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# Power Industry Market Analysis Seminar

**Presented by Combined Cycle Journal, CCJ ONline, and GRiD Today**
**Featured speaker and discussion leader: Jason Makansi, president, Pearl Street**

**February 21, 2017 • Reno, Nevada**
**(The morning after the 501F Vendor Fair)**

## Schedule

8:00 Continental breakfast

8:30 – 11:30 Main presentation (with a short break at 10:00)

11:30 – 12:30 Box lunch and extended Q&A and discussion

12:30 Adjourn

## Registration

The fee for this event is $350. To register, please visit http://www.ccj-online.com/ccj-marketing-seminar or simply scan the QR code with your smartphone or tablet. Contact Bob Schwieger, bob@ccj-online.com or 702-869-4739, with any questions.

## Mission

Provide a necessary dose of market reality to help you develop realistic tactical and strategic sales and marketing plans.

## Description

The power industry is undergoing gut-wrenching transformation. Economic growth has been tepid at best; therefore, electricity demand has been weak or negative. Coal is receding. Nuclear is threatened. Baseload generation is undervalued. Gas is as inexpensive as it's been in recent memory. And the forward price curve probably hasn't been this favorable over your entire career. Environmental restrictions are like throwing more proverbial straw on the camel's back. After being a topic of discussion for a decade, the "brain drain" has become hard reality. Variable renewable generation wins in political mindshare.

Grid participation is dynamic—rattled minute to minute by intermittent wind and solar; ancillary services, balancing and day-ahead markets; baseload unit retirements, and many other factors. Some gas-fired combined cycles have had more than five owner names on the shingle over the last 10-15 years. Peaking gas turbines are running in intermediate load. Intermediate load units are running baseload. Some supercritical coal units cycle from min to max load every hour to fill in around renewables.

And in the shadow of all of these clearly visible trends is the most potent market driver of all— value and opportunity are moving downstream, away from large power generation facilities and long transmission lines and towards the distribution end of the grid. Distributed energy, microgrids, off-grid/on-site systems, net metering, behind the meter, local electricity storage, rooftop PV, and even fuel cell appliances all are vying for a share of what some call the "transactional" grid.

## Seminar leader

Jason Makansi is a regular contributor to Combined Cycle Journal and is chairman of the Editorial Advisory Board for CCJ's sister publication, GRiD Today.

He has been guiding clients serving the electric power industry for 15 years. His career spans almost 40 years, beginning with engineering positions at the Tennessee Valley Authority and at a major East Coast refinery, through his 18-year tenure at Power magazine, the last six as editor-in-chief. He has published three industry professional books—including Lights Out: The Electricity Crisis and The Global Economy and What It Means To You (John Wiley, 2007), which was favorably reviewed by major media outlets across the country, including The Wall Street Journal and Boston Globe.

An engaging speaker, Makansi has keynoted several major industry events—including, the annual conferences of a major electric cooperative, the Electric Power Conference, ISA Power Industry Symposium, CCJ's Integrating Renewables conference (2011), and an annual meeting of the National Rural Electric Cooperative Association. Plus, he has presented at numerous user-group meetings on control systems, diagnostics, prognostics, and other digital transformation technologies.

CCJ COMBINED CYCLE Journal

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# Low-load impacts, solutions for HRSGs, SCRs

**Combined Cycle Users Group**
**2016 Conference Report**



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Heat-recovery steam generators (HRSGs) and the associated selective catalytic reduction (SCR) units often take a back seat to gas and steam turbines at combined-cycle facilities. That was not the case at the Combined Cycle Users Group (CCUG, www.ccusers.org) conference in San Antonio, Aug 22-25, 2016.

Several users shared their experiences on HRSG and SCR O&M issues arising from cycling and low-load operation. Vendor and consultant experts added to the general bank of knowledge around performance, diagnostics, condition assessments, and engineering solutions. Registered users can access these informative presentations on the PowerUsers website at www.powerusers.org.

## What price low-load operation?

Not surprisingly, the need to address performance issues during cycling, low-load, and start/stop operating regimes dominated mind share at the conference. After all, being flexible, adaptable, and resilient are the watchwords in the industry today.

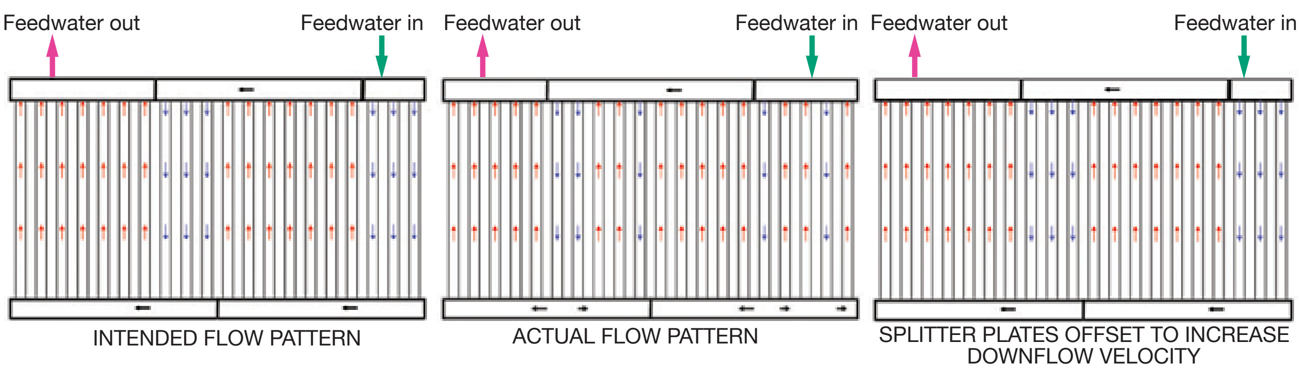
Bryan Craig, PE, HRST Inc's director of engineering, reviewed the following HRSG risks during low-load operation:

- Economizer flow instability.
- High superheater and reheater metal temperatures.
- Partial operation of 2 × 1, 3 × 1, and 4 × 1 plants—that is, when not all of the gas-turbine (GT)/HRSG strings are in operation.
- Attemperator overspray.
- Catalyst temperature.
- Oxidation of non-pressure-part components.

With respect to the first risk, the example Craig cited was compelling: An HRSG unit of a 2 × 1 facility operated 18 years at baseload (down to 60% GT capacity) with no economizer tube leaks, then experienced multiple tube leaks after three years of cyclic operation during which the unit was frequently turned down to 45% of GT capacity.

What happens under these conditions is called buoyancy instability—when the downward velocity (most panel-type economizers have a few tubes with downward flow) is too low, and buoyancy of warm water causes flow instability, reducing heat transfer.

Stagnant and reverse-flow tubes become hotter than neighboring tubes, leading to tube thermal stress. Perhaps the greatest consequence is that




**1. Economizer panels** may not behave as designers intended during operation because of buoyancy instability. Sometimes a fix is easy, such as moving one or more splitter plates, but usually not

leaks can occur at tube-to-header welds which are difficult to access for field repair.

Possible solutions include eliminating the down-flow tubes, increasing flow velocities, or reducing stress at weak areas. To increase velocities, the economizer splitter plates can be repositioned to achieve more down flow than up flow, but this also increases risk of flow accelerated corrosion (FAC) unless done properly (Fig 1).

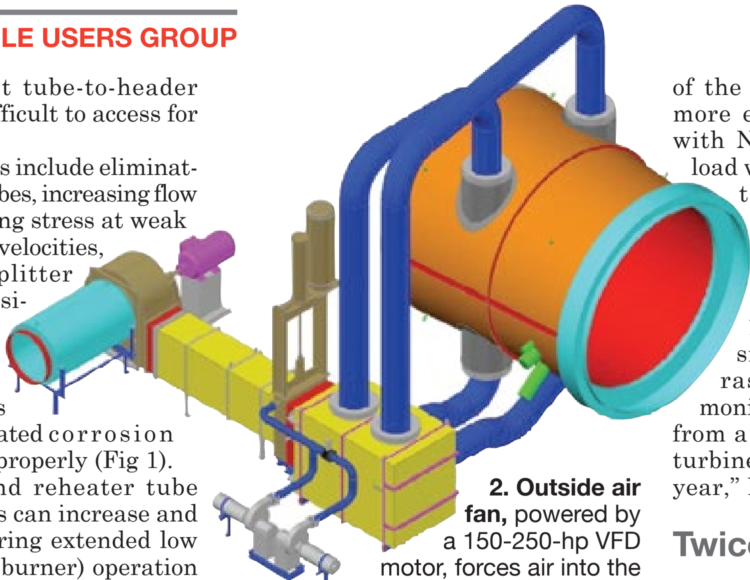
Superheater and reheater tube metal temperatures can increase and cause problems during extended low load, unfired (duct burner) operation (when temperatures in the first HRSG module are often at their highest) and when the GT is operating at low load. In the latter situation, the exhaust temperature for many GTs is at its highest. Because the attemperator is keeping the steam temperature constant inside the tube, the differential between outer and inner surface temperatures increases as GT exhaust gas temperature increases.

This creates what Craig called a "vicious cycle" inside the tube. Internal oxide growth increases, slowing heat transfer further, and increasing tube temperatures more. High metal temperatures reduce creep strength; reduced wall thickness increases tube stress. Combined, they can shorten tube life considerably.

When you add the attemperation effects, the problem gets complex in a hurry. HRST has solved problems like these through a combination of superheater and reheater tube shields and/or installation of its trademarked Quenchmaster air attemperation system (Fig 2). However, the potential impact on performance (heat rate, capacity) should be considered.

Steam separation in the HRSG steam drum is aggravated with one or more GTs *not* running in a multi-GT facility. The steam turbine is a constant volume machine, notes Craig, so running one unit of a 2 × 1 plant approximately doubles the velocity through the steam separator, and running one unit of a 4 ×1 plant about quadruples it (if the steam turbine isn't throttled back).

Steam separation equipment must be designed for the worst-case conditions. If not, reheater drains and cold-reheat piping should have automated condensate detection and removal; reheaters of offline HRSGs should be equipped for isolation; and the units should be assessed for uneven cold reheat flow distribution which can lead to high metal temperatures in units receiving less flow.



**2. Outside air fan,** powered by a 150-250-hp VFD motor, forces air into the GT exhaust stream just ahead of the HRSG inlet duct via four nominal 24-in.-diam pipes. Small fans supply sealing air to the damper

## Ecomax™ for HRSGs

EthosEnergy Group's Bill Barras and Chris Chandler discussed how the popular tuning system for GTs is being expanded to include HRSG optimization. Chandler, whom Barras described as the person who "built" Ecomax, said, "this product is for HRSGs with attemperation problems." Essence of the new capability: The software "integrates HRSG pinch points, relative to tuning, directly within the control of the gas turbine fuel/air ratios."

Ecomax is a software tool which optimizes performance in real time, rather than at one or two discrete periods during the year. Among other things, it allows a unit to be "self-tuned" after a combustor, hot-gas-path, or major inspection. Barras reminded the audience that the software is not model-based; it uses live real-time data. It pursues one theme at a time—for example, minimum $NO_x$ emissions.

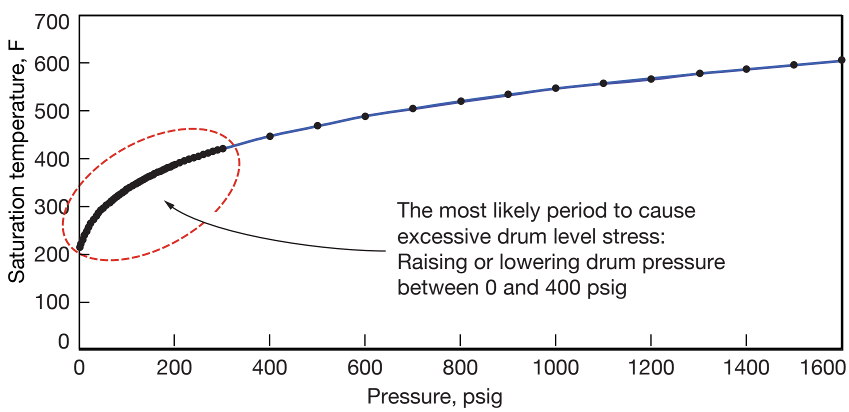
The reported primary benefit of the new feature is the unit can more easily remain in compliance with $NO_x$ emissions limits at part load while avoiding common HRSG thermal issues experienced under reduced gas flow and higher turbine exhaust temperatures. The expected turndown improvement is about 10%—subject, of course, to site-specific conditions. Barras noted further that Ethos monitors 70 units for its customers from a remote M&D center. "Steam turbine optimization is coming next year," he added.

## Twice-daily cycling

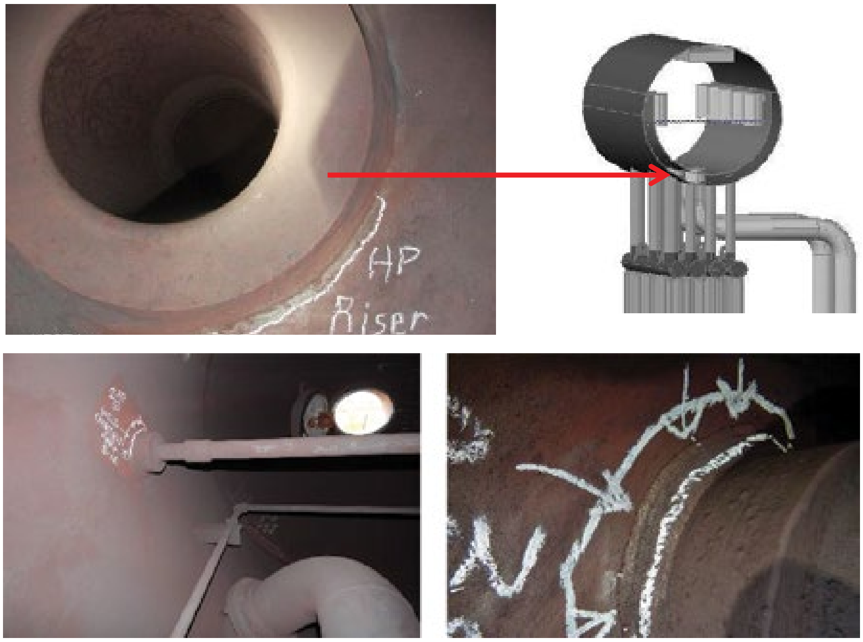
If you think you're cycling a lot now, maybe you haven't seen anything yet. At least, that was the implicit message of one user representing multiple plants for which the owner is actively planning for an operating regime characterized by two starts per day. The CC units essentially were designed for baseload operation 10 years ago. Like most facilities facing such scenarios, these operate in a wind/solar intensive region.

While there are many O&M, compliance, performance, and budgeting issues associated with such a change, an important consequence is that critical HRSG components—such as attemperators—will wear out twice as fast (as if attemperators weren't already enough of a problem). In general, a thorough evaluation by the owner/operator concluded that more HRSG tubes, as well as critical valve and pump parts, should be stocked. These same components would require more frequent maintenance to avoid impacts on plant and system reliability.

Although the budgeting is still a work in progress, the initial assessment shows that balance-of-plant maintenance for twice-daily cycling




**3. Highest steam** saturation temperature differential, a precursor to HP drum stress, is experienced at the beginning of the steam-raising process, when pressures go from 0 to 400 psig




**4. Cracks are discovered** with greater frequency in such drum penetration welds as the cracked riser nozzle weld (top) and the blowdown nozzle

**5. Drone inspection** technique is used above an HRSG silencer to check internals for structural integrity, and to avoid subjecting personnel to safety and other hazards.

would increase by $2.50 to 4.00/MWh. Here, BOP includes everything except the gas and steam turbines and their respective auxiliary skids

## More frequent drum weld inspections

Another consequence of twice-daily cycling, and more frequent on/off cycling generally, is likely more numerous steam-drum weld cracks. A diagram shown in a second presentation by HRST, this one by Lester Stanley, explains why: Going from 0 to 400-psig steam pressure creates the greatest and fastest temperature differential in steam saturation temperature (Fig 3).

Thermal stresses, in turn, lead to higher stress on the HP drum nozzle and shell welds (Fig 4), especially when pass-through partial-penetration welds are used.

The balance of Stanley's presentation reviewed planning strategy for inspections, several effective inspection techniques—including visual inspection (by someone who knows what they are looking for), phased-array ultrasonic testing, and magnetic-particle inspection.

Stanley advocates applying the joint API (American Petroleum Institute)/ASME standard API 579/ASME FFS-1, for "fitness for service," developed to "make informed decisions about defects found in-service during inspections." When conducting repairs, don't neglect any opportunity to improve the weld procedure and avoid weld repairs which may lead to additional stresses.

## SCR impacts

Low-load operation leads to changes in temperature, mass flow, and mixing characteristics in SCRs. Andy Toback, Environex Inc, reviewed several items to be considered for maintaining compliance. They include, for startups:

- Expect an increase in catalyst activity with higher temperature.
- Requirements for dilution air temperature in the ammonia delivery system may change.
- Modifying the SCR system control logic may help you comply with stack emissions earlier in the startup cycle.

For low load operation, Toback recommends:

- Analyzing operating data to determine catalyst performance requirements at each load condition
- Testing catalyst condition, along with operating data, to project remaining life—low load operation may shave a year or more off of the catalyst life.

If the operating profile is expected to be the same for many years (although who can forecast that), consider adjusting the catalyst formulation when it comes time for replacement. The ideal temperature for an SCR catalyst is 700F, notes Toback, but adjusting the formulation can extend performance from 400F to 1000F.

## A bird, a plane. . .a drone

Drones are getting more attention these days, although most of the material seems to focus on understanding the bewildering matrix of federal, state, and local rules and regulations restricting their use. They are being considered more often for getting a peek at areas which are impossible, difficult, or just plain inconvenient to access (Fig 5).

One user at the CCUG meeting described experience with early application of drones for these purposes. Equipment listed as potential subjects for inspection are elevated structures, such as stacks, silencers, valves, and pipe racks; HRSG interior and exterior; cooling towers; and high-energy piping. In time, drones likely will be incorporated into regular preventive maintenance programs and activities, noted the presenter.

The user case detailed was inspection of a silencer for structural integrity of internal components, coating system integrity, and mechanical connections. Many of the potential advantages of drone use are obvious, but some worth mentioning include reducing exposure of crew to safety risks, avoiding scaffolding and/or crane costs, and the ability to manage the inspection at the plant level without corporate resources.

The chief limitation is that if anomalies are identified, they can only be addressed by conventional means. In other words, you'll need scaffolding or crane or an elevated crew to do the repairs. The inspections are also limited, in this plant's experience, to line-of-sight of the camera on the drone which is easily impaired by obstructions and poor lighting. There can be loss-of-signal issues around thick metal components, too.

Still, the conclusion here is that accelerated use of drones at power stations is inevitable. The technology is advancing rapidly. As long as the regulatory framework doesn't inhibit the applications, drones are best considered another form of automated, labor-saving device, not unlike borescopes and other cameras used to inspect equipment internals. CCJ

# Heed deck-level lessons from catalyst replacement projects

Complying with emissions regulations is usually binary. If you're out of compliance, you don't run. Catalysts for nitrogen-oxides ($NO_x$) and carbon-monoxide (CO) emissions compliance don't last forever. And fresh catalyst isn't supplied from the marketplace overnight.

Thus, the $NO_x$ control system—comprising the gas turbine's performance and exhaust levels, the catalyst itself, the ammonia supply and distribution grid, analyzers, exhaust-flow distribution, and sampling ports and methods—must be regularly monitored, inspected, and tested to anticipate when replacement is necessary *before* the unit is out of compliance.

Today, virtually all combined cycles (CCs) come equipped with systems for selective catalytic reduction (SCR) of $NO_x$. Catalyst sampling and testing, gas-path monitoring, and catalyst replacement are well-honed activities, usually performed by specialized service firms, with catalyst suppliers. Yet there are always things you can learn from others' experiences.

## Tag team

In a unique presentation at the Combined Cycle Users Group (CCUG), Jimmy Daghlian, NV Energy, and Phyllis Gassert, Talen Energy, both members of the volunteer organization's steering committee, teamed up to review respective experiences with recent catalyst replacement projects. The 70+ slides, available to registered users at www.powerusers.org are a veritable guidebook outline on the subject, the kind of material which, alone, pays you back in spades for the price of admission to such user conferences.

Team CCJ encourages anyone facing catalyst replacement now or in the future—that includes readers at simple-cycle and cogen facilities, as well as CCs—to access the slides. Here, the editors have extracted only the salient lessons and tips which you likely won't find in a textbook, an OEM's guidance materials, or a consultant's recommendations.

## Big-picture stuff

The greatest lesson offered by Daghlian and Gassert is that the lowest bidder for the project isn't necessarily the one providing the greatest value—at least when you evaluate on a five-year basis. When initial costs and five-year operating costs and savings, based on performance guarantees for ammonia consumption and fuel attributed to overcoming pressure drop across the unit, are combined, a spread of over $150,000 annually was revealed across four bidders for one project.

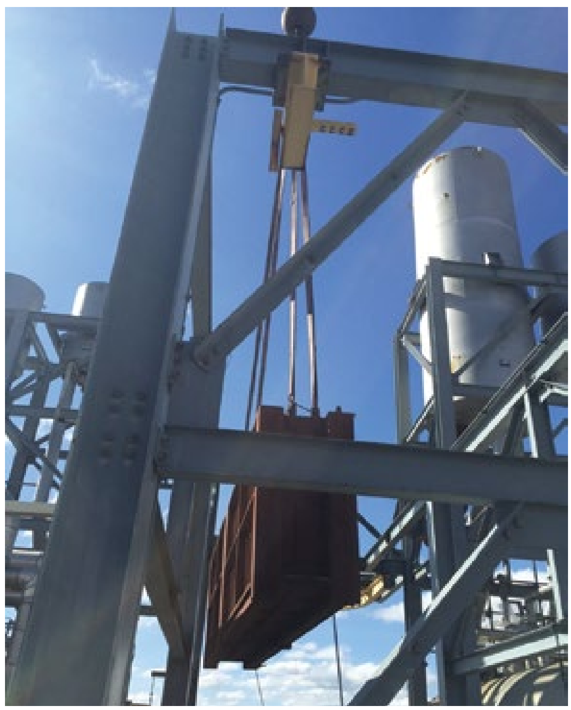
Second critical big-picture item is that, based on the speakers' experience, you should budget at least 18 months to plan a catalyst replacement project; the lead time for catalyst delivery is one third to one-half that. Third, consider asking the catalyst supplier to meet $NO_x$/CO limits more stringent than your permit to build in margin on such a critical performance parameter.

When evaluating service firms, know that every sampling company employs different sampling protocols, instrumentation, and methods. Be very concerned if the sampling company is not requesting as much operating data as you can give them. Make sure your catalyst inspection firm is experienced in catalyst cleaning. Consider a service which provides regular catalyst tracking in real time without coming offline to take samples.

If you don't have the proper emissions measuring apparatus at the gas-turbine (GT) exhaust, or it isn't working properly, you'll have to back-calculate inlet SCR $NO_x$ and CO levels from engine performance tests. These should be conducted under the worst conditions for emissions; for example, after water washing the compressor and output is not degraded. Often,

**1. Have extra bolts on hand** in case you have to destructively remove the reactor lid bolts (left)

**2. Make sure the HRSG trolley works** if you plan to use it for removing and installing catalyst modules (right)

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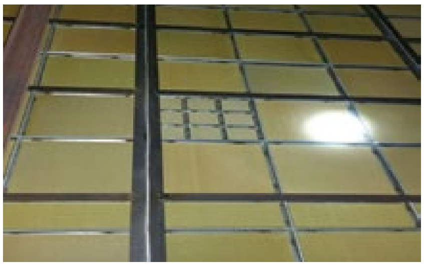
**3. The crane** will take up a significant amount of space during the project, so survey the laydown area carefully



**4. Adding a sample block** is a good idea, along with retaining a clean catalyst block as a reference to judge when cleaning is necessary

**5. Gasket material around the roof** of this SCR unit was found in a completely degraded condition

poor catalyst performance is masked by elevated reagent injection.

It may go without saying, but worth reminding, that engine performance must first be assessed to make sure compliance issues reside with the SCR. Of course, all analyzers must be properly calibrated.

## Sweat the small stuff

Here are other items to consider:

- Check to be sure you can remove the reactor lid. At one site, bolts had to be destructively removed (Fig 1) and available spare bolts used as replacements. If you don't have spares, make sure you can obtain these bolts.
- Factor into the bid spec the impact of power-augmentation/duct-burner operation and any other GT upgrades that my change your emissions output.
- Don't mix up catalyst manufacturers and catalyst installers on the bidders' list. Installers don't supply, suppliers don't install.
- Completely clean all the ammonia injection grid (AIG) lances when cleaning or replacing catalyst. This may require a separate contractor. Piping will often exhibit significant deposition which affects performance.
- Verify all SCR unit measurements. In one case, the catalyst was found to touch the roof.
- Make sure you have adequate testing ports installed around the perimeter. One site had to add 18 ports to ensure thorough monitoring of the mixing volume around the catalyst modules.
- If you plan to use the HRSG trolley supplied by the OEM during construction, make sure it is operable beforehand (Fig 2).
- Evaluate in detail the plant laydown area (Fig 3) around the HRSG. The crane requires a huge plot space. At one site, 20 dumpsters were necessary to hold and haul away the spent catalyst.
- Break down the cost items (labor, insulation, compressed air, welding, confined-space rescue) in the bid spec—especially scaffolding—as it's a good way to explain outliers.
- Allowing all the bidders to crawl the unit will result in much better response to the bid spec. One site paid each of the bidders for this time and effort, money reportedly well spent.
- Inspect between the catalyst layers, if possible, even though there may be little space between them. One unit under consideration had 5 in. maximum between catalyst modules 1 and 2.
- Request that a sample block be included with each new catalyst module and hold one block back to serve as a baseline for comparison when catalyst cleaning evaluations are conducted (Fig 4).
- Pay special attention to gaskets and sealing around the unit. At one site, gasket material around the roof was found to be in extremely poor shape (Fig 5).

## Bid-spec prep

Make sure the bid spec includes material guarantees (modules, frames, and seals) as well as performance guarantees (catalyst activity, catalyst life, unit pressure drop, ammonia consumption, ammonia slip, and $SO_2$ to $SO_3$ conversion) and correction curves. A pre-bid meeting and multiple pre-outage install meetings should be expected. Finally, the spec should include the number of testing elements and any additional instrumentation.

