel (ULSD) had been stored in the tank for about the last three years.

The plant's proactive O&M staff proceeded with research, sludge analysis, and consulted with petroleum engineers to determine root cause and how to prevent this problem in the future. Staff learned that water gets in a diesel tank provides a habitat for hydrocarbon-consuming bacteria, which produce acetic acid as a byproduct of dining. The acid, in turn, degrades the fuel and promotes corrosion.

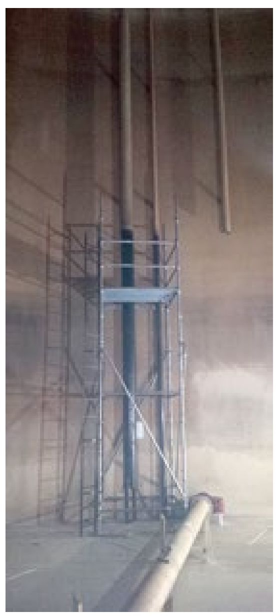
A lesser-known fact: Today's ULSD contains surfactants which change the interfacial surface tension of the fuel and makes it difficult to separate water from the oil.

The bottom line: Pleasant Valley had to implement some mods and practices to ensure the backup fuel is kept moisture-free to the degree possibility and maintained at the highest possible quality.

Here are some of the steps taken:

- Eliminate leakage oil/water return to the main storage tank by redirecting it to a holding tank. An operating procedure dating back to COD called for the purging of fuel lines with water when the gas turbines were shut down after burning oil. The resulting water/oil mixture was collected and forwarded to the main oil tank.
- Insulate the tank breather vent to reduce condensation buildup and the ingress of water into the tank (Fig 7). The tank is insulated so there was the potential for a large amount of warm, humid air to occupy the headspace.
- Reduce humidity of the headspace of the fuel tank by installing a system to apply a continuous purge of ultra-dry air (Fig 8).
- Implement a fuel-truck sampling procedure to ensure the oil received does not contain water.
- Install a 4-micron tank filtration system to remove contaminants and bacteria, thereby prolonging fuel stability.
- Implement a tank sampling, testing, and bottom-drain procedure to swiftly remove any traces of water before it becomes a problem.
- Extend the downcomers in the fuel tank from about half height to near the bottom of the vessel (Fig 9) to promote more complete mixing and heating.

By eliminating all sources of possible water ingress, staff expects the dramatic improvement in fuel quality will be maintained, thereby assuring reliable operation on fuel oil and eliminating the need to dispose of large amounts of degraded fuel in the future. CCJ



7. Breather was insulated to reduce the buildup of condensation and the ingress of water into the tank (left)

8. Continuous purge of ultra-dry air controls humidity in the headspace (center)

9. Downcomers were extended from the middle of the tank to near the bottom, ensuring more complete mixing and heating of the oil (right)

Tuaspring

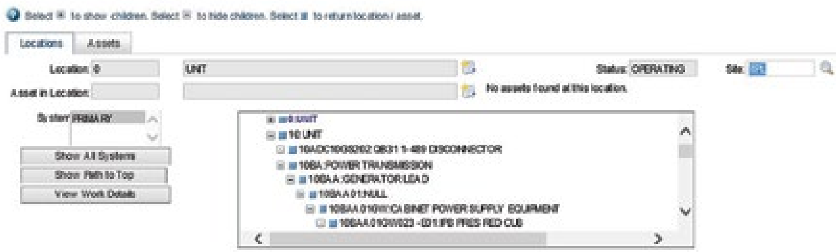
Use of best available automation, technology minimizes staffing costs

Hyflux Energy Pte Ltd's first generating plant began transmitting power to Singapore's 230-kV grid in August 2015. The Tuaspring Cogeneration Plant, a combined power and water-desalination facility, delivers 411 MW to the wholesale power market while producing 70-million gallons per day (gpd) of water. The facility is equipped with a Siemens SCC5-4000F single-shaft combined cycle capable of firing both LNG and distillate; generator is hydrogen-cooled and the control system is T3000.

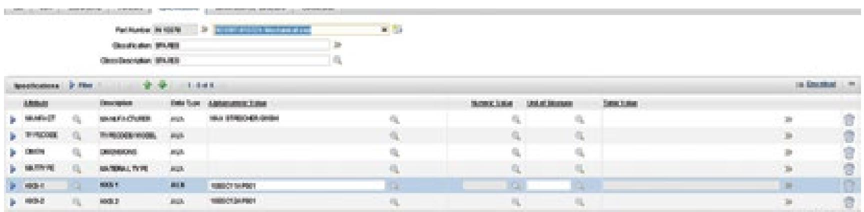
NAES Corp is the O&M contractor, with the highly experienced Dean Motl managing the company's staff onsite. Representing owner Hyflux in plant activities are Kannan Kumar, VP of O&M; Vishnu Senathyrajah, maintenance manager; and Hue Nah Han, assistant VP of IT.

Subject of this entry in CCJ's 2016 Best Practices Awards program is the pre-commissioning activities at Tuaspring focused on minimizing O&M costs by improving workplace efficiency. As one area of improvement, plant management sought the best available automation and technology to minimize manpower costs.

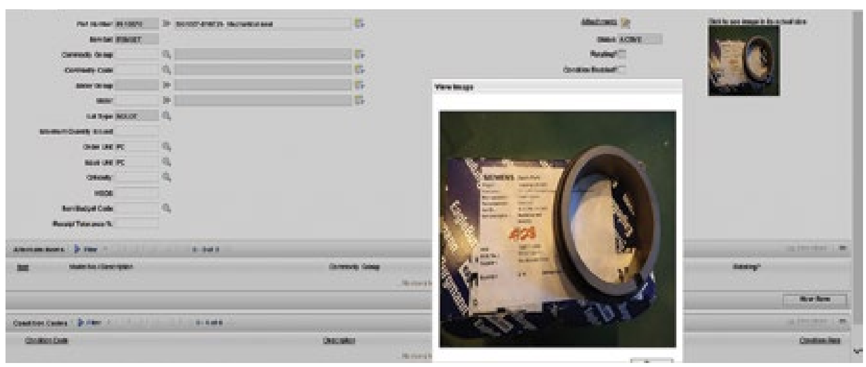
First step in developing a solution was to analyze the required business processes to determine which software platforms would best serve the plant's



1. Asset drill-down in Maximo matches the Siemens-provided KKS asset list



2. Inventory system provides three ways to query detailed spare-parts information



3. Photos linked to spare-parts inventory streamline work planning

4. Master permit-to-work and associated permits are routed electronically through the approval process

needs. Participants agreed that a fully integrated enterprise asset management system (EAM) should be the core of the IT infrastructure. After researching the options, the evaluation team recommended IBM's Maximo as the choice that would best suit the owner's and the plant's requirements.

Before soliciting bids for the EAM system, staff compiled a detailed bid specification that ensured the EAM platform would support the required business processes using Siemens KKS™, the existing asset structure. Using KKS as the foundational asset structure would enable a centralized and defined hierarchy where the EAM modules would interface.

By design, the KKS system employs a comprehensive hierarchal breakdown structure from the unit to the component level. This resolution allows quick queries of all plant asset information. The plant team worked with the Maximo integration company to design the asset drill-down to match the Siemens-provided KKS asset list (Fig 1).

With the asset structure established in Maximo, all of the EAM modules use the KKS asset tables connecting the matrix of information. This facilitates automation of the key activities:

- Barcoded inventory management
  - Strategic spares
  - Consumables
  - Tooling
- Procurement initiation, interfaced to Oracle ERP
  - Contract management
  - Vendor management
- Work-order management
  - Defects/corrective
  - PM/predictive
  - Warranty
- Safety: Permit-to-work process (5 × 5 risk assessments)
  - Lock out/tag out (LOTO)
  - Confined-space permits
  - Hot-work permits
  - Working at heights
  - Excavation
  - Radiographic testing
- Operations shift logs

Having barcoded inventory management integrated into Maximo allows the facility to maintain strict control of its critical and costly spares. The inventory system includes detailed records of each spare part that can be queried by asset (KKS) number, part number (PN), or drawing position number (Fig 2).

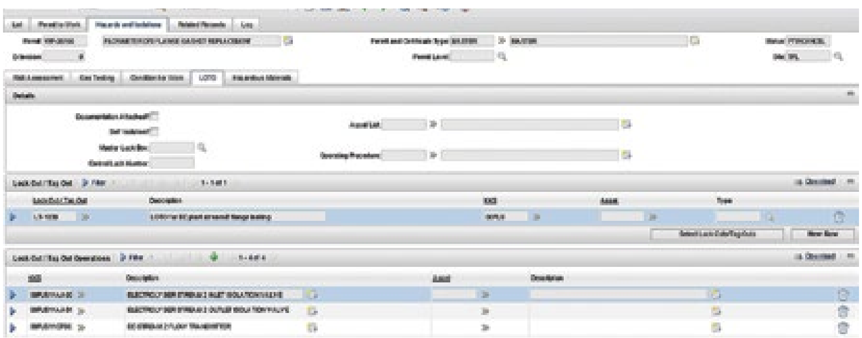
Tuaspring's plant engineers then undertook the arduous task of linking high-resolution photos of each spare part to facilitate visual ID when researching spare parts needed for work orders (Fig 3). This added detail streamlines work-planning, especially in the case of urgent emergent work.

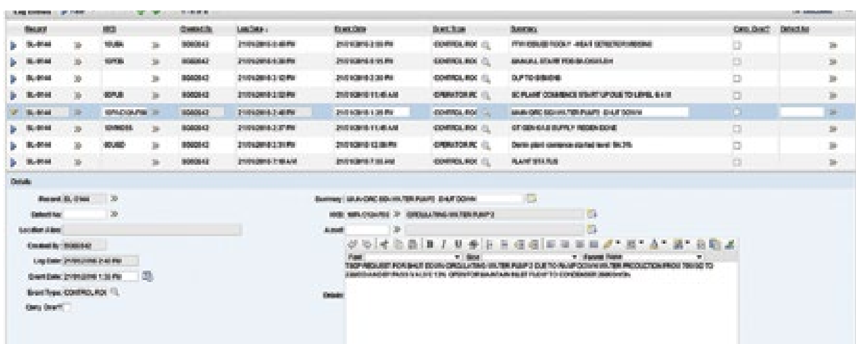
For procurement initiation, the new EAM interfaces to Oracle ERP, which improves workflow by reducing paperwork and expediting approvals. Instead of hand-carrying procurement requests to get approvals, they are routed through Maximo, which digitally transfers the requests to Oracle ERP across the secure corporate network. As an added benefit, Maximo also pushes the plant inventory balance across to the ERP system, providing real-time inventory balance records between the plant site and the finance department.

As inventory spares are consumed, they are charged to the work order. Each work order is linked to an asset (KKS), and each asset is linked to the associated budget code. This integrated matrix back to KKS allows the facility to develop cost reports to the unit, equipment, or component level for either the plant or the finance team.

Before an individual can work at the facility, a permit to work (PTW) is required, and the EAM system also has streamlined this process. The

5, 6. Electronic permit-to-work in Maximo includes a LOTO system (below) which prints the tags using a dedicated LOTO printer (right)





7. Electronic shift logs replace the traditional hard-copy logbooks

KKS asset structure integrates a completely electronic safe work permit. Standard NAES Safety Management Procedures, customized to reflect local regulations, are used as the administrative design basis for Maximo's PTW process.

In this framework, the process flows seamlessly from the work order to an electronic 5 × 5 risk assessment (RA) and subsequently to a master PTW (Fig 4). The results of the RA identify which additional permits are required—such as LOTO, confined-space, hot-work, etc (Fig 5). The master PTW and associated permits are routed electronically through the approval process.

The electronic PTW function in Maximo also includes a LOTO system, which electronically prints the tags using a dedicated LOTO printer (Fig 6). This significantly decreases the time spent by the operations engineer preparing PTWs.

The EAM system provides electronic shift logs to replace the traditional hard-copy logbooks (Fig 7). Every shift-log entry is time-stamped and associated with a specific KKS number. Because it's integrated with the KKS asset structure, operating engineers can raise a defect request directly from the shift-log module. All staff members are alerted to these defect requests when they meet each morning to review the previous day's shift logs.

Finally, the facility has plans to integrate the EAM system with condition-based monitoring data. Plant engineers are exploring the interface of live plant operating data from the plant historian to the EAM. In concept, the data would trigger automated work orders, based upon predetermined parametric values. This progressive automation would further enhance plant reliability by pre-emptively identifying equipment reliability concerns before failures occur.

Results. As energy markets become increasingly competitive, business processes supporting lean and effective staffing plans become ever more critical. Using an EAM system as a central platform allows teams to work together more efficiently and cost-effectively. Although Tuaspring is new to the market, a wholly integrated EAM platform positioned it to compete effectively from Day One.

Along with the EAM, plant personnel designed and integrated fully electronic systems for document control, punch list/warranty tracking, and performance monitoring and security control. By incorporating these systems, Tuaspring has automated nearly all of its plant business processes. CCJ

1. PG&E's Colusa Generating Station complies with one of the most restrictive air emissions permits in California

Downtime duration dictates different 'agility' decisions

The common theme through every recent visit to a combined-cycle (CC) facility is agility—adapting to the real-time pricing dynamics of grid markets and growing renewable-energy penetration by investing in agility options. But the specific goals for each site, and how they are achieved, can be markedly different. Because the state has the toughest emissions laws in the land, California stands apart.

But at least the emissions limits are fixed. Everything else about operations at today's CCs is unpredictable.

CCJ recently visited Pacific Gas & Electric Co's (PG&E) Gateway Generating Station, near Antioch, Calif, and chatted with staff from headquarters and the utility's Colusa Generating Station (Fig 1) about a two-hour drive northeast.

Like most CCs designed and installed about five or more years ago, high efficiency was the goal because the units were expected to run at high capacity factors (CF). Based on the last few years, "expected" has all but disappeared from the plant lexicon.

Last year, 2015, was a low hydro year for PG&E—less than half of an average water year. Gateway and Colusa picked up the slack. Colusa's capacity factor was 62% (full capacity, with duct burners), Gateway's slightly higher. The GTs at Colusa had only about 50 starts each, and Gateway had about double that number. In some months, the units started up only once or twice and remained on for days. In other words, the units ran more like they were originally intended.

During the prior two years, Colusa's CF was more like 43% or 44%, and in 2013 the Colusa machines had double the number of starts that they did in 2015. This year, report Alvin Thoma, director of fossil and solar O&M, Tim Stafford, Gateway's acting plant manager, Ed Warner, Colusa plant manager, and Steve Royall, director of hydro generation O&M, the common pattern is the Colusa units are running regularly but are frequently scheduled to cycle off during the middle part of the day—exactly the inverse of what is traditionally thought of as the most important time to be online.

One common (though not consistent or predictable) load profile has been to start up and ramp to full load between 3 and 5 pm as the sun wanes and people return home, and then back off to minimum load or 1 × 1 operation in the middle of the night. Starting about 5 or 6 in the morning, the GTs are ramped up at between 14 and 17 MW/min up to full output, only to be shut off entirely by 9 or 10 am.