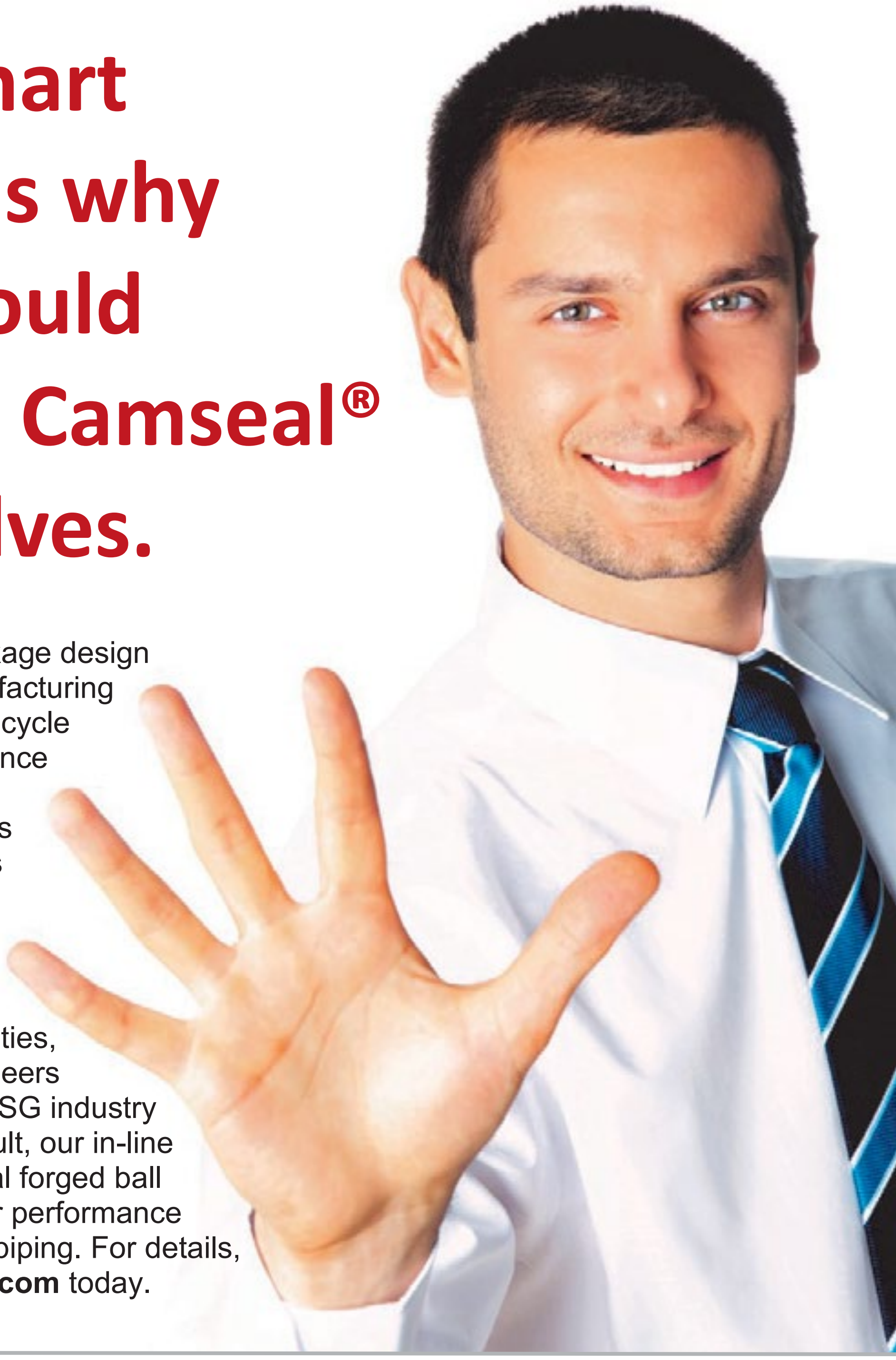
## Visual inspection

This should be conducted ahead of catalyst testing and include the following:

- Visual evidence of insulation or other debris deposits, if possible between upstream and downstream catalyst cells.
- Discoloring across the catalyst bed.
- Catalyst shifting and misalignment.
- Deteriorated seal strips and metal seals, and fraying/fretting of soft seals.
- Flow bypassing at interfaces of support structures and catalyst.
- Fraying (evidence of decomposition) and wetness (oil or moisture contamination) of catalyst itself at both lower- and upper-level locations.

When sampling the catalyst, take three or four samples from different heights and sides of the catalyst bed, because velocity profile and deposition can vary significantly. If catalyst depth is two blocks or more, take samples from the trailing edge in line with the sample blocks. Have the coupon samples tested at various temperatures and flows that match the operating conditions of the unit. CCJ

# Five Smart Reasons why you should Specify Camseal® Ball Valves.



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# Users reveal their 'softer' sides

Plant personnel often think of training on equipment as "hard" skills development, and the people side as "soft" skills, yet most everyone implicitly recognizes that the two are symbiotic. The 2016 Combined Cycle Users Group (CCUG) conference (San Antonio, August 22-25) focused on meeting the challenges of soft-skills development.

Many combined cycles today operate under what may be the most dynamic market conditions experienced in decades—ownership changing every few years; new rules, opportunities, and penalties taking hold in grid markets; growth in variable generation; an aging workforce; and ever-tighter environmental restrictions. Thus, it is even more critical that organizational development—often called people, policies, and procedures (3Ps)—reflect this dynamic environment.

Of course, it is also fair to say that the industry isn't exactly in a period of prosperity. Electricity demand in most parts of the country is flat, low, or negative, consistent with anemic economic growth. Average wholesale power prices are at historic lows. Reducing overhead costs is a natural consequence and, a management priority. People cost money.

In short, not only do plants have to do more with fewer people, but those remaining must have a larger portfolio of skills to accommodate the greater uncertainties. If this isn't enough, NERC's reliability and physical and cybersecurity standards are moving many fossil plants towards 3Ps resembling nuclear plants. Thus, CCUG's focus is timely and relevant.

Keep in mind that many of the programs you are exposed to may be largely fresh buzzwords attached to age-old processes and procedures. That doesn't make them any less important, just that there are valid past experiences to draw from.

Copies of CCUG presentations supporting the highlights below can be accessed by registered users at www.powerusers.org.

## Incident review

Mistakes and mishaps are inevitable. Learning from them as an organization is not. That begins with a formal post-incident review and remediation program. Having a framework or methodology to conduct one is essential. Three primary components are risk assessment, root cause analysis, and human performance review.

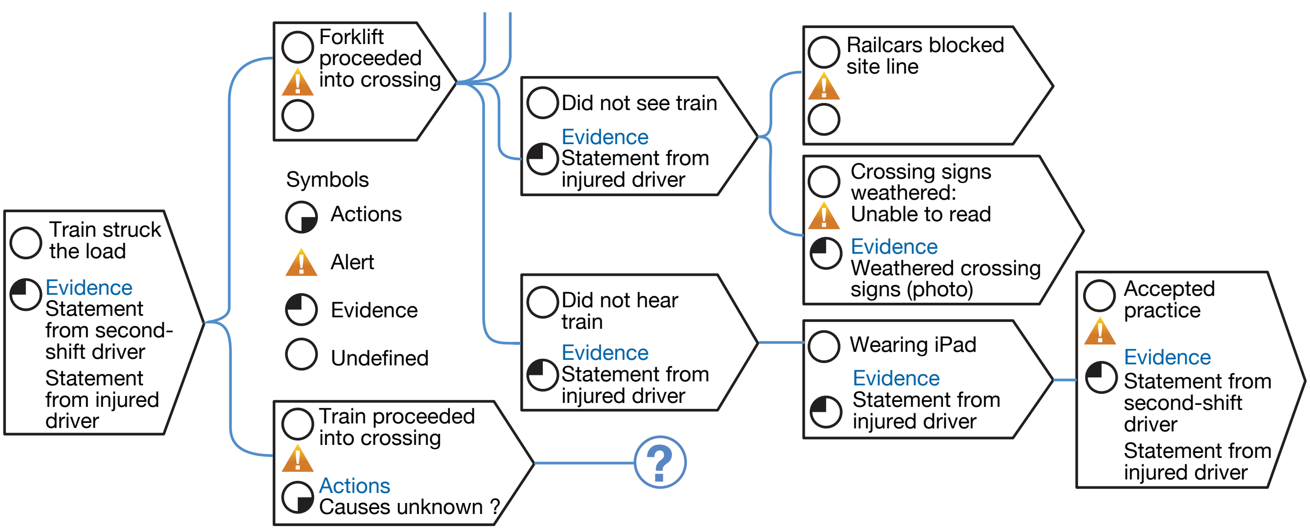
A representative from a small non-utility generator (NUG), in describing his company's program, noted that characterizing the risk is what should drive the methodology. Incidents are partitioned into Levels 1-3 using Table 1, which shows the probability of occurrence versus consequences. Generally, Level 1 incidences are low-risk near misses, with discretionary remedial action. Level 2 incidents are characterized as OSHA recordable and/or less than $500K property damage, with remedial action taking place when appropriate or schedulable.

Level 3 incidents have greater than $500K property damage and represent serious risk to the business and personnel. These last incidents can be severe enough that the plant must be shut down until remedial action is taken.

Next step after characterizing the risk is analyzing the incident. The speaker advocated a simple root cause analysis (RCA). Low-risk events are usually analyzed and mitigated through a one-on-one discussion between the person or persons involved in the incident and the supervisor. Level 2 requires a formal RCA which is escalated in a Level 3 situation.

In the low-level incidents, the objective is to keep asking "why" something happened, with all answers grounded in facts and evidence, until the root cause is identified. For higher-level incidents, a formal cause and effect RCA is implemented, using wishbone diagrams (Fig 1).

Once the root cause (or causes)




**1. Fishbone diagrams** are used as part of RCA to understand "why" various things happened to cause the incident

is identified, a human performance review takes place to understand what led to the cause and how prevent the incident from recurring. Culpability may lie with the individual or with organizational weaknesses. Here, it is also important to look for generic implications across the fleet and make sure the conclusions and analyses are communicated.

## Old-school techniques

An industry veteran from a California municipal utility stressed that old school techniques such as "walking down the plant" (Table 2) were still essential for identifying physical and cybersecurity gaps. Key is maintaining a healthy skepticism and questioning attitude.

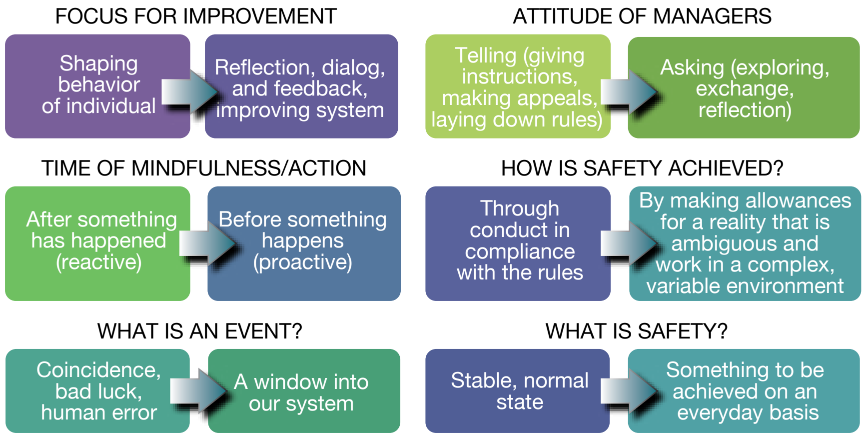
His advice was also to deploy people who are *not* familiar with the systems; they will ask lots of new questions. Also, divide the plant into zones to make the job manageable and avoid "random" inspections. Anything that looks out of the ordinary or suspicious should be recorded—on cards, notebook, or audio or digital device.

Peer-to-peer audits with someone from a nearby industrial facility also were recommended. That is certainly a good way to have new questions posed about your facility, and discover gaps from your neighbor which might apply at home.

One security gap identified and mentioned in the presentation was tracking and discarding of uniforms and hardhats with the facility's logo. These could be used by the wrong people to gain access, and obtained, for example, from a trash bin. In one case, an inspector at a peer facility was able to check out a company maintenance truck wearing a vest and hardhat. Guards decided it was okay to forego an ID check. The discovery led to a new policy at the powerplant to shred old vests and break old hard hats, rather than toss them into the garbage.

Another discovery was security camera sight lines partially blocked by vegetation.

**Old school reliability.** Experience in applying techniques from the emerging field of "resilience engineering" was reviewed at length by representatives from one of the country's largest combined-cycle owner/operators. From the material presented, it was clear that resilience engineering is simply an extension of reliability-centered practices to focus on anticipating changes and adapting to them.




**2. Maturing towards the resilient organization** depends on being proactive versus reactive, behaving as a team versus acting as a collection of individuals, and accepting ambiguity in daily activities versus strict compliance with rules

### 1. Categorizing the risk an incident poses drives the methodology for analysis, remediation

| Likelihood of occurrence or exposure for a selected unit of time or activity | Negligible | Marginal | Critical | Catastrophic |
|---|---|---|---|---|
| Frequent | Medium | Serious | High | High |
| Probable | Medium | Serious | High | High |
| Occasional | Low | Medium | Serious | High |
| Remote | Low | Medium | Medium | Serious |
| Improbable | Low | Low | Low | Medium |

Level 1=Low risk, Level 2=Medium risk, Level 3=Serious and high risk
Frequent=Likely to occur repeatedly, Probable=Likely to occur several times, Occasional=Likely to occur sometime, Remote=Not likely to occur, Improbable=Very unlikely, may assume exposure will not happen

Distinctions were drawn among reliable, resilient, and robust. Reliability is about an output, a result. Robust refers to something sturdy and solid, but "brittle," whereas resilience is a system property of being able to self-heal. Resilient work teams (Fig 2), which learn to recognize *early* when something isn't working right, rely on a diversity of knowledge and perspectives. Some of the thinking involved may be counter to traditional quality and safety methodologies, the presenters observed.

To push the resilience concepts out to the plants, this owner/operator relied on the center of excellence (CoE) approach. One plant was selected to be the CoE, adapt the practices of high-reliability organizations, and begin to think as a team, rather than a collection of individuals. Other facilities learn from the CoE plant.

One area identified for improvement—nothing new here, a source of performance errors for decades—is the shift turnover period. The "tool" employed as a lever of understanding and change is the after-action review, essentially a 360-review of the task following completion based on these questions:

- What was expected to happen?
- What actually happened?
- What surprised us?
- What went well and why (what should we do the same)?
- What can be improved and how (what should we do differently)?
- What did we learn that would help others?

The greatest "palpable" change for the plants, it was said, is the comradery felt by the site staff. A more concrete consequence, perhaps, is staff now practices O&M procedures before they are

### 2. Questions to consider when visually inspecting a pump/motor skid

- Are the foundation bolts installed correctly?
- Is the oiler full? Is it on the correct side?
- Does the pump "sound" right?
- Is it clean?
- Is there evidence of new or even old leaks?
- Is the foundation drain plugged or clear?
- Is the machine labeled correctly and completely?
- Are there any missing fasteners, handwheels, parts?
- Is the instrumentation tubing crimped?
- Is there evidence of unusual vibration?
- Are there any signs of corrosion?
- What is the condition of paint/coatings?
- Are all safety devices properly installed?

**Two-minute drill**

LOOK FOR ERROR TRAPS

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

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

performed. These so-called human performance or human-factors-engineering techniques were instituted decades ago at nuclear plants.

In a sense, resilience engineering is what other manufacturing facilities went through in the 1980s when they had to face down the threat from overseas competitors. No longer could auto plants or steel mills operate "base load" and churn out the same product. They had to become more nimble, adaptable to customer needs. Thus, quality circles, total quality management (TQM), and continuous improvement techniques (quality oriented) took priority over the rote efficiency of production techniques (volume oriented) from earlier decades. Later these evolved into Six Sigma and other defects-management programs.

What powerplants have to do today is eliminate "defects" while responding to new requirements of their customers, usually the ISO or RTO or a utility managing greater ratios of variable generation in the daily mix.

## STAR and STOP

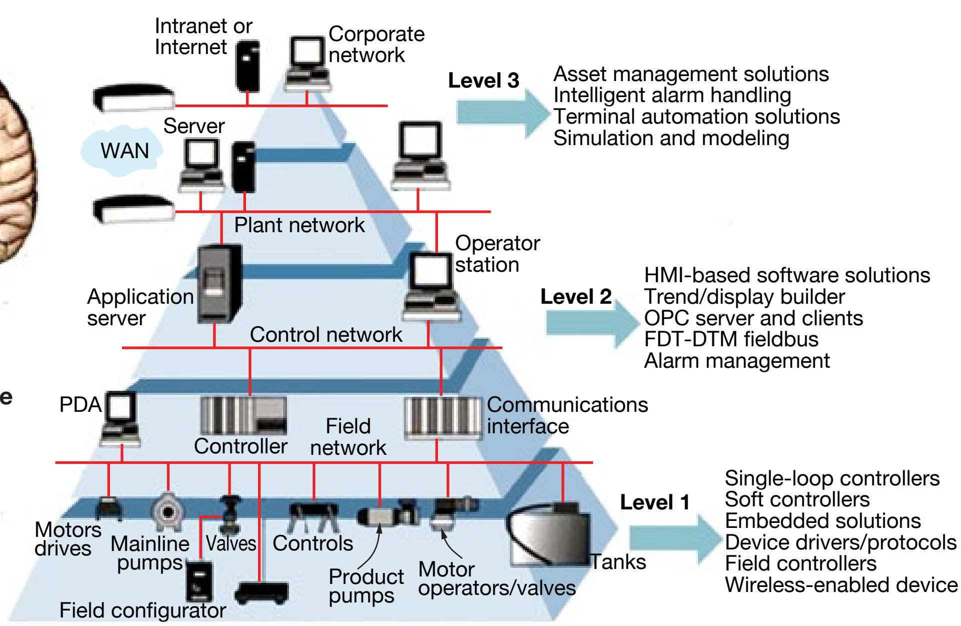
Recognizing that 80% of all events are caused by human error (versus equipment failure) and that 70% of all human error is a result of organizational weaknesses, one western utility operating mostly in a regulated arena initiated a broad corporate human performance improvement (HPI) program. While it includes many of the concepts described above, three components important at the plant level are:

- The self- or peer-check STAR technique—or stop, think, act, review.
- The two-minute drill—a conscious pause for situational awareness—Where am I? What am I going to do? What could go wrong? What hazards are lurking? How could another person get hurt? And so on (Fig 3).
- STOP—a pause in task performance to ensure key details of the task have been addressed.

The goal of STOP is to "fail conservatively," if for example, the task isn't going as expected, anxiety is experienced, conditions have changed, assistance is required, and the task otherwise needs to be "stabilized." Overall, the objective of the program is to provide very simple tools so that it is easy for plant staff to incorporate them into everyday culture.

## What to expect with VPP

The OSHA Voluntary Protection Program (VPP) is a way to proactively manage safety while complying with OSHA regulations through partner-




**4. The digital asset intelligence platform** is, in effect, a digital "brain" working in concert with the human operators to run the plant and achieve performance goals

ing with the regulatory body (CCJ, 2Q/2014, p 4). It is not for the faint-hearted, based on the nevertheless extremely positive experience of one plant in Virginia. Here are some of the characteristics and consequences of that experience:

- It took much longer than anticipated to set up the program and takes time beyond normal working hours.
- The plant submitted 85 pages of documentation to OSHA in support of the program.
- Recertification is required every three to five years.
- OSHA will show up unannounced to check up on plant staff behaviors related to safety and "they measure stuff," for example the space between top ladder steps and platforms.
- If an inspector finds something during an inspection, you have until 4 p.m. that day to correct it; otherwise it goes into the official record.

  The plant added zone inspections to its monthly safety inspection activities and tailored corporate safety notebooks to be more site-specific.
- There's "plenty of admin for VPP after the fact"—in other words, work doesn't end when you get your VPP flag.



A hot topic arising from the experience was how many hours an employee can work. Apparently, there is no OSHA policy on the matter. It's an important question—workers usually want as much overtime as they can get, but mental acumen deteriorates with lack of rest. This plant settled on 12 hours a day for seven days, arrived at by realizing that time for decompression, driving, eating, etc, has to be factored in. As a reference point, the plant's major OEM contractor limits workers to 10.5 hours per shift.

A second positive consequence noted is that employees now hold contractors more accountable for their actions with respect to safety. This is also critical, as plants can have dozens or even hundreds of contractors onsite for outages, depending on what type of outage and how many units are affected. More attention is paid to escorts, sign-in procedures, and entrance security during outages. This facility went the "extra mile" and earned a VPP Star designation for its attention contractor safety (CCJ, 1Q/2014, p 88).

Perhaps the greatest impact is that employees feel good about the program, they feel *safe*, according to the report at the meeting.

## Knowledge management

The final soft-area presentations addressed plant knowledge management (KM) from two perspectives—transferring knowledge among members of the staff and the emerging digital asset intelligence platform. Over the next decade, 50% of workers in the electric power industry will be eligible to retire. KM includes concepts to ensure that mission critical knowledge doesn't walk out the door.

The first presenter made a distinction between explicit knowledge which can be codified and articulated in language, and tacit knowledge residing in individual's minds. Tacit knowledge is often not recognized as sharable, because it is so embedded as part of how that individual interacts with the equipment after so many years of experience. The important point is that deliberate, conscious methods must be cultivated, and time scheduled, to capture tacit knowledge for the benefit of the organization.

What is likely to replace much explicit and tacit knowledge in the plants, according to the second presenter, is the knowledge acquired and available for dissemination by the growing capabilities of the digital data and information systems—the hardware and software for control, automation, monitoring and diagnostics, archiving, and data analysis and trending. DAI is often represented by the buzz phrases big data, the industrial Internet, the Internet of things, and the digital or virtual plant.

According to this presenter, today's dynamic operating environment is driving the integration of DCS/automation systems with once-disparate performance software capabilities towards a seamless platform (Fig 4). Many software and automation companies are vying to be the brand name on the outside; others will likely become "Intel Inside."

Advanced pattern recognition and data analysis lead to prognostic capability, an extension of M&D, or the ability to identify and mitigate anomalous equipment behavior well before it reaches an alert status in the alarm system. In other words, the system can detect potential issues before the typical control system alarms for the human operator.

Soon, according to automation platform suppliers, a digital version of the plant will be available to operate as a real-time simulator, allowing operators and engineers to "test" equipment modifications virtually and validate them before they are imposed on the actual equipment.

Automation systems can be designed to "close the loop" and make the decisions an operator otherwise would, although few seem willing to go that step today. In essence, a digital "brain" works alongside the human operators to achieve plant performance goals.

One analogy is the self-driving automobile, which is likely to become commonplace in five to 10 years, according to many reports. Most combined-cycle plants have so-called "one-button" automated start sequences (although operators are still required for some tasks). Today's airplanes are largely run on auto-pilot; the human pilots are there, anecdotally, for passenger comfort, and of course to intervene under abnormal conditions.

The presenter suggested that the digital brain must be developed, designed, and nurtured over the lifecycle so that it reflects all of the relevant processes and procedures being applied (and described above) to achieve superior performance and avoid incidents, accidents, and catastrophic loss. Not only would such an exercise rationalize staffing with the digital capability, but ancillary benefits are probable in insurance costs, avoiding software duplication, re-considering sparing philosophy in light of advanced M&D and prognostics, better and more consistent performance, and others. CCJ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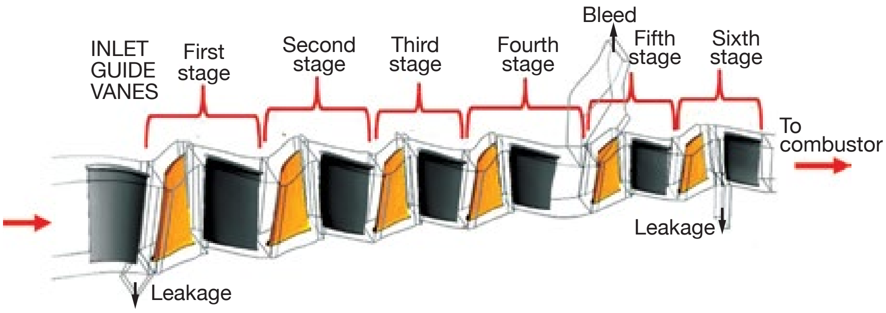
# Understanding stall, surge

**By Lee S Langston,** professor emeritus, UConn

Axial-flow compressors are used in the majority of large gas turbines, both in powerplants and aircraft jet engines. Over the last 75 years these compressors have been improved continuously, today achieving component efficiencies of more than 90%. However, no matter how advanced, they must be carefully controlled in their operation to avoid the power-robbing effects of *stall* and the convulsive effects of complete flow reversal, brought about by *surge*.

Although modern design and fuel control systems are capable of keeping a gas turbine in electric generation service away from operating conditions conducive to stall and surge, it is important to know something about each condition. With this as an enjoinder, let's look at how an axial compressor operates.




**1. Gas path** is traced through inlet guide vanes, rotating blades, and stationary vanes in a gas turbine's six-stage axial compressor

## Axial compressor basics

To efficiently compress a gas over a range of operating conditions is not an easy task. About 50% to 70% of the output of the turbine component in a gas turbine is used to drive its compressor. Contrast that to a steam plant where only about 1% of the turbine output is used to power feedwater pumps to resupply incompressible water to the boiler.

Axial compressors get their name because gas-path air flows in more or less a straight line in an axial direction, parallel to the gas turbine's axis of rotation. The compressor is assembled in stages, each stage comprised of a ring of moving rotor blades (or blades), mounted on a rotating disc or drum, and a downstream ring of case-mounted stationary stator blades (or stators).

Blades do work on the gas-path air flow, increasing its static and total pressure, and kinetic energy. Stators remove blade-induced swirl velocity, thereby decreasing kinetic energy, serving to also increase static pressure and align flow for blades in the next stage.

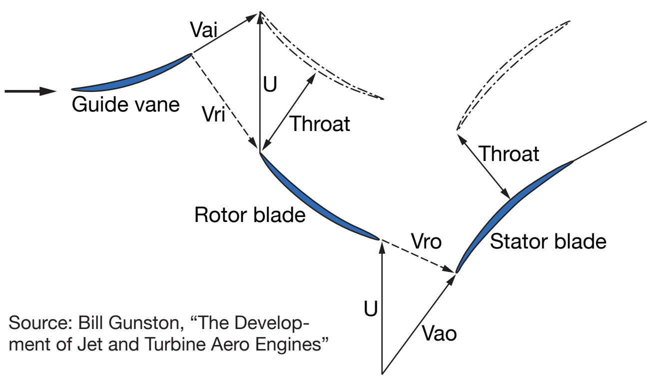
Compressor blades and stators then operate on gas-path flow to produce what aerodynamicists term an *adverse* pressure gradient in the flow direction—that is, from low to high static pressure. This is analogous to pushing water up an inclined channel, with many small, rapid brush strokes. If the incline (akin to the compressor pressure ratio) is too steep, the water runs backward, down the slope.

By contrast, gas-path flow in a turbine operates in a decreasing static pressure field in the axial direction. This is termed a *favorable* pressure gradient: think of water being brush-stroked down a declined channel.

## Multistage axial compressors: The basics

The gas path in a typical single-spool six-stage axial compressor is shown in Fig 1. Air enters IGVs (inlet guide vanes, which are not present on all gas turbines) and passes through each of the stages, on its way to the combustor section. Each stage increases both the gas-path static and total pressure.

Typically, each compressor stage in an industrial gas turbine (IGT) oper-




Source: Bill Gunston, "The Development of Jet and Turbine Aero Engines"

**2. Velocity vector diagram** illustrates the gas flow path across an axial compressor's inlet guide vane and its first-stage blade and stationary vane (stator blade), where:

- Vai is the absolute velocity (relative to the engine) at the inlet to the first-stage rotating blade;
- Vao is the absolute velocity of the gas as it exits the rotating blade;
- Vri is the velocity relative to the blade at its leading edge;
- Vro is the velocity relative to the blade at its trailing edge;
- U is the rotational velocity.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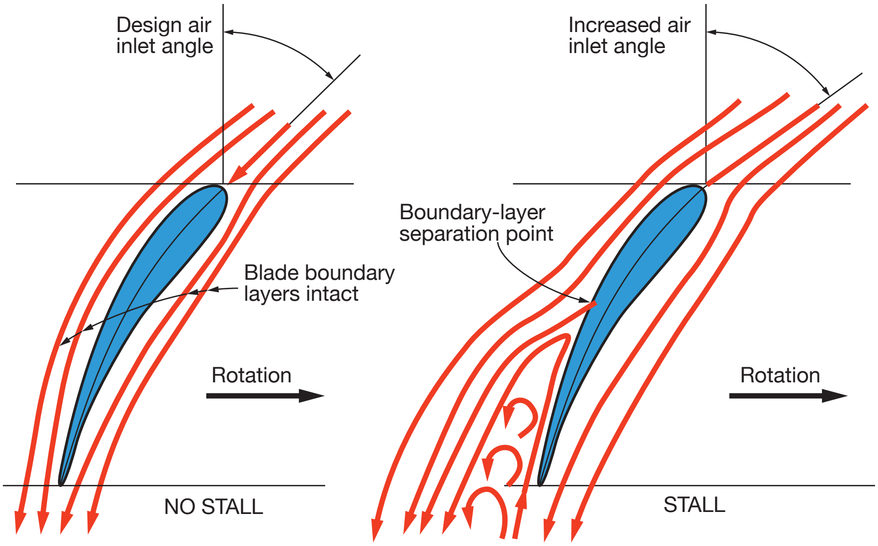
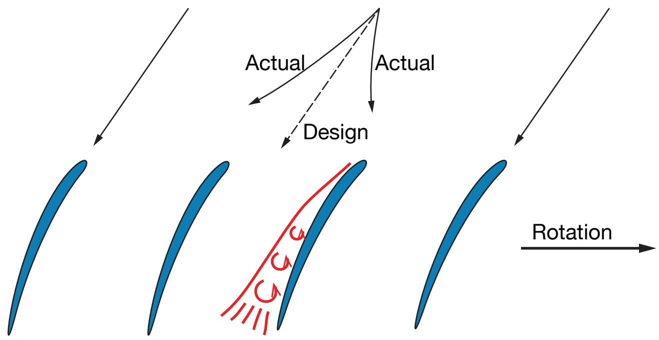



**3. Flow over a blade** at design conditions is at left, with an increase in the air inlet angle at the right—the latter causing a stall. Boundary-layer separation could be caused by a reduction in air velocity or an increase in engine rpm




**4. A single-blade stall** is conducive to stalls of other blades, and the formation of a stall cell. Next phenomenon is a rotating stall

ates in a pressure-ratio range of more than 1.0:1 up to about 1.4:1. To calculate a machine's compression ratio, simply multiply the pressure ratios for each stage. Example: Referring to Fig 1 and assuming each stage has a pressure ratio of 1.2:1, the compression ratio would be 1.2 to the nth power, where "n" is the number of stages—six in this case. The result: 2.99:1.

The benefit of a high compression ratio is top performance. Bear in mind that the thermal efficiency of a gas turbine increases as pressure ratio is increased. To illustrate: In the early 1950s, an axial compressor with 15 stages might have had an overall pressure ratio of 4:1. Today, GE's most advanced F-class gas turbine, the 7FA.05 gas turbine (231 MW), has a 14-stage compressor with an overall pressure ratio of 18.4:1.

This represents a reduction of one stage and an almost five-fold increase in compression ratio in seven decades of compressor design progress. Pressure ratios of the latest frame engines go as high as 30:1; those for aeroderivative machines, up to about 40:1. Such compression ratios translate to gas-turbine thermal efficiencies in the 35% to 45% range. The earliest IGT (1939) had an efficiency of 18%.

As Fig 1 shows, the compressor gas path narrows in going from the first to the sixth stage. Given that the average gas-path velocity in an axial direction is relatively constant for a GT compressor, as pressure and air density increase in the direction of flow the blades and stators become shorter. Tip-clearance issues can occur in high-pressure stages because the allowable clearances are more significant for shorter airfoils.

## Compressor stall

An engineer may begin the design of an axial compressor using velocity vector diagrams for just the IGV and the first compressor stage (Fig 2). They will identify the necessary air inlet flow angles for blades and stators to meet the desired operating conditions.

The resultant air-flow streamlines around a compressor blade are shown in Fig 3 (left) for the design flow angle. (The sketch for a stator would be similar, but without rotation.) Going from low pressure at the blade's leading edge to a higher pressure at its trailing edge, the streamlines closely follow the blade's suction and pressure surfaces.

The flow around the blade is controlled by its *boundary layer.* This is a very thin, almost immeasurable layer of air on the blade surface, within which the viscous frictional effects are concentrated. The velocity changes in the boundary layer from that of the streamlines just outside it to zero (relative to the blade surface) at the blade surface.

The existence of a boundary layer was introduced by the German engineer Ludwig Prandtl in 1904—an appropriate time to profoundly influence the design of aircraft as well as turbomachinery, in the last century and today.

Boundary layers are very sensitive to the conditions brought about by adverse pressure gradients, which is what a compressor produces. Thus the designer is careful to insure that boundary-layer separation does not take place at design air inlet angles.

When air inlet angles (measured in the axial direction) are increased, separation of the blade boundary layers can occur, as shown by the streamlines around the blade at the right in Fig 3. Here the streamlines on the suction side do not follow the blade surface aft of the boundary-layer separation point. This compressor blade is *stalled.*

Stall immediately increases stage aerodynamic loss: The blade lift goes down and the desired pressure increase is not achieved. The larger air inlet angle precipitating the stall could have been caused by a drop in air velocity as might occur from a sudden downstream backpressure event—for example, one resulting from a blockage in the combustor or turbine—or an upstream flow disturbance. Other separation causes could be blade surface roughness or excessive tip leakage.

When one blade goes into stall, it can cause an upstream blockage which diverts approaching stage flow (Fig 4). This is conducive to increases in the air flow angles for adjacent blade passages—in a direction opposite to rotation. If flow angles are large enough, these blades also will stall, forming a so-called *stall cell.* If the stall cell itself moves, it becomes a *rotating stall,* which spins opposite to compressor rotation, at about half the shaft speed. Needless to say, rotating stalls can greatly reduce blade life, because of the increased stress and vibration they cause.

## Compressor surge

Rotating stall can morph into the extreme case of a compressor performance failure called *surge.*

In the words of compressor expert Ivor Day, stall is a disturbance of compressor flow in the tangential direction, while surge is a disturbance

**5. Surge is in evidence at takeoff.** Flame duration is very short—milliseconds

in the axial direction. During stalled operation, the average air flow through the compressor is steady, but during surge, the flow rate will rapidly (milliseconds, msec) pulse—sometimes so violently that reverse flow is induced, often accompanied by a loud "bang."

In extreme cases, a sudden combustor-induced flame may shoot out the back end of the machine (Fig 5) and possibly out of the compressor inlet as well. Thus it's important to avoid surge.

## Preventing stall, surge

As explained earlier, the onset of stall (and surge) can be traced back to the behavior of the boundary layer on compressor blades and stators. Since this is the result of the basic physics of boundary layers, no "cure" has been found to eliminate stall.

When an OEM designs a new compressor it usually is tested to see when it will stall, using hindsight to determine what conditions to avoid. Then engine control systems, such as Fadec (Full-Authority Digital Electric Control), are programmed to keep the operating point of the compressor well away from the so-called stall or surge lines. Variable-pitch stators (to control flow angles), compressor bleeds, casing treatments, and tip clearance controls all are used to avoid stall conditions.

The study of stall and surge is a very active area of R&D in the worldwide gas-turbine community. According to Robert Mazzawy of Trebor Systems LLC, who in 1980 was one of the first to report on surge-induced structural loads, researchers have found that subtle modal waves are precursors to the rotating stall that precipitates surge. The hope is that detection of such waves will allow the Fadec to prevent stall and surge.

The fundamental problem is the nominal time period required for the actuation of a variable stator or a bleed is about 200 msec. This contrasts with the time period for the development of rotating stall and surge which is on the order of several rotor revolutions. One rotor revolution for an aircraft gas turbine typically is about 5 msec, while for a large IGT it might be as long as 20 msec. The difficulty of having the Fadec sense a precursor and take the necessary activation to prevent stall and surge becomes obvious when considering the disparity of these time intervals.

Despite the difficulties of sensing modal-wave precursors, there have been some successes in utilizing a Fadec to sense an impending stall/surge in sufficient time to either prevent its occurrence or limit repetitive surges. One example has been with twin-spool aircraft gas turbines where the initial stall originates in the fan stream from FOD damage or excessive clearance or flow distortion from nacelle inlet separation.

Here's what likely would happen: Fan stall leads to loss of flow capacity which causes the low-rotor speed to increase above the normal level for the engine power setting. A higher-than-normal low-spool rotor rpm coupled with a normal high-spool rotor speed elevates the low-pressure compressor (booster) operating line to its stall line, resulting in rotating stall and eventual surge. The time required for the low spool to increase its rpm is now sufficiently long for the Fadec to sense the unusual relationship between low- and high-spool speeds and be able to activate a bleed to prevent the occurrence of surge.

Another example: Aircraft gas turbines operating in severe rain or hail storms where extra fuel is required to process and evaporate the water being swallowed by the engine. Here again, the Fadec can sense the abnormal amount of fuel flow for the power setting and take preventive action to prevent any engine instability.

Neither of these examples would be applicable to IGTs but they serve to illustrate that given enough time for the Fadec to sense an unusual mode of operation, it is possible to prevent stall/surge. CCJ

# Best Practices Awards

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

The Best Practices Awards program, launched in late 2004 by **CCJ**, has as its primary objective recognition of the valuable contributions made by owner/operator personnel to improve the safety and performance of generating facilities powered by gas turbines. The program continues to evolve by encouraging entries pertinent to industry-wide initiatives.

In 2016, plants were recognized for best practices in water management, O&M, performance improvement, fast start procedures, monitoring and diagnostics, outage management, and safety. One-third of the entries focused on O&M best practices, 27% on performance improvement, 17% on safety.

There are two levels of awards to recognize the achievements at individual plants: Best Practices and The Best of the Best (BoB). The five BoB awards presented this year were profiled in the 1Q/2016 issue (Dogwood Energy, Doswell Energy, Brandywine Cogen, Pleasant Valley Generating Station, and Tuaspring Cogen). Also profiled in 1Q were Waterside Power and Lawrence and Worthington Generating Stations. The second quarter issue featured Best Practices from Athens, Effingham County, T A Smith, Armstrong Energy, MEAG Wansley Unit 9, Green Country, Paris, and Brooklyn Navy Yard Cogen.

## In this section:



**2017 CCJ Best Practices Awards**

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# Millennium

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**Plant manager:** Mark Winne

## A better approach to electrical-relay response training

**Challenge.** Millennium Power personnel believed a better approach to electrical-protection training was needed. Typical documentation consists of one-line drawings designed by engineers to implement plant protective equipment. One-lines are not designed for ease of troubleshooting: they lack description of the faults, and they do not contain corrective actions or guidance should a fault occur.

In most electrical events, the fault location is not readily apparent, and not every event results in obvious equipment damage. Plant staff must work backwards and be able to work from the relay information to locate and remediate faults. The information on the one-lines could be presented in a format more suited to troubleshooting.

Millennium one-lines consisted of approximately 10 different protection drawings prepared by several different engineering firms. All the drawings followed general IEEE convention but used nomenclature specific to the OEMs and EPCs. They were made by engineers to be read by engineers. In addition, they were developed in the context of how to protect the equipment rather than how to locate a fault.

**Solution.** Plant personnel developed a documentation package that flows from the relay observations to the fault. It contains guidance on faults, instructions for recommended testing, and remediation required to return equipment to service (sidebar).

The package includes training on equipment specific to the plant. The training and documentation package also includes a series of expected relay and damage observations for common electrical faults.

Not only do these provide a basis for comparison during an actual electrical fault, they make causality response training much more relevant. Each operator receives a bound set of reference materials containing electrical trip guidance and examples of causality responses.

**Results.** At most power stations, troubleshooting of complex electrical faults is a relatively infrequent experience, and misunderstanding the true nature of an event can have catastrophic consequences. Too often, the drive to meet commitments and generation schedules compels operators to make hasty, uninformed decisions.

This package gives the operator the tools, knowledge, and guidance to make well-informed decisions and set in place an appropriate course of action. Sometimes, the right answer is to stop and call for help; however, knowing when to do that is key. These guides lead the operator to the right decision and have proven to be money well spent.

**Project participants:**

Tim Sheehan, plant systems superintendent

Bill Lovejoy, chief engineer, NAES Corp

### How Millennium helps guide operators tasked with troubleshooting

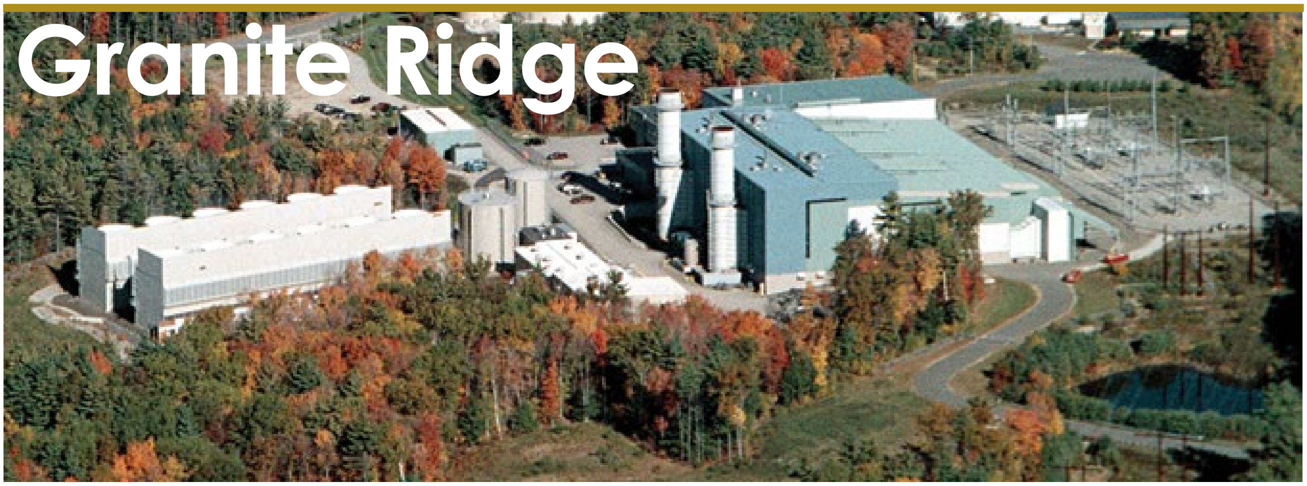
The following example is for a 59G or 59N neutral overvoltage. Millennium has four neutral overvoltage relays—one each Beckwith M-3420 and M-3430 for both the steam and gas turbine/generators.

A 59GN trip indicates a grounded phase between the generator neutral and the low side of the GSU bushings. As one phase goes to ground, the voltage on the neutral increases to maintain the 3-phase relationship. This is a common trip. It can occur at field flashing when one phase fails to build voltage or it can occur immediately after closing the generator breaker when closing in on a grounded isophase. It frequently occurs with a 59 phase overvoltage.

Reset directions: Review oscillography, isolate the machine and isophase, and measure resistance to ground. On the first pass there is no need to break out the three phases at the generator neutral or GSU delta connection. However, if the readings are low it is necessary to break out the connections to determine and isolate the phase to troubleshoot.

It is possible to re-energize without measuring the resistance to ground. The neutral transformer limits the ground current flow below a level that would damage the generator core. However, the elevated voltages on the ungrounded phases (1.7 × normal) significantly increase the chance of a second fault developing to ground on those phases. IMPORTANT: If a second ground develops, significant ground current will flow and possibly destroy the unit.

# Granite Ridge



## Eliminate sodium hypochlorite, bromine, non-oxiding biocides from cooling system

**Challenge.** The cooling-tower system at Granite Ridge Energy (GRE) relies on treated city wastewater (grey water) for makeup. It contains significant levels of ammonia, phosphate, and total suspended solids (TSS)—including bio-solids.

To control bacteria and algae in the recirculating system, GRE added significant quantities of bleach, activated bromine, two different non-oxidizing biocides (also considered algaecides) and a bio-detergent.

The challenge was to find a safe and environmentally sustainable way to disinfect bacteria and control algae throughout the cooling-tower system—one that would significantly reduce or eliminate the substantial quantity of disinfectant chemicals needed for "complete control" of bacteria and algae.

Specifically, the plant's objective was to control bacteria (planktonic colonies) in the bulk recirculating tower water as well as bacterial slime (biofilm and sessile colonies) and algae throughout the tower. Staff based its search for a solution on the following information:

- Bacteria in the bulk water are mostly aerobic—pseudomonas, coliform, and legionella—with some anaerobic sulfate-reducing bacteria (SRB). The SRB are most prevalent beneath biofilms and sludge, but if abundant they can also exist in the aerobic conditions of the bulk tower recirculating water. Bacterial colonies found in the bulk recirculating water are also known as planktonic colonies and can be associated with health concerns.
- Bacteria in slime (biofilm) attach to system surfaces such as piping, heat exchangers, and tower fill where they produce the slime to protect the colony and proliferate. Bacterial slime tends to degrade equipment performance and reduce the life cycle of wooden cooling-tower structures. Bacterial colonies

### Granite Ridge Energy

*Owned by Granite Ridge Energy LLC*

*Operated by NAES Corp*

730-MW, gas-fired, two-unit, 1 × 1 combined cycle (501G) located in Londonderry, NH. The facility is now owned and operated by Calpine Corp

**Plant manager:** William Vogel


**Purate** (left) produces chlorine dioxide to minimize the use of chemicals for controlling algae on cooling-tower structural members (right)


found in the biofilm are also known as sessile colonies and can include pseudomonas, coliform, legionella, and SRB.

- Algae attach to cooling-tower structures such as the structural beams, water-dispersing fill media, drift control media, internal walkways, and fan shroud areas. They negatively impact tower performance, wooden structures, and safety.

**Solution.** GRE worked with its water-treatment consultant to develop a safer, more environmentally sustainable approach to reducing its disinfection and algae control chemistry. After investigating several options, staff went with a safe, proven process for generating chlorine dioxide ($ClO_2$) to minimize the use of chemicals at GRE.

The process makes use of existing sulfuric acid, already onsite for controlling tower pH, as well as Purate™, a proven, stand-alone system that produces $ClO_2$ safely (Fig 1).

**Results**. Using the Purate $ClO_2$ generator, plant achieved complete control of bacteria and algae throughout the cooling-tower system as summarized below:

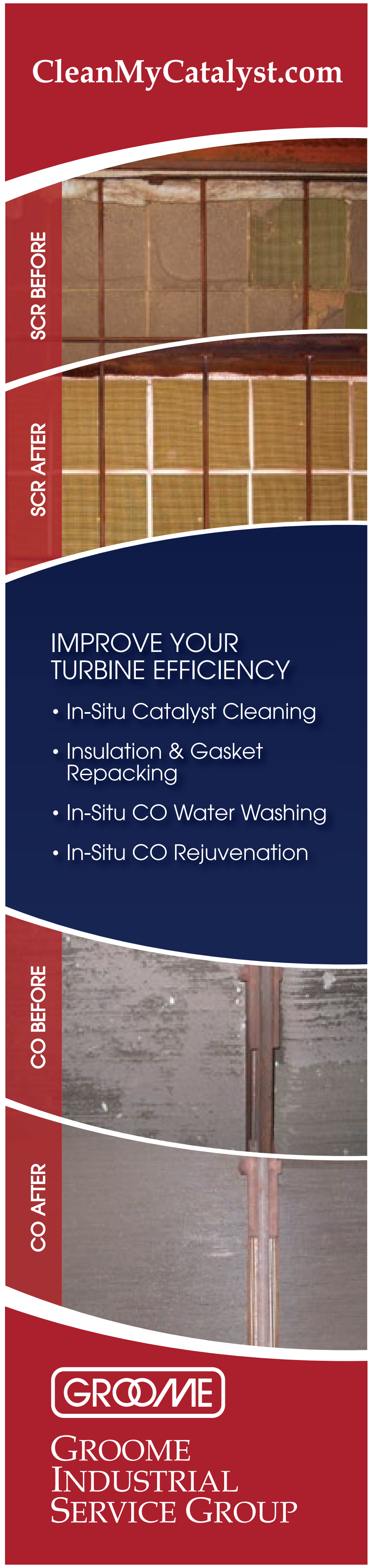
- Substantial reduction of bulk-water bacteria (planktonic colonies).
- Significant reduction of bacterial slime and biofilm (sessile colonies).
- Significant reduction of algae on the wooden tower structure, plenum, and fan shroud areas (Fig 2).
- Zero presence of legionella in the bulk water.
- A reduction of 1.5 deg F in differential temperature across the cooling tower through better cleaning of fill and drift-eliminating media.
- Reduced sulfate in wastewater discharge because of decreased use of sulfuric acid.
- Ability to maintain higher pH in cooling tower, because $ClO_2$ is not pH-dependent.

Even better, staff achieved these outstanding results while establishing safe, environmentally sustainable conditions by eliminating the use of the following chemicals in the tower's recirculating water system:

- Sodium hypochlorite.
- Activated bromine.
- Two non-oxidizing biocides (algicides).

Personnel also noted that switching to $ClO_2$ generation reduced corrosion in the system by raising the tower pH and contributing less sulfates and chlorides.

**Project participant:** Jim Barrett



# New Harquahala

## Emergency response binder facilitates incident reporting

**Challenge.** Powerplants have numerous reporting guidelines and protocols when it comes to safety, environmental, and specific emergent situations. New Harquahala Generating Co (NHGC) is no different in that regard. Locating the documents and making sure everyone knows where all of the necessary procedures, guidelines, and flowcharts are located can be challenging.

This is especially true when new employees are involved and/or the process is not often used. It is critical when the facility is in the midst of an emergent situation when you need clarity as to the process necessary and location of the guideline information.

Having defined locations and quick access to the necessary material makes a serious event successful and much easier to manage correctly, particularly when the event happens at times with minimal staff available.

**Solution.** A binder containing guidelines for necessary actions—including:

- Contact information for NAES, owners, plant personnel, sabotage or bomb threat, EMS, fire, and spill response organizations.
- Emergency response call form and event log.
- Bomb threat checklist and procedure.
- Spill response procedure.
- Fire response procedure.
- Injury response procedure.
- Plant-specific incident flowchart.

The binder is specific to the plant and identified by color coding to differentiate from other materials. Copies of the binder are located throughout the facility at all phone locations and updated as necessary and reviewed annually for edits.

**Results.** For hands-on training, the binders have been used during plant drills and exercises, proving to be a valuable tool for clarification of necessary actions to be taken, depending on the specific emergency.

**Project participants:**
Andy Duncan, plant manager
Kim Steffen, EH&S manager
Mike Terry, compliance/training coordinator

**New Harquahala Generating Co**

*Owned by Talen Energy*

*Operated by NAES Corp*

1080-MW, gas-fired, three 1 × 1 combined cycles (501G) located in Tonopah, Ariz

**Plant manager:** Andy Duncan

# Fremont

## Combustion-turbine solenoid-valve relocation

**AMP Fremont Energy Center**

*Owned by American Municipal Power*

*Operated by NAES Corp*

703-MW, gas-fired, 2 x 1 combined cycle located in Fremont, Ohio

**Plant manager:** Craig Bonesteel

**Challenge.** The plant was built in the early 2000s and remained in some state of lay-up until it went commercial in January 2012. The Siemens 501F machines responded as expected and provided much needed relief to MISO and PJM markets. Their efficient design and cookie cutter compartmentalization make the 501F machine a desirable machine in the heavy industrial combustion turbine market. It is also what can create unforeseen problems for operations and maintenance personnel.

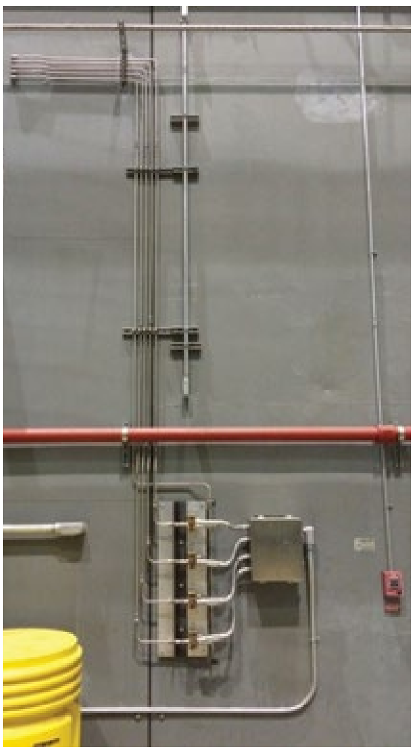
The fuel-gas solenoid valves (pilot, OST and SOV) were installed inside the gas turbine compartment at the upper right-hand side. The solenoid-valve temperatures, as indicated with thermal imaging, in that part of the compartment can reach 300F. These high temperatures caused multiple solenoid valve failures.

As indicated in the CMMS system and according to other information, on average, the maintenance technicians were replacing one solenoid per machine per month. These DC, high temp solenoids on average had a cost of about $800. The cost alone, based on historical data, means the plant spent in excess of $40,000 in replacement valves.

**Solution.** The maintenance team, plant engineer, and O&M manager decided to move the solenoids outside of the compartment. Using the existing taps, the maintenance team ran piping directly out of the compartment and down to a mount on the right side of the compartment (photo). The power source for the solenoids, likewise, was rerouted in the same way.

**Results.** Relocating the gas-turbine solenoid valves outside the enclosure reduces the risk of premature failure from overheating. To date, since moving the solenoid valves, there have been zero failures.

**Project participants:** Ed Malone, Josh James, Josh Lidstrom, George Danko, and Michael Bement




**Lea Power Partners LLC**

*Owned by FREIF North American Power I LLC*

*Operated by Consolidated Asset Management Services*

604-MW, gas-fired, 2 × 1 combined cycle (501F) located in Hobbs, NM

**Plant manager:** Roger Schnabel

# Cooler enhancement for instrument air compressor

**Challenge.** Lea Power Partners' combined cycle was designed with dozens of air-operated valves (AOVs) to enable reliable remote valve operation; two 100%-capacity, 407-cfm compressors provide instrument air for AOV operation. The compressors were susceptible to shut down on high temperature in summer, interrupting air flow to the AOVs and potentially tripping the plant.

**Solution.** Staff purchased and installed radiators for the air compressors, tapping into the existing plant chilled water system for cooling water. Fans were installed in front of the radiators, shrouds were fabricated to maximize air flow across the radiators.

**Results.** Chilled water flowing through the radiators in summer has reduced the operating temperature of the compressors, eliminating high-temperature trips.

**Project participants:**
Roger Schnabel, plant manager
Richard Shaw, O&M supervisor
Kelvin Mendenhall, senior mechanical tech

# Cybersecurity safeguards prevent control-system breaches

**Challenge.** Cybersecurity attacks on powerplant computers and PLCs from hackers have been increasing each year. Flash drives, DVDs, and CDs used by plant personnel and contractors were bypassing the firewalls set up to protect the computer servers used for the plant's DCS and for systems recording operational data and storing files—such as for a continuous emissions monitoring system (CEMS)..

These devices may be carrying malware capable of disabling plant systems or allowing hackers to control them. Additionally, the design of the stick flash drive is such that it could be filled with a bank of capacitors that when inserted into a USB port, could charge the capacitors and allow a large capacitance discharge that could destroy a server's hard drive.

Contractors must be allowed to access the plant's servers for collection of data during testing. Data collected on portable media could be sensitive and must be protected should a flash drive be lost with encryption and password protection.

**Solution.** To protect the plant's vulnerable digital systems from being manipulated by hackers, a variety of safeguards have been implemented at Lea:

- Allow use onsite of only one specific kind of flash drive.
- Train all contractors and site personnel on the use and design of this specific flash drive, so they can identify it by sight and prevent another type of flash drive from being used.
- Train all personnel on the encryption of files stored on the designated flash drive to protect data in case a flash drive is lost.
- Set up kiosks to verify that the flash drives, DVDs, or CDs that will be used on the plant's servers are malware-free before using them.