More recently, the dispatch schedule from the ISO has been wrong as often as it is right, with units called on exceptional dispatch to run when not scheduled, and to shut down when scheduled to run.

Colusa and Gateway aren't yet experiencing two-start days, but the PG&E operations staff expects that mode is coming as the utility keeps pace with

Other notable plant features

The 2 × 1 Gateway Generating Station produces a nominal 580 MW with GE 7FA.03 gas turbines and a GE D11 steam turbine. The plant was purchased in 2006 from Mirant Corp, and formerly called Contra Costa Unit 8. It was the utility's first new powerplant in 20 years. At the time, one design objective was to minimize use of fresh water, so air-cooled condensers were selected to achieve that goal.

An ammonia-based GT inlet air chiller system also was intended to help meet plant objectives, but it never performed as expected. Leaks in the anhydrous NH_3 system were persistent, the supplier went out of business, and other issues plagued the unit. Ambient temperatures at Gateway are somewhat lower than at Colusa because of the plant's proximity to a river.

2-4. Steam-turbine heating blanket at Colusa is key part of unit agility, shown at the crossover piping (2), at the high-pressure turbine section (3), and the blanket PLC control panel (4)

the state's push towards the renewables mandate of 50% in 2030. Today, PG&E's renewable energy supply is already nearly 30% (including hydro).

Emissions before electricity

No one awake in the industry would be surprised to learn that both PG&E plants have to meet annual, quarterly, and daily NO_x and CO emissions levels. But the "event" limits may not be common knowledge.

Gateway and Colusa both have to adhere to separate hot-start, warm-start, and cold-start event emissions limits. On top of this, Colusa has to meet a *hard limit* for each hour of the startup period as a permissive to proceed through the next stage, or hour, of the start. Because Colusa is a more recent facility (coming online in 2010), its emissions are more constrained. "Colusa has one of the most restrictive permits ever written," said Warner.

At Colusa, the maximum NO_x emissions allowed during a hot start are 152 lb/hr; the cold-start limit at Gateway is 452 lb/start. The PG&E plant officials stress that if there is any indication during startup that this total will be violated, the plant incurs a forced outage instead.

"Under no circumstances do we violate the permit, even if the grid is strained," insisted Thoma. In other words, emissions violations are treated like safety issues. Plants with the best safety "culture" give their facility staff the right to stop production if there is any safety concern, with no recriminations. PG&E also applies this rule to emissions.

NO_x and CO emissions limits at Colusa are 2.0 ppm and 3.0 ppm, respectively.

Electric blanket comfort

GE presented PG&E with the usual menu of agility options—OpFlex, new seals pack, NO_x reduction, advanced steam path design, steam turbine heating blanket, and others. Operations personnel found that considering the options in the context of different downtime periods between starts was helpful to the analysis. Different options have different value points depending on whether the unit is down for six hours, overnight, 24 hours, or over a weekend.

So far, Colusa has gone with OpFlex and the heating blanket (Figs 2-4). The plant believes the technology saves up to an hour during cold and warm starts, when deployed, and keeps hot starts under an hour (from over 80 minutes prior to having the technology). The plant has only had a few opportunities to use the blanket to date, but it has "performed as expected" when in service, noted Warner.

In addition to keeping the turbine warm, the equally important purpose of the blanket is to heat the top and bottom casings *uniformly,* within 50 deg F of each other. To do this, heating is precisely controlled through a programmable logic controller (PLC) system. Other than that, "just think of it as an electric blanket (electric heating elements inside conductive material) underneath the turbine's normal insulation layer," Warner suggested.

It's a little more complicated than that. There are 24 low-voltage/high-current control zones on the shell, such that heating starts at the high-pressure end at 650F, at 975F at the inlet/barrel section, and at 550F for the intermediate section. Those are some impressive temperatures for resistance heating.

Solar takes on some cycling too

While PG&E's goal is to maximize solar generation, operations staff also has adapted the utility's solar PV (152 MW) facilities for agility too. The control logic has been tweaked, and inverters were purchased which can "cycle" on/off. This provides additional operating flexibility, especially in over-generation situations. "Inverters have to cycle on and off when there is cloud cover, so this over-gen flexibility isn't putting undue strain on the inverter hardware," explains Thoma.

PG&E's owned solar PV is a drop in the bucket compared to the over 3500 MW of total solar the utility has on its system and the 2000 MW of rooftop solar PV in its territory. But every little bit of agility helps when you are managing generation assets in a time when the word "expected" has lost its meaning at the operating level.

The real value of the technology will come as ramping and cycling needs grow in line with meeting the ever higher renewable-energy mandate. For example, when the plant is shut down for an entire weekend, or over 60 hours, the blanket will keep the steam turbine between 500F and 700F. In essence, with the combination of the blanket and Opflex, the steam turbine is no longer the limiting factor to ramping to full output.

Keeping the turbine components warm also reduces stress caused by thermal cycling. Fuel savings are considerable too, 66-million Btu per start. At a $3/million Btu price for natural gas, that's almost $200,000 in a 100-start year. And in a state where every molecule of emissions counts against you, avoiding an average of 52.5 lb of CO and 75 lb of NO_x per start is a critical bonus. The price tag for the heating blanket was south of $1 million, suggesting that the benefits will quickly pay back the investment.

OpFlex, explains Royall, is a technique to take advantage of the conservative design factors included in the original automation package. In other words, the control sequence is tweaked to capture as much of the margin as possible without sacrificing component life. The GE engineers worked closely with the plant operations staff to refine and improve the startup process.

BOP considerations

PG&E undertook an exhaustive evaluation of cycling at Gateway and Colusa from a reliability perspective, especially under a two-start-per-day regime. Many recommendations fell out of that effort.

One aspect of the effort was to rank the components from a spare-parts perspective. No surprise, the boiler feed pumps came out on top. The original design of Colusa called for two 70% capacity pumps. As a result of the study, a full motor/pump/hydraulic coupling will be warehoused onsite. "We can't run at full output with a 70% capacity pump," said Thoma.

Colusa also is a zero liquid discharge plant (Gateway is not), which aggravates cycling objectives. One thing that resulted from a comprehensive review of the water/steam system was that when the plant breaks vacuum on a start, you have to re-establish the water/steam chemistry. The plant had additional steam drains to accommodate higher flow but found that they could surpass the temperature limits of the ultra-filtration units. Therefore, they added a fin fan cooler designed for the heat rejection from the additional blowdown. CCJ

Recalculating. . .plant value/cost in the transition to grid support

If you don't know what the "duck curve" is, you must have retired from the power industry five years ago. For those still scratching their heads, see Fig 1. The duck curve is what higher and higher penetration of renewable energy looks likes to a grid operator, who begins to have nightmares about the rising slope of those two daily ramps.

But this is what the duck curve "looks" like to a combined-cycle (CC) plant filling in around the renewable capacity (Fig 2). Operating hours go down, starts go up, and equivalent availability suffers.

Jesse Murray, NV Energy's director of renewable programs, suggests many CCs will see such "transitions" as more utility and distributed solar and other forms of distributed generation (DG) come online. "Competition at the wholesale level is well understood," Murray notes, "but competition at the retail level may not be." Until that gap closes, CCs are well-suited to fill in around renewables and retail DG because of their flexibility and relatively low operating costs.

DG units can have benefits for, but also impacts on, the grid, Murray notes. Either way, each DG device enjoys the luxury of using the grid for "virtual storage" of electricity, a benefit that isn't always recognized or understood. For example, he says, a rooftop solar PV unit typically is not sized for when large appliances start up. But the stress of the in-rush of current and voltage, or spike, isn't felt by the homeowner because he/she is interconnected to a healthy, reliable grid.

Nevada is aggressively replacing thermal generating resources with solar energy, though unlike its giant neighbor to the west, the transition is proceeding more "organically," not through costly mandates. The bottom line: NV Energy has approximately 400 MW of utility-scale solar energy in production with nearly that much in construction and DG fractions. The

utility provides net metering support to 20,000 solar PV and other DG customers currently, with 12,000 more in the queue. Happily, NV is four percentage points above its state RPS requirement of 20%.

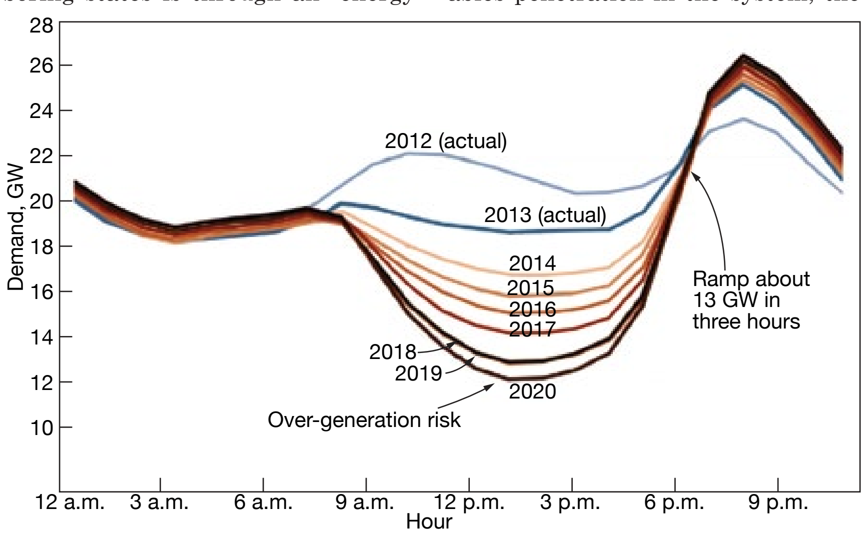
Utilities and grid operators have no choice but to make sure the grid can handle all intermittent renewable and large-scale generation in the aggregate. One way this is done on a regional basis for California and neighboring states is through an "energy imbalance market," a structure for 5-min and 15-min ancillary services to be procured by the grid and plant operators paid.

"NV Energy isn't part of an ISO or an RTO but is a member of the energy imbalance market," notes Murray.

Tracy's transition

Murray illustrates what a "transition" can look like with NV Energy's Frank A Tracy Generating Station 4/5, a 1 × 1 combined cycle unit. The "4" refers to the plant's 6FA gas turbine/generator and the "5" to the 46-MW steam turbine/generator. Yes, you read that right. Tracy has the first of less than a handful of 6FA machines running in the North American 60-Hz market.

While it's clear from Fig 2 how Tracy's operating modes have changed over the last several years, what the chart does not show is that Unit 4/5 effectively became a marginal resource from management's perspective. While this was caused by newer units coming online at Tracy, not by greater renewables penetration in the system, the



1. The infamous California ISO (CAISO) "duck curve," showing the expected growth in the twice daily ramp as renewable capacity rises, as well as the potential for over-generation midday transition experience can serve as a proxy for others facing marginal unit status.

"Beginning in 2009, Tracy 4/5 kept getting over-dispatched for several years," Murray said. "The annual forecast showed 2000-3000 operating hours but it chronically operated in the 4000- to 5000-hr range. It was 'out of the money' for energy but necessary for reliability. Because the unit was so close to the margin, it was difficult to get a reliable forecast when it took only a few dollars of variation in market prices to drive it into profitability for ancillary services."

The doughnut hole. "Northern Nevada [where Tracy is located], is a doughnut hole from the perspective of the regional grid," Murray pointed out, "it's somewhat isolated, and Tracy provided critical grid support in this timeframe, the only unit that could provide voltage support to a high-density load pocket of Reno-Sparks. In fact, Tracy 4/5 was often dispatched as a synchronous generator for reactive voltage support during periods of low load. As renewables penetration rose, Tracy's critical position became even clearer.

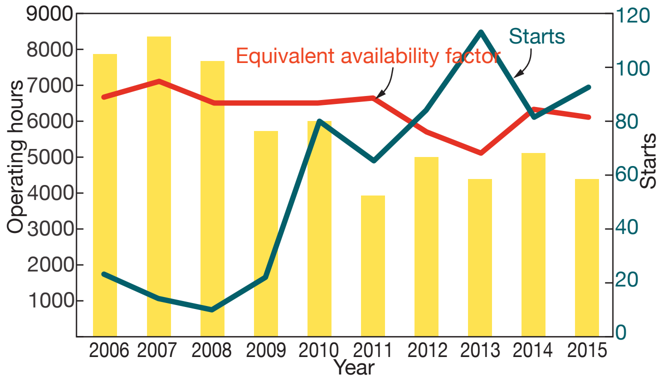
The issue, it turns out, is that the operating-hours forecast was sensitive to the production model's fuel price assumption. A nickel change could dramatically increase the spread in the operating-hour forecast range.

This uncertainty spilled over to the O&M plan for the unit.

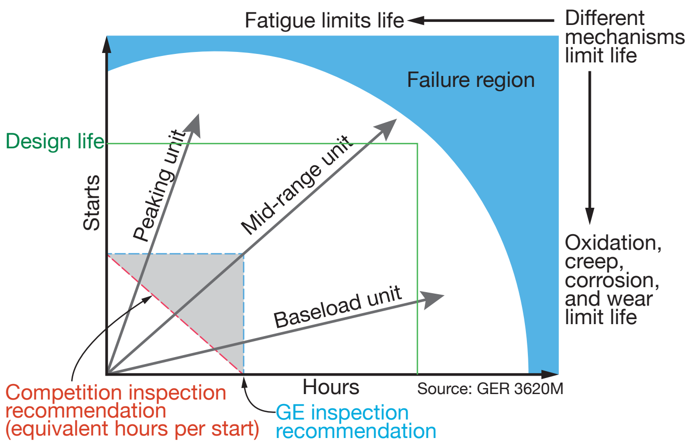
"When outages were conducted, Tracy 4/5 was scrutinized ever closer from a value-engineering perspective," recalled Murray.

It's pretty easy to see how a potential death spiral emerges. Low operating hours forecast, minimum dollars allocated for repair and upkeep, yet a rising number of starts and operating hours consistently higher than forecast.

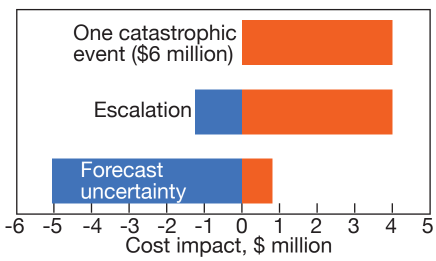
Aggravating this is the small size of the 6FA fleet in the US, perhaps numbering in the single digits. Parts were quickly made obsolete, and NV Energy was self-managing maintenance (without long-term contracts). "Parts limitations under a deep cycling regime are a serious problem," said Murray.