**Results.** Hackers are prevented from interfering with critical computer servers.

**Project participant:** Michael Barnett, regulatory specialist

# GT upgrade yields significant operational improvements

**Challenge.** Improve plant output and efficiency to meet a growing need for gas-fired combined-cycle power.

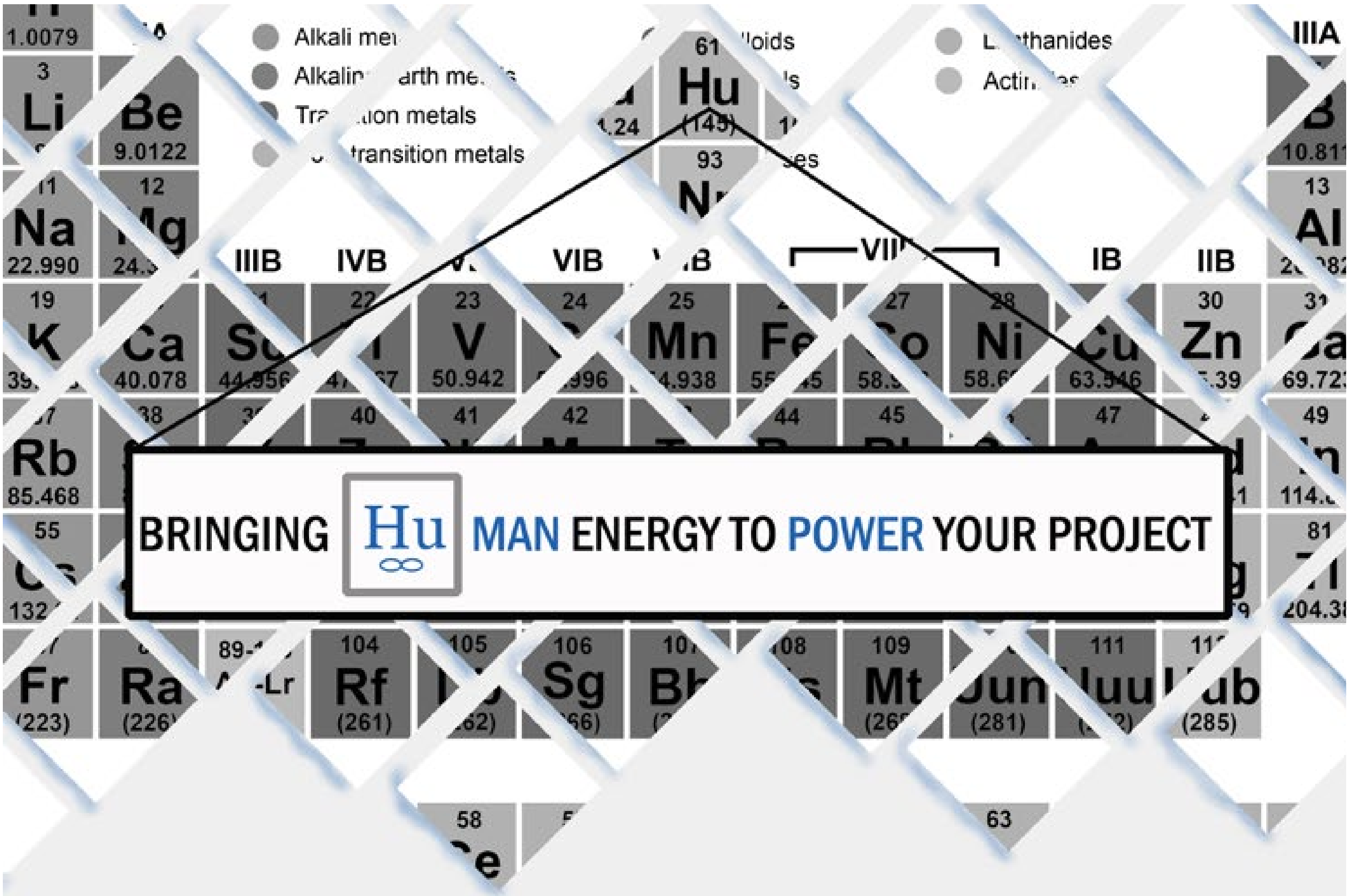
**Solution.** During a scheduled gas-turbine major inspection (MI), Lea Power Partners engaged OEM Mitsubishi Hitachi Power Systems Americas to install the company's F4 upgrade on Lea's two M501F GTs. The upgrade includes an advanced thermal barrier coating and a new cooling design for Row 1 and R2 turbine blades and vanes to increase power output.

R1 compressor blades also were replaced during the scheduled MI, upgrading the existing double-circular-arc airfoil design with the latest multi-circular-arc design.

**Results:**

- Improved simple-cycle output by an average of 7%.
- Improved the simple-cycle heat rate by an average of 1.5%.
- Improved combined-cycle output by 3.25%.
- Improved combined-cycle efficiency by reducing net plant heat rate by 2%.

**Project participants:**
Roger Schnabel, plant manager
Richard Shaw, O&M supervisor
David Baugh, asset manager
Todd Witwer, EVP western operations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# GRID TODAY

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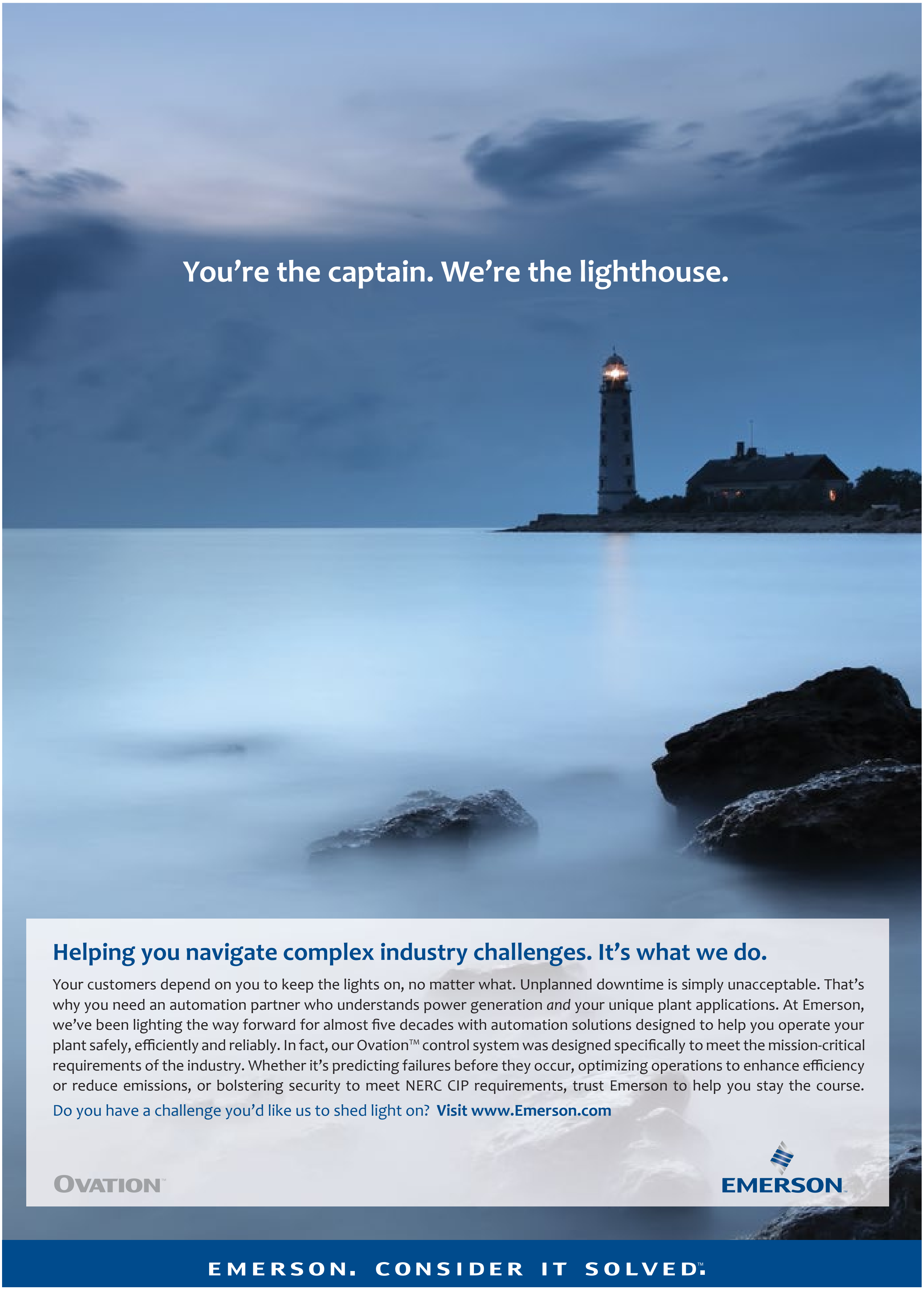
# The transactional nature of today's electric power industry

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# Paradigm shift—from 'big iron' to the distribution end of the value chain

Writing about the future of electricity grid operations under a new presidential administration and Congress may be fraught with foolishness. However, several broad trends are likely to continue regardless of what our new leaders decide, how angry the losing half of the electorate is, or how the new opposition party plays its losing hand.

First, the de-carbonization of the generating fleet is continuing. This is a no-brainer. It's been happening for over one hundred years, though in fits and starts. Coal units are being shuttered and the capacity is being replaced with variable renewable generation and gas-fired units. It would be better if less of that de-carbonization lately wasn't at the expense of economic growth.

Second, with the exception of EPA's Clean Power Plan, now before a Supreme Court minus one justice, and the agency's legacy Clean Air Act Amendments, energy policy is largely being driven at the state level. Reliably "blue" states are pushing de-carbonization harder than reliably red states.

The third trend is perhaps the most critical. Grid operations are becoming more dynamic and less certain. Use whatever buzzy phrases you like—smart grid, transactional grid, "grid-edge" technologies, distributed energy resources (DER), resilient grid, microgrids, customer-centric grid, demand side management, flexible energy resources, variable energy resources—they all add up to something far less predictable in real time than the "big iron" centralized approach to grid buildout and operations under a regulated monopoly.

After spending a day attending my new local utility's Integrated Resource Plan (IRP) stakeholder meeting, I decided to amuse myself by reviewing the IRPs or long-range asset plans for every utility in every other place I've lived. It's a geographically diverse set of plans. I added a few others for good measure.

The common threads are pitifully low demand growth, displacement of coal assets by renewable and gas-fired facilities, need to maintain reserve margins, threats of nuclear-unit and baseload-plant closures, and reducing carbon intensity.

I was more struck by the anemic *aggregate* attitude towards the three things that arguably will change the future of grid operations the most—DER, energy storage, and electric- vehicle infrastructure. The reason is obvious, I suppose: Utilities live and die by the regulatory compact and all three of these growth drivers and areas for potential returns on investment are fraught with regulatory uncertainty.

At a Technology and Transportation Summit a few weeks ago, I proclaimed, "If the state commission would allow electric utilities an 8% to 12% regulated rate of return on investments in electric-vehicle infrastructure, you'd see EVs and charging stations everywhere!" The same holds true of storage and DER.

Grid-scale and behind-the-meter storage is the one asset class across the production and delivery value chain which can manage the dynamics of the future grid, accelerate de-carbonization, advance DER, and improve resilience. Large-scale storage makes electricity like every other commodity and the grid less like a huge just-in-time inventory machine. Storage, in fact, is an asset class on the cusp of a commercial frenzy.

So what's the problem with the regulators when it comes to these exciting growth drivers? Why the "disconnects" among the commercial interests who want to sell DER, storage, and EVs, and the utilities who keenly desire new investible assets?

It's all about the playing field and the players allowed on it.

Most businesses communicate directly with their customers. Utilities are unique in that they largely have to communicate to customers and stakeholders *through* the regulatory process. Despite efforts to make this communication transparent, commissioners are either elected or appointed by elected officials. This makes the regulatory process politically charged. Communication *through* a political body is rarely expedient.

Politics is, in one sense, all about redistribution of money and opportunity. While the goal may be to "lift all boats," inevitably some sink. At this point, what's holding DER, storage, and EVs back is not technological but political. It's about who gets to "control the ball" and who gets to play. The regulated utility business model worked well for fifty years to electrify the nation and was the backbone of the "big iron" buildout we have today. But plenty of stakeholders are not interested in deploying that model for the future.

The new regulatory playing field is being established. When it's reasonably "certain," we're likely to see a feeding frenzy on the order of the merchant generation boom of 1997-2004. We're also likely to see many more new entrants on the field since the barriers to entry on the customer side are lower than on the transmission side.

Then we'll see the inevitable famine afterwards and the demise of companies that grossly oversell their future to inflate their stock prices. Enron did this a decade and a half ago and while they took down much of the merchant business with them, arguably the company, which ultimately proved a fraud, catalyzed the entire merchant sector.

In the meantime, owner/operators of existing plants have to meet more dynamic and unpredictable operating schedules, usually with fewer resources than were available last year. Our entire industry has been re-ordered over the last twenty years because customers and elected officials focused on what's coming out the stack, the *byproduct,* not the convenient and affordable *product* their lives and lifestyles depend on.

Now it's being re-ordered because new stakeholders are capturing the "mindshare" at the customer end of the business. Make no mistake. Few, outside of those who conduct self-serving surveys, are actually *asking ratepayers* what they really want. Merchant generation and competitive retail supply didn't get started because a majority of ratepayers wanted either. It got started because a group of the nation's largest industrial consumers of electricity wanted to lower their energy costs.

By the same token, DER is advancing not because throngs of ratepayers are petitioning the PUC to have control over their electricity infrastructure. Instead, new entrants with DER, energy efficiency, storage, rooftop solar, and EV products are seeking to disrupt the old order.

As all this rolls forward, the utility obligation to serve at lowest cost hasn't gone away. But as the regulatory frameworks and business models shift downstream to the distribution end of the value chain, "big iron" has to become far more malleable to make sure the lights stay on.

**Jason Makansi,**
President, Pearl Street
*Chairman, Editorial Advisory Board*

# Gas-fired peakers become 'cycling' units in the heart of baseload coal country

A visit to every power station these days elicits a story that doesn't square with a traditional understanding of the electricity industry but makes perfect sense under today's market conditions. The latest is Armstrong Energy, comprising four dual-fuel, simple-cycle GE 7FA.03 gas turbine/generators installed in 2002 and five 3-MW engine/generator sets installed last year. All four GTs have fogging units to boost capacity.

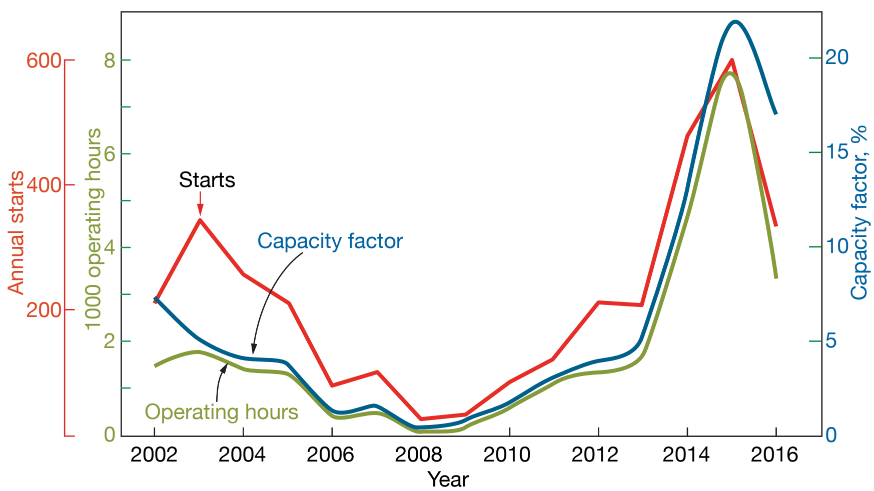
The site is less than 90 minutes northeast of Pittsburgh, in the heart of coal country, across the street from the 1700-MW (two unit, coal) Keystone Generating Station, and not far from the 1700-MW (also two unit, coal) Conemaugh Power Plant and the 1880-MW (three unit, coal) Homer City Generation LP. Also of significance, Armstrong is adjacent to a 17-billion-ft³ gas storage facility, ties in to a 500-kV transmission line half a mile away, and from the site you can see several of the gas wells drawing from what is commonly known as the Marcellus Shale.

Armstrong's original purpose as a peaking facility may be in the rear-view mirror for a long time. Dramatizing the shift in "operating tempo," Matt Denver, plant manager, pointed to a large screen of performance stats in his office showing that the four units experienced a total of 29 starts in 2008, while last year the starts increased to just shy of 600.

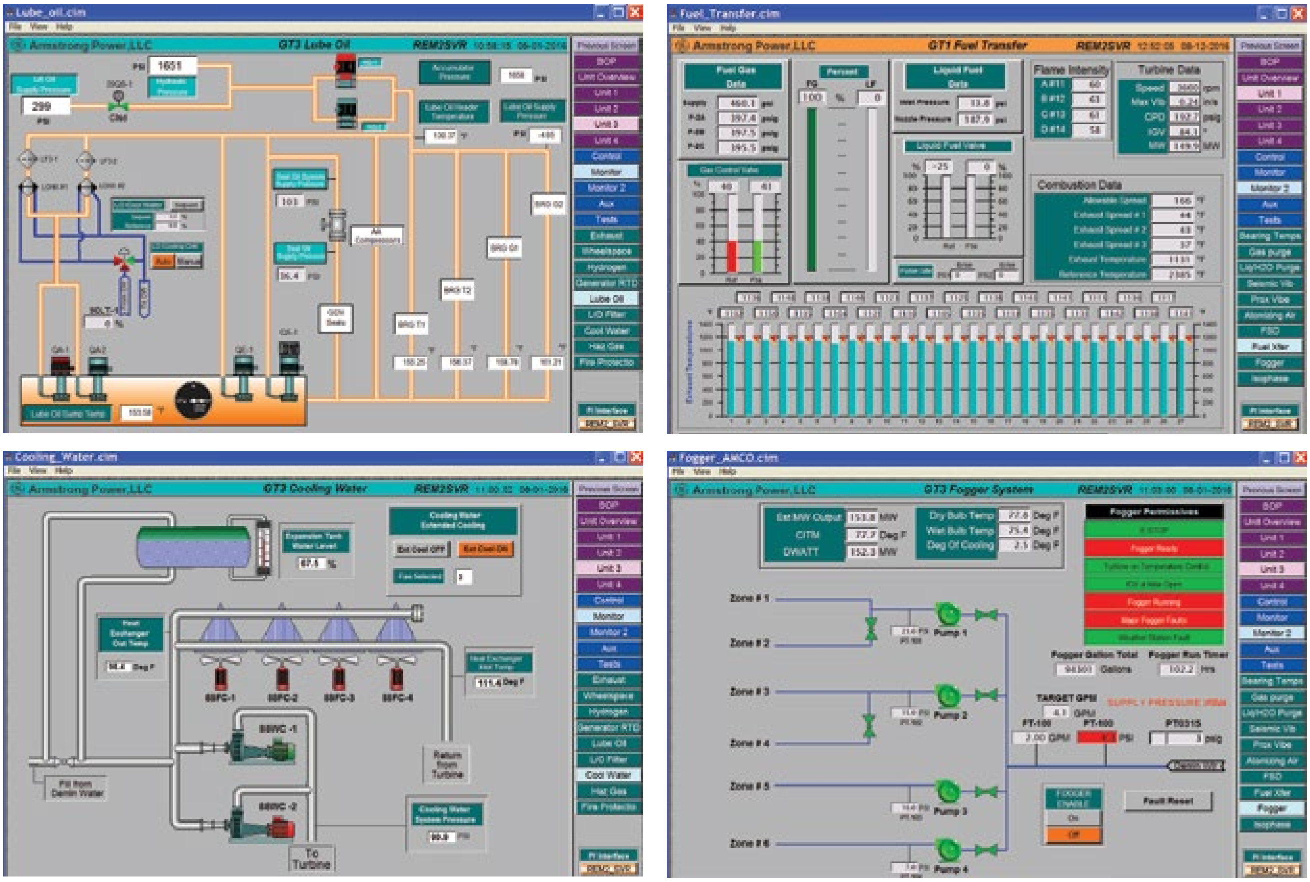
The number this year is expected to be even higher. "We've been reclassified as a cycling plant, no longer a peaker," he explained, "and typically the units run over 10 hours before shutting down—seven days a week!" In this case, cycling refers to daily start/stop. "When we are dispatched, the units run at full output," Denver said.

In any case, it's a stunning mental picture, a gas-fired GT peaking facility surrounded by large coal units dispatched at the low end of the range typical for a combined cycle (Fig 1).

In fact, the units are dispatched so often, a challenge confronting the plant is the emissions limits in the operating




**1. Armstrong Energy,** with four dual-fuel simple-cycle 7FA.03 gas turbine/generators, was designed as a peaking facility. Today it exhibits annual operating hours, capacity factor, and starts characteristic of the low end of a typical gas-fired combined-cycle range




**2. The accelerated operating tempo** has caused Armstrong staff to bolster continuous M&D capability. Screens custom-built by the plant staff in the Mark VI control and automation system are shown above for the lube-oil system (top left), cooling water (bottom left), fuel supply (top right), and inlet fogging (bottom right)

permit. "We can go to 28.8% capacity factor (CF)," Denver said, "above that, the owners have to make decisions about significant capital investment in emissions control, perhaps SCR or DLN 2.6+ mods." Even in the shoulder months of spring and fall, a couple of units are running, with the others in outage.

While most of Armstrong's output is sold into the energy market, the plant also participates in the capacity performance market. "The penalties are huge, so reliability has taken on new meaning." To be prepared when power is critical, PJM goes into what it calls a "performance assessment hour," or PAH, and has no obligation to notify the plant that one is coming. "Armstrong has 15 minutes to start up, close the breakers, and get its megawatts into the grid," Denver said.

According to PJM documents, every generating resource must comply with the requirements of its host transmission operator. "That means with no excuses." Denver elaborated: "You get bonuses for meeting PAH obligations, which are paid from the penalties charged to the non-performers."

Fuel-oil operating hours for the Armstrong units are not insignificant. Thirteen percent of the total operating time has been on oil since 2002. "These aren't just for testing of the fuel-oil systems, either," Denver stressed.

Armstrong has been deemed "critical infrastructure" by PJM (though, importantly, not by NERC), hence the addition of 15 MW of engine/generator capacity for black-start capability. "Our ability to fire fuel oil drove that expansion," Denver explained.

Under the current vagaries of the natural-gas market, much Marcellus supply is currently "shut in," meaning it either doesn't have access to transmission for delivery to distant markets or the prices are too low and demand too scant. As a result, "at times, we can get fuel for under $1.00/million Btu," said Denver. He added, "our plant is fed from the suction side of the gas storage facility across the street."

At that gas price, even simple-cycle machines apparently can *dis*place coal capacity bidding in the market and economically *re*place older, inefficient coal capacity being retired.

## Maintenance philosophy changes

"Obviously, the maintenance program has to be aligned with the new operating regime," noted Peter Margliotti, gas-turbine specialist and member of the 7F Users Group steering committee. Armstrong has a contractual services agreement with the OEM but it is starts-based, typical for peakers, he stressed.

"Today, when something breaks in one unit, we fix it in all the other units as soon as possible," he added.

Intervals between major maintenance events have been shortened. "It seems hot-gas-path (HGP) inspections are coming around the corner all the time now," Margliotti said. "We've had two HGPs with the third and fourth due within the next year. We've also done generator inspections, and we saw no dusting; they were immaculate!"

Some of the physical modifications conducted to enhance reliability under the faster operating tempo include:

- Compressor enhancement package (known as Package 3).
- Bellows modifications.
- Exhaust flex-seal upgrades.
- Fire protection system.
- Fuel-system modifications.
- Improved igniters.
- Digital generator-protection (DGP) upgrade.
- Variable-frequency drives on the cooling-water pumps.
- Fuel-oil valving improvements.

One area of significant change is in monitoring and diagnostics (M&D).

GRiD TODAY

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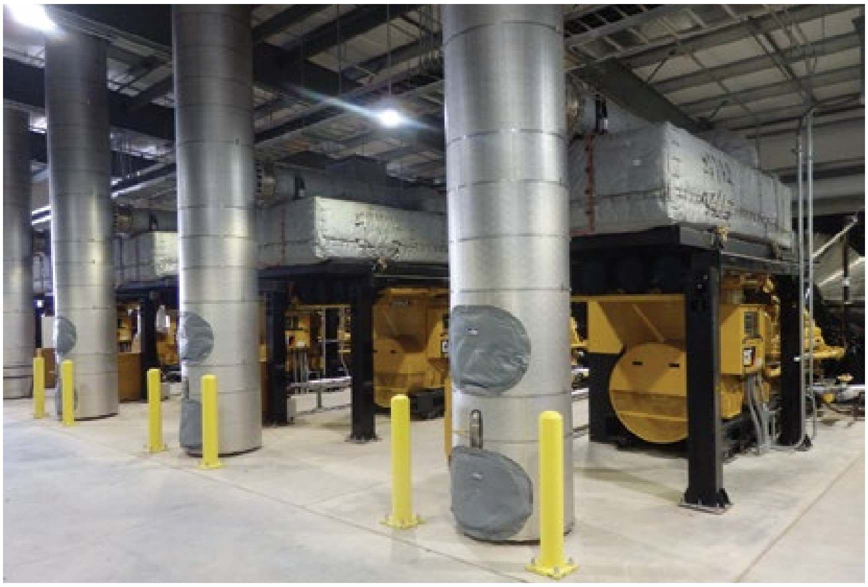
## In this issue:



**On the cover** NV Energy's 520-MW Silverhawk Generating Station sits behind the 20-MW Apex Nevada Solar project, which supplies power to the utility under a long-term agreement



**3. Armstrong added five 3-MW engine/generator sets** last year in response to PJM's RFP for new black-start units in Western Pennsylvania

"We're monitoring metallurgical creep of the blades, nozzles, and casing, and deformation issues as if we had combined cycles," Margliotti noted, "as well as remotely monitor more sub-system parameters— including lube oil, cooling water, atomizing air, fire protection system, and instrument calibrations." Margliotti and his team have designed custom screens in the Mark VI automation system for this purpose (Fig 2).

Both Margliotti and Denver credit their small, but dedicated staff for the continuing success of the plant in the face of dynamic market changes. "We haven't had a lost-time accident since inception," claimed Denver. Five of the seven permanent staff have been at the facility since commissioning. "These guys and gals are all cross-trained through our in-house developed training programs, and we manage our own outages, each GT specialist takes a turn in leading the next outage."

## Adapting to PJM's needs

Making Armstrong Power a black-start-capable station was a sizeable task. The project had an impact on many of the station's current systems.

The black-start building houses five Caterpillar C175-16 (tier 4) diesel/generator sets (Fig 3). Each unit can produce 3 MW of power at 1800 rpm and all are fed by a 2300-gal diesel storage tank located in the black-start building. A 2500-gal urea tank is used for the CEM (clean emissions module) system. There is a dual-source air compressor and dryer system installed to provide air to the CEM unit. This avoids being tied into the station instrument air system.

The motor control center houses the 4160-V breakers for all five generator sets and both bus tie breakers. The control room features touchscreen HMI that allows safe operation of the equipment by being separated from the high voltage and noise produced by the diesel/generators.

Addition of the black-start equipment completely changed the electrical operation of the station. Breakers were added to the 4160-V busses to allow for synchronization with the diesel/generators. Protection schemes for the 4160-V breakers had to be changed to allow for the new emergency mode of operation. Emergency mode enables the selected priority diesel/generators to start and automatically close into the dead 4160-V bus when loss of power to the station is detected on both incoming lines.

Two diesel/generators synchronized to the 4160-V bus can successfully pick up the load of the entire station with all four gas turbines on turning gear. That is important—if the station suffers a power loss when all four gas turbines are generating, the diesels can supply the needed power to safely return the four units to turning gear and allow the rotors to cool correctly.

Construction of the project was managed by GT Specialist Bryan Miller and occurred between December 2014 and May 2015. The majority of the foundation and underground conduit work was conducted during freezing and inclement weather. Progress was maintained by working under a giant inflatable bubble. Extensive excavation was needed for the addition of cable trays, fire protection, and fuel supply lines. The combination of frozen ground and natural limestone slabs made excavation a serious challenge. **GRiD**

**A vibrant commercial market for grid-scale storage** in the US is at least five years out, despite declining cost curves for the prevalent technology option, a supportive legislative framework in key US markets and ISOs, and so-called mega-factories ready to ship hundreds of units. Shown here is a DOE-funded demonstration project in Pennsylvania

# Regulators, ISOs set the table; suppliers served few orders

*Editor's Note: The status report below draws broad insight from a consultant's engagement with high-level representatives from countries interested in US grid-scale storage technologies, regulations, and applications—including attendance at the Energy Storage Association's 2016 Conference in Charlotte, NC, April 25-28, plus meetings with US storage system suppliers, California utilities, CAISO, and other stakeholders.*

What is clear from being immersed in the grid-scale storage space (here *not* addressing behind-the-meter storage) for 10 days is that state and federal regulators in key states and regions, along with the respective organized-market independent system operators (ISOs) and regional transmission organizations (RTOs), have laid the foundation for grid-scale storage to compete against traditional options for supplying grid services. In California, there is more than a foundation; there is a mandate for a modest amount of storage capacity to be procured, as well as multiple pieces of legislation supporting grid-scale storage.

The importance of this regulatory framework in the electric-power industry should never be under-estimated.

Unfortunately, the viability of storage options—whether technical, commercial, economic, lifecycle, safety, and reliability, or otherwise—is still being called into question by the utilities charged with integrating storage into the grid. And the market for new grid assets, in general, is questionable in the near term given persistent and historically low electricity demand in most regions and lackluster economic growth.

Bottom line: Storage still lacks *replicable, compelling payback-driven* applications to attract either private or regulated-rate-of-return financing. The goal, after all, isn't a market the size of one or two typical combined-cycle plants annually, which is what the total market size is today. This, despite the fact that cost for the prevailing technology, the variety of batteries classified as lithium-ion, keeps plummeting and, according to one report, only 40% of the world's manufacturing capacity is currently being utilized.

One California utility specialist conceded that, if not for the mandate, there are less expensive ways to provide the same services. Another utility in the state, involved in multiple distributed and bulk-storage pilot, demonstration, and assessment projects, reported that storage "is not expected to be an attractive commercial investment until the 2025-2030 time frame." Yet the mandate requires the state's three investor-owned utilities (IOUs) to install over 1300 MW of storage by 2020.

If that's the sentiment in what everyone agrees is the *most* attractive state for grid-scale storage, system suppliers which have invested in hundreds of thousands of square feet of manufacturing space may be sitting with idle assembly lines for years to come, unless behind-the-meter installations dominate in the near-term.

Leaders of a pre-conference workshop at this year's Energy Storage Association (ESA) meeting identified and elaborated on the multiple value streams available for developers to monetize a storage asset. FERC has weighed in positively through several rulemakings to support use of storage for a variety of ancillary services among the ISOs and RTOs.

Congressional legislation now allows storage paired with solar to qualify for a generous investment tax credit (ITC). That should have been music in the ears of the prominent solar developers who started pursuing storage with gusto a few years ago, except several of them are facing insolvency and corporate restructuring.

**DOE-funded demonstration project** in Texas pairs wind with large-scale storage

The California ISO (CAISO) offers ancillary-services payments (spin, non-spin), regulation up and down, resource-adequacy type capacity payments, and proxy demand response; a flexible ramping product is coming. PJM has Reg-D frequency regulation payments as well as capacity payments for non-generating resources. The Midcontinent ISO Inc (MISO) allows for short duration "stored energy resources" and a flexible ramping product is imminent. Storage is thought to be ideal for providing short- and long-duration cycle ramping.

NYISO and ISO New England Inc both have created means for storage participation. Hawaii wants fully dispatchable solar (accomplished by pairing solar with storage) to displace diesel generation. Oregon has also passed legislation requiring utilities in the state to begin procuring initial storage capacity by 2020; New York may not be far behind.

The seminal challenge is that, beyond the mandates, none of these value streams typically can support a storage asset investment. Even "stacking" multiple value streams rarely vaults the threshold for financial viability.

Broad technical challenges still loom, at least from the owner/operator perspective. System integration is one. Control and communications systems are another. One R&D-oriented stakeholder noted that control systems are "a focus of industry efforts today." An OEM, which supplies everything to a storage system *but* the battery, stated that inverter technology must be optimized. "All inverters respond differently to the grid," a company specialist said, "and the more inverters there are, the greater chance that they will interfere with each other."

Safety and lifecycle issues are paramount with owner/operators. One utility representative reported that the availability of the storage system (including power electronics, telecommunications devices, wireless communications, etc) for an all-solar home demonstration program was "abysmal." That's not a word you hear very often in public-utility presentations on technology.

Another utility hired an independent consulting company to evaluate safety issues for each storage system "offer." Apparently, in California, the CPUC has no authority over a third-party storage provider. Thus, it falls on the utility to make sure a storage asset doesn't take out the grid, or a large chunk of it, or a neighborhood.

One grid-scale storage specialist points to two landmark projects which could accelerate the pace towards a viable commercial market: a 100-MW (400-MWh) battery project in Southern California serving as the equivalent of a peaking gas-turbine unit, and a 52-MWh project in Hawaii serving as "fully dispatchable solar power." Success would demonstrate technical and financial viability in two well-recognized use cases. However, the peaker displacement project is not scheduled to be online for another five years. The dispatchable solar project could be online much sooner.

Other trends present opportunities. For example, in California, the energy portion of the average utility bill is declining or stable, but demand charges are rising. This presents an opportunity for storage to shave peaks and reduce demand charges. One company's business model is designed around reducing demand charges using storage and automated load shedding at the site, and sharing the savings with the customer.

The recently passed Assembly Bill (AB) 327 has removed legacy ratemaking rules resulting from the California energy crisis of 2000-2001, and has rationalized rules pertaining to net metering, renewable incentives, and who pays and how much to maintain the grid for all ratepayers. AB327 also requires the state's utilities to develop and submit plans for developing distributed energy resources—including storage.

Although it is not clear who ultimately wins or loses as AB327 is implemented, what is clear is that the state is driving a distributed-energy paradigm over the traditional centralized "big-iron and long wires" approach of the last century.

Here's another dichotomy: The state's utilities repeatedly find that bulk energy storage, pumped hydroelectric (PHS), and compressed-air energy storage (CAES), are economically viable but the "push," as one director called it, is towards small distributed-energy systems and the "deployment of new technologies." Nevertheless, this utility expects a move to a bulk storage project within five years, although it could be CAES, PHS, or a large flow battery.

Utilities in the vanguard of storage deployments and investment hail the present as the time to "try" new technologies. Utilities use words like "learning," "understanding," "long-term," and "strategic investment" when describing their programs and investments in energy storage. Suppliers, on the other hand, need to feed the beasts of their mega-factories now.

While California's AB2514 legislation (the "storage mandate" bill) requires IOUs to procure 2% of their peak load as storage (1% for the municipals and irrigation districts), there are caveats in the bill regarding cost-effectiveness. One might interpret this as a potential "off-ramp" for utilities. But it's not that easy, noted one utility spokesperson.

The California Public Utility Commission (CPUC) is obligated to conduct an independent evaluation of cost and benefits as a "second opinion" and reportedly can impose penalties on the utility depending on what they conclude. Also, if other utilities find a technology economic, then the case for the utility which concluded the opposite is weakened.

Those sitting on vast manufacturing capacity, most of them lithium-ion battery suppliers, may have another challenge when the market finally hits that mythical knee in the curve: competition from other technologies. Advanced flywheels, a plethora of flow-battery chemistry systems, better lithium-ion options, advanced lead-acid batteries, and systems which combine batteries and ultra-capacitors are all on the cusp of breaking through the demonstration phase and into commercial applications.

Finally, if a commercial grid-scale storage market is struggling to emerge in the US, then it is embryonic in most other parts of the world, with the exception of Europe, China, and other developed countries like Japan, Korea, and South Africa. Countries like Brazil, Jordan, India, and others with ambitious renewable capacity additions are just now getting acquainted with grid-scale storage.

It might be surprising to learn, for example, that a major utility in India is targeting one-third of its generation to be renewable-energy based within a decade or so. The country in general faces a 2% deficit in energy and 3% deficit between peak demand and capacity. Jordan seeks 10% of its electricity to be supplied by renewable resources by 2020.

Significant wind capacity is being added in Brazil, where in the northern part of the country wind capacity factors can be between 50% and 70%. Unfortunately, the population centers are to the south where, according to a spokesperson, the wind characteristics are "completely different." This creates a potential need for massive amounts of storage, the spokesperson indicating that the logical option would be at least 2000 MW of PHS.

In sum, let's just say, in the US anyway, there are "seams issues" among the owner/operators who have modest expectations and needs *at best* for the next five years, regulators and ISO officials who have diligently legislated the grid-scale storage opportunity over the last 10 years, and suppliers which have built out manufacturing capacity for orders they needed yesterday. **GRiD**

## DG: When the merely viable becomes the truly commercial

It is clear that the regulatory framework is evolving rapidly for distributed generation (DG) and the "transactional grid" to challenge, or perhaps more appropriately, complement the traditional centralized "big iron," one-way paradigm of the last century.

However, there's another critical hurdle which must be overcome. DG has to evolve from a vast suite of *viable* and cost-effective technologies to a few suppliers of engineered systems, based on a dominant design, providing warranties expected by purchasers. In other words, DG has to become truly *commercial*, not merely viable.

Large gas turbines are an excellent analogy. They were viable and cost-effective many years before approximately 200,000 MW of these machines, in simple cycle and combined cycle, were added to the US electric system during the 2000-2005 "bubble." At that point, there were essentially four major suppliers and a dominant design based on can-annular combustion systems.

While indications are that lithium-ion technology could be the dominant grid-scale distributed- storage platform, this is far from a foregone conclusion. A dominant microgrid platform doesn't yet exist.

This is critical because purchasers, whether under the regulated-rate-of-return utility model or private investment, have to minimize operational/lifecycle risk.

That doesn't happen overnight. And it doesn't end. Even before the industry's large-gas-turbine feeding frenzy subsided, vibrant user groups were established around every major gas-turbine design platform. Participants actively manage operational and lifecycle risk by sharing experiences as a fleet, just with different owners.

Reports from owner/operators on actual field experience with DG systems paint a different picture than those from the advocacy wing of the business. One of the most recent, based on a three-year battery demonstration program in California, listed, among others, these broad operational issues:

- Pricing differentials between charging and discharging were not high enough to offset the round-trip efficiency of the battery system, around 75%.
- Charging rates and the battery's state of charge (SOC) interfered with ISO bidding.
- Managing the financial impact of the system's parasitic loads was a challenge throughout the project.
- There was a significant learning curve between the ISO and the owner/operator regarding SOC assumptions which ultimately required changes to tariff construction.
- Problems with the software the ISO was using to dispatch the facility had to be resolved.

The report also concluded that, while the battery technology demonstrated would be classified as "long duration," current market dynamics do not favor this technology class.

Grid-scale storage is a seminal transactional, two-way asset class. However, the experience summarized above shows that the "two-way" aspects of operations are the most problematic. It is also typical; review of many other reports on storage field experience, and presentations at industry events, reveals similar challenges.

Interestingly, the transactional aspects are a primary technical barrier for microgrids. A presentation by officials from the California Energy Commission at a microgrid workshop in May concluded, through industry survey efforts, that "technical barriers related to interoperability of technologies and components from different vendors using varying control and communications protocols in new and legacy systems requires a high degree of customization." Interconnection issues were also diverse and complex.

For this reason, forming user groups around grid-scale DG systems may be appropriate, as a start to share experiences with integrating these systems into ISO bidding and operating procedures; control, communications, and SCADA platform functionality; reliability standards; grid interconnection; and other aspects. As dominant designs emerge, splinter user groups can form around specific systems or OEM platforms.

Other reasons for organizing user groups sooner rather than later:

- Most DG grid-scale storage technologies have catastrophic-events issues, especially thermal runaway and fire risks, which must be addressed.
- Most utilities that have evaluated grid-scale storage have not found compelling use cases or economics.
- Many systems are being supplied from Asia; quality control and supply chain oversight are areas that can be explored immediately.
- Most microgrids are still custom one-off efforts; value and systems engineering could benefit from early user engagement.

# Is the plant worth the price? Due diligence 'gotchas'

By Jeff Schroeter, EnEx Advisors

**Due diligence** around combined cycle plant transactions has become far more complicated today as markets become more dynamic and investment horizons shorten

What does the legal term "due diligence" really mean? One thing is for sure: The diligence period before closing the sale means buyer beware, or *caveat emptor*. During this period, the buyer is entitled to research the true value of an asset *from the buyer's perspective*.

We all like to get a great deal. We all can get passionate about the new purchase. We've all shopped for a home or a car, and it's easy to let our emotional side get the better of our rational side. We want to believe what the seller (or the agent) has told us, the crack in the wall is cosmetic, not structural, or the wheezing sound from the engine has been there since it was brand new.

But a $100+ million combined-cycle powerplant is not a used car, or even a house, though the same healthy skepticism should prevail. Typically, owners make only the bare minimum investments in an asset they plan to sell. Due diligence (DD) is the buyer's opportunity to adjust the purchase price, or at least understand the risk factors, before money changes hands. But the dynamics of today's power industry has made the DD period much more challenging.

## Transactional industry

Powerplants change owners frequently. Many of these transactions are caused by the merchant nature of power markets like Ercot, CAISO, or PJM. Another reason is that private equity funds have very specific buy and hold horizons, often as short as six to 10 years. Many combined cycles commissioned around the Y2K timeframe are now on their second or third owners, some on their fourth or fifth!

Many factors determine asset value: physical location within a power market (localized congestion value), a long-term power purchase agreement (less merchant risk of production revenue), long-term service agreement around major components (gas and steam turbines), and plant safety record. But other factors not as transparent to plant staff affect plant value as well—including fuel supply agreement and pending environmental restrictions. Buyers want to be assured of paying a fair market price for a flexible asset that can adjust to market changes.

Today, the DD assessment is complicated by a host of additional factors. Peaking gas-turbine plants are experiencing rising capacity factors because of the favorable prices and projections for natural gas. Combined cycles designed to displace coal back in the 1997-2003 time period were quickly relegated to low-capacity-factor duty as the price of natural gas shot up.

More recently, after gas prices moderated and compliance costs for coal ballooned, gas-fired combined-cycle capacity has been displacing baseload coal in many parts of the country. And grid operators are constantly introducing new rules and regulations to balance competitive market procurement of services with reliability of service.

## Eight areas of concern

The DD period, often about 60-120 days, is an opportunity for a prospective buyer to review all asset records, contracts, permits, and legal commitments. DD team members should include engineers, attorneys, environmental scientists, project finance modelers, and investment bankers. This team's only mission is, simply, to assure that the purchaser knows what he/she is buying, identify all risk factors, and adjust the asking price accordingly.

Today, your team should have *specific and deep* expertise in the following areas:

- The markets involved.
- The model series of equipment and its current condition, including repair cycles.
- The regulatory and compliance envelope the plant has to function within.
- Dynamic grid operations and financial models which account for hourly and even sub-hourly pricing and bid opportunities.
- O&M contracts, both from the legal and O&M perspectives.
- Fuel delivery and supply.
- Real estate and commercial issues.
- Insurance requirements.
- Staffing and training.
- Controls, monitoring, and diagnostics.
- Automation and knowledge management platforms prevalent at power stations.

**Deferred maintenance,** especially around the gas and steam turbines, probably is one of the largest and obvious areas of concern, but not necessarily easy to quantify. This is more of an issue in the merchant markets where long-term Power Purchase Agreements (PPAs) do not exist. In Ercot, for example, average term of thermal-plant sales contracts are about four to seven years. A 15-year-old project may have delayed major expenses which would mean the new owner would have to pay for them much sooner than expected.

A complicating factor in assessing deferred maintenance is the plethora of machines which have come off of their original OEM service agreements, the varied repair companies and repair techniques now being widely applied, and the changing operating regimes and owner/operators. Repair techniques are aligned with remaining life of the components and current operating duty. Some may not be fully proven.

In addition, while there may be maintenance records for review, the staff and owner may have relied heavily on outside expertise. Finding these experts and interviewing them, or hiring people for the DD team who can assess the work, may be difficult.

**Reviewing remaining cyclic life** of the equipment is also a key area for evaluation. Most fossil-fired powerplants constructed in the last 50 years were designed as baseload units. As markets shift or newer, more efficient plants enter service, the operating profile tends to change.

Two areas of concern are HRSG life and SCR/CO catalyst life, which naturally receive less attention than the primary turbine/generators. Repairs or replacements in these areas can be major items which must be planned for years in advance.

**Real estate issues,** such as the land title and environmental contamination, should be assessed for additional insurance against defects or unknown risks. These are important to mention because much of the DD work tends to be centered on the major equipment. If new debt is being placed on the project, the new owner must factor in the cost for changes to insurance premiums.

**Spare equipment inventory** is a major consideration. For example, does the plant have a spare boiler feed pump in its warehouse? What is the contingency plan to deal with a failure of a step-up transformer? Generally, utility-owned plants carry more major equipment spares than merchant or IPP facilities. The old adage, "you don't invest in something you're planning to sell," comes into play.

**Asset management contracts** are usually transitioned and then renegotiated with the new owner. Be sure that the transition process does not disrupt cash flow and opportunities for selling power on the grid, especially if in a merchant market. Similarly, O&M contracts are often under a five-year renewal cycle. Many members of the existing plant labor force will often be retained by the new contractor which may, however, bring in a new plant manager. Given the M&A activity with OEMs and service firms, sorting out these contracts will be anything but straightforward.

By contrast, Contractual Services Agreements (CSAs) often are *not* renegotiated and are just assumed by the new owner. This usually is a net positive for equipment availability but it can have a negative cost effect if the agreement was based on an obsolete operating regime. An example is an agreement that only allows × starts per year without expensive overage charges because that is what the unit was doing years ago. In the current market, the plant may need to start 2× times annually. The cost implications of a contract adjustment for the new owner could be a potential "drag" on profitability.

**Energy delivery** contracts often are renewed or renegotiated by the new owners. Major changes only would be warranted because of poor performance or excessive fees. However, participation in most ISO and RTO markets around the country only gets more complicated. Grid operators constantly struggle with ensuring reliability while opening up more grid services to greater competitive forces.

Transmission reservations with wires companies may have a huge effect on plant profitability if the plant now operates fewer hours. There are examples of this being a significant cost, particularly in the CAISO market. Also in this category are the various NERC and FERC reliability and cybersecurity compliance issues, which also only get more complicated year to year.

Depending on the state and market ISO/RTO, a return to a regulated power market for a plant with an expired PPA can significantly impair its value. In some markets, the buyer of last resort is the local utility which may not even want a contract with the plant. A corollary to this issue is when a gas-fired plant finds itself in a fast-growing renewable energy market. In this case, annual energy production may be far less than expected.

**Fuel transportation** contracts should be reviewed based on the expected operation envelope of the project. Some peaking projects may have significant annual transportation reservation charges or imbalance penalties which could affect bottom-line revenue. The new owner may decide to add a second gas connection to the plant to obtain a more competitive transportation deal.

**Controls, automation,** and knowledge management platform is a final area where DD assessment gaps are likely to persist. Digital and wireless technology is advancing rapidly—much more rapidly than the physical equipment. The wise buyer will pay as much attention to how the plant is, and will be, monitored and automated, and how data and knowledge are captured, disseminated, processed, and used in decision making; cybersecurity and grid security issues; and the interaction of staff with the automation and training platform. The fact is, today much less expertise actually resides at the plant, instead being dispersed throughout what some call the "meta-organization."

Other broad areas for attention include environmental attributes and compliance with air, water, and solid-waste regulations; taxes, subsidies, and government incentives; and qualitative values such as community relations and labor relationships. **GRID**

### About the author

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## Co-ops and DG: You want it, we'll build it

Before the advent of competition, electric utilities collaborated all the time. Electric cooperatives still do. They form cooperatives for everything. The cooperative model was created when it became clear early in the electric industry's history that the investor-owned utility (IOU) model couldn't shake enough profit from the trees in the hinterlands.

Rarely do cooperatives go it alone, especially on national policy issues. As an example, unlike IOUs, every state has a cooperative association looking after common issues below the national level.

Most co-ops are, literally, wed to their G&T. They are governed by "all-requirement" supply contracts, with a 5% to 10% exemption here and there for renewables. The G&T guarantees the loan from the Rural Utility Services with those contracts. For this reason, distribution co-ops frequently look askance at renewable *mandates* because they tend to strand generation assets already under contract. But it's important not to confuse the mandate with the resource.

Wind, for example, tends to huff at the wrong time of day. Co-ops solve that problem by using wind-generated electricity to heat hot water off peak. Hundreds of thousands of such units constitute a giant thermal battery.

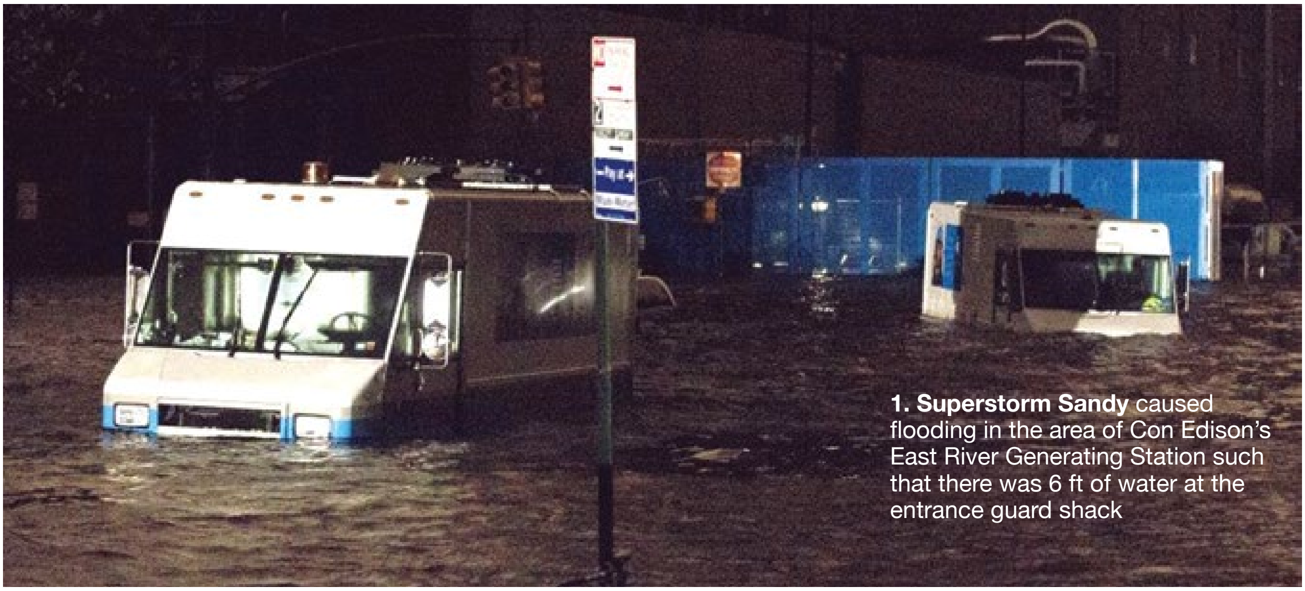
Solar DG is a bit different. It can function as demand side management, a way for co-ops to peak-shave.

Co-ops like community solar, or solar gardens, which they sell on a subscription basis, usually in watts; the "planting" is in 40-kW increments. Doing so can accommodate some 80% of homes unsuitable for rooftop PV.

Co-ops loathe making members pay for something they don't want, another difference with the IOU; the latter knocks back a healthy return on investment (ROI) for capital projects and can, in effect, bill the ratepayer a second time for kilowatts supplied.

When you serve a small number of ratepayers, each voice is amplified. Co-ops strive to treat every member fairly. Providing renewables on a "you-want-it-we'll-build it" model has worked well. Some IOUs have become, in effect, regulated distribution companies (discos). But that doesn't mean their customers are going to be any happier about paying for something they don't want.

**Mark Glaess,** Consultant
GRiD Editorial Advisory Board



1. **Superstorm Sandy** caused flooding in the area of Con Edison's East River Generating Station such that there was 6 ft of water at the entrance guard shack

# New practices for resiliency: Con Edison and Superstorm Sandy

More frequent catastrophic events, weather-related or otherwise, are becoming a fact of life for generating facilities. When they occur, they focus the collective mind on minimizing the impacts from the next one. At Consolidated Edison Co of NY Inc's East River Generating Station, recovering from "Superstorm Sandy" (Fig 1) offers some lessons learned and new practices for resiliency.

Sandy resulted in all manner of new concepts and "big think" projects for protecting Manhattan and the rest of the city from (1) incrementally rising seawater levels and (2) more frequent and more severe storms. Both are thought to be the projected consequences from long-term changes in global climate.

Manhattan of course is unique, for obvious and not so obvious reasons. In the latter category are the facts that it is a constrained load pocket with respect to electricity delivery and much of its infrastructure is relatively old. Let's


2. **Moats around critical equipment** at basement level were raised by more than 2 ft (left); moats were added in other areas—such as around control cabinets (right)

just say that adding, refurbishing, or replacing infrastructure in Manhattan is in a class by itself when it comes to complexity, permits, and regulations. Imagine trying to build a new powerplant on the island. Thus, existing, "close in" sites like East River become that much more valuable and critical.

The plant not only supplies 700 MW of electricity into one of the country's most critical load pockets, but also 50%, or 5.8-million lb/hr to Manhattan's extensive steam network, one of the largest in the world. Eight 345-kV transmission feeders tie into the plant, an indication of East River's central role in the city's electricity delivery.

Although the plant dates back to 1926, it was repowered and expanded in 2005 with two GE 7FA.03 gas turbines and two 600-psig heat-recovery steam generators (HRSGs), said to include the largest duct burners in the world. Five packaged boilers also were installed around 2001 and two older units—including one 1500-psig and one 1800-psig unit—still operate. The gas turbines were later upgraded to 7FA.04s which raised efficiency by 2.5% and output by 12 MW per unit.

The 7FAs at East River are baseload units because, like many cogeneration plants, electricity is a byproduct of steam production. Flexibility to produce both is paramount. The huge duct burners allow greater steam production, which is critical during the peak cold winter season. The boilers and HRSGs are dual-fuel; the plant has 15-million gallons of fuel oil stored at the site. Steam first enters a massive ring header before it heads out through distribution mains to the network. No condensate is recovered which makes water treatment that much more complex.

## Sandy strikes

It was the rapidity of the storm "surge" as much as the delta height of the breach which combined to force the plant offline during Sandy. "There was six feet of water in the guard shack area at the entrance to the plant, and much critical equipment in the basement was immersed in three and a half feet of water at the apex of the surge," said Michael Brown, plant manager. Basement level at the plant is 4.5 ft above river water level.

The plant is located in the lowest flood zone of the borough. Even though the plant staff began planning for the storm five days prior, nothing like Sandy had occurred before, so little could be anticipated. Plant personnel put sandbag barriers around critical equipment and relocated emergency and other vehicles to higher ground. Mains were isolated as a pre-emptive measure.

"It was three feet over a breach event recorded in 1821, and the plant was designed with one and a half feet of margin over the worst storm known at the time," said Brown.

He continued: "The packaged boilers' electrical distribution area was in real bad shape, three 13-kV transformers were damaged beyond repair, and we had to remove and refurbish 130 motors and pumps!" The arcing in one of those three transformers was responsible for lighting up the lower Manhattan night skyline, the image from the storm that made its way around the world.

Despite the calamity, the plant recovered house power by early Tuesday morning, less than 12 hours after the storm surge. The gas turbines were back in operation within two days. "We had to configure the operable equipment to get auxiliary power back," added Brown, "we were fortunate to have 66 of the plant's 200 staff who remained and worked tirelessly during the event."

Some critical equipment already had flood protection but the utility has spent millions more at East River to make it more resilient the next time. Examples include:

- Pumps and motors at ground level, already protected by a moat, had walls raised by more than two ft (Fig 2).
- Drain manholes were added in strategic locations.