2. This what the duck curve looks like to a combined-cycle plant that has to fill in around renewable energy on a daily basis



3. The mid-range unit poses the greatest uncertainty with respect to potential failures. An "n" ratio of 25 to 50 is the risk zone in which multiple failure mechanisms can result. Therefore, LTSAs with OEMs often include costly penalties to accommodate units like Tracy 4/5



4. Present value of an LTSA can swing wildly depending on factors such as inclusion of catastrophic-event coverage, escalation, and uncertainty in the production forecast

Contingency plans

The key to managing through this transition was to replace the O&M plan based on an average scenario with several plans having timelines which accommodate the sensitivity in the operating forecast. "Management needs as much flexibility as possible, and the goal is always to make it to the next outage at lowest possible cost. Nevertheless, some work/spending has to occur to cover uncertainties."

One way this is accomplished is Tracy 4/5 relies on non-OEM parts and repair. According to Murray, the LTSAs are most difficult to negotiate for a cycling unit that operates between a traditional peaker and baseload, because the critical components have the most design life expended (Fig 3). Units like Tracy 4/5 face a double whammy: Parts are obsolete and difficult to obtain, and design life evaporates faster. "It's not easy to accommodate contingent pathways and arrive at an economical LTSA," Murray stressed. This is evident from Fig 4.

Murray's team had to get comfortable with non-OEM parts and repair, "though that has its challenges," he conceded. Tracy 4/5 staff competitively bids parts and service for every outage. The relative risk has to be managed, as well as the marketing hype: Third-party providers often claim they can repair parts beyond their expected life cycle.

By contrast, OEMs tout "genuine" quality parts; but Tracy had two large "quality-driven" issues from parts supplied by the OEM. "In one case, said Murray, "we had S1B failures (close to liberation) during a third repair/replace cycle, after only 4000 hours into the maintenance cycle."

He advises that others insist on a detailed quality control (QC) plan from the vendor and consider an independent QC as a hedge. Another consideration: The evaluation criteria for whether parts can withstand another repair cycle may be less stringent if the work scope is outside of an LTSA, as the vendor faces less risk.

Clearly, condition-based maintenance becomes paramount under "transition" circumstances. Tracy Station, in general, takes advantage of enhanced borescope inspections, parts life extension and upgrades, and optical scanning technologies. The facility also is a customer of NV Energy's relatively new remote monitoring and diagnostic center, which, among other things, formalized a discovery and communication process with the plant. While Murray doesn't point to the "big catch" that some M&D centers often tout to the industry, he acknowledges the NV Energy center's contribution to evidence-based outage planning. CCJ

Consider eddy-current inspection of refurbished S3Bs prior to next use

Learned at the
2016 conference

7F USERS GROUP
Next meeting:
May 15-19, 2017
La Cantera Hill Country Resort and Spa
San Antonio, Tex

Gas turbine owner/operators that do not send key personnel to user-group meetings may be taking unnecessary financial and safety risks. There is, perhaps, nowhere better to learn about issues you should be aware of. Consider the recent liberation events associated with third-stage buckets (S3B) in 7FA gas turbines. This was an agenda item of great interest to attendees at the 2016 conference of the 7F Users Group, May 9-13, at the Rosen Shingle Creek Hotel in Orlando.

The group received an alert on S3B failures from a user at the 2015 meeting and was reminded of it only a few weeks before this year's conference by a post on the 7F Forum describing another such failure. Yet another third-stage liberation event was reported a week before the users would gather in Florida. In sum, the editors identified six 7FAs that have experienced S3B failures, and one 9FA.

The OEM's proactive response to the latest two incidents included a preliminary explanatory message for posting on the 7F Forum prior to the meeting, a formal presentation on the issue right after the keynote on GE Day (Thursday, May 12), and a deep dive during the interactive hot-gas-path (HGP) breakout Thursday afternoon, which included participation by about half of the user attendees.

GE's experts said they believe the underlying cause of the failures is casting defects that caused one blade in each of the affected machines to fracture. The liberated airfoil segment then tore up other S3Bs (Fig 1), sending metal fragments downstream as far as the heat-recovery steam generator (Fig 2). In one instance, the trail of metal terminated at the first row of tubes in the HRSG, with any remaining airborne shards entrained in the exhaust stream captured by the field of finned tubes without damage to pressure parts (Fig 3).

In the latest case, affected components have been sent by the OEM to a third-party for analysis, to help determine the root cause. This could take until yearend, or longer, depending on what investigators find. Believing casting quality is likely the

1. The upper third of one third-stage turbine bucket liberated and caused all this damage

2. Pieces of turbine buckets liberated, providing a pathway to the HRSG

3. The few remaining pieces of turbine buckets entrained in the gas-turbine exhaust stream were stopped by the first row of finned tubes in the HRSG, without damage to pressure parts underlying issue, as a first step GE reviewed x-rays for third-stage buckets made from three months before to three months after a failed bucket was cast. Task takes one experienced person about 24 hours to check x-rays for all 92 buckets in the third row. A positive result of this investigation was that several units were shut down for inspection.

GE participants in the 7F meeting appeared confident that S3B failures of the type experienced thus far were unlikely to occur after about 6000 hours of service (for repaired buckets). They also viewed S3B fractures as a low risk for operators, pointing to the company's experience in repairing and inspecting more than 55,000 S3Bs over the years. The reliability of these airfoils was cited at 99.2% through three HGP inspections.

The OEM is keeping an open mind regarding cause as the investigation proceeds. Its plan is to follow up with the users in early summer with progress report and to update owner/operators perhaps as frequently as monthly thereafter.

Case histories

Key facts associated with each of the liberation events, as told to CCJ by the owner/operators of the affected engines, are summarized below:

Case history 1: 7FA.03, 2016.

S3B failed 3600 hours following a major inspection (six months into a planned four-year interval). Bucket row came from another of the company's units following its refurbishment by the OEM in 2015 after 29,000 hours of service. Repair process involved fluorescent penetrant inspection (FPI), rejuvenation of buckets by hot isostatic pressing (HIP), and FPI again. Important to note is that four of the 92 buckets fell out during refurbishment; plant did not know if the bucket that failed was a replacement for one of those. The crack grew inward from the trailing edge about 1.5 in. before failure. Note that S3B cracks typically are found between about 3 and 10 in. off the base of the 18-in. airfoil.

Unit maintenance is under an LTSA and the OEM replaced the third stage with pre-owned buckets having about 2000 hours of service and no repairs. Project took 20 days.

The gas turbine tripped on high vibration (50-60 mils) as measured by proximity probes; reading on velocity probe was 0.98 ips. Unit came down and went on turning gear; 26 hours later personnel were in the exhaust end. There was some bearing wear and oil seals were replaced. Hard rubs were in evidence in the compressor. The exhaust frame took a beating but it was repairable.

Case history 2: 7FA.04, 2016

Failure happened after 800 hours of baseload operation following a major inspection that included an AGP (advanced gas path) upgrade by the OEM with new third-stage buckets. This was the only incident involving new buckets and may be an "infant-mortality" issue—different from the other five failures profiled here. They occurred on buckets that had been repaired at least once, possibly pointing to the need for refinements to repair processes by all participants—third parties as well as the OEM.

Case history 3: 7FA.03, 2015

Buckets repaired at 48,000 hours by the OEM, failure occurred in less than 3000 hours following a return to service. Damage to exhaust casing, flex seals, and piping was experienced.

Case history 4: 7FA.03, 2013

Rotor was replaced in the affected

machine in 2003; the replacement rotor came bladed with new second- and third-stage buckets. Those buckets were removed for refurbishment by a third-party repair shop in 2009, after 48,000 hours of service. Following refurbishment, the set of buckets was warehoused until installed in a different unit in 2013. The upper one-third of one bucket liberated during a vibration event after operating for less than about 30 hours.

Post-accident review revealed 89 of 92 buckets "looked good." The other three had different part numbers and appeared "more used." Investigators assumed that the OEM was three buckets short when the new third-stage set was installed in 2003. Two of the three buckets appeared to have been slightly used, the remaining one "very-well-used." The well-used bucket, and the one that failed, exhibited large grain sizes, significant grain-boundary oxidation, and creep voids under the microscope.

Case history 5: 7FA.03, 2013

Buckets repaired at 48,000 hours by the OEM, failure occurred in less than 3000 hours following a return to service. Damage to exhaust casing, flex seals, and piping was experienced.

Case history 6: 7FA.03, 2013

Buckets repaired at 48,000 hours by the OEM, failure occurred in less than 3000 hours following a return to service. Damage to exhaust casing, flex seals, and piping was experienced.

Rejuvenation

One independent metallurgist/repair expert told the editors he agreed with the OEM's assessment that a casting flaw is the likely underlying cause of the failures on repaired buckets. He said a scratch—such as that incurred during the removal, handling, or reinstallation of buckets—or casting flaw creates a stress riser and a starting point for the failure to proceed. HIP or other heat treatments, designed to "heal" *certain* fully internal flaws can exacerbate some defects, in effect "triggering" the flaw.

High-cycle fatigue is generally thought to be the mechanism causing rapid propagation of any crack that may develop shortly after a return to service. The incident thumbnails above show all failures occurred, in round numbers, within about six months and in less than 3500 operating hours following restart after repair.

A second metallurgist/repair expert cautioned against jumping to conclusions as to failure causes without proper metallurgical analyses of the failed buckets, including the identification of any flaws that may have contributed to the problem. Until this is done, he said, it really is difficult to properly identify the role that any one factor, such as HIP, might have had on the failure.

The expert offered two possible scenarios of how damage might occur as a result of the repair process. The first is where the casting contains one or more near-surface defects—such as those caused by shrinkage during the casting process. In this case, there would be a thin membrane of material between the flaw and the surface that can be effectively "burst" by the pressure of the HIP gas.

The second is where there are tight oxide-filled cracks at the surface. The oxide prevents detection by the fluorescent penetrant used to verify the buckets are crack-free. The exposure to HIP, or vacuum heat treatment, can reduce oxides and allow detection of defects by penetrant.

In both scenarios, the flaws already exist and are merely exposed to NDE by the HIP process. From a structural point of view, the integrity of the component would be the same, he said. Going further, the expert offered that, based on his decades of experience, it was extremely unlikely that HIP could make an existing subsurface flaw structurally worse and conducive to crack propagation.

A user told the editors that the sequence of shop operations—including grit blasting, penetrant examination before HIP, HIP, and penetrant inspection after HIP, etc—came into question and was changed by one service provider to reduce the likelihood of defects being masked by the repair process. However, another failure occurred even after the process changes reportedly were made, indicating there's more work to be done.

Another possible consequence of HIP, one of the experts said, was the possibility of HIP distorting the bucket. This is a potential consequence of any heat treatment, he continued, where residual stresses from original manufacture or service are relieved. This is why dimensional inspection of components is an important part of any repair process. Unrecognized distortion of shrouded buckets can change the loading of shroud interlocks and influence the cyclic behavior of the buckets.

Inspection

For an understanding of inspection processes best suited to warn of possible impending issues in turbine blades after repair or in service, CCJ turned to Advanced Turbine Support LLC. In a telephone interview with Mike Hoogsteden, director of field services, and inspection experts Dustin Irlbeck and Brett Fuller, here's what the editors learned:

Ultrasound, radiographic, eddy current, and penetrant inspection techniques are the alternatives. The OEM relies on fluorescent penetrant inspection (FPI) in its shop repair process and recommends it for field checks. FPI has the benefits of being inexpensive and unlikely to produce a false indication. However, it will not recognize a tight crack or lurking problems just below the surface of the airfoil.

Radiography is a "full-volume" inspection method, used primarily in the shop to check bucket internals. It relies on a density difference to identify a fault and a crack might not be revealed. Plus, a radiographic inspection is extremely time-consuming, taking perhaps four or five times as long as eddy current (EC).

Advanced Turbine Support suggests EC for 7FA S3B inspections. It is faster than both ultrasound and radiography and can "see" surface cracks as well as anomalies near the surface of the airfoil. The company has more than 18 months of successful experience inspecting last-row turbine blades in 501F and 501G machines. The protocol developed for this work has been used recently to inspect last-row turbine buckets in 7FAs.

Advanced Turbine Support's experience on 501 engines identified casting issues that suggested a tightening of manufacturing and repair specifications. The EC equipment the company uses requires inspectors to scan each bucket multiple times on both the suction and pressure sides of the airfoils to cover the complete blade width, plus one pass with a pencil probe on both the leading and trailing edges.

As for manpower, Hoogsteden said a team of two qualified technicians can check the 92 third-stage buckets in a long shift (12 hours). Buckets not installed in the turbine can be inspected on a bench in about half that time. One user said he was considering making EC scans a part of the company's incoming inspection procedure for repaired S3Bs to back up the OEM's FPI effort. CCJ

Cool valves, piping improve engine reliability when called to burn oil

Presentations and discussion at meetings of the 7F and 7EA Users Groups and CTOTF™ often call into view problems owner/operators are having with the liquid-fuel systems on their dual-fuel engines—in particular, unreliable starts and unreliable fuel transfers from gas to oil. A couple of years ago, the sure solution for some users rarely called to operate on oil was to disable or remove their "unnecessary" liquid-fuel systems. A benefit of this approach was less-complex and less-costly annual inspections.

But yesterday is not today in the continually evolving business of electric generation. Many owner/operators, now unable to operate profitably on energy sales alone, must provide the grid ancillary services to boost revenue. Some of these services require dual-fuel capability to assure reliable power production on oil should gas supplies become tight, or unavailable—as happened in New England a couple of winters ago. Thus some users are re-commissioning their liquid-fuel systems; others are installing liquid-fuel capability on gas-only engines, and liquid-fuel systems are a headline item—once again.

Information shared at user-group meetings points to two ways to improve the reliability of dual-fuel gas turbines (GT) on oil starts and fuel transfers: Continuous circulation of oil through liquid-fuel-system components, and active cooling—including the use of water-cooled valves, manufactured by JASC (Tempe, Ariz), to prevent coking of oil in critical check valves and assure proper seating.

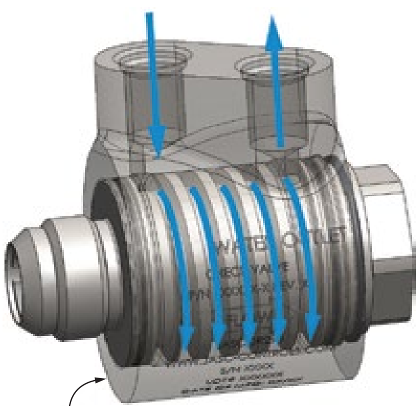
The coking problem many users experience with standard liquid-fuel check valves occurs after switching from oil to gas. Oil remaining in check valves, which are located close to the combustion section of the unit, is exposed to high temperatures. Above about 250F that oil is oxidized. The resulting coke coats check-valve internal surfaces (and fuel lines as well) and restricts the movement of valve parts and the flow of oil.

Once this occurs, a check valve will not open and close properly until it is overhauled, which requires special equipment and skilled technicians to assure its better-than ANSI Class 6 seal in the reverse-flow direction. The most common trip during fuel transfer is on high exhaust-spread temperature—caused almost exclusively by check valves "hung-up" on coked fuel.