**3. In all, 19 moats were installed at East River** after the storm. As built, no moat existed at left; addition is at right


**4. The seal perimeter at East River** was hardened. Water ingress points discovered in abandoned doors and windows (left) were sealed with additional concrete barriers, brick, and mortar (right)

Joy Faber

**5. Iconic buildings** of the Manhattan skyline reflect the value of Con Edison's East River Generating Station to the city's energy infrastructure

- Intake tunnels were closed and sealed off.
- Rigging beams were installed above critical pumps.
- Barrier door seals were added or hardened.
- Nineteen moats were added for equipment which had none before (Fig 3)—such as at the gas-turbine control cabinets—often with sump pumps, some as large as 1000 gal/min.
- Dozens of new floodgates were added at entrances for people and machinery, along with six trash pumps throughout the plant.
- The concrete perimeter around the plant was raised several feet in locations where water could enter, such as through old doors and windows (Fig 4).
- A backup diesel/generator was removed and reinstalled on an elevated platform consistent with the new design flood level of 18.2 ft.

Having its own machine shop in the Van Nest section of the Bronx helped Con Edison recover quickly. "We do all of our own repair, outage, and construction services work here—including that for 7FA maintenance," Brown said. The plant keeps a full gas-turbine compressor shaft in storage at the company's warehouse in Astoria, Queens.

One of the most difficult situations to deal with under these circumstances is water hammer. As most steam-plant engineers know, bad things happen when cold water hits high-pressure, high-temperature steam lines. Salty water also isn't kind to most anything made of steel. The plant was fortunate to avoid any sustained damage from water hammer.

Con Edison's budgetary documents available from the web show that the utility plans to spend $65-million on resiliency projects for East River between 2013 and 2017. Objective is to satisfy a new FEMA 100-year flood level plus 3 ft.

According to "Chapter 6: Utilities" from the document, "A Stronger, More Resilient New York," issued by the mayor's office (Bloomberg at the time), the city lost more than 90% of its steam production capability during the storm, and it took 12 days to restore it fully. Getting East River back online promptly obviously contributed mightily to restoring essential energy services to the city.

What's more, 88% of its steam generating capacity, 53% of in-city electric generation, 37% of transmission substation capacity, and 12% of large distribution-system capacity lies in the 100-year flood plain. All of those figures are expected to grow in the coming decades.

## High-profile customers

East River is justifiably proud of its role in serving the city's steam needs (Fig 5). After all, you can't get higher profile customers than The United Nations, World Trade Center, Metropolitan Museum of Art, Rockefeller Center buildings, marquee New York hospitals, and major high-rise residential and office complexes.

One interesting attribute of Con Edison's steam quality is that it is "FDA-compliant," which means it can be used directly for such functions as sterilization and humidification, the latter essential, for example, in preserving art works in museums. GRiD

**1. Wall plaques at Empire District Electric Co's Riverton Power Plant** (right) illustrate its rich history, beginning with a hydroelectric unit in 1905, and later including an old Corliss steam engine. Today a 1 × 1 gas-fired combined cycle, commemorated by the middle plaque, dominates the site. The old brick building at the right housed the steam engine


# Repowering prepares century-old plant for decades more life

Much can happen to a powerplant in 111 years, but perhaps more so in the last decade than the previous 10. Empire District Electric Co's Riverton Power Plant, located in the Southeast corner of Kansas, is one of the oldest continuously operating generating facilities in the country (Fig 1). Its history reflects the broad trends in the industry past and present, but most recently it could be considered "the poster child" for what is happening to coal-based electricity.

On May 1, 2016, Empire completed commissioning of Unit 12 (Fig 2), which began as a gray market 150-MW Siemens V84 gas turbine/generator (Fig 3) operating in simple cycle beginning in 2007. Originally configured for future combined cycle, a 100-MW Siemens VAX-type steam turbine/generator (Fig 4), Nooter Eriksen triple-pressure heat-recovery steam generator (HRSG), cooling tower, water treatment units, and stack were added during the repowering project of the last two years.

Meanwhile, the last two 1950s-era coal units were retired, the coal handling facilities have been reclaimed, and the coal-unit powerhouse will be demolished. Over the last 10 years, these two units had been retrofitted to first co-fire natural gas, then again to burn 100% natural gas but they were rarely "in the money" for dispatch. Several smaller, older peaking gas turbines at the site are still in service (Fig 5).

What started out more than a century ago as a single hydroelectric generator (sidebar) is now a 100% gas-fired facility. Space freed up from removal of the coal facilities can accommodate a future CC unit.

The justification for the project was straightforward: Repowering was the most economical way to meet the EPA's new emissions mandates for mercury, sulfur dioxide, and particulates under the Air Toxics (Title V) provision of the Clean Air Act. Thus, it was strictly a coal-to-gas capacity displacement project.

Burns & McDonnell Engineering Co, Kansas City, served as EPC contractor for the repowering project.

## Smooth commissioning

Blake Mertens, VP for energy supply, and Ed Easson, plant manager, credit several things for a relatively smooth commissioning period. Perhaps most importantly, Empire co-owns and operates the State Line Plant (a 2 × 1 CC powered by 501F gas turbines) only a few miles away across the Missouri-Kansas state line. Riverton operators were able to train at State Line and much of what was learned about design and operation was applied at Riverton.

**2. The heat shield** located behind the GT exhaust stack allowed gas-turbine operation during construction and installation of steam-system components

Minor issues during commissioning, which began in November last year, included:

- A few flange and casing bolts were over-tightened. While these were "small parts, they could only be replaced from Europe," said Easson, which took weeks.
- Steam turbine and steam cycle issues kept the unit down for most of January.
- Mechanical seals and flange seals broke, requiring fixing.
- A seven-day outage was caused by a tube leak located in the middle of a difficult-to-access tube bundle in the HRSG.
- Although the steam-turbine gearbox may be unfamiliar to many in the industry today, it reportedly posed no issues, although Mertens and Easson noted that "making sure it is precisely aligned caused some frustration during commissioning."
- Optimizing the phosphate-based feedwater chemistry took some doing.

Easson and Mertens proudly noted there were no operator errors which forced the unit offline during commissioning.

## Flexible operation

Like most CC units these days, Riverton 12 was designed for flexibility in following market demands, and intermittent resource supply, notably wind. "Riverton is uniquely positioned to boost up the wind in the western half of the state," noted Mertens, "typically we get paid for voltage support at night, and energy during the day." The plant operated essentially 24/7 during its first three months of commercial operation. "At average natural gas prices of $2.50/million Btu, we're anticipating the CC will achieve 60% capacity factor," Mertens said.

The gas turbine is designed and permitted for unlimited starts and operating hours. The GT can put 150 MW on the grid in as little as six to seven minutes, a hot start of the steam cycle can be accomplished in less than two hours. Experience at State Line (and, undoubtedly, the 1 × 1 configuration) has allowed Riverton to staff three operator/technicians per shift rather than four. Total Riverton plant staff is 22.

The HRSG duct burner adds flexibility. Steam-turbine output is 117 MW with full duct firing, and 80 MW without it. The design heat rate is "well under" 7000 Btu/kWh with the duct burner idle, and around 7000 Btu/kWh with full duct firing, said Easson.

A 3-MW electric startup boiler provides some warm-up steam for the steam cycle, although it is not sized for full warming during steam cycle roll-ups.

**3. V84 gas turbine,** rated 150 MW, began operating as a peaking unit in 2007

**4. VAX steam turbine** features an LP module (foreground, just beyond the condenser in yellow), a generator (box in center), and an HP module geared down to 3600 rpm (above)

**5. Exhaust plenum** of an older peaking gas turbine "peeks" out from between the old coal-fired units' powerhouse (slated for demolition) and other facilities at the site (left)

6. **HRSG tube panel** is put into place during construction

Permitted NOx emission limit is 15 ppm at 15% $O_2$. To achieve this, the HRSG includes an SCR. Initially, $NO_x$ level out of the GT was permitted at 25 ppm.

To maximize operating flexibility during the conversion from simple to combined cycle, a heat shield was installed at the GT exhaust, as shown in Fig 2. It allowed the GT to operate simple cycle with the steam cycle under construction.

## Design features

Mertens and Easson point to the steam-turbine arrangement as an innovative design feature. It is arranged perpendicular to the gas turbine which reportedly reduced the required piping runs and racks; improved heat rate by 40 Btu/kWh; allowed more equipment to be located inside the building, helping with freeze protection; and reduced capital costs by 5%. As the plant is hemmed in by the river and the lake, it also allowed for a compact overall footprint. "It is, literally, right up against the HRSG," Easson noted, "which did involve some construction challenges."

Features of the HRSG (Fig 6) important to the plant include: use of full penetration welds; sizing, routing, and locating suitable drain lines to enhance steam cycle roll-up; use of hangars and floating inlet and outlet headers on tube bundles; and use of high-strength drum and header materials (P91).

**HP steam-turbine module** (left) is geared to 3600 rpm (above)

The VAX HP steam turbine module operates at 9000 rpm, and is geared to 3600 rpm between the turbine and generator shafts (Fig 7).

In sum, Empire was able to repower Riverton, repurpose the staff (no layoffs were involved and the community's tax base remains intact), and meet EPA's mandates, therefore continuing to operate, hopefully for several decades more. GRiD

## Riverton's history includes hydro, coal

Riverton began life as a 3-MW hydroelectric plant (two 1.5-MW units and eight "waterwheels") adjacent to the Lowell Dam around 1905. The plant was built to serve the area's booming zinc and lead mines. In turn, Empire District was formed in 1909 through the merger of several small utility generation and wires companies (and others, such as an ice company) active in the earliest decades of organized electricity service. Typical of the period, these utilities were merged into multiple investment holding companies, which ultimately were integrated into Empire.

Next, a small coal-fired 25-cycle Corliss steam engine named "Old Kate," used to supply the 1904 St. Louis World's Fair, was relocated to Riverton. A 2-MW steam turbine was added in 1913 to extract additional energy from the Corliss engine exhaust, an early example of repowering. Six small coal units were added between 1910 and 1925. In 1920, Riverton was reputed to be the largest steam plant in Kansas.

Although today gas has completely displaced coal, use of natural gas actually started at Riverton with the addition of Unit 7, a 38-MW coal/gas unit, in 1950 and a 54-MW coal/gas unit in 1954 (the capacity replaced by the recent repowering project). In 1964, a 12-MW gas turbine was added, and then two 32-MW GT peakers in 1988.

**1. Vintage 160-MW steam turbine** (left) was repowered at Victoria Power Station in 2007-2008. Internals of the unit's high- and intermediate-pressure sections are at right

# 1950s-vintage plant revamped for today's Ercot market

If country music stars sang about powerplants, the Victoria Power Station, Victoria, Tex, might be a good choice. It's a story about ordinary people doing heroic things in the face of constant adversity. With new owner Rockland Capital ready to invest in another turnaround (CCJ, 3Q/2015, p 6), a period of stability may be near.

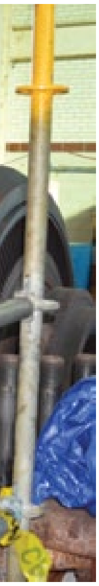
Imagine a gray-market (though never operated) gas turbine/generator *and* HRSG landing in a 1950s-vintage central station and then proceeding through several equity owners and third-party operators over the next 10 years. Meanwhile, the Electric Reliability Council of Texas (Ercot) market is changing radically as a result of burgeoning wind power coming on the system.

## Singing those country blues

Central Power & Light Co, a utility since acquired by American Electric Power, was owner and operator of the gas- and oil-fired facility when commissioned in the 1950s with two small steam turbines (by today's standards)—a 240-MW Westinghouse machine and a 160-MW GE D5 turbine/generator (Fig 1). The plant was mothballed in the 1980s, ran some in the 1990s, and was shut down permanently in 2002.

In 2006, the plant was purchased by an independent power producer which soon was acquired by another IPP—one affiliated with a gas supplier. The intention was to repower the D5 steamer with a gas turbine and heat-recovery steam generator (HRSG, Fig 2). The owners purchased a gray-market Mitsubishi 501F machine and had it cleaned up at the OEM's shop in Florida. Bibb Engineers was the engineering firm of record. At the same time, the steamer was taken apart and "refurbished," but, according to Jeff Martin, plant manager, "not much needed to

**2. Gray-market gas turbine package** (left), a Mitsubishi 501F, was purchased for the repowering, along with a Vogt (Babcock Power) HRSG (right)



**3. Two 138-kV transmission lines** and several 69-kV lines connect with Victoria, giving it a critical position within the Ercot South market

be done to it."

"Everything is a custom job in a plant like this, a huge science project," Martin said. All the legacy equipment was inspected, removed, and sent to shops in Corpus Christi—even the original 5-kV switchgear and river-water pumps, "all at low dollar."

Original controls were gutted and a hybrid control scheme with Wood Group (now EthosEnergy Group) turbine control logic and Yokogawa DCS components added to automate the legacy steam turbine. The original feedwater-heater extractions had to be blanked off and steam bypass valves added for startup and shutdown.

Mitsubishi's NetMation controls the GT, but the plant's DCS was supplied by Yokogawa. Integration was handled by Wood Group. Natural gas is purchased from Kinder Morgan off of a Tejas pipeline. Although there are several other pipeline options in the immediate vicinity (this is Texas after all) the pressure is low and the plant would have to pay for a compressor booster station.

GT first fire and steam blows were conducted in late 2008. "We had lots of unit trips in the 2009-2010 timeframe, while learning about the reconfigured equipment," Martin noted. "Our ops team learned from the Mitsubishi folks how to operate the unit, although there was a bit of a language barrier to work through." Problems with the dynamic characteristics of the GT were resolved. Perhaps surprisingly to some, the combined cycle (CC) met all of its performance specifications.

Originally, the plant operated primarily in the summer (Victoria is southwest of Houston towards Corpus Christi), and then under a tolling agreement in 2012. "We survived the big freeze of 2011, but not without incident," Martin noted. "We discovered our heat tracing and insulation systems were lacking, two of our triple-redundant transmitters on the HRSG drum level (the two exposed to the north) froze up." But the ones on the south side worked. The plant wrapped transmitters to keep them warm, and used heat lamps and wind breaks to keep other critical devices from freezing. "We were online within one hour of our scheduled dispatch time," Martin said.

Victoria Power's location in the Ercot South market made its capacity critical. Two 138-kV buses are connected from the plant's substation, as well as several 69-kV lines (Fig 3). During the unprecedented freeze, "We thought of ourselves as the 'little engine that could,'" Martin added.

In 2013, the plant began independently bidding into the day-ahead market, and attained a 38.4% capacity factor with 144 GT starts and 3600 GT operating hours. Rated summer capacity was 290 MW, 305 in winter, at a heat rate of just under 8000 Btu/kWh. Keep in mind that 50 MW of that output requires duct-burner firing.

Late in 2012 the unit came down on forced outage, and one day after getting back online, one of the old 138-kV insulators failed on the bus. That kept the plant down for a while.

In 2013, with the Ercot wind power coming on strong, Victoria achieved 200 starts as a merchant plant. "We cycled on and off almost every day in the peak seasons," Martin said. Post-2013, low energy margins in the Ercot market made operating as a merchant plant less than profitable. As a result outages were pushed out, and maintenance deferred, restricted to essentials only. The plant went up for sale in 2015.

## New lyrics of redemption

Rockland Capital's purchase of the plant from the banks holding the debt was finalized Jun 1, 2016. It was last dispatched on May 17 because of equipment issues, so it was coincidental that the unit was in an outage at the time of purchase.

A high differential pressure across the GT inlet air filters and high vibration (6 mils) in the low-pressure (l-p) section of the steam turbine had to be addressed. "The steamer had been whisper quiet after a major outage in 2014 up through late spring 2016," Martin noted. The apparent cause of the vibration: Liberation of erosion shields from the blades in the final l-p stages.

According to Keith Feemster, Rockland's owner representative for the site, "With the peak money-making season approaching, the new owners quickly got the staffing up from 13 to 18 people, paid the lingering invoices, met with local contractors and the chamber of commerce, and added a summer-run incentive bonus. The last included a metric for getting the current outage done date-certain—full-bore reputation management, in other words.

**One forward priority** is to make the plant more responsive; startup times have to be improved, Feemster said. "When the steam turbine is hot, we can get to full load in two hours and fifteen minutes. However, a cold start takes much longer, because the plant is following the old GE starting and loading charts. The GT also requires a "spin cool" procedure on shutdown to avoid uneven cooling.

"We're looking at our options to keep heat in the machine," Feemster continued, "and other flexibility options." For one, the GT stack damper was never commissioned. "We plan to put that into service," Feemster added. The previous owners obtained a permit to add a second CC unit, but this expansion project is on hold for now. The duct burners also provide flexibility and another option under review is a couple of PowerPhase units (CCJ, 2Q/2014, p 20).

The plant also is investigating operating schemes which will achieve a lower sustainable capacity—such as 80% of full load— in start times (hot) of less than an hour. In other words, sacrifice megawatts for responsiveness to dispatch. "We're hoping to have this in place for the summer 2018 peak season," Feemster said.

Improving reliability is another

**4. Cooling-tower and circ-water pumps** are scheduled for overhaul to assure continued reliable operation

priority (Fig 4). "Switchgear, cooling tower, and circulating-water pumps all need overhauls. Plus we have to meet the reliability standards required by Texas authorities; pass an environmental, health, and safety (EHS) audit; and implement a final solution for the steam-turbine vibration." Obviously, there's much on the plate as some of the equipment, like the generator step-up transformer (GSU) and lube-oil coolers, is close to 60 years old.

The plant has an LTSA with PSM for the GT. Although the maintenance schedule is similar to a 7F, Mitsubishi still requires the combustion inspection interval of 12,000 hours (GE has done away with the CI, now goes from hot gas path to HGP). "We've not had a significant failure event with our GT," Martin stated, although several major components are now PSM replacements, such as Rows 1 and 2 blades and vanes, transition pieces, and combustor baskets." Martin expects longer life from these upgraded components.

The steam-turbine outage in 2014/early 2015 was significant. Given that the machine had not undergone a major overhaul since 1985, "it was in really good shape," Martin noted, although it apparently hadn't run much between 1985 and 2002. Overall, the unit has undergone 700+ starts since the repowering project was commissioned.

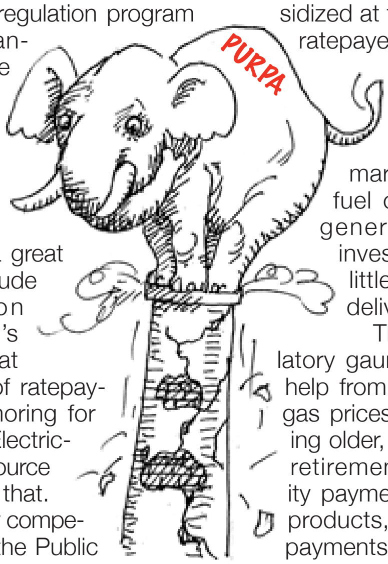
One best practice with such legacy equipment: Be responsive to problems. "Anything that appears small, such as a leak, has to be addressed immediately," Martin said. The plant has no predictive maintenance expertise on staff, such as vibration analysts or thermography specialists. "We rely on contractual services for predictive maintenance," Martin concluded, "and we rely on our employees who know the equipment intimately." **GRiD**

*Elephants in the room*

## What Cost Price Signals?

Electricity markets are failing. They are failing because they cannot overcome the distortions heaped on them by layer upon layer of regulation.

Recall recent history. Virtually every state electricity deregulation program began with guaranteed electricity rate reduction or rate protection for most consumers, a strange way to inject competition based on price signals but a great way to later conclude that competition lowers rates. Let's also remember that the vast majority of ratepayers were not clamoring for deregulation; the Electricity Consumers Resource Council (Elcon) did that.




Actually, industry competition started with the Public Utility Regulatory Policies Act (Purpa) mandate for utilities to purchase electricity from "qualifying facilities" at their "avoided cost."

Today, baseload power has declining value. $CO_2$-free nuclear and modern coal plants can't effectively bid into ISO markets. Under threat of closure, nuke owner/operators are lobbying for subsidies which allow them to at least pay the bills. Net-metered rooftop PV customers are being subsidized at the expense of all other ratepayers, most of whom can't afford PV. Non-utility renewable project developers are driving towards zero marginal-cost facilities (no fuel costs, little O&M) with generous production and investment tax credits and little obligation to firm their deliveries.

The environmental regulatory gauntlet around coal, with help from historically low natural gas prices, is doing its job, forcing older, smaller coal plants into retirement. ISOs offer capacity payments, response flexibility products, and ancillary services payments because market price signals fail to provide proper incentives to build new capacity. FERC had to offer adders to capital-investment rates of return and a program called "Multi-Value Projects" to support regional transmission.

Even the best spreadsheet models can't make a pretty picture of investing in a multi-decade asset based on a day-ahead or hourly price signal. To boot, there is barely any real-time price margin to exploit.

At the meter, most customers still don't have time-of-use rates for making rational decisions about energy use based on price signals. Meanwhile, distribution utilities subsidize efficiency products, and are in the unenviable position of investing in less use of their product.

As Mark Glaess, consultant and former executive director of the Minnesota Rural Electric Assn, recalls, "In the 1990s, Minnesota electric cooperatives offered green energy, 3% of the customer base thought that was a good idea, and the legislature extrapolated it to a 25% renewable mandate."

Today's ISO is one giant NERC-policed regional transmission utility, a vast bureaucracy intermediating wholesale electricity among distribution utilities, saddled with the obligation to serve, and various classes of generators separated by regulatory dislocations into buckets ranging from highly desirable to untouchable.

Maybe it's time to start with the ratepayer, actually listen, then work backwards into the supply chain.

# Plant knowledge platform emerges from the old DCS

Participants in the 29th annual conference of the Ovation Users Group, hosted by Emerson Automation Solutions' Power & Water, in Pittsburgh, July 24-28, 2016, were, as in past years, treated to a plethora of advanced capabilities and current experiences with what is now the dominant automation system at US combined-cycle facilities. (See following article for more conference coverage.)

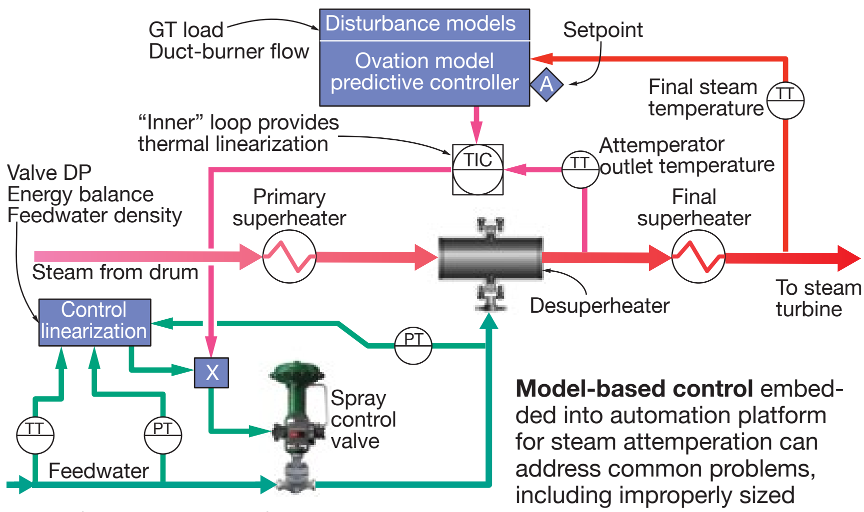
Based specifically on the information presented, it is fair to say that the distributed control system (DCS), which later became the digital control system, is becoming a term of nostalgia. It is being replaced by a plant knowledge platform integrating control algorithms, real-time and historical plant data, synchronized simulation, monitoring and diagnostics (M&D) and prognostic capabilities, and immediate decision support for plant staff from the digital platform itself as well as from remote experts monitoring and overseeing plant systems.

This is, of course, an industry trend, not limited to Emerson Ovation™. But coverage of multiple automation user groups over the last several years shows that Emerson may be pushing the envelope faster and harder than others.

## The plant—and the virtual plant

If you're wondering what all this will mean for the person sitting in the control room, imagine two large screens. On the left is the plant in its current operating mode. On the right is the "virtual plant," a high-fidelity digital simulator of the physical plant. The plant simulator screen is "synchronized" with current plant operating data with the push of one button. The simulated plant can be made to "run" up to 10 times faster than the real plant.

This allows operators and engineers to test things in real time. If the test ends up tripping the virtual plant, it's of no consequence. Operating issues can be identified before they occur and addressed before they do physical damage or impair performance. All of this plant experience is captured digitally, and automatically, for knowledge transfer to those with a need to know.




**Model-based control** embedded into automation platform for steam attemperation can address common problems, including improperly sized valves (usually oversized), valve seat erosion, and poor or insufficient mixing

## Step by step

Several elements (or aspects) of Ovation virtual, and even augmented, plant reality are being demonstrated in the field today. Southern Company, for example, is demonstrating "embedded simulation," essentially an Ovation workstation with a running simulator. A coal-fired plant in the West is demonstrating how embedded pattern-recognition and predictive-analytics algorithms provide early warning for fan/motor issues (2Q/2016, p 83).

In-house Emerson vibration data and analytics for critical rotating equipment, such as the main turbine/generators and feedwater pumps, have been integrated into Ovation. The integrated Ovation Health Monitoring Module is undergoing beta testing at a 535-MW coal-fired unit.

The overall objective is a "virtual human learning environment," according to Robert Yeager, president of Emerson Automation Solutions' Power & Water, which provides plant staff with knowledge and experience in real time. One issue which has to be addressed is avoiding the "alarm flood" which occurred 10 years ago with advanced DCS.

With regard to M&D and prognostics, "the idea is to identify anomalies at the data rates of the DCS (compared to external pattern recognition software packages), or 100 microseconds, make the right experts aware of the anomalies, and address them before they become big problems." Earlier coverage of the 2016 Ovation User Group meeting addressed this feature (reference above).

In an exclusive interview, Emerson's Rick Kephart noted that the human-machine interface becomes even more critical in linking the real- and virtual-plant worlds. "The operator of the future will be able to always 'look ahead' with the simulator screen," he elaborated, "but must still be keenly aware of what is happening now." How to best present the information is still being worked out, but models are available from other industries—such as aerospace flight deck simulators and control systems.

Ultimately, the goal is to avoid human error by integrating the virtual knowledge environment in a way that assists the human operators and experts.

From the M&D perspective, another way to imagine the impact of these trends is much of the capability that today resides at the centralized M&D centers (see special report, 4Q/2013), built out by many utilities and owner/operators over the last 10 years, can now be migrated back to the plant automation and knowledge platform.

## Business applications too

The integrated platform doesn't just include advanced control, M&D, and prognostics. Emerson's Ranjit Rao discussed the addition of advanced power applications, defined as those having a "business driver." So-called sequential automation using embedded sequence flow charts (SFC), for example, allows operating sequences or procedures to be more precisely controlled, reducing the variability which crops up among different operators and their operating styles.

Model-based predictive control (MBC) can be used to calculate optimal trajectories of process variables under startup, shutdown, cycling, and other dynamic (non-steady-state) conditions. An example is the ability to pre-emptively position attemperator sprays to control superheat and reheat steam temperature (figure) *before* the temperature actually begins changing in the wrong direction.

Embedded MBC, in one case study, was able to increase operating steam temperature by 8 deg F, without the temperature excursions previously experienced during load changes, resulting in an immediate heat-rate benefit. In another case, the mean error around main steam and reheat steam temperature was reduced to less than 1 deg F with a standard deviation of 1 deg F on a gas-turbine ramp from 0 to 180 MW.

Rao stated that, in one case, statistical analysis combined with embedded SFC was able to reduce fuel use during startup by 58% compared to the baseline. More precise control of process parameters also reduces stress on valve movement, valve stems, rotating equipment, and, for that matter, any equipment which has to physically move to respond to process signals.

Statistical analysis also can be applied to startup signatures to reduce fuel consumption or achieve other performance goals.

Similarly to pattern recognition, sequencing schemes for starts, stops, and cycling have been applied for years at gas-turbine-based plants. The difference here is that they are now being embedded into the comprehensive knowledge platform anchored by what used to be called the DCS.