To get a first-hand look at the issues faced by owner/operators with dual-fuel GTs, the editors spoke with one 7FA and one 7EA user, both active participants in user-group activities.

7FA experience

Experience was shared by a station equipped with five simple-cycle 7FAs and one 2 × 1 7FA-powered combined cycle. All engines at the facility are equipped for dual-fuel firing and have DLN2.6 combustion systems. Plus, all have JASC water-cooled liquid-fuel check valves—14 per GT (one per combustor). JASC valves were installed on the first engine at this site in 2006. Worldwide, more than 500 industrial gas turbines worldwide now are equipped with JASC water-cooled liquid-fuel valves.



1. Water cooling-circuit flow path is described above

The peakers each start 120 to 150 times a year and operate up to about 3500 hours annually these days. The combined-cycle is a mid-range unit. With plenty of gas available, unit run time on distillate typically is less than 50 hours a year—most of that time to keep the liquid-fuel systems exercised and to identify maintenance issues.

Management expected long runs on oil when the polar vortex hit in 2015. Plant personnel prepared for that event with comprehensive fuel-system testing and maintenance, but the threat to gas supply never materialized and the plant only ran a day or two on oil.

The few check-valve problems experienced over the years have been cooling-water related. Water for valve cooling comes from the closed cooling-water system, which recirculates a mixture of water and glycol. The fin-fan cooler for the peakers supplies water at about 130F in summer; that for the combined cycle, about 150F. Such hot water for cooling is not problematic because the goal is to keep the check valves under 250F.

The user interviewed recalled that fuel-transfer reliability was in the low 60s (percent) with standard check valves and the reason why the plant switched to JASC. Today, transfer reliability is in the upper 80s. Note that not all fuel-transfer failures are related to the check valves. Bypass, stop, and control valves, flow dividers, and servos share the blame; plant personnel have to pay close attention to all fuel-system components.

In fact, performance of the water-cooled liquid-fuel check valves (Fig 1) have been the least of the plant's worries, the editors were told. Air in the liquid fuel system was said to be the biggest impediment to reliable operation—it can extinguish the flame in a can and trip the unit. Here's how air gets into the system: When hot oil cools its volume decreases creating a void. Air entering the system at any point in the fuel-oil system gets pulled into the vacuum pockets.

A patient transfer from gas to oil prevents flame blow-out by air. Gas is always available at this utility-owned plant and operation on oil begins with a startup on gas. While still in Mode 1, oil is introduced and the two fuels are co-fired for about 60 seconds. Then oil is shut off and the unit runs on gas for another minute or so. The first step then is repeated four more times: The fuels are co-fired, and then gas alone, and so on. Next, the gas is shut off with oil running alone, absent the threat of an air pocket.

Installation of the check valves and the supporting cooling-water circuit was not difficult. Plant personnel prefabricated all the water lines after the trial installation, which took about two days per unit. Staff also did the valve installation—typically a day for each engine. Early on the check-valve cooling circuit was operated with a delta P that was too high: 50 psi. Overcooling allowed unwanted wax to come out of solution. Reducing the differential pressure to 12 psi eliminated the issue.

To assure that the plant maintains fuel-transfer reliability at a high level, check valves are removed at each combustor and hot-gas-path inspection and returned to JASC for servicing—this to avoid a failed fuel transfer caused by a check-valve problem.

After speaking with plant personnel, the editors met with Schuyler McElrath at the JASC booth during the 7F vendor fair to learn more about air pockets and how to avoid them. McElrath is a 25-year GE veteran who specialized in fuel-system design and testing for most of his OEM career.

He said users often think that exhaust temperature spreads are the result of air in the system. In his experience, when a significant amount of air is trapped in the fuel system, the turbine will trip and send a diagnostic alarm stating there was an excessive fuel-flow fault. This trip occurs when the flow divider spins faster than expected because air is being compressed.

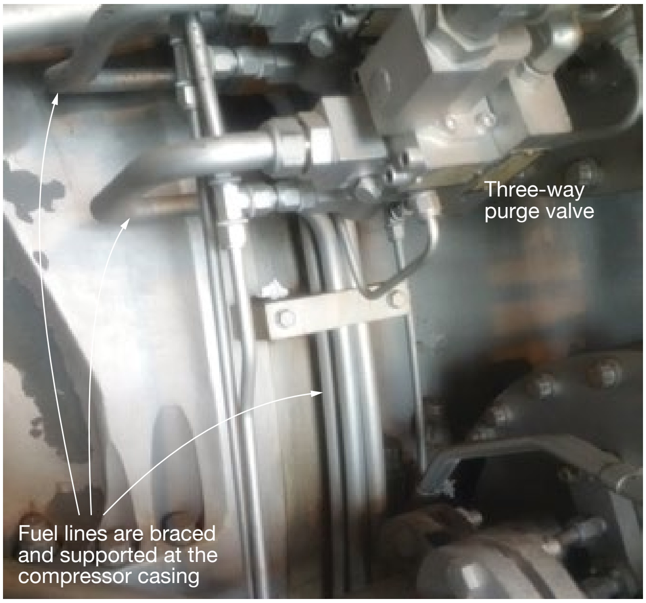
McElrath believes that for users experiencing high spreads and/or exhaust-temperature trips during

1. Impact of coke formation in fuel lines

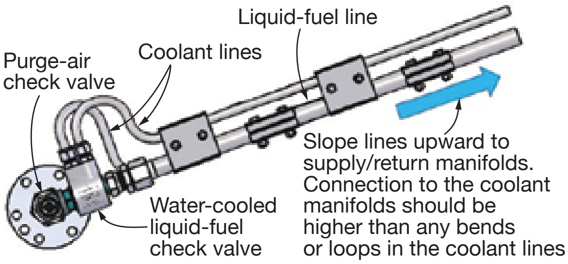
Fuel piping design figures prominently into the formation of a tar-like substance capable of clogging water-cooled liquid-fuel check valves, water-cooled three-way purge valves, fuel distributor valve inlet screens, and fuel-nozzle passages. The routing scheme for fuel piping on many large GE gas turbines uses either the compressor casing or combustion-section casing as a bracing point.

While these locations are convenient, they often are not practical because temperatures of the casings can exceed 500F, causing any stagnant fuel in the piping to reach very high viscosity. Bear in mind that high viscosities can adversely impact fuel transfer and cause one or more of the following problems: cold spots in turbine exhaust, high exhaust temperature spreads, fuel-system evacuation, deposits of the tar-like substance on nozzles, and coke formation in fuel lines. Regarding the last, in fuel lines that have been evacuated but still subjected to high-temperature turbine casings, coke formed on the tubing wall can break loose and plug fuel nozzles during thermal expansion and contraction events.

To mitigate coke formation in affected fuel lines, JASC suggests re-routing of fuel supply tubing away from the compressor casing and/or combustion wrapper where cost-effective. Alternatively, you might consider the company's thermal-clamp technology to cool fuel-supply lines by transferring heat to the existing cooling-water supply and return lines (refer back to text Figs 3 and 4).



2. DLN fuel system shows primary and secondary liquid-fuel lines and uncooled three-way purge valve



3. Thermal clamps actively cool stagnant fuel lines and contribute to structural support

fuel transfers from gas to liquid *without excessive fuel-flow faults,* the problem likely is caused by fuel becoming increasingly viscous as it transitions to solid coke (Sidebar 1). He recommends that turbine owners who have upgraded to water-cooled valves run on liquid fuel at least monthly to mitigate this problem.

2. Thermal relief valve protects fluid system components

JASC's Thermal Relief Valve (TRV, photo) has two operating modes: relief and shut-off. In the "relief" mode, when heating of the liquid fuel trapped between the stop and check valves raises fluid pressure to 150 psig (nominal setting), the TRV's poppet lifts to allow a small amount of fuel (think cubic centimeters) to flow into a drain pot, relieving pressure. This process continues until the fuel reaches thermal equilibrium.

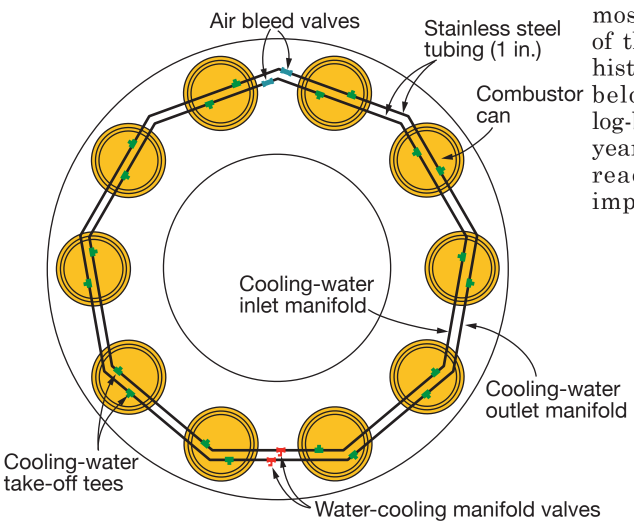
In "shut-off" mode, fuel pressure loads the poppet against the shutoff seat, thereby closing off the fuel's drain path and the gas turbine operates normally. Actuation of the TRV is passive. A small amount of fuel (cubic centimeters again) is vented during poppet actuation, but the duration of this action is so short that flow rate and volume drained cause no disruption in normal turbine operation. When fuel-system pressure is reduced—such as during normal engine shutdown or fuel transfer—the poppet transitions back to "Relief" mode.

For new upgrades to water-cooled valves, McElrath suggests relocating fuel piping away from hot turbine casings (Fig 2) and using JASC's recently introduced thermal clamps to provide continuous cooling of fuel lines (Fig 3). Thermal clamps can increase the intervals required for exercising the system from one month to as many as four. The thermal relief valve is another new JASC product for liquid fuel systems. It is designed to prevent over-pressurization of the liquid-fuel system when oil is trapped between the stop and check valves and tries to expand when exposed to casing heat (Sidebar 2).

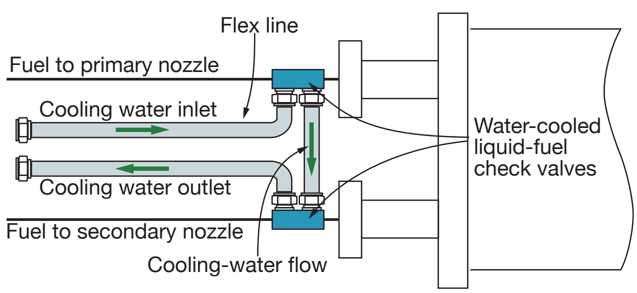
7EA experience

The 7EA dual-fuel engine profiled here is equipped with a DLN-1 combustion system. Installed 20 years ago, it is still doing 120-150 starts annually; plant staff was challenged by operational issues on distillate. Water-cooled liquid-fuel check valves were only one part—perhaps the most important part—of the solution. Engine history in bullet points below, compiled from log-book entries over the years, is worth a quick read to illustrate the importance of exercising standby fuel systems regularly if you expect them to perform properly when needed.

- Historically, this unit had operated on gas in a satisfactory manner.
- Periodic operation on oil was confirmed by the need to replace leaking liquid-fuel check valves in December 1996.
- In fall 1998, the buildup of coke was sufficient to damage some crossfire tubes, which were repaired/replaced. Coking issues persisted and more crossfire tubes were replaced about six months later.
- A spate of operational problems traced to liquid fuel led to the replacement of check valves with the OEM's newly designed three-way purge valves in fall 1999. The job report claimed proper operation through all load ranges on gas and



4. Cooling-water manifolds, supply and return, are made of 1 in. tubing



5. Cooling water flows from primary-fuel check valve to secondary-fuel valve in series oil, as well as successful fuel transfers.

- Coking issues soon reappeared. Evidently, the unit would operate on gas for hours with distillate trapped in the liquid fuel system. Later attempts to run on oil would be unsuccessful. Historical documentation appears to indicate that plant personnel just gave up on liquid fuel at that point and ran on gas.

Fuel quality. The foregoing findings prompted thinking about the quality of fuel in storage. Analysis revealed a stability rating of 15, indicating the fuel was unstable; a stability number above 7 is unsatisfactory. Fuel treatment brought the stability rating down to 2, but it just doesn't stay there—especially in the heat and humidity characteristic of this southern plant site. Semi-annual retesting was recommended, with follow-up treatment when necessary.

Additional tests were run on the "satisfactory" fuel to better understand its tolerance for heat. Utility engineers determined that GT compartment temperature can get as high as 300F and wanted to know how long it would take for the fuel to start forming particulates at that temperature. The answer: six hours. That meant any liquid fuel remaining in the system probably would begin to coke during the next run on natural gas.

The first hot-gas-path inspection in January 2003 revealed some secondary fuel-nozzle tubes were plugged with carbon deposits. During tuning after the HGP, engineers found some secondary liquid-fuel "pigtail" lines completely plugged with carbon.

Fuel lines and nozzles were cleaned in the spring and the plant began testing on liquid fuel again in June. No issues were encountered in the primary circuits, but the water injection system for the secondary circuits had problems—the most obvious was frozen flowmeters, attributed to lack of exercise.

An inspection and rehabilitation plan was prepared for the water injection system, but work was postponed for more than a year because personnel were reassigned to address other company issues. The days of unit-dedicated staffs at this public utility were history by that time.

Testing resumed on liquid fuel in June 2005, but a high temperature spread at 12 MW with only the primary nozzles in service tripped the unit. Liquid fuel sat in the pigtail lines for almost two years while the unit operated on gas. According to the Mark V control system's timers, the 7EA had accumulated only seven hours of operation on liquid fuel since COD nine years earlier.

It was clear that proper operation of the liquid-fuel system hinged on reducing the exposure time of oil to high heat or reducing the temperature of the oil, or a combination of both. One idea was to purge oil from the system (end cover to burner front) using nitrogen or atomizing air.

Problem with this approach was the risk of flame out on transfer from gas to oil under load because of empty fuel lines. In addition, there would still be some seals and O-rings in the three-way purge valves exposed to distillate and they would be prone to deterioration and gum-up by particulates.

JASC's water-cooled check valves were evaluated and considered at least part of a viable solution to the coking issue. They would allow changing fuels under load while holding valve temperature below the threshold for particulate formation. Experience at other sites confirmed this. The valves, tubing, and other components recommended by JASC were ordered and plans made to modify the liquid-fuel system during the combustion inspection (CI) planned for January 2008.

The switch to the JASC solution was not simply a matter of cutting out a few valves, welding in some new ones, and hooking up water supply and return lines. Also needed was OEM

6. **Hydrolazing** is no small task; flatbed holds all equipment required

3. Smart Fluid Monitor contributes to liquid-fuel system reliability

The Smart Fluid Monitor (photo) remotely monitors and reports coolant flow and temperatures, as well as piping-system integrity. It assures adequate coolant flow is available to critical components, such as water-cooled liquid-fuel check valves, allowing for extended operational intervals. The device is sensitive enough to detect small flow discrepancies between cooling-water supply and return lines.