With proper upfront analysis, Emerson may be willing to provide guarantees around some of these performance benefits, such as fuel savings and heat-rate gains. In addition, Ovation experts are available to assist plant staff in monitoring equipment and assessing operational performance for the various operating regimes plants have to deal with today. As one example, Emerson acquired

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## A unifying platform

The value of the integrated platform can be significant. According to Steve Schilling, VP of technology, network equipment costs can be reduced by 50%, systems integration costs by 40%. There's reduced commissioning time and fewer spare components are required.

Today's plant knowledge platform could include the GT control system; the steam-cycle control system; the plant DCS; a separate data network and historian; various PLCs operating in the water treatment, fuel delivery, and HRSG duct-burner areas; and various software packages, including vibration monitoring, thermal performance, and pattern recognition around critical components. Today, all of these require separate data links, protocols, and network transmission devices linking to the control system at most plants.

A considerable amount of complexity is avoided by integrating all of this, to the extent possible, into one platform—with a sole source for cybersecurity solutions to boot. CCJ

## Low bidder may not be the vendor you want

One of the eye-opening presentations this year involved a state-of-the-art coal-fired plant which experienced what can only be described as a failure by the original automation system supplier to design, deliver, and service a suitable system. It's a lesson in the need for oversight of the automation platform in a day and age when it is, essentially, the brains of the plant.

The unit, with an ultra-efficient supercritical boiler, was declared "commercial" in December 2011, but plant representatives elaborated after the presentation, stating the unit commissioning was never really completed. Three and a half years later, with Emerson Ovation taking over in summer 2014, the plant was finally operating with some semblance of normalcy by spring 2015.

The prior automation system vendor had anywhere from 10 to 25 control engineers onsite for the performance test, declared it passed, and then left one engineer behind. Twenty minutes after ownership was transferred, the boiler and turbine controls began ramping in opposite directions. The unit had to be tripped at an output dangerously above its gross capacity. Subsequently, say plant officials, "we experienced 200 GADS events in the first year." (GADS is the NERC Generation Availability Database System.)

Apparently, the design and commissioning of the boiler and turbine controls coordination was not completed because of inconsistencies in operation, ancillary subsystems like fabric filters were inadequately addressed, and the plant was unable to change anything. Nothing was intuitive. "Over 100 separate DCS issues were identified," officials noted, including the following:

- Inconsistent boiler/turbine coordinated control.
- Operator workstation blackout.
- Lack of bump-less transfer schemes.
- Lack of balancing circuits to multiple control devices.
- Inconsistent operation of HP steam bypass valve.
- Inconsistent operation of lead/lag devices.
- Lack of device permissive and first-out information to the operator.
- Poor I/O partitioning of critical inputs.
- Difficulty troubleshooting complex logic structures and hidden functions.
- Low chance of survivability during a runback.

A more minor issue, at least in the scheme of things, was that overall control needed to be far more precise so that the plant could participate in the PJM regulation market.

Needless to say, Emerson came in and retrofitted Ovation concepts and standards while retaining what could be salvaged of the original software design. "We especially liked the open-access platform," company officials said. Emerson retrofitted a system with 11,000 I/O points, 7000 logic files, and 280 graphics files, and developed standards which could work with the original system, according to the owner/operator presenter, *all in six months.*

Post rehab, online availability increased from a low of 73%, to more than 98%, capacity factor was raised from 68% to over 98%, forced outages were significantly reduced, 20-MW/min ramping was demonstrated, and startups became consistent. Another result: The number of alarmed points was reduced to 325 critical ones, from 24,000 previously!

# Checklist: Apply these best practices for lifecycle care

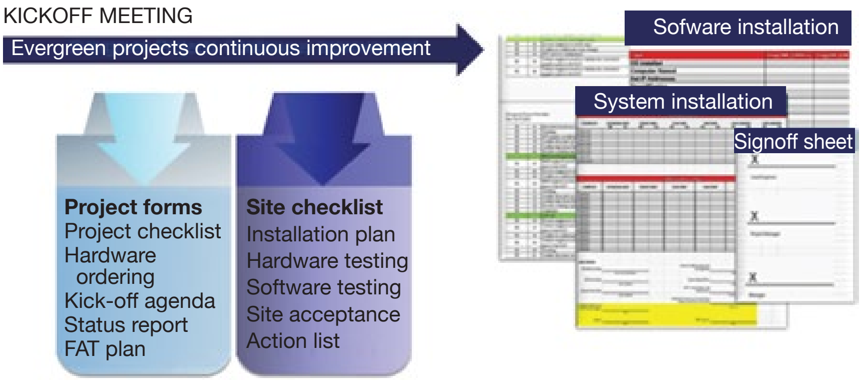
You want to believe the lifecycle care program purchased with your control systems transfers most of the risk to your OEM. After all, much like an insurance policy, you're paying for protection against technological obsolescence and maintenance issues. But the reality, as illustrated here through one utility's experience, is that successful implementation requires considerable owner/operator-OEM interaction and oversight.

What follows is derived from a presentation at the 2016 Ovation Users Group (OUG) Conference, held in Pittsburgh, July 25-28, plus an interview with a utility representative who recently concluded a program to upgrade systems at 13 separate power stations. However, it should be clear that the basic practices can be applied to any control-system lifecycle program.

Emerson Automation Systems calls its lifecycle care program "Evergreen." In one sense, it is analogous to an LTSA or CSA for turbines and generators because it not only addresses basic maintenance issues but technology upgrades and new software/hardware releases as well. This is critical because digital and control-system technology has a lifecycle of five to 10 years—far shorter than the physical systems. Components include (depending on what is covered in each program) network switches and media converters, controllers, workstations, and power supplies.

On the advanced technology side, control systems are becoming "knowledge platforms" and so Evergreens also include the latest operator applications and algorithms, security programming, wireless capabilities, embedded process historians, model-based control, diagnostics, trending, and decision support. Some of these identified in the presentation are:

- Updated turbine, boiler, and excitation control schemes.
- Updated remote valve positioners (RVP).
- Ovation Security Center (a means of constant interface between user and OEM to attend to cybersecurity and patch management while the plant is online).
- Machinery health monitor and trending packages.
- HART and wireless HART for communication with field devices.
- Replacing old serial link controllers (RLC) with Ethernet link controllers (ELCs), for communication with virtually all other third-party devices and changing of communication protocols without upgrading.




**Much preparation** is required to successfully implement a control-system lifecycle upgrade program

From the OEM side alone, much preparation is required (figure). The scope has to be agreed on, systems have to be walked down and inspected in the field, the "system state" has to be reviewed, the factory acceptance test (FAT) has to be planned, hardware and software have to be tested, and a bill of materials has to be written up. Control systems interface with other digital assets so other party licenses have to be reviewed. According to Emerson's Mike Brown and Chris McClellan, "there are at least 15 documents for every Evergreen upgrade, part of the internal audit, which must be signed off on by customer and OEM."

Control-system alarms have to be carefully managed to prevent alarm flood to operators. Therefore, owner/operators need an alarm-management philosophy incorporated into the upgrade. If the upgrade includes replacement of the old Q-line I/O with Ovation I/O, then you need an accurate list of every Q card in every card frame in the system, including the attributes location, type, and group.

## User perspective

According to Alliant Energy's Wes Whitley, also OUG president, NERC's Critical Infrastructure Protection Standards (CIPS) were the driving force to upgrade the utility's entire powerplant fleet through Evergreen at a cost of millions, 5% to 10% of that for software upgrades. His experience was greatly assisted with checklists and other tools developed through the OUG executive board.

The scope of this program should not be under-estimated. "The only thing that remained the same was the physical I/O," Whitley stressed, "and the screen graphics and control sheets." Across the fleet, the scope included new Dell computers, replacement/conversion of older controllers with the latest versions, new controller software, new I/O software, new firmware to interface with the controllers, new monitors, new domain controller for NERC-CIPS compliance, anti-virus servers, and a new process data historian.

Let's face it, it's almost a new control system, and a testament to how fast the technology advances.

Identified below are a dozen areas Whitley suggests you consider for your best practices checklist. In his experience, controllers, system registrations, and other items were captured well, but power supplies were not. Seven of them were missed at one plant. Circuit breakers and fuses also are easy to overlook.

He says you can't be thorough enough when putting together the checklist.

**1. Software freeze date.** There could be three to four months between when the as-configured backup was done and when the new software was installed. Emerson has a tool to compare control sheets.

*Recommendation:* Run the compare tool just before you take the old system down; it will show every difference.

**2. Controller consolidation.** Ask questions like, "How much capacity is available in the current controllers?" and "What points come out of the controller for the upgrade?" There's the potential to reduce the number of controllers (and corresponding power supplies).

*Recommendation:* Run the Emerson program which shows how every controller is connected to the one under consideration, or at least gain an intimate understanding of this in other ways. Good money is at stake when considering future upgrades, both in hardware and software costs.

**3. Setpoints.** According to Whitley, Ovation doesn't store setpoint algorithm values, not even the most currently used. This is a critical configuration management issue. The more you automate, the less operators remember, even the name of the setpoint, much less the value.

*Recommendation:* Make sure you have a record of all your set-point values. Adding all setpoints to the historian is a good idea for both Evergreens and to trend changes in equipment operation.

**4. Dress rehearsal.** Part of Evergreen is to upgrade controllers. This may include media converters (copper to fiber, fiber to copper), power supplies, and other attributes. You should know what the OEM plans to do with each component of the system.

*Recommendation:* Go to the OEM's field office and review where things are located, what will be done with each device, etc—basically a complete dress rehearsal. This can lead to overlooked cables or other equipment, time constraints that may affect other outage tasks, resource deficiencies, illogical installation order, etc. Be sure to understand the needs of other outage support such as equipment that needs to run, etc.

**5. On-scan vs off-scan points.** Some rationale needs to be imposed on which points will be scanned and which ones won't. Otherwise, operators may suffer with nuisance alarms. Limit switches must be checked as well. Some may have failed without anyone (or the right people) knowing about it. Alliant found upwards of 50 suspect off-scan points at one unit.

*Recommendation:* Review every point for its value, if it is not being scanned; fix points/switches/field devices as necessary.

**6. Reconciling control sheets.** All tuning, timers, setpoints, and deadbands have to be reconciled in the controllers. Temporary changes have to be accommodated. Alliant found 200 points not reconciled at one plant.

*Recommendation:* Conduct a control-sheet audit onsite.

**7. Ovation Control Builder (OCB) points.** These can connect to the graphics on the HMI screens. The Evergreen upgrade process can generate new OCBs which can cause graphics errors. An Emerson tool is available that searches for every OCB point connected to graphics.

*Recommendation:* Create names for every OCB point used on graphics, rather than relying on, searching for, and replacing new OCB points.

**8. Licensing.** Users are entitled to a certain number of points in the historian; however, you can't discover that on your own, Emerson has to tell you how many you are allotted and how many you have used. Licenses from others, like the PI database and Emerson AMS Device Manager (which provides intelligent diagnostics for individual field devices), have to be considered.

*Recommendation:* Review the Ovation licenses (especially the historian and ELC) as well as all third-party licenses.

**9. IP addresses.** These are critical for NERC CIPS compliance. Lots of work is involved if you enter an incorrect address.

*Recommendation:* Be overly cautious with IP addresses and provide any proposed changes to Emerson as soon as possible. At a minimum, notify Emerson of impending changes at the kickoff meeting.

**10. Workstations.** There may be redundant operator workstations and an opportunity to consolidate or reduce them. New graphics cards now available allow multi-window viewing on HMI screens.

*Recommendation:* Be careful not to put Network Interface Cards (Ethernet) in the full slot. Quite often the HMIs have only one empty full slot and using this for a NIC card will make it difficult to add a multi-window graphics card because the Ovation Highway Interface may need to be fully uninstalled, which can be very time consuming.

## Emerson Process Management now Emerson Automation Solutions

Emerson Electric Co has consolidated its five business segments (Emerson Process Management, Network Power, Industrial Automation, Climate Technologies, and Commercial and Residential Solutions) into just two: Emerson Automation Solutions and Commercial and Residential Solutions. Emerson Automation Solutions essentially is what was Emerson Process Management, the entity likely most familiar to owner/operators of generating equipment, plus a few other companies. Some businesses, such as Network Power, which makes power systems that work with telecommunications and data networks, were spun off.

The restructuring, announced in mid-2015, was finalized Oct 1, 2016 to build value for customers, employees, and shareholders. The realignment is said to create a highly focused portfolio organized around a solutions-centric business model to deliver on the company's promise: "Consider it Solved."

**11. ELC cards.** Users can't generate mass database files for an ELC card (third-party devices, PLCs, etc). This could result in the user having to add hundreds of points.

*Recommendation:* Set up ELC cards prior to the FAT.

**12. Network switch configurations.** These may change because of NERC CIPS.

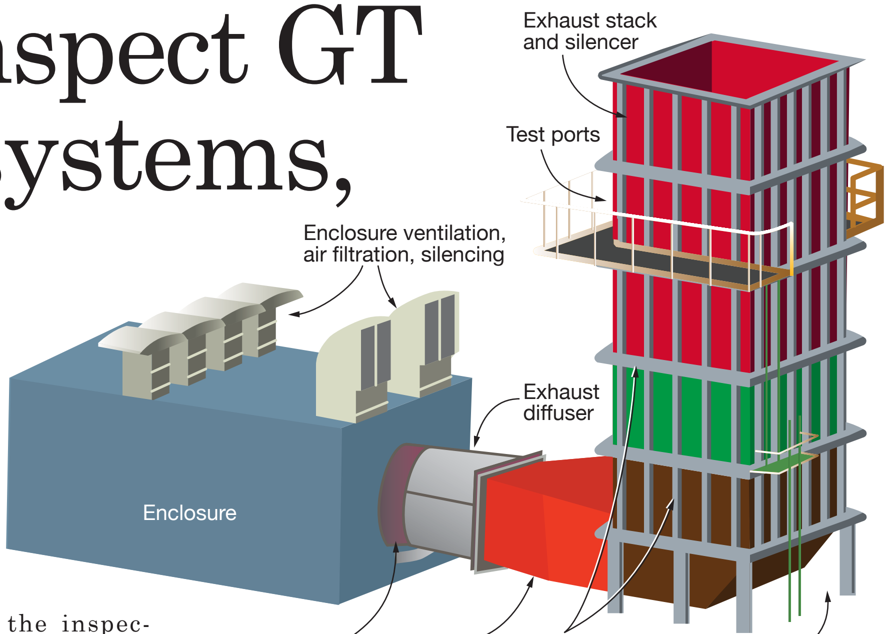
*Recommendation:* Fully discuss new network topologies at the kickoff meeting.

Once the upgrades are complete, retain all the results of the site walkdown for future Evergreens. Some components, such as power supplies, are not captured via software. Special or non-standard equipment may not be captured either. Keep a running log of changes/additions/subtractions, etc, to minimize the potential for errors next time. Include notes such as reduction of controllers, HMIs, I/O cards, ELCs, etc. This provides a history of what was changed and why.

These practices were very successful in upgrading Alliant's entire fleet. At some plants, Evergreens were implemented with as little as four hours of downtime on a four-unit network. CCJ

# How to inspect GT exhaust systems, what to look for

**By Bill Grace,** UniversalAET™




When it comes to exhaust systems for gas turbines (GTs), it seems hardly a day goes by that we aren't asked to answer one of the following questions:

- When will our exhaust duct and/or exhaust baffles fail?
- When will our expansion joint blow out, expel GT exhaust, and create a dangerous situation?
- Will my exhaust baffles collapse, cave in, and create a potentially catastrophic failure?

Since there is no sure way to predict the exact time of equipment failure, conducting regular and rigorous equipment inspections is the best form of insurance against unexpected downtime or a catastrophic event. A well-conducted and thorough inspection can identify both immediate areas of concern and longer-term issues requiring ongoing attention.

When it comes to GT exhaust systems, the checklist provided in the sidebar identifies what your inspection team should look for. Access an 8½ × 11 in. version of the checklist, designed for convenient use in the field, by scanning the QR code with your smartphone or tablet.

Checklist

However, before beginning the physical inspection, it's important to pull together an equipment history. The solutions provider you select for repairs and upgrades will want to know unit age and its commissioning date. Also, what has been repaired/replaced over the years. The typical mode of operation—baseload, daily cycling, or standby power—is required as well; plus, the expected operating regime going forward.

Once this information is compiled, the inspection is conducted to determine exhaust-system condition. These results, combined with the data from intended use, age, replacement components, etc, comprise the final report.

Here's what to focus on when inspecting your equipment:

**Support steel.** Starting with the foundation and support steel, evalu-

1. Outside shell: poor

Outside shell: excellent (new)

2. Expansion joint: bad

Expansion joint: good

## Condition-assessment checklist for GT exhaust systems

| Component | Condition* |
|---|---|
| *Structural and support steel* | |
| Anchor-bolt condition: loose, rusted, cracking, missing | ____ |
| Grout condition under base plate to foundation: cracking, missing | ____ |
| Overall condition of support steel: | |
| ■ Legs | ____ |
| ■ Cross bracing | ____ |
| ■ Hardware | ____ |
| *Exhaust duct, external* | |
| External shell: peeling paint, hot spots | ____ |
| ■ Mounting flanges/stiffeners | ____ |
| ■ Mounting hardware: loose, missing | ____ |
| ■ Gasket material between duct sections | ____ |
| Expansion joints: torn belt, loose hardware | ____ |
| ■ Gasket material between flanges | ____ |
| Silencer duct: external shell, peeling paint, hot spots | ____ |
| ■ Mounting flanges/stiffeners | ____ |
| ■ Mounting hardware: loose, missing | ____ |
| Silencer stack: external shell, peeling paint, hot spots | ____ |
| ■ Mounting flanges/stiffeners | ____ |

| Component | Condition* |
|---|---|
| ■ Mounting hardware: loose, missing | ____ |
| *Exhaust duct, internal* | |
| Inside liner sheets: missing, torn | ____ |
| ■ Channel flanges | ____ |
| ■ Hardware: loose, missing | ____ |
| Expansion joints: inside liner sheet, loose hardware | ____ |
| Silencer duct: internal liner sheets | ____ |
| ■ Mounting flanges/stiffeners | ____ |
| ■ Hardware: loose, missing | ____ |
| Exhaust baffles, perf sheets | ____ |
| ■ Pack insulation: missing | ____ |
| ■ Baffle guides/supports: loose, missing | ____ |
| *Enclosure doors* | |
| Accessory compartment: | |
| ■ Door frame, insulation | ____ |
| ■ Hardware, handles, hinges | ____ |
| Turbine compartment: | |
| ■ Door frame, insulation | ____ |
| ■ Hardware, handles, hinges | ____ |
| Load compartment: | |
| ■ Door frame, insulation | ____ |
| ■ Hardware, handles, hinges | ____ |

* Write "G" for good condition, "A" for average; "B/P" for bad/poor

ate the anchor bolts, grout, and steel members: Are they rusted or cracked? Are any pieces missing? How does the cross-bracing look? These are the critical components in that they support and provide a solid footing for the engine exhaust system (Fig 1).

**External exhaust-duct casing.** A comprehensive visual inspection can provide an indication of good or bad duct—or even something in between. Visual inspection is influenced by the type of siding—appearance or acoustical. If the internal insulation is missing and hot exhaust gases expose the external shell to temperatures in excess of 750F, then the material will crystalize and total corrosion of the carbon steel is possible.

Under these conditions, "pin-size" holes will start to form and turn into larger holes. These typically result in the site performing some temporary patches to "cover" the holes. Patches are only a short-term solution—additional deterioration will occur. The rate of deterioration depends on the amount of cycling need to meet load demands.

**Expansion joints.** Even if properly sized for the movements of the duct from one piece to another, and installed properly, expansion joints will fail over time; they are "wear and tear" items. From the outside, it's fairly easy to determine the condition of the fabric belt and whether it's good or torn—you'll notice the "bad" in Fig 2 is leaking exhaust gas. Excessive growth aside, only an internal inspection can address most of the reasons contributing to these failures.

**Silencer duct.** Moving to the external shell of the silencer duct, what applied to the exhaust duct also applies here. Look for peeling paint and hot spots, and at the condition of stiffeners. The exhaust stack has the same inspection criteria.

Once the outside shell of the duct, silencer section, and stack have been inspected, going inside the exhaust duct will give an indication of what is happening with the inside liner and insulation pack on the side walls, plus the exhaust baffles used for sound attenuation (Fig 3).

**Inside liner sheets.** Some things to look for here include the following:

- Is the internal hardware in place and solid, with the weld holding up?
- Has any of the hardware been "sheared off" because of excessive growth of the liner sheets?

Keep in mind that as the mounting hardware loosens and is sheared from the bolt/stud, the sheets have a tendency to become loose/rip, etc (Fig 4). When this happens, the inside insulation pack material may disengage from the area that protects the inside casing material; hot spots and peeling paint can occur if the condition is ignored.

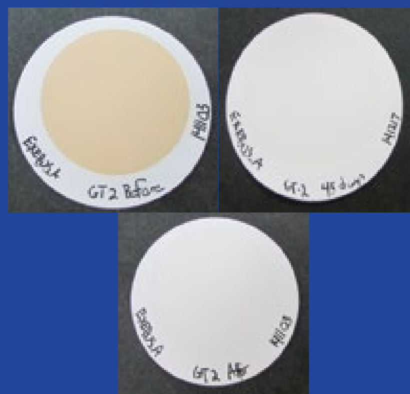
**Exhaust-silencer baffles** are

3. Baffle installation

Baffles after installation

American Chemical Technologies, Inc.

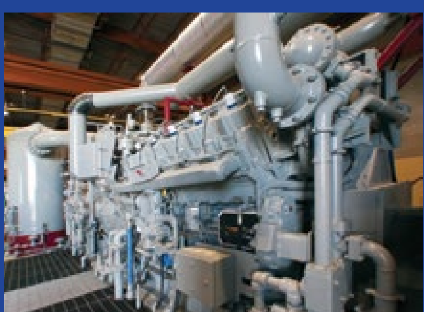
# PAG-Based Lubricants that Provide Your Plant Reliable Solutions



**EcoSafe® Revive™** - Base oil modifier that can be incorporated into any commercial hydrocarbon-based turbine lube oil to significantly reduce the issues associated with varnish formation and product instability. The addition of EcoSafe® Revive™ shifts the polarity and increases the solubility of the existing hydrocarbon base oil. In addition, it regenerates phenolic and aminic antioxidants.


**EcoSafe® TF- 25** - Premium non-varnishing turbine fluid for gas & steam turbines. EcoSafe® TF-25 is formulated to reduce friction and eliminate the thermal degradation issues of static discharge and micro-dieseling. These inherent characteristics in today's turbine oils lead to the formation of varnish, and the issues of servo valve sticking, failed starts, and trips.

**EcoSafe® EHC** - Increased system reliability, FM Approved, non-sludge or varnish forming, environmentally friendly, fire resistant, has no worker health or safety issues, and will provide a long fluid life - even when subjected to the catalysts of moisture and heat.



**SynLube P12** - Non-varnish or sludge forming, synthetic rotary screw compressor fluid that is especially effective in applications where fluid is exposed to elevated temperatures for extended periods of time.

Tel: (800) 938-0101
Web: www.AmericanChemTech.com

4. Internal liners and channel guides: poor

Internal liner pans: bad

Internal liner: excellent (new)

5. Baffles tearing away from frame/damaged

among the components that take the most abuse from exhaust flow. Depending on operating conditions (baseload or cycling) and baffle design, the perforated sheets can suffer fatigue and become loose or even separate from the baffle frame that holds in the insulation pack for sound attenuation (Fig 5).

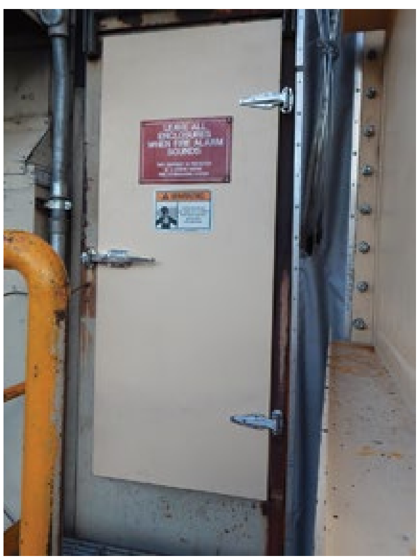
Once the perforated sheets begin to tear or crack, there's a greater chance of the insulation pack migrating downstream. If that happens, turbine noise will increase. Maintaining baffles in good condition is critical to long-term reliability and to keeping your neighbors and employees safe and comfortable.

**Enclosure doors,** including turbine- and load-compartment doors, have a tendency to get extremely hot during GT operation. Some of the specific areas to inspect include these:

- Exterior door frame, because of its exposure to the elements.
- Door exposure to high internal temperatures—because of leaking flex seals, for example—can cause thermal corrosion of the paint and steel substrate. Be sure to check the condition of the door's insulation pack and hardware (hinges and latches).
- Check seal/gasket material for corrosion caused by back splashing and water entrapment.
- Look for panel distortion from rough use; this can cause loss of sealing and increased thermal cycling.
- Check for corrosion from scratches, gouges, and other defects introduced into the paint.

The bottom line: Keeping your system in pristine condition can be a challenge, but maintaining it can avoid unexpected outages, downtime, or a serious failure. If you don't have resources ready to do the necessary maintenance or inspection, there are field-service professionals who can help you establish and maintain an inspection schedule and procedure that works for your plant. CCJ

6. Enclosure door: poor



Enclosure door: excellent (new)

# COMBINED CYCLE USERS GROUP

# Seventh Annual Meeting

**Sheraton Grand at Wild Horse Pass, Chandler (Phoenix), Ariz**

**August 28-31, 2017**

**Please mark your calendar and plan to attend**

**Registration opens in April at www.ccusers.org**

The CCUG Steering Committee invites your input for the group's Seventh Annual Meeting. Here are some of the ways you can participate and make your attendance more productive:

- Suggest a topic for inclusion in the program.
- Make a short presentation on best practices, lessons learned, HRSGs, control systems, plant outage management, diagnostics and prognostics, knowledge management, training, safety, employee retention, fuel systems, emissions control, heat rejection systems, etc. Can be 5, 10, or 15 minutes, or longer.
- Bring a thumb drive to the meeting with a couple of photos describing a problem at your plant and ask your fellow users for suggestions on a solution. Think of this clinic as free consulting by those who walk in your shoes.

## The CCUG Steering Committee

Top row (l to r): Dr Robert Mayfield, *Tenaska Inc;* John Baker, *Riverside Public Utilities;* 2016 Chair Steve Royall, *PG&E*

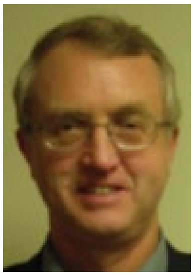
Bottom row: Jimmy Daghlian, *NV Energy;* 2016 Vice Chair Phyllis Gassert, *Talen Energy*

Camera shy: Brian Fretwell, *Calpine Corp*

**Email Vice Chair Phyllis Gassert (phyllis.gassert@talenenergy.com) with your thoughts/ideas today.**

# 2016 Individual Achievement Awards

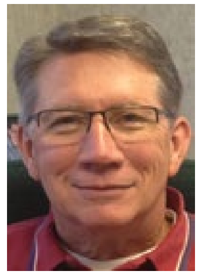
*Individual Achievement* recognition is earned by industry professionals who have demonstrated excellence throughout their careers in the design, construction, operation, and/or maintenance of generating facilities powered by gas turbines. The five outstanding individuals profiled below were selected by a special CCUG committee to receive their 2016 Individual Achievement Awards during the organization's Sixth Annual Conference in San Antonio.