The instrument's ability to control cooling-water temperature helps guard against waxing that can be experienced with some oils at low temperatures, as well as protecting against coking.

support to modify the Mark V controls from three-way purge-valve operation to water-cooled liquid-fuel check valve operation. A third-party engineering and field-services firm was retained as technical advisor for the CI which essentially was a modified HGP that took nearly eight weeks and included the following tasks:

- Convert from three-way purge valves to water-cooled (70/30 mixture of water/glycol) check valves.
- Replace first-stage turbine nozzles, which exhibited severe cracking.
- Clean the fuel-oil system to assure as-new-as-possible condition prior

7. **High-pressure water** cuts through the coke and flushes it out

to restart.

- Repair exhaust frame.
- Analyze turbine casing crack.
- Replace fuel nozzles.

Cooling-water supply and return manifolds were installed (Fig 4) to serve all combustors in parallel. Fig 5 shows that cooling water flows to the primary fuel nozzle first and then to the secondary nozzle (Sidebar 3).

Cleaning of the fuel system required an effort that should not be underestimated. A holistic approach was used to make sure the job was done properly. Hydrolazing was used to cut through coke in fuel lines and remove it from the system. System clean-up took about a week. Truck with necessary equipment is in Fig 6, some of the coke removed in Fig 7.

Among the problems identified: (1) The flow divider was gunked up, corroded, and inoperable (Fig 8); it was replaced. (2) The selector valve was plugged (Fig 9) and refurbished. (3) Purge-air solenoids for the secondary-fuel circuit were found inoperative.

All work complete, recommissioning of the liquid fuel system was reasonably straight-forward. The system was exercised monthly until mid-2013, meeting expectations. The utility's standard 30-min test: Unit is started on gas, which always is available at this site, switched to oil and run up to at least 60 MW, allowing check-out of the primary and secondary purge-air and water-injection systems. Then load is reduced and the unit transferred back to natural gas for shutdown. After shutdown, atomizing air and check-valve cooling water continued to run for eight hours.

In May 2013, a cross-fire tube failed and operations personnel noticed an increase in pressure at the fuel nozzles serving combustion cans Nos. 2 and 9. Investigation revealed that the fuel lines for cans Nos. 2 and 9 were closer to the compressor discharge case (CDC) than the fuel lines serving the unit's other 12 cans.

Engineers believed liquid fuel was "cooking" in those lines while the unit was operating on gas and the coke particles released were plugging fuel-nozzle passages. An outage was scheduled to replace the failed cross-fire tube and to do fuel-nozzle maintenance. However, the unit was needed, and with plenty of gas available, it continued to run. Thus far, three outages scheduled for these activities have been postponed. In the meantime, monthly tests on oil have ceased.

One reason was personnel and procedures. Personnel changes at the supervisory and operations levels were frequent, creating an inexperi-

8. Flow divider was gunked up, corroded, and inoperable

9. Selector valve required work to unplug ports ence factor that militated against consistent operating practices. Many people "passing through" never fully understood, or properly followed, the successful procedures developed years earlier for exercising the liquid-fuel system.

Another reason was the cost of testing—estimated at about $30,000 monthly. That's huge when you consider the unit had never been called to run on oil, since the fuel-system upgrade in 2008. The log book only indicated running for load on oil a couple of times and for hours numbering in the single digits. Example: The engine ran for 2.5 hours on oil in June 2009 and that was it for the year.

JASC has been listening to users. To *eliminate* test firings on oil, thereby saving an ongoing expense as well as reducing emissions, the company has been talking up its Zero Emissions Equipment (ZEE) Performance Test system now in the final design stages (Sidebar 4). CCJ

4. ZEE keeps liquid-fuel systems ready for service without test firing

Back-up liquid-fuel systems must be exercised regularly—typically monthly—to assure their reliability when needed. In some cases, the operator is following guidelines provided by the OEM, in others there's a grid requirement.

When exercising the system in the usual manner—either starting/running/shutting down on oil or starting on gas, transferring to oil, and then going back to gas for shutdown—remember that you (1) risk tripping the unit because of high exhaust-temperature spreads, (2) pay a premium for the test fuel, and (3) have to deal with the significant emissions associated with burning diesel fuel.

JASC is developing its Zero Emissions Equipment (ZEE) system to improve the performance of back-up liquid-fuel systems. The company says the starting reliability of large industrial gas turbines on gas exceeds 97%, according to industry data, or about double that when oil is burned.

For most applications, ZEE permits plant personnel to operate the back-up distillate system through the entire operational range of fuel flows and light-off to full-speed/full-load without actually burning fuel. All system components are operated and flowed using the GT's electronic controls. All equipment in the fuel system is tested, from the main fuel tank to the control valves at the fuel nozzles, as part of the process.

Users report new ways to leverage investment in PI

OSIsoft LLC's PI System™ is a mainstay at US combined-cycle facilities, indeed throughout the electricity supply chain and allied energy industries. Those who use/have PI may be surprised at how expansive it has become for some owner/operators.

During the obligatory "bragging rights" session at the OSIsoft Users Conference in San Francisco, Apr 4-7, 2016, senior management reported that the company now has 70% of the North American energy market. While the basis for that figure wasn't disclosed, you don't need a doctorate in data science to know that PI serves in a vast number of powerplants and most power-generation companies.

Over 2500 facility managers and staff, along with 400 watching live around the globe, participated in the event. PI is installed at 17,000 sites across 120 countries. The company has experienced torrid growth; the number of employees has doubled over the last six years. With a wry smile, one executive assured the audience that they still have more developers than account managers.

Senior management stressed these takeaways:

- PI has left the legacy of the plant data-historian "server" behind. OSIsoft is a data infrastructure "cloud" company and has been deploying several new products to support this, among them OSIsoft Cloud Connect and OSIsoft Cloud Services.
- The company is "embracing the idea of partnerships like never before." It has formed industry vertical user groups, and speaks of an "ecosystem with OSIsoft Marketplace."

A deeper dive into the user presentations, plus discussions with PI product managers and partners, suggests that the main theme of the confab is leveraging a site's investment in PI and reducing the need for separate applications which traditionally access PI data.

One user described how an IPP in the Philippines is now handling heat-rate monitoring functions in PI ProcessBook and PI Analytics. Responding to a participant during the Q&A, he noted that the company has EtaPRO™, GP Strategies' popular Thermal Performance & Condition Monitoring System, but plans to phase out its use and migrate those functions to PI. Another user demonstrated PI's suitability for advanced pattern recognition (APR) and transitioning from calendar-based maintenance to condition-based maintenance.

During the product demo session, following the formal presentations, one PI product booth displayed visualization capabilities which pretty much suggested a plant no longer needed separate alarm management software if they have advanced PI capabilities.

Certainly it isn't a coincidence that standalone software companies that offered APR (Smart Signal Corp and InStep Software LLC, among others), alarm management (MatrikonOPC), and heat-rate monitoring have been acquired by the big dogs of the industry over the last five years. At the same time, DCS automation platform suppliers have been integrating this functionality into their offerings.

Broader applications

As well-seasoned as PI is at plants and central performance monitoring facilities, PI infrastructure is now being deployed in far broader and deeper ways—for example:

- A large UK gas supplier, "getting out of the powerplant business and into distributed small-scale generation," uses PI infrastructure to operate and monitor DG units and manage the *transactional* interface, as well as handle energy time-shifting functions for customers. As a gas "G&T," the company is able to trade as a portfolio on the wholesale side while settling customer transactions site-by-site. The firm's representative stated that up to 20 GW of DG could benefit from this service in the UK alone.
- A wind portfolio owner/operator in Japan monitors weather and wind-turbine conditions to forecast wind energy availability through PI infrastructure and, importantly, communicate with the grid operator regarding their daily ramp forecasts. More than 40 wind sites are part of this development program.
- An Arizona utility, reportedly ranked fourth in solar-based power production (in the US), is applying PI infrastructure to monitor its (utility-owned) nine 10- to 40-MW solar PV facilities. The company hopes to expand its use to the 59 commercial-scale and 50,000-100,000 residential solar PV units interfaced with the utility's grid. This program, in collaboration with EPRI, has a straightforward payback: For every one-half percentage point improvement in renewables forecasting, the utility can save approximately $1-million annually in natural gas costs trying to "follow" the sun.
- PI infrastructure, integrated with a major PLC/DCS platform supplier, is now the "standard" infrastructure serving 21 North American breweries for one of the largest global beverage companies.
- One of the largest utilities in the country has made PI infrastructure part of its "productivity through technology" initiative, being implemented as (1) a centralized performance monitoring facility for seven combined-cycle facilities, (2) as an advanced forecasting capability for its wind facilities scattered between the Mississippi River and the Rocky Mountains, and (3) for more efficient and maintenance-minded cycling and dispatch of its fossil assets. "A strong centralized PI system through an enterprise agreement with OSIsoft" is at the core of the initiative. CCJ

SPS® partners with OSIsoft

Strategic Power Systems Inc, Charlotte, has partnered with OSIsoft through the latter's Connected Services program to expand its services to powerplants. The ORAP® database, well known to virtually every gas-turbine owner/operator, is popular with users and OEMs as a way to aggregate engine performance data on a fleet-wide, unit-model basis.

SPS can now achieve a greater fidelity for the aging characteristics data collected from its client sites, improve mission data collection and analytics (starts, stops, cycles, etc), reduce manual entry, and automate reporting to NERC, for which SPS is an official data reporting entity and "trusted party."

Fidelity of data is key for NERC CIPS V compliance, according to SPS President Sal DellaVilla. Thermal performance monitoring now also can be conducted through the ORAP platform. For one customer with three plants in Texas, the expanded services have reduced the cost of traditional results engineering duties by 85%. Such experts can be deployed for higher-value activities.

Next stop: Vegas

The officers, directors, breakout chairs, and staff of Western Turbine Users Inc knew the organization's 25th anniversary celebration in 2015 would be a tough act to follow, but the 26th Annual Meeting in Palm Springs, Mar 20-23, 2016, was upbeat as usual and certainly exceeded the editors' expectations.

This testifies to the leadership's ability to reinvent itself year after year and to keep up with the information needs of its members. Western Turbine continues to host the largest gathering of gas-turbine users worldwide. This year about 350 owner/operators of GE aero engines serving on land in electric-generation and natural-gas pipeline applications, and at sea for ship propulsion, were in attendance.

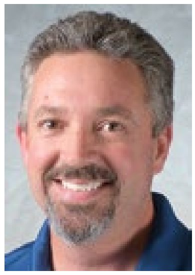
Program development already is underway for the 27th Annual Meeting at the South Point Hotel in Las Vegas, March 19-22, 2017. Don't let the 27 fool you: The turbine users who incorporated the Western Turbine Users in fall 1990 had been meeting "unofficially" since 1982 in plant break rooms to discuss problems/solutions, best practices, lessons learned, etc.

The group's mission has not changed over the years. One reason is the leadership's strong connection to the past. Example: Treasurer Wayne Kawamoto and Historian Mike Raaker have been actively involved in the organization since the early 1980s. Plus, you have the positive influence of people like Sal DellaVilla of SPS®, Steve Johnson of S J Turbine Inc, Brian Hulse of APR Energy, and Turbine Consultant Mark Axford, among others—all of whom have worked proactively with WTUI at least since its incorporation.

President Chuck Casey, a protégé of WTUI's long-term leader, Jim Hinrichs, opened the meeting and announced changes in the organization's leadership team:

- John Baker, chairman of the LM2500 breakout session for the last decade, was "retiring" from this voluntary position at the close of the 2016 meeting. Gary Grimwade, Riverside Public Utilities, Clearwater Cogeneration Facility, will take over the chair's responsibilities beginning in 2017.
- Ed Jackson, Missouri River Energy Services, was elected vice president after completing his three-year term on the board of directors.
- Bryan Atkisson of Riverside Public Utilities assumed responsibility for the New Users Session, beginning with the 2016 meeting. Previously he served as a board member and LM6000 breakout session chair.
- Elected to the board of directors were the following: Andrew Robertson, Wellhead Services Inc; Charles Lawless, Southern California Edison Co; and John Hutson, J-Power USA Generation LP's Orange Grove Energy Center.

For a current listing of officers, board members, break-out session chairs, and support personnel, visit www.wtui.com.



Casey

Continuing, Casey, the utility generation manager for Riverside Public Utilities, said this was the fourth consecutive meeting with more than 1000 total attendees. The 2016 conference actually hosted more than 1200 participants from 19 countries.

Next, Kawamoto was introduced to present the treasurer's report, which was accepted by the membership unopposed. The treasurer also announced that the 2018 meeting would be back in Palm Springs.

The depots

The success of Western Turbine meetings is underpinned by the technical and financial support of the OEM and the four depots licensed by the GE to inspect and repair the engines addressed by the group: Air New Zealand Gas Turbines (ANZGT), Auckland; IHI Corp, Tokyo; MTU Maintenance Berlin-Brandenburg GmbH, Ludwigsfelde, Germany; and TransCanada Turbines (TCT), Airdrie, Alta.

Representatives of the depots work closely with the WTUI leadership to prepare "lessons" for each of the breakout sessions. Deliverables include notebooks, given to participants, which review recent service bulletins and service letters issued by the OEM; summarize depot findings since the last meeting; explain causes of performance

WTUI golf tournament brings users, vendors together

The Western Turbine Users' 26th anniversary golf tournament drew more than 100 players to the 7173-yard course at the Escena Golf Club in Palm Springs, Calif, Sunday, March 20. The popular social function, held annually before the conference officially begins, was organized this year by Charlene Raaker, Wayne Feragen, Wayne Kawamoto, and Jim Bloomquist.

Sponsors: Turbine Technics Inc (coffee, water, and towels), SSS Clutch Co (golf balls), and AAF Filters (chipping contest).

Individual achievements

Ladies' long drive: Janice Shoegren
Closest to the center line: Beth Kallaene
Men's long drive: Gabe Golden
Closest to the center line: Jay Dunkelman
Closest to the pin (hole 3): Jeff Dietz
Closest to the pin (hole 5): Zach Almont
Closest to the pin (hole 8): Fred Keeler
Closest to the pin (hole 12): Andy Stewart
Closest to the pin (hole 17): Wes Knapp

Team achievements

First-place team, -10 (62): Greg Jacobs, Mike Wayne, Wes Knapp
Second-place team, -9 (63): Raymond Perez, Alan Hermann, Greg Atkinson
Third-place team, -9 (63): David Ehler, Brian Hulse, Vance Manning
Fourth-place team, -8 (64): Wayne Feragen, Wayne (Maddog) Kawamoto, Joe Jackson, Jim Bloomquist
Fifth-place team, -8 (64): Jay Dunkelman, Jeff Martin, Tim Ahn, Greg Young

loss and how to correct them; and provide the fundamentals of critical-parts life management.

The knowledge contained in the notebooks, and that shared by experts during the meeting, provide comprehensive, low-cost training for all those involved in the operation, inspection, and maintenance of aero engines. Electric power generators obviously agree with the value proposition offered by Western Turbine because each year first-timers comprise between one-third and one-half of the user attendees.

Here are some highlights from the short presentations by depot representatives:

- ANZGT's Commercial Manager Mal Waite stressed the company's focus on the LM2500 base model and the LM5000, and safety. He also said Bob Cox was now located in Southern California to help guide business interests.
- IHI's General Manager Takashi Yamamoto told the group the company was very active worldwide, detailing its inspection and maintenance services for LM2500, LM2500+, LM5000, and LM6000 engines at Level 4 shops in Japan and Level 2 shops in the US, Thailand, and Australia.
- MTU representatives discussed the company's package, upgrade, and engine relocation services for all models of LM2500, LM5000, and LM6000 gas turbines. Jay McClaugherty Sr and Paul Zembrodt were the recommended customer contacts at the New Braunfels (Tex) shop.
- TCT's Darcy Simonelli and Dale Goehring focused on the company's safety and in-house training programs. They talked about TCT's three-year run without a lost-time incident as well as no recordables in 2015. Safety observation cards are a cornerstone of the company's program to identify unsafe acts and practices, potential incidents, and other safety concerns. TCT supports a comprehensive three-year training program for about six apprentices recruited annually.

The Axford Report

Mark Axford, the Houston-based consultant considered by many to be the leading independent expert on gas-turbine (GT) markets, predicted at last year's Western Turbine meeting that US orders for GTs would *decrease* by 10% (capacity basis) in 2015 compared to 2014; he also predicted that worldwide orders would *increase* by 10%.

The actual numbers, announced by Axford at the 2016 conference, showed the US market exceeded expectations in 2015 with orders *up* by approximately 6%; worldwide, orders essentially were what the consultant had predicted. The US "fraction of the action" was about one-fifth of the global book.

For 2016, the consultant expects both US and worldwide orders to *decrease* by 10%.

Globally in 2015, GE and Siemens took about 80% of the gas-turbine market. Mitsubishi-Hitachi was a distant third; Alstom received no orders. Egypt played a major role in Siemens' success with 2015 orders for eight combined cycles and seven simple-cycle units totaling nearly 5800 MW of capacity.

Recall that GE benefitted significantly in 2014 from Egypt's order for 20 TM2500s and 14 LM6000s (total of about 3000 MW) and in 2013 from Algeria's order for more than 7500 MW of GT capacity.

Axford breaks out the aero stats for WTUI attendees. In North America, 2015 aero orders totaled more than 3000 MW, he told the group, with 93% of the order book going to GE—half of that for service in the oil and gas industry (horsepower of mechanical-drive units was converted to megawatts for the purposes of this analysis). Worldwide, aero orders in 2015 totaled nearly 8000 MW, up about 1000 MW from a year earlier. GE garnered 67% of the total aero business outside North America.

The LMS100, launched commercially in 2004, had its best year ever in 2015, with 17 orders—including 12 from US utilities and four for Canadian LNG service. Orders for LM6000s—more than 1000 units since 1990—slipped to 14 in 2015, the lowest total since 1992.

Aeros versus frames. The split between aeros and frames has remained relatively constant for the last several years, with the latter capturing 84% to 88% of the business (capacity basis). But aeros remain the clear choice among users of gas turbines rated between 18 and 65 MW, which includes all the LM engines supported by WTUI. Last year, aeros captured more than 70% of the orders in this market segment.

Axford

In North America, frame orders totaled more than 14,000 MW, with more than 5000 MW for Mexico. There was virtually no Canadian activity in 2015. GE booked 50% of the business, Siemens 34%, and Mitsubishi-Hitachi 16%. Three-quarters of the orders were for GTs larger than 175 MW installed in combined cycles.

Simple cycle versus combined cycle. About 55% of the GT capacity ordered last year for the US will be installed in combined cycles, the balance in simple-cycle applications.

Economic climate, observations. Axford closes his annual presentations with a look at economic and market trends. Here are some takeaways from his presentation at the 2016 Western Turbine meeting:

- Don't expect US crude to go above \$60/bbl in 2016.
- LNG exports from the US began in February 2016, with the first shipment going from Cheniere LNG, Lake Charles, La, to Brazil. Five US export terminals are likely to be in service by 2020.

  Projections by experts suggest 6.5 to 8.0 bcf/day of gas eventually will be converted to LNG for export. Estimated impact on the price of domestic gas ranges from 15 to 25 cents/million Btu.
- US assessment: Axford sees America challenged by soft demand and little need for new generation. Utilities are focused on investing in wires and a guaranteed return, he said, while IPPs are hurting in competitive markets. In the oil patch, drilling and service companies are struggling to stay alive. Plus, renewables subsidies are having a huge negative impact on GT orders: the effect of extending wind subsidies through 2021 is the capacity equivalent of 380 LM6000s, while extending solar subsidies through 2021 equates to the loss of an additional 360 LM6000s.
- Europe still is in recession. Power demand is soft and orders for GTs will reflect that in 2016. Germany is retiring nuclear generating stations and adding low-cost coal-fired units—go figure.
- Canada is being clobbered by falling oil prices and currency valued at 76 US cents per Canadian dollar.
- Mexico is a bright spot in North America. Electricity and energy reforms are working and the pace of change is accelerating. Pipelines and powerplants are being built at a historic rate.
- In Asia, LNG prices, linked to crude, are down sharply: \$19 million Btu in 2014, about \$9 today. This will stimulate GT orders. Will Indonesia follow Egypt and Algeria as the next bonanza for gas turbines?
- In Africa, Nigeria has huge potential if the independent power movement is successful.

The SPS Report

CEO Sal DellaVilla and his team of engineers at Charlotte-based Strategic Power Systems Inc (SPS®) have actively participated in Western Turbine meetings since the organization's incorporation—both by taking notes during the user sessions for posting on the user group's website, and by providing benchmarking statistics in support of the LM2500, LM5000, LM6000, and LMS100 fleets.


DellaVilla

At the 26th Annual Meeting, notes were compiled by:

- Olivia Woodlee, for the LM2500 breakout sessions, chaired by John Baker, plant manager, with an assist by Garry Grimwade, both attached to Riverside Public Utilities' Clearwater Cogeneration Facility.
- Karl Maier, for the LM5000 breakouts, chaired by Perry Leslie of Wellhead Services Inc's Yuba City Cogeneration.
- Steven Giaquinto, for the LM6000 track, chaired by Andrew Gundershaug, plant manager of Calpine Corp's Solano Peakers.
- Tripp DellaVilla and Bob Steele, for the LMS100 sessions, chaired by Jason King of the CPV Sentinel Energy Project.

The notes summarize, in chronological order, the user and vendor presentations and discussions that aired during the breakout sessions at the three-day conference. These are accessible to registered users at www.wtui.org. Presentations made by the OEM's representatives are available for review on the GE Portal.

ORAP® update. CEO DellaVilla stressed to the editors that the benchmarking stats so vital to owner/operators hinge on active participation by users in the ORAP program, which allows SPC to aggregate information and provide WTUI members meaningful analytics.

"Our efforts to provide the high-quality information required for decision-making demands automated collection of data from the control system," he said. "We bring this to the attention of owner/operators now because our engineers and analytics team are seeing more and more issues related to the manual submittal of data," the CEO continued.

For example, SPS does not provide any metrics for starting reliability because its experts are concerned that the information submitted to the company regarding starts is increasingly inaccurate and they are not confident in the starting reliability data to provide it as an industry benchmark.

As stated in IEEE Standard 762, the document SPS uses to guide the processing of ORAP data, "a starting failure is an unsuccessful attempt to bring a unit from shutdown to the in-service state within a specified period (which may be different for individual units). Repeated initiations of the starting sequence without accomplishing corrective repairs are counted as a single attempt." Simply, if the unit does not reach breaker closure in a specified period of time, it is considered a failure to start.

"Additionally," DellaVilla said, "we are questioning much of the information reported to us from NERC GADS. We continually see issues in the fidelity of the data as that information relates to causes of downtime and duration. Our engineers have conducted a data-quality comparison referencing one of our long-time customers that recently moved from submitting data directly to us versus submitting NERC GADS data.

"We found NERC GADS data are inherently high-level and do not have the same granularity of detail that ORAP requires. Plus, NERC GADS does not require users to identify component-level root causes to forced-outage events, a detail that creates

Table 1: Key performance indicators developed from ORAP® simple-cycle RAM metrics

Parameter	2015 Aero	2010-2014 Aero
Peaking units:		
Annual service hours	350	356
Annual starts	95	86
Service hours/start	3.7	4.1
Service factor, %	4.0	4.1
Capacity factor, %	4.0	4.2
Availability, %	93.6	91.9
Reliability, %	96.7	96.3
Cycling units:		
Annual service hours	1863	2193
Annual starts	166	162
Service hours/start	11.2	13.5
Service factor, %	21.3	25.0
Capacity factor, %	13.9	17.8
Availability, %	91.8	92.2
Reliability, %	96.6	96.5
Base-load units:		
Annual service hours	7185	6935
Annual starts	48	56
Service hours/start	151.2	124.4
Service factor, %	82.0	79.2
Capacity factor, %	70.6	66.5
Availability, %	93.4	92.8
Reliability, %	97.1	97.4

issues when trying to compare this customer to the rest of the fleet.

"These data also raise concerns with the manufacturer. Periodically, we conduct quality reviews with the OEMs. During these reviews we often are questioned on the accuracy of events that have been submitted from NERC GADS reports. All the issues identified above make it difficult to use NERC GADS data to allow meaningful and accurate comparison with the rest of the fleet in ORAP."

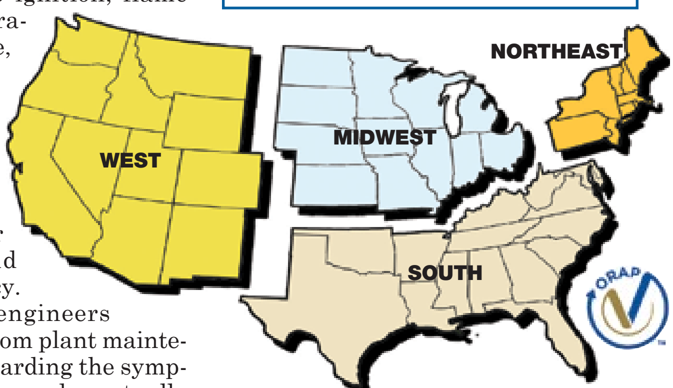
The easiest way to remedy these issues is by use of automated data collection from the control system. By automating the data, the system records each mission, from startup to shutdown—including all major states from signal to start, through the permissives, to ignition, flame established, acceleration, breaker closure, through each change in load state, to shutdown, and then the cool-down period. This is the only way to eliminate human error and ambiguity and ensure data accuracy.

However, SPS engineers still require input from plant maintenance personnel regarding the symptom, corrective action, and eventually

Table 2: Comparing capacity (CF) and reserve standby (RSF) factors regionally

Parameter	2015 Aero	2010-2014 Aero
West:		
CF, %	16.4	23.8
RSF, %	66.1	61.8
Midwest:		
CF, %	9.0	9.1
RSF, %	79.1	77.4
Northeast:		
CF, %	21.3	14.9
RSF, %	65.7	71.5
South:		
CF, %	12.5	15.4
RSF, %	76.4	75.0

Note: West includes Alaska and Hawaii



the root cause of outages to ensure that the full scope of the event is captured correctly. There always will be a human element to this reporting.

That said, SPS has prepared the latest RAM KPIs from ORAP (Table 1). Its engineers have completed an exhaustive review of the data and analyzed it for accuracy. The information compiled in the table comes from 627 aero units for 2015 and 1067 units for the 2010-2014 period. The aeroderivative gas turbines in the sample include engines from GE, P&W, and Siemens AGT (formerly Rolls-Royce) and represent units operating worldwide.

Note that there was very little change in annual operating (service) hours for peaking units from the 2010-2014 period to 2015; availability was up about 1.7% for 2015 and reliability increased slightly. Cycling units operated 330 hours less in 2015 than they averaged in 2010-2014; availability dropped by 0.4% while reliability improved slightly (0.1%). Base-load units operated 250 more hours in 2015 versus 2010-2014 while starts decreased.

The regional analysis in Table 2 shows capacity factor was down by 7.4% in the West, with reserve standby factor in that region up by 4.3%. Another significant change was the 6.4% increase in capacity factor in the Northeast in 2015 compared with the previous five-year period.

WTUI, CCJ to collaborate on

The Western Turbine Users and CCJ will work together to expand the sharing of best practices among owner/operators of GE aero engines.

WTUI Vice President Ed Jackson, plant manager of Missouri River Energy Services' Exira Generating Station in Brayton, Iowa, said the organization's mission is to help members better operate and maintain their plants, and a proactive best practices program would support this objective.


Jackson

First step in the plan is to add a one-hour session on best practices to the Special Presentations portion of the technical program (Tuesday afternoon), beginning in 2017. At WTUI's 26th Annual Meeting in Palm Springs, Jackson encouraged attendee support of the initiative and explained how users can participate and benefit from the experience. Three aero plants were recognized for their best practices this year during the Tuesday luncheon: Waterside, Lawrence, and Worthington. Their best practices are summarized below.

Waterside

Waterside Power LLC, an emergency oil-fired peaking plant located in Stamford, Conn., is equipped with three trailer-mounted TM2500s capable of generating a total of 72 MW. It is owned by FREIF North American Power I LLC and operated by Consolidated Assert Management Services (CAMS) with a staff of three: Plant Manager Bill Jolly and Technicians Colin Cameron and Robbie Nelson.

ISO New England requires this facility to meet the grid's generation requirement within 30 minutes of an electronic or telephone dispatch. Important to note is that ISO-NE recently implemented much stronger penalties for not meeting the 30-min dispatch requirement and for the failure to provide reserve.

The inability of this relatively small project to meet grid needs even one time could jeopardize the plant's future. Thus, the three best practices shared this year by the plant staff focus on reliability improvement through automation, an ongoing initiative. Since the reliability improvements

best practices

were implemented, the plant has maintained a 100% performance factor and an equivalent forced-outage rate demand of zero.

Generator emergency lube-oil (LO) system. As installed, Waterside required considerable manual intervention to operate the plant in accordance with recommended procedures. Example: To monitor and control generator bearing temperature, an operator had to start and stop the emergency LO pump manually when required to maintain a start permissive. The turbines would lose their start permissive when bearing temperatures fell below the required minimum. Loss of the permissive would have had a major negative financial impact on the project.

There was another concern, too. If the system was not monitored closely, the pump would run longer than required, increasing the parasitic power draw and adding to equipment wear and tear.

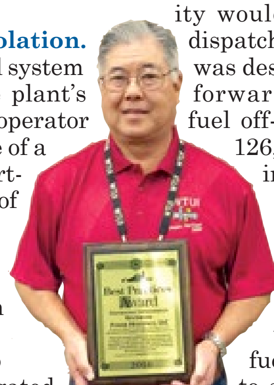
The pump only had to run during peak hours when the plant was in the 30-min reserve mode.

Plant elected to automate the system. The operations team opted to change the logic so when the units were in auto-synch mode (used only during the 30-min reserve periods) the generator lube-oil system would maintain bearing temperature within the manufacturer's specifications. Shutdown was initiated at a predetermined point to conserve wear and tear on the equipment, excess power consumption of AC fans and motors, and excess battery draw on the DC system.

There has not been a loss-of-start-permissive attributed to bearing temperature since commissioning of the automation feature. "Flawless" is the term used to describe the performance of the upgraded system.

Automation of fuel isolation. If a leak occurred in the fuel system provided with each of the plant's TM2500 engines, the shift operator would not have been aware of a malfunction until a fire started or a substantial amount of fuel was lost. Because of the time it would have taken for the operator to respond, a plant shutdown was likely. With capacity and availability critical to success, plant staff investigated ways to reduce this operational risk.

A control system upgrade and the installation of a motor-operated valve on each unit's auxiliary skid reduced the risk of loss of generation and/or equipment caused by fire or a major leak. The system is tied into the HMI and visual status of valve position always is available. The operating system alarm summary/shutdown screen was updated to accommodate the upgrades, which have performed flawlessly and reduced the operator's time away from the control room.



1. Wayne Kawamoto accepts Best Practices Award for Waterside

Fuel building fire protection. The reliability of Waterside's fuel forwarding system was investigated by plant staff. Reason: If system operation were interrupted, the facility would be unable to meet its dispatch requirement. The plant was designed with two 100% fuel forwarding pumps, two 100% fuel off-loading pumps, and two 126,000-gal storage tanks (one in ready reserve).

Personnel had some concerns about their ability to maintain plant reliability at the level demanded by the grid with no fire detection system installed in the fuel pumphouse. Were a fire to start, building and equipment could be lost before first responders got to the site. This would cause a total loss of generation and the ability to make the plant available for future dispatches until a temporary fuel system was in place or the existing fuel building and equipment were replaced.

Also, not having fire-detection capability meant the shift operator would have to leave his or her post periodically to visually confirm there were no issues within the fuel building. Absent the operator from the control room, there was no one to monitor plant performance and insure Waterside was meeting desired dispatch parameters.

Waterside installed a cross-zone thermal fire detection system and provided indication of system status to the local control room at each TM2500 as well as the main control room. Cross-zoning of the thermal detection system assures the plant's fuel system would not trip from the loss of a single signal, or the failure of a single detection device, while still providing adequate system/plant protection in the event of an actual fire.

When both zones are activated, the system shuts down the turbines and helps isolate all potential fuel sources—including the fuel forwarding pumps that otherwise would continue to feed the fire.

Real-time monitoring of the fuel building by the fire detection system has reduced the amount of time the operator must be away from the control room to monitor the system locally. Immediate indication of an abnormal thermal condition in the fuel building also reduces significantly the chances of a total system loss in the unlikely event of an actual fire.

2. Lawrence Generating Station is equipped with six gas-fired LM6000s

WTUI Treasurer Wayne Kawamoto, plant manager of Corona Cogeneration Plant, accepted the 2016 Best Practices Award for Waterside (Fig 1).

Lawrence

During annual inspections of the generator line-side cubicle, Lawrence Generating Station (Fig 2) personnel occasionally found corrosion, with minor evidence of moisture intrusion. Staff inspected and replaced door gaskets as necessary, but snow accumulates on top of the cubicle during winter and the melt-off leaked into the interior, as indicated by water stains. Concern was that with an increase in wintertime dispatches, additional protection was required to guard against corrosion and potential arcing failures.

After evaluating the risks, Lead O&M Technician Matt O'Hara, O/M-ICE Tech Robert Bauman, and O&M Tech Jared Thomas collaborated to identify an effective way for preventing

3. "Top hat" design prevents snow accumulation and water from entering the generator line-side cubicle

4. Matt O'Hara is all smiles accepting the Best Practices Awards for sister plants Lawrence and Worthington

5. Aerial photo of Worthington's four LM6000 peakers also shows location of the glycol storage tank and vault

snow accumulation on the cubicle and water intrusion. The "top hat" design made by a local metal fabricator was the solution (Fig 3). O'Hara accepted the awards for both Lawrence and Worthington (Fig 4).

Since the top hats were installed, inspections have revealed no evidence of water intrusion; the tops of the cubicles are dry and snow-free. The additional protection will extend component life and prevent a possible catastrophic failure caused by arc flash.

Lawrence is an LM6000-powered, 258-MW, 6 × 0 gas-fired peaking station located in Lawrence County, Ind, co-owned by Hoosier Energy (four units) and Wabash Valley Power Assn (two units). Robert VanDenburgh manages the facility for NAES Corp, the contract operator.

Worthington

Safer, faster chiller winterization

Hoosier Energy's 174-MW Worthington Generating Station (Fig 5), a 4 × 0 gas-fired peaking station powered by inlet-chiller-equipped LM6000s, was designed to operate from April through October and later modified for year-round peaking power. Wintertime operation required lay-up of the chillers, plus freeze protection of the chilled-water system by use of a glycol/water mixture and an auxiliary boiler.

Each spring and fall, Worthington personnel had to change out the glycol solution for summer and winter operations, respectively. In winter, the fluid contains 35% glycol, in summer less than 10%. The following procedure had been used since the plant went commercial:

1. Drain chilled-water/glycol loop into the glycol tank using the educator. This removes about 30,000 gal, but leaves about 12,000 gal in the system which has to be drained manually using a sandpiper (low flow rate; constant supervision required) and totes.
2. Load a 1000-gal poly tank on a trailer and move it to the vault using a forklift.
3. Connect a 2-in.-diam hose to the supply riser at the vault and pump glycol into the poly tank unit it's full.
4. Load hoses and sandpiper onto the trailer and drive the fully loaded poly tank to the 50,000-gal glycol tank.
5. Remove the sandpiper and hoses. Connect a hose to the bottom of the poly tank at one end and to the glycol tank at the other end.
6. Pump glycol from the poly tank into the glycol tank using the sandpiper.
7. Load hoses and sandpiper into the trailer and drive the empty poly tank back to the vault.
8. Repeat steps 2-7 as necessary. Task can take up to four days using three operators 12 hours per day.

6. New eductor isolation valve

7. Glycol fill line

Several problems were identified with this procedure, including these:

- Safety and environmental concerns associated with moving the loaded totes.
- Excessive overtime payments.
- Restrictions on plant operations during the transition.

Plant had to streamline the transfer process to eliminate these issues.

Worthington staff—specifically Plant Manager Robert VanDenburgh, Lead O&M Tech Matthew O'Hara, O&M Tech Bruce Button, and O&M/IC&E Tech Jason Robertson—collaborated and developed a new procedure requiring a few plant modifications, including elimination of the low-flow sandpiper. The following physical changes were made to the system:

- A valve was added to isolate the eductor (Fig 6).
- A tee was installed in the supply riser line with an isolation valve and fittings (Fig 7) to connect to a transfer pump.
- A properly sized, skid-mounted transfer pump was installed to replace the sandpiper (Fig 8).

8. New skid-mounted transfer pump

When the improved system was commissioned, the following new procedure was implemented:

1. Drain the glycol/water solution into the glycol tank using the eductor.
2. Connect a 2-in. hose (about 15 ft required) from the supply riser to the new 2-in. connection at the eductor station.
3. Isolate the eductor using the new isolation valve shown in Fig 6.
4. Pump glycol from the riser to the glycol tank using the new skid-mounted pump and existing eductor piping until the system is empty.

The bottom line: Two operators can perform the new procedure in only about eight hours (total of 16 man-hours), meaning the plant can be restored to full operation in a single shift instead of the four full days it used to take (144 man-hours, 40% of that at the overtime rate). The new procedure completely eliminates the safety and environmental hazards associated with the old one. CCJ

Gray market GT successfully 'emigrates' from US to Canada

John MacIsaac, president, Newfoundland & Labrador Hydro, a subsidiary of Nalcor Energy, had only good things to say about ProEnergy Services LLC's (Sedalia, Mo) handling of a fast-track project to get a 120-MW gray market gas turbine/generator from the US up and running within eight months at the utility's Holyrood Generating Station, Newfoundland, Canada. The biggest challenge, he said, was "mapping the installation and permits across all applicable Canadian standards and labor requirements."

The fuel-oil-fired Siemens 501D5A machine is producing 130 MW, better than the guaranteed ISO rating of 122 MW, and has met or exceeded expectations for uptime, availability (>95%), and emissions compliance. MacIsaac further lauds ProEnergy for coming within two weeks of the original eight-month schedule and within 8% of the project budget.

"They had to commission the unit through the Christmas holidays," he noted. Projects like this one normally take 18-24 months.

While the turbine itself is capable of firing either natural gas or fuel oil or both, it was originally built for natural gas. ProEnergy modified the unit for No. 2 oil, including the water injection system for NO_x control, before it was shipped from the warehouse where it had been stored and maintained for five years according to OEM recommendations.

Along with installation of the GT, ProEnergy, acting as EPC, provided a fully enclosed facility, water treatment equipment, water storage, redundant black-start capability, grid interconnection, road work, step-up transformer, ventilation, fire protection, and SCADA interconnection.

"The original intention was that the unit would serve as a peaker," MacIsaac said, "but it's logged more hours supporting generation with ancillary services. We moved through the targeted annual operating hours [less than 500] by the end of November 2015."

The aggressive schedule was motivated by customer service interruptions suffered in the utility's service territory the previous winter because of a severe stretch of frigid weather.

MacIsaac concluded by stating, "we did the right preliminary work, we developed a good plan and constantly measured daily against the plan, we solved issues in real time, and we benefitted from solid teamwork among ProEnergy, its Newfoundland subcontractors, and our in-house staff."

Pinning of GT vanes prevents shim migration, fretting wear

Rodger Anderson of DRS-Power Technology Inc, a former GE engineer with F-class compressor design experience, was approached by several 7F Users Group attendees at the 25th anniversary meeting (May 2016) seeking details on "reported" failures associated with the pinning solution he developed to prevent both shim migration and severe fretting wear on compressor vanes.

A surprised Anderson sat down with the editors to review his success story. He said vane pinning has been ongoing for 14 years with over 100,000 vanes pinned in more than 200 gas turbines. Total operating hours of pinned vanes exceeds 5 million. To date, he continued, there have been no vane failures attributed to pinning that he knows of. He did recall a failure of *one* pinned vane a long time ago, but there were other contributing factors.

A year or so into Anderson's pinning program a couple of pins—not vanes—fractured. Failure analysis revealed high stress as the cause. The pin design was changed to reduce the stress level and the number of pins was doubled. No problems have been reported since that solution was implemented more than a decade ago.

Anderson pointed out that if a pin were to fracture, the consequences would be minimal. Any pin fragments would be contained, not liberated into the flow stream. The pin would have done its job of protecting the vane hook fit from severe wear. The vane would continue operating just as the OEM designed it, he said.

UDI directories, databases provide latest generation-market intelligence

Chris Bergesen, editorial director for UDI products at S&P Global's Platts (formerly McGraw-Hill Inc), called to say the 2016 edition of the respected publishing group's *Who's Who at Electric Power Plants* has been released. Often thought of as the industry bible for those doing business at generating stations in the US and Canada, the "yellow book" contains more than 750 pages of information on nearly 4700 generating facilities of all types.

Data published in the authoritative directory are gathered from thousands of direct surveys, annual reports, websites, and other industry and government sources, and compiled into corporate and powerplant site profiles for easy access and use. Details and sample pages are available online at www.platts.com/udi-data-directories.

Don't want paper? An enhanced PDF directory is available on a CD. Bookmark and indexed links supplement standard Adobe search functions allowing easy access to the directory's plant design and contact information. A look-up spreadsheet can be filtered to identify plant sector, fuel, technology, and capacity targets.

Want more than the US and Canada? Subscribe to UDI's *World Electric Power Plants Database,* updated quarterly. It contains design specifications for more than 200,000 generating units (at nearly 100,000 plants) of all sizes, technologies, and fuels owned and/or operated by regulated utilities, independent power producers, and industrial firms in more than 230 countries.

Thank you, Pat Myers

Myers

An email arrived from Pat Myers at the end of April to say he was retiring from AEP. The Ceredo Generating Station manager is taking a "work break to have some R&R"—at least for the remainder of this year. Myers gets a big "thank you" from the editors for his unselfish sharing of information of great value to gas-turbine owner/operators—the 7EA users in particular. He deserves industry recognition for spearheading the drive for a solution to the clashing problem that dogged the 7EA fleet for years.

Myers was recognized by the Combined Cycle Users Group in 2013 with the organization's Individual Achievement Award. The citation below was written at that time.

"Pat Myers' career contributions to American Electric Power (AEP) and the Ceredo Generating Station that he manages are believed "immeasurable" by colleagues. Like many in the industry, Myers is a mechanical engi-

neer who got his start at the General Electric Co as a field engineer. Later, he spent a couple of decades with the Columbia Gas Transmission Co before transitioning to AEP.

"Following a series of relatively recent natural-gas explosions that caused deaths and considerable loss of property, Myers was appointed chair of an AEP internal team that designed and implemented venting and purging procedures for that fuel. This work earned Myers industry recognition and speaking assignments and his company a top Best Practices Award from the Combined Cycle Journal.

"Myers has been the de facto leader of the 7EA Users Group steering committee for several years. This organization, which covers 7B-E models, as well as 7EAs, has benefitted considerably from his willingness to share knowledge and experience.

Training on generators, transformers, large motors

Izzy Kerszenbaum, PhD, PE, well respected among electric utilities for his in-depth knowledge of things electrical, and for his ability to explain complex theory in common language, offers several training seminars annually of value to generating plant personnel. These include the following:

- Design, operation, and maintenance of large turbo-generators.
- Operation, maintenance, testing, and monitoring of large power transformers.
- Operation, monitoring, and protection of electric generators.
- Fundamentals of electric motors and diesel/generators.

Visit www.izzytech.com for details.

Mega-Watt Consulting LLC opens its doors

Derek King, looking 10 years younger after retiring from Brush Electrical Machines Ltd at the end of last year, was at the Western Turbine Users' 2016 conference to introduce his new company, Houston-based Mega-Watt Consulting LLC (www.mega-wattconsulting.com), to attendees requiring guidance on the servicing and upgrade of their generators. King is best known by owner/operators for his work in managing the US service business for Brush.

SPS introduces portal for reliability benchmarking, analytics

The ORAP® Analytics Portal, a real-time business intelligence platform, is introduced by SPS (Strategic Power Systems Inc). CEO Sal DellaVilla told the editors, "This portal provides each of our customers with an Internet-based solution that revolutionizes the way ORAP delivers key data metrics to support business decision-making needs."

Customers now have the ability to both visualize the performance data for their plant in near real time and can customize it to the specific needs of their respective organizations. The portal allows for relevant "peer group" selection, enabling customers to benchmark their

DellaVilla

1. Harry Allen Generating Station building an impressive safety record

assets against the selected group. Plus, analytics that show total plant KPIs, including combined cycle and other multi-unit configurations, are now available. Visit www.spsinc.com and click on the video link to learn more.

Enviable stats from Harry Allen Generating Station

The leadership and O&M teams at NV Energy's Harry Allen Generating Station (Fig 1) embrace safety and reliability with purpose and pride as evidenced by the following statistics:

- No lost-time accidents since commissioning June 1, 2011.
- No OSHA recordables since July 25, 2013—more than 1000 days.
- A 433-consecutive-day run without a power-block outage, which was interrupted for a day by a transformer safety concern.

Mitsubishi Hitachi Power Systems update

- Orders for the company's 44th and 45th J-series gas turbines (19 in commercial operation), rated 327 MW each, are received from Iberdrola SA as part of the 890-MW 2 × 1 Noroeste combined cycle expected in service 2019. CFE (Mexico's state-owned utility) awarded Iberdrola a 25-yr power purchase agreement to build, own, and operate the facility in Los Mochis, Sinaloa state.
- Earlier, two 501Js were ordered by Tenaska Pennsylvania Partners LLC as part of a 2 × 1 combined cycle being built in South Huntington Twp (Westmoreland County). Award includes a long-term service agreement.
- NTE Energy, St. Augustine, Fla, orders a M501GAC gas turbine as part of a 475-MW 1 × 1 combined cycle scheduled for service in Cleveland County, NC, in 2018.
- Paul F Browning is appointed president and CEO of MHPSA with the retirement of Dave Walsh, who had been with the organization since its formation in 2001 with six employees. That number has grown to more than 2000 today. Browning has deep executive experience with Irving Oil Co, GE, Solar Turbines, and Caterpillar Corp.
- The first US-manufactured 501J shipped from the company's Savannah Machinery Works to GRDA's Grand River Energy Center in late January to replace a coal-fired unit. It is scheduled for commercial operation in 2017.

2. Siemens had orders for 76 SGT-8000H gas turbines by March; 19 were in operation

Siemens update

- Panda Power Funds awards Siemens a 23-year maintenance agreement for its Panda Hummel Station, a 1124-MW 3 × 1 F-class combined cycle powerplant under construction in Pennsylvania. All 15 Siemens gas turbines (11 F-class, four H) ordered by Panda since 2012 have LTSAs in place with the OEM.
- The company's Berlin gas-turbine factory ships its 1000th engine, a SGT5-4000F (V94.3A), to Qatar, where the 300-MW unit will be installed in the Umm Al Houl combined-cycle plant. The 1000 GTs were purchased by customers in 65 countries over a period of 44 years.
- Saudi Aramco announces that its "In-Kingdom Total Value Add" program to localize the energy value chain with respect to manufacturing and service, train and employ young Saudi nationals, and foster future prosperity in the country has achieved a major milestone with the production of the first gas turbine at Siemens' Dammam Energy Hub. The unit will be installed at Saudi Aramco's Jazan refinery.
- Siemens Power Generation Services Div, headed by CEO Randy Zwirn, unveils its Digital Services for Energy product, powered by Sinalytics, at Germany's Hannover Fair. The intelligent knowledge system combines "Big Data" with the company's comprehensive domain expertise to support customers.
- Clean Energy Future selects Siemens as the turnkey supplier for its 940-MW 2 × 1 SCC6-8000H Flex-Plant™ in Ohio to support renewables integration.
- The company reports its fleet of 19 operating H-class gas turbines passed the 200,000-hr mark in January (Fig 2). Siemens had sold a total of 76 SGT-8000H machines by March—including 39 for 50-Hz service, 24 of those for three projects in Egypt. The first commercial H engine entered commercial operation in 2011 in Irsching, Germany. Three units for the 60-Hz market were sold to Florida Power & Light Co for its Cape Canaveral Energy Center in 2013.
- In other news, more mundane F-class gas turbines have been purchased for the St. Joseph Energy Center in Indiana as part of its 670-MW 2 × 1 combined cycle. . .Peru's Termochilca SA hires Siemens to upgrade its simple-cycle Santo Domingo de los Olleros plant to combined cycle by addition of an SST-900 steamer. . .Holland (Mich) Board of Public Works orders low- and medium-voltage equipment and transformers for its new Holland Energy Park combined cycle previously ordered from the company. . .Stadtwerke Duesseldorf AG reports its 1 × 1 Lausward combined cycle achieves 604 MW (net electrical output) and a world-record 61.5% efficiency during preliminary testing.

Briefs

GE Power agrees to acquire the heat-recovery steam generator business of Doosan Engineering & Construction to help accommodate the growing demand for its combined cycles.

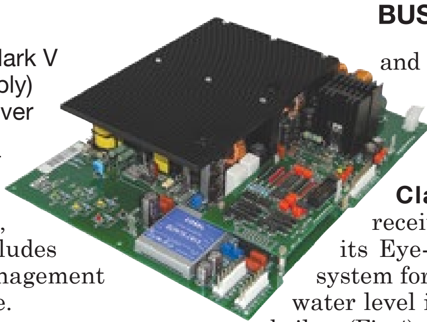
J-Power USA selects NAES Corp to operate four Long Island (NY) generating plants: Edgewood Energy LLC, Equus Power I LP, Pinelawn Power LLC, and Shoreham Energy LLC.

Chromalloy opens a state-of-the-art coating line in its Tilburg (Netherlands) facility to provide GT manufacturers and operators it's A-12 aluminum diffusion coating for protecting turbine components against corrosion and oxidation.

ProEnergy Services LLC announces the award of five-year O&M contracts for the simple-cycle peaking plants Rocky Road Power, Elgin Energy Center, Gibson City Energy Center, and Shelby County Energy Center by affiliates of Rockland Capital LLC. ProEnergy will provide site management, planning, scheduling, and maintenance services. The company also was selected by Prairie Power Inc as the EPC contractor for a turnkey 42-MW LM6000PC addition to its Alsey Generation Station.

Ludeca Inc announces partnerships with Easy-Laser, a Swedish manufacturer, to promote and sell the next generation of laser systems for industry, and with SDT Ultrasound Solutions to offer products for leak and fault detection and optimized bearing lubrication.

ATCO Emissions Management renames itself Innova Global Ltd, a roll-up that includes ATCO Noise Management and Higgott-Kane.



3. GTC rates its Mark V TCPS (power supply) an improvement over the OEM's

GTC introduces an "improved" Mark V TCPS (power supply), which it says offers better performance, high reliability, and longer life than the OEM's original card (Fig 3). For more information, visit www.gasturbinecontrols.com.

Emerson Process Management completes a combined-cycle optimization project that delivers operational improvements and reduces fuel use—specifically, a 67% reduction in average 2 × 1 hot-start fuel consumption. Additionally, average transition energy consumption—the fuel used to bring another GT/HRSG train online and blend it with the running units—is reduced by 31%.

MTU Maintenance announces Statoil, the Norwegian oil and gas company, has extended its maintenance/repair/overhaul contract for GE LM industrial gas turbines for another seven years. The Statoil fleet includes LM2500, LM2500+, and LM6000 engines. The agreement also covers onsite services and spare parts.

Clark-Reliance Corp receives a US patent for its Eye-Hye® SmartLevel™ system for remote indication of water level in power and process boilers (Fig 4). The patent recognizes the uniqueness of the system's self-diagnostic technology, which monitors the condition of its sensing probes required to maintain system accuracy. When probe cleaning is necessary to maintain reliability of level indication, the device notifies the control room.

4. Eye-Hye® SmartLevel™ monitors the condition of its sensing probes required to maintain system accuracy and reports any issues identified to the control room

Continued from p 3

of the Generator Users Group, doing the lion's share of the work. This spring he presented, once again, at the International Conference of Doble Clients, driving from his Schenectady office to Boston. Some readers might ask, "What's the point?" Here's Tony Bennett's thinking on the matter:

"Let me tell you about retirement. All of my friends who retired are dead. I don't care what you do, you have to keep busy."

Clyde Maughan's career achievements as an engineer, mentor, and colleague are recognized at the ASME Power Division meeting in Boston, July 31, 2013. Maughan presented at the conference on stator-winding ground protection

The Combined Cycle Users Group recognizes Clyde Maughan for his lifetime contributions to the industry with its 2013 Individual Achievement Award

The Generator Users Group introduces the annual Maughan Award with its presentation by Chairman Kent Smith of Duke Energy to Clyde Maughan at the organization's first meeting in Las Vegas

Below, some of Maughan's long-time industry colleagues provide a few thoughts about the man you might not be fortunate enough to know:

"Clyde is an inspiration to us all. His tireless promotion of the IGTC for the benefit of the international generator technical community is one example and one of the reasons for the global forum's success as indicated by its current membership of 3400. In Clyde's six-year membership, he has served as moderator and made over 400 technical contributions, as well as donated and made accessible, free-of-charge, many publications and books."

Bill Moore, *National Electric Coil*

"Happy 90, Clyde. Congratulations on this great milestone. You have been a technical guiding light for many of us in the large turbine/generator business for years. You taught countless engineers about the most complex and elusive issues related to these machines. I wish you many more years of health and continuing contribution to our industry."

Izzy Kerszenbaum, PhD, PE, FIEEE, *IzzyTech LLC*

"I have worked with Clyde and various of his clients on several root-cause analyses. He is consistent:

- He pulls the group to come together and get to the best technical outcome possible.
- He forms detailed, logical conclusions from the facts, and from his large bank of experience.
- He never misses an opportunity to educate.
- He asks the right questions; and understands the answers.
- He is a force for good in the industry.

Neil Kilpatrick, *Siemens*

"Clyde presented a short IEEE paper in 1970 on the application of ac high-potential testing and stator life prediction. We (I was working for a major utility at the time) took this idea and expanded it to the application of 2E+1, the test value for a new machine winding, to predict the remaining service life of vintage generators. The 2E+1 overpotential test was applied to dozens of stators, ranging from 35 to 55 years of service at the time they were tested. Up to now, 25 years later, none of the 18 generators that passed the test have failed. The bottom line: Clyde was correct in predicting the remaining service life of large generators through a simple test. To my knowledge, he was the only one to do it."

J E Timperley, PE, FIEEE, *Doble Engineering Co*

"When I first met Clyde in the 1980s, he was recently retired from GE. By standard units of measure, I was young/he was old. Now we're both old—by all units of measure. Looking back, whenever there's been an issue to be resolved, Clyde has been like a dog with a rag. Never lets it go. And when it comes to finding the facts, he's like Deputy Dawg. No rock goes unturned.

"Scouring the planet like a bar of soap, Clyde has accumulated a vast library of failures and fixes that he's shared for the good of all. Invaluable. Although we've suffered through a few lumps from butting heads (Clyde has a really hard head), I feel blessed for the years we've worked together. That's the kind of stuff ya can't buy.

"Thanks Clyde. Have a great 90th and another 90 to go with it. You da man!"

Mike Bresney, *AGT Services Inc*

"I first saw Clyde when he gave a presentation on generator maintenance. It was clear that he was extremely competent and eager to share his knowledge. He had a calm, friendly confidence paired with a good sense of humor. Several years later I worked with him on a publication and quickly realized he also was a warm and generous person. Anyone who has met Clyde knows what I'm talking about.

Mathias Svoboda, *SvoBaTech Inc*

"While I have known of Clyde's many contributions to the electric power industry some 40 years, I have only had the pleasure of working with him over the past 12. He has been a kind, patient, and supportive mentor with apparently boundless energy. Clyde has been so dedicated that over his nearly 70-year career, he has gotten to train at least two generations of engineers who follow in his footsteps with awe and admiration of his depth and breadth of knowledge. I have worked with Clyde on generator problems in adverse conditions over all hours of the day and night and he has always displayed a contagious enthusiasm for what he does. I am honored to call him a friend."

John A Demcko, PE, *Arizona Public Service Co*

"Clyde Maughan has done what many of us hope to do: Find significant and meaningful life after 'retirement.' He did it in a way that has included the donation of a generous portion of his time to ensure that the next generations of engineers in our industry would benefit from the knowledge he's been carrying around in his head for more than 65 years.

"And he has provided us all with an example of what it means to be a mentor, through his leadership in the IGTC Generator Forum as well as by his participation in the Generator Users Group, EPRI, and many other industry conferences over the years. With these examples, he challenges the next generation of the "brain trust" for generator knowledge to continue this mentoring.

"As IGTC webmaster, I often receive comments from the group's members. These comments inevitably include the recollections of meeting Clyde at an industry conference, the gracious impression he made on them, and the usefulness of the technical information he imparted. As a capstone for an illustrious career, who could ask for more?"

Jane Hutt, *International Generator Technical Community*

"Since first meeting him, I have been impressed by Clyde's selfless commitment to the power generation industry. Anytime he encounters an issue affecting generator reliability, Clyde investigates it thoroughly through a diverse variety of contacts, often writing papers to share his findings with the entire industry and making it a point to expose the issues to as many groups as he can.

"I first met Clyde on a case involving a legal issue and learned from that experience, while he would sometimes take a legal case, Clyde much preferred to take jobs where he could train people on how to better operate and maintain their generators. When he is not training engineers as part of a customer contract, we often find Clyde educating customers in public forums. His relentless investigation, and generous publication and presentation of findings, certainly have contributed to more reliable power systems."

Jim Lau, *Siemens*

"Although it is nice to be young, it is not a small achievement to get old. Clyde definitely managed to become the oldest person I know, but he has achieved much more: He became the best teacher in our industry, always willing to share his immense knowledge. Happy birthday, Clyde."

Mladen Sasic, *Qualitrol Corp*

"Clyde Maughan turning 90, and still active as a generator expert! The world benefits from his knowledge and his well-known willingness to share it. Most of us were not even born when he started working at GE. He is a person of amazing dedication to generator technology. He is a star."

Greg Stone, *Iris Power LP*

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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.

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

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AECOM

Power Business Unit specializes in single-point management for grassroots, retrofit, and expansion projects for power industry clients, having engineered and/or constructed more than 280,000 MW of electricity worldwide.

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.

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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.

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Experienced provider of noncorrosive and nonabrasive cleaning services for all types of power generation equipment with no secondary contamination, significant reduction in downtime. Available nationwide, 24/7, using OSHA-trained techs, and registered with ISNetworld and Browz.

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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.

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

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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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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.

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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.

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DEKOMTE de Temple

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

ECT

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.

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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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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.

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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

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Leading independent manufacturer of high-voltage generator stator windings with expertise in design and manufacturing of stator windings for any size, make, or type of generator. This includes diamond coils, Roebel bars—including direct cooled, inner-gas, and inner-liquid cooled bars—and wave windings.

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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.

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Reduce costs and optimize performance with the world's leading diversified OEM of motion, flow, process control, filtration, and sealing technologies, providing precision engineered solutions for the power generation market.

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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.

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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.

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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.

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

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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.

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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.

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.

TEServices

Superior metallurgical experience in managing components, creating repair and bid specifications, selecting the repair and coating vendor, and verifying them during the refurbishment of critical IGT components when your company does not have the resources available.

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.