Rodger Anderson


Ed Barndt


Andy Donaldson


Wayne Kawamoto


Rick Shackelford

## Rodger Anderson, PE

Manager of Gas Turbine Technology, *DRS-Power Technology Inc*

Rodger Anderson has spent his entire professional career of more than 50 years supporting electric power producers. The Minnesota farm boy began his journey at GE shortly after earning a master's degree in mechanical engineering. Over the next 29 years, Anderson would work extensively on the design of rotors and airfoils for heavy-duty gas turbines, and manage development programs that produced three engine designs, flange to flange.

His next stop was Hartford Steam Boiler Inspection and Insurance Co as gas turbine manager. Duties there included development of engine-specific guidelines for loss avoidance. In mid-2001 Anderson joined what today is DRS-Power Technology Inc as manager of gas turbine technology, his current position. The company is an engineering services business focused on machinery and systems design for naval and commercial powerplants.

Anderson is respected for his practical gas-turbine solutions benefiting owner/operators—including compressor vane pinning to mitigate the effects of hook-fit wear. A proactive supporter of user groups, he alerted large frame operators to the fretting of compressor vane bases caused by clocking of rotating blades and also worked closely, pro bono, with the 7EA Users Group to investigate the root cause of clashing.

## J Edward Barndt

Senior Vice President, *Rockland Capital*

There isn't nearly enough space here to summarize Ed Barndt's four decades of experience in power generation. Today he oversees plant operations and asset management for Rockland Capital's nearly 4000-MW portfolio and conducts technical due diligence of acquisitions under consideration.

Barndt is a proactive, confident leader who honed his skills managing generating plants worldwide. He is a distressed-assets "turnaround" expert. One example is the Eagle Point Combined Cycle Facility, where he recently led a renovation and upgrade project that uses steam from the plant's previous cogeneration operation to increase output by 70 MW and reduce heat rate by about 700 Btu/kWh.

Prior to joining Rockland, Barndt was VP South Asia for Globeleq with full responsibility for two combined-cycle stations and a barge-mounted diesel plant in Bangladesh that together produced 30% of the country's electricity. An earlier overseas assignment was as general manager of the Taweelah A2 Power and Desalination Station in Abu Dhabi. Between these two international assignments, Barndt was plant manager of InterGen North America's Cottonwood Energy Facility in Texas, which is equipped with four 1 × 1 F-class combined cycles.

## Andrew M Donaldson, PE

Vice President of Projects, *Worley Parsons*

One could characterize Andy Donaldson's career as a study in power engineering diversity; he's participated in the design of just about everything since joining the consulting firm Burns & Roe as a mechanical engineer in 1971 with a master's degree from Stanford University. Early work was mostly on nuclear and coal-fired units, but interspersed were diversified assignments—including wood and peat firing, fluidized-bed boilers, potato processing, etc.

Donaldson left Burns & Roe after about 10 years, moving to Stearns-Roger Engineering Corp in Denver where he spent the better part of a decade contributing to a wide variety of industrial, utility, and non-utility generation projects involving alternative fuels, emissions control, gasification, etc.

In 1987, Donaldson returned to the East Coast, putting in a few years at WorleyParsons before accepting the CEO position at Technicon Enterprises Inc, a small engineering firm. He returned to WorleyParsons three years later where Donaldson's involvement in gas-turbine projects increased in response to market demand.

He recognized early the value of user groups. An ASME Fellow and past chairman of the society's Power Division Executive Committee, Donaldson believed design engineers needed feedback to assure the F-class plants being purchased in large numbers in the late 1990s would meet expectations. So he convinced ASME to let him start a Combined Cycle Users Group in 2000.

Donaldson chaired the group though 2008, attaching it to several industry events during the early years to hold down costs. However, the group never really gained traction until it began operating autonomously in 2011. Today, CCUG is conducted successfully under the PowerUsers umbrella along with the Generator, Steam Turbine, and 7F Users Groups.

## Wayne T Kawamoto

Plant Manager, *CAMS Juniper CA LLC's Corona Cogeneration Plant*

Wayne Kawamoto's involvement with gas turbines and user groups go way back—more than three decades. It would be difficult to identify someone who has volunteered more time to the development and operation of a user group than he has given the Western Turbine Users Inc.

The 1974 civil engineering graduate was just turning 30 when assigned by then employer Hawaiian Independent Refinery Inc to commission, in 1983, the first US land-based LM2500 electric generation package designed by Stewart & Stevenson.

Kawamoto's close association with other owner/operators began in 1986, when those who would form and incorporate WTUI in 1990 gathered in plant break rooms for meetings. He has been a proactive and vocal user since, affectionately called "maddog" by industry friends. Kawamoto became WTUI treasurer when the group incorporated and continues in that position today; he also has served as a director of the organization.

Kawamoto spent 17 years as plant manager of Wheelabrator Norwalk Energy Co, a 28-MW combined-cycle cogeneration facility which provided electricity to Southern California Edison Co and steam and chilled water to a nearby hospital. He has managed Corona Cogen, powered by an LM5000 STIG-120, since. Interesting to note is that Kawamoto participated in the SCAQMD emissions reduction rulemaking process by demonstrating the viability of using steam injection for reducing $NO_x$ emissions.

## Rick Shackelford

Division Director, Power Plant Operations, *NAES Corp*

Rick Shackelford has spent his entire 37-year power-industry career on, or close to, the deck plates—serving as plant engineer, electrical maintenance supervisor, O&M supervisor, and plant manager. He was appointed division director earlier this year. Shackelford is best known by CCUG members for his 16 years of service as manager of J-Power USA's 800-MW combined cycle, Green Country Energy.

He has a passion for sharing powerplant experiences, information, and resources to benefit others, and the industry in general. Illustrations of his efforts include the following;

- Member (and past chairman) of the Oklahoma State University Institute of Technology's Power Plant Technology Industry Advisory Board. This includes sponsoring a student internship at Green Country Energy.
- Vice chair of the CTOTF™ Combined Cycle Roundtable.
- Host and facilitator of an annual two-day 7FA combined-cycle mini-conference attended by a dozen utilities and IPPs in the Oklahoma area.
- Presenter before the Oklahoma House of Representatives and others in support of increased funding for technical education. CCJ

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

Siemens Energy Inc's second technical conference for owner/operators of its F,G, and H gas turbines, held Sept 18-21, 2016 at the Rosen Centre in Orlando, was rated a "success" by attendees sharing their views after the meeting. Nearly 150 global customers from 65 companies participated. **CCJ's** editorial team, unable to attend because of schedule constraints, asked Christie Robinson, representing the OEM's frame-owner office and product-line managers, to prepare the summary below.

This brief roundup will help identify subject matter on the program of importance to your plant/company. Then it is up to you and your colleagues to access specific presentations via the Customer Extranet Portal (CEP). Contact the Siemens representative for your plant if you have difficulty accessing the information needed.

Ed Bancalari, head of Siemens' large-gas-turbine product line opened the meeting with a video on what it takes to shape the future. His presentation focused on conference improvements, a regional view for each frame, an understanding of customers' challenges, how innovation is being used to increase customer value, digital portfolio, and a reminder to keep the entire plant in mind when it comes to expanded-scope solutions. An interactive poll was conducted to help the OEM better understand customer information requirements, concerns, etc.

Highlights of the meeting included presentations by the OEM's technical experts, closed user sessions, networking opportunities, a vendor fair, and a multi-day Siemens product technology and innovation showcase which included guided tours (new in 2016) conducted in English, Spanish, Arabic, and Korean.

## Mature F-class engines

Shantanu Natu, mature F frame owner, led the session covering the F through FD3 engines. Chris Muller opened with a presentation on the air separator and torque tube, reviewing rub events and their root cause, and Siemens mitigation recommendations. Included was an update on the recent

## Stay tuned

Siemens Energy Inc's engineering and marketing teams already are planning the next customer conference for owners of its F, G, and H gas turbines, motivated by the positive feedback received on the 2016 meeting. Plan is to have the next meeting in Orlando in September 2017. Users who missed this year's conference can access the presentations on the Customer Extranet Portal (CEP). Contact the Siemens representative for your plant if you encounter difficulty getting the information needed.

Don't miss the next meeting. Contact Kelly Lewis (kelly.lewis@siemens.com) or Dawn McCarter (dawn.mccarter@siemens.com) to receive details on the 2017 Siemens Customer Conference when they become available.

air-separator axial-rub event experienced in the fleet, plus details on the FD6 hybrid rotor as a design improvement that eliminates the air separator.

Bill Borman followed Muller with a review of rotor-air-cooler (RAC) filters that covered different designs and fleet experience. Mike Olejarski then addressed bellyband configurations, fleet status, and current recommendations.

Michael Hale's presentation on the R4 turbine-blade seal-pin RCA included a status report on design improvements—such as the enlarged seal-pin slot modification, blade springs, and optimized platform gap for the R4 blade. Chris Wetzl followed with a turning-gear time-reduction product developed by Siemens. In addition to reducing the time spent on turning gear, it provides peaking units instant-start capability.

The following session covered fleet findings on specific sections of the gas turbine—such as the compressor, combustor, turbine, casings, and rotor. Included were the effects of component findings on operation, performance, and repairs, as well as available improvements, controls, and O&M guidelines. The presenters were Dan McLean (compressor), Eric Schwirtz (combustor), Veronica Arocho-Pettit (turbine), and Marty Hall (casings).

Steve Dowman next updated the group on methods to address turbine-cylinder four-way joint leakage—such as alternative bolting sequence, sealants, box modification, and seal weld for vertical joint. Also covered: A status update on weld-repair recommendations to address four-way-joint cracks. Natu closed out the first day with a presentation on Siemens' long-term commitment to the F-class frame.

On Day Two, Jorge Cobian updated users on the DC lube-oil system, covering product bulletins and maintenance recommendations. A blade-path-spread case study by Gary Hildebrandt followed.

Ben Bassord then conducted a voice-of-the-customer (VOC) session on power diagnostics. It covered diagnostic-findings and monthly operations reports, 24/7 hotline support, and communication between plant and power diagnostics center.

The next session focused on the actions taken by Siemens to improve the quality of new parts (presented by Robb Chubb), repair parts (Anne Schneider), and field services (Mike Guerrero and Doug Hoffman).

Mike Salvatore presented case studies and lessons learned on plant-modernization and plant-upgrade solutions, including the following: FD6 partial package with ULN 3.0, advanced low-load-turndown 2.0, FD3 thermal performance upgrade (TPU) and single-piece exhaust (SPEX), and DF42-to-DLN conversion.

Last topic of the day was digitalization, presented by Edwin Castaneda.

Topics included the Sinalytics platform, digital services, and product portfolio. The speaker showed how digital services can improve plant availability, efficiency, and flexibility. Users later met in a closed session to coordinate feedback. The steering committee of engine owners/operators communicated the feedback to Natu and his team.

## Advanced F-class engines

The Siemens SGT6-5000F advanced frame sessions (F4, F5, F5ee), conducted in parallel with the mature F sessions, were led by Service Frame Owner Cristi Nemeth. Following her opening remarks, Brian Bohinski updated users on the market penetration of the advanced Fs, stressing again Siemens' commitment to continued development of F frames.

Next, Milt McCarty reviewed the advanced F combustor and turbine validation and inspection results from the fleet-leader units. Perhaps the most important point made: The advanced F combustor and turbine have successfully demonstrated reliable operation to the extended intervals of 25k and 33k EBH (equivalent baseload hours), respectively.

Javier Jimenez updated users on compressor-inlet-manifold crack indications found on some F5 units. Acoustic blankets were said to dampen the vibration that cause the cracking; they are available as a product improvement.

Dustan Simko and William Clark reviewed experience with the advanced F compressor. Simko's presentation addressed minor issues affecting the accuracy of variable-guide-vane (VIG) angle measurement and improvements to angle-measuring instruments introduced in new-unit production and also available for retrofit in service units.

Clark discussed the overall status of the advanced F compressor, including an overview of the design progression from F4 to F5 to F5ee. Of particular note in his presentation was the status of the compressor lock-bolt issue highlighted in coverage of the first meeting (3Q/2015, p 32). No further incidents of the lock-bolt issue have been reported, and mitigations are available for installation during opportunity outages.

Peter Rimmington closed out the compressor topics with a discussion of limits regarding the field blending of compressor airfoil damage.

McCarty returned to the podium to share findings observed in the advanced F combustor; Jonathan Mount did the same for the turbine section. Barton Pepperman followed with an update on the turbine exhaust, including the favorable field experience with SPEX as well as with resolutions to current issues with the expansion joint and the F5ee HEX strut-support blocks.

Olejarski discussed the Direct Air Injection System (DAIS), designed to mitigate casing thermal distortion after shutdown and reduce the probability of blade tip rubs that could debit unit performance. Simko returned with a technical review of the lube-oil system and bearings used in the advanced F, followed by Cobian on

### Vendor fair participants

American Thermal Solutions Inc
Bearings Plus Inc
Caldwell Energy
Coverflex
Crossby Dewar
Hydro Air Hughes
Kingsbury Inc
Lectrodryer LLC
Macemore Inc
ORR Protection Systems
Paragon Technologies
Piedmont Bushings & Insulators
Pilgrim International Ltd
Pioneer Motor Bearing Co
PME Babbitt Bearings
Precision Iceblast Corp
Safway Group
Universal AET
Voith Turbo Inc
WESCO Distribution Inc


product improvements and recommendations to enhance the reliability of the DC lube-oil system.

Hildebrandt was next with an educational discussion of operational support provided by service engineering and the Power Diagnostics Center (PDC), including a case study of a blade-path-spread issue that was resolved by successful collaboration among the customer, service engineering, and the PDC.

Day Two started with a closed session for users, followed by presentations by Chubb, Schneider, Guerrero, and Hoffman updating attendees on the application of quality processes in new manufacturing, repair, and field service.

Abhijeet Tiwary and Edwin Castaneda presented on advanced technologies and digitalization, the former covering advanced NDE—including online monitoring of flow-path components and advanced manufacturing methods. Castaneda outlined Siemens' approach to the use of data analysis for improving performance and reliability. Service Frame Owner Nemeth reviewed the F-frame evolution and reiterated once more Siemens' commitment to the fleet.

Greg Perona made the final presentation of the conference—a comprehensive look at mods and upgrades available to owners. It included multiple thermal-performance packages, wet compression, and gas-turbine autonomous control optimization. Later, the users met in a closed session to provide feedback to Nemeth and her team.

## 501G fleet

The topic generating the most discussion in the 501G session, chaired by Frame Owner Mark Carter, was an update on the R1 turbine-blade fracture issue. Rusty Van Hoose presented the latest fleet findings and conclusions from the RCA. The fracture was attributed to a flow disturbance caused by severe burn-through on the leading edge of the R1 vane.

Frank Ayoung-Chee followed with a presentation on the corrective actions to address R1 vane distress. Instrumented testing of the baseline airfoil was conducted to verify and calibrate analytical models. The results were used to develop a mitigation design for the R1 vane which increases backflow margin, improves impingement cooling, and supplies additional film cooling to the leading-edge area of concern.

The design mod can be implemented on the existing inventory of R1 vanes to minimize the lead time for issue resolution. Instrumented verification testing of the new vane design is planned for this fall. Additional design work on the R1 vane is under consideration.

An RCA update also was provided by Manish Gurao on the turbine-rotor through-bolt failure. Although rare, these bolts can fail when debris accumulation contributes to high contact stresses, which are conducive to cracking by fretting fatigue. High-cycle-fatigue (HCF) cracking ensues, with overload rupture an eventuality. The discussion focused on the design mitigations to provide additional margin against failure.

The primary path is the application of low-plasticity burnishing, a surface treatment intended to greatly improve a through-bolt's margin against both fretting and HCF crack initiation and propagation by adding a deep compressive residual stress field to the bolt surface. Additional potential bolt/disk redesign efforts and the recommended mitigations for the RAC circuit to minimize debris accumulation also were presented.

The upcoming performance upgrade offering for the 501G gas turbine, the Next Gen combustion system, was presented by Jim Pettit, who covered system benefits and design, test results, and implementation timeframe. Next Gen promises increases in power output, operating reliability, unit availability, and starting reliability across the ambient operating temperature range.

The combustion-system components are based upon advanced fleet design and experience with the ULN system. They are robust, designed and built to withstand higher firing temperatures and to offer the potential for extended operating intervals. The system recently completed a rigorous battery of tests in a test rig that confirmed performance goals for the new combustion system had been achieved—including lower emissions and an increase in flashback margin.

The ignition system, now static, was said to have performed flawlessly, providing high confidence in the starting-reliability improvement experienced with the advanced-frame designs. Turbine components have improved thermal-performance coatings to accommodate the higher firing temperatures of the latest machines. Multiple components, including the R1 turbine vanes, have an improved cooling scheme. Implementation and testing of the performance upgrade is planned for late 2017 to early 2018.

## H fleet

Siemens 8000H engine owners and operators from around the world came together to the conference in Orlando for the second time. The agenda was developed by direct input from customers because a steering committee had not been formed prior to the meeting. However, this during the 2016 closed user's session, a steering committee was selected by owner/operators to represent the 8000H user community.

Dave Lawrence, the 8000H frame owner, kicked off the event which provided multiple sessions over two days. Below is a sampling of the sessions conducted:

- *Frame overview and fleet status* included an announcement for a new web-based communications forum which will be trial tested and rolled as soon as practicable.
- *Fleet experience.* Presentations allowed users to dive deeper into specific topics.
- *An 8000H vendor fair* and parts showcase was conducted. Some of the latest technologies/components were on display and a customer interactive digital screen was available to further inform.
- *Mods and upgrades* reflected how Siemens is working with users in the product development process.

## Steamers, generators, etc

Multiple parallel-track breakouts were conducted following the gas-turbine sessions to update attendees on generators, steam turbines, and controls. A new breakout session at this year's conference included guided tours of the parts showcase with expert engineers in multiple languages. Here are some notes from each track:

**The generator team** provided direct responses to requested topics on the AeroPac, Modular, and BIC fleets. Frame Owner Scott Robinson reviewed the installed generator fleet for the F, G, and H gas turbines, touting its high availability and reliability. An update on AeroPac spark erosion topic also was provided.

Justin England, Generator Service Engineering (GSE), gave a status report on the continuing RCA for AeroPac key-bar stud separation. Justin Shingle, manager of generator specialty services, followed with a review of the recent service bulletin for parallel-ring-tab inspection, plus inspection recommendations for the Modular generator product line.

GSE's Jon Anderson conducted a tutorial on modal testing of the Modular generator stator endwinding before providing an overview of the SGen-1000A end-block service bulletin. Alex Oyler of GSE updated attendees on Performance Plus™ carbon seals, including a review of fleet operational history and the OEM's ongoing work to improve this product.

Eric McDonald, director of generator specialty services, presented on new capabilities— including the elevated-frequency test and GVPI stator repair options. A Q&A session covered all generator topics, both on and off the agenda.

**The steam-turbine sessions,** led by John Walsh, engineering management, reviewed details of the KN and HE frames. Topics discussed included maintenance, outage planning, titanium blades, and a wide variety of available upgrades—including ruggedized hydraulic turning gear, EH skid upgrades for reliability, failed thermocouple simulations for continued plant operation with instruments that cannot be repaired with the unit online, coupling-bolt installation improvements, automated forced cooing, and a package of control logic upgrades for enhanced turbine operations.

**The controls session** was led by Tom Delia. Presentation topics included development status and field experience of the gas-turbine autonomous control optimizer (GT-ACO). This product line offers a fully autonomous and adaptive control strategy designed to provide continuous optimization for emissions, dynamics, and firing temperature while maintaining GT power output.

Session also included detailed presentations on the implementation of the SPPA-T3000 Release 7.2 pilot project implementation and the integration of the advanced operations "applications." The criticality of cybersecurity and the implementation of best practices and requirements for meeting the latest NERC-CIP standards were presented as well.

**The product technology** and innovation showcase continued throughout the week. Guided tours were conducted of each booth in English, Spanish, Arabic, and Korean, and questions were answered in real time. Highlights included the following:

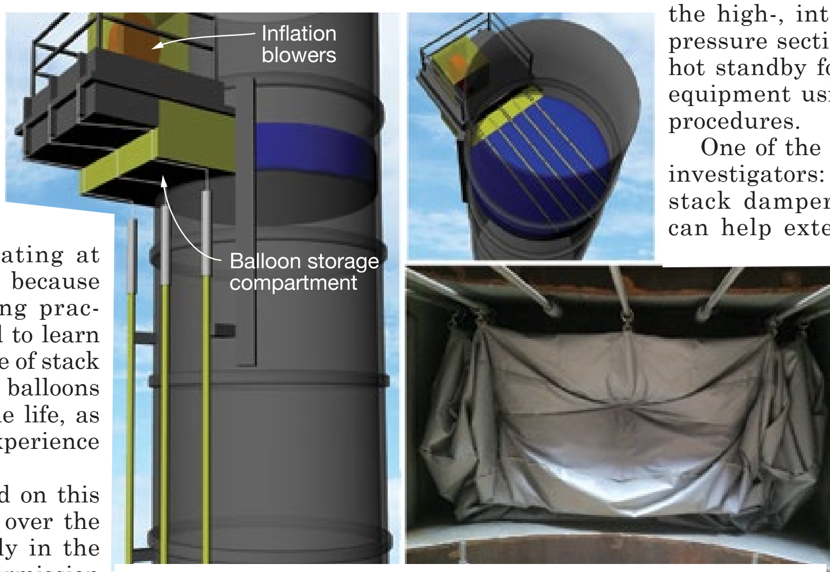
- F, G, and H components and technologies.
- SPPA-T3000 Release 7.2, cybersecurity, and excitation training.
- Digital products.
- Digital photonics production.
- NDE findings.
- Field service tooling.
- Vision scope.
- Debris /RCIE.
- Fluid system services.
- PhotoBox.
- Repair inspection-data collection.
- Performance maintenance gas-turbine component repair.
- Footprint generator.
- O&M training.
- Digital data collection.
- Diversity and Inclusion Council.
- Field technology services.
- Environmental health and safety.

# Keep heat in cycling HRSGs to mitigate thermal fatigue

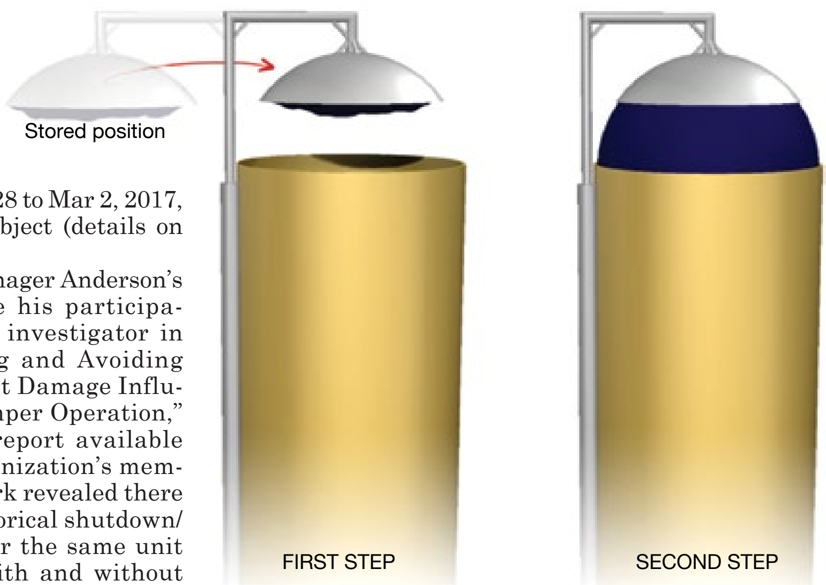
An F-class user recently called CCJ's editorial offices concerning the impact of cycling on wear and tear of HRSG components. Plant personnel believed thermal-fatigue damage to critical components might be accumulating at an accelerated rate because of current operating practices and he wanted to learn more about the value of stack dampers and stack balloons for extending fatigue life, as well as industry experience with them.

CCJ has reported on this topic several times over the years, most recently in the 2Q/2016 issue, "Intermission control: Reducing downtime risk to HRSGs." The editors recommended that the caller contact Bob Anderson, the HRSG consultant and expert on the publication's Editorial Advisory Board. It just so happens that the upcoming "HRSG Forum with Bob Anderson," Charlotte, Feb 28 to Mar 2, 2017, will address this subject (details on facing page).

Former plant manager Anderson's credentials include his participation as a principal investigator in EPRI's "Evaluating and Avoiding HRSG Pressure Part Damage Influenced by Stack Damper Operation," a December 2009 report available to the research organization's members. Anderson's work revealed there was a dearth of historical shutdown/hot-standby data for the same unit or similar units, with and without a stack damper. He believes not much has changed since 2009 in this regard.




**1. Automated stack balloon arrangement,** at left, shows storage compartment to keep the balloon out of the flue-gas stream when the gas turbine is in operation (see also photo, lower right); inflation blowers are above that compartment. Photo at the top right shows balloon deployed and inflated




**2. Stack seal design** in testing shows balloon, protected under cap in the stored position at left, is moved over the stack (center) and deployed (right)

The most striking attribute of the data collected and reviewed, Anderson recalled, is the great variability in the pressure-decay rates for the high-, intermediate-, and low-pressure sections of HRSGs during hot standby for generally identical equipment using similar operating procedures.

One of the conclusions drawn by investigators: While it is apparent stack dampers and duct balloons can help extend the fatigue lives of pressure parts in cycling units, their potential benefits can be overwhelmed by one or more contributors—such as leaking steam or feedwater isolation valves, lackadaisical isolation-valve operating procedures during shutdowns and startups, and the addition of cold water to drums after the gas turbine is shut down.

Anderson went on to say that thermal-fatigue damage occurs in various pressure parts during all startups. The greatest damage, he continued, is suffered during an immediate restart after a trip, followed by cold, warm, and hot starts—in that order.

Stack closures (damper and balloon) only delay the loss, Anderson said, when used without steam sparging, because they only benefit if the unit is restarted before the gas-path temperature decays to ambient. This can occur within four to 18 hours depending

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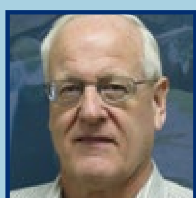
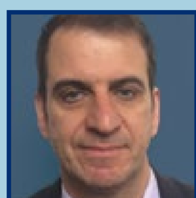
Bob Decoussemaeker, GE POWER

Madeline Dean, Exelon Energy

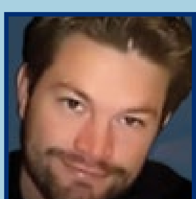


Barry Dooley, Structural Integrity

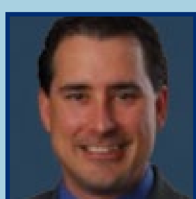


Jean-Francis Galopin, CMI Groupe

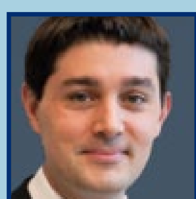
Jeff Henry, Applus RTD



Ben Privett, OGE Energy



Scott Wambeke, XCEL Energy



Jake Waterhouse, Dekomte

## Key topics, quality speakers and networking

- Drones for HRSG Inspections
- Optimum Cycle Chemistry Control of CCPP/ HRSG & How to Achieve It
- ASME Code Issues Relating to Advanced Materials & What You Should Know about P91
- Design Challenges for 600°C (1112°F) HRSGs
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on how well the HRSG is bottled up, how well the stack/breeching is insulated, and how promptly the gas path and steam/water systems are isolated.

Two more points to consider:

- Steam and/or water leaking or being drawn from the HRSG (the HP section in particular) during layup accelerates temperature decay significantly, with or without stack closure.
- If steam is drawn off to maintain turbine seals, a damper or balloon will have very little benefit.

Anderson said, based on his experience, plants that cycle frequently and can accommodate a damper, prefer it over a balloon. However, engineering is an important part of the decision-making process. Example: Retrofit of a stack damper may not be possible without encroaching on the minimum unobstructed distance from CEM probes. In such a case, a duct balloon might be your only choice.

Keep in mind that retrofit dampers typically cannot be installed at the top of an existing stack because it is not designed for the additional weight at that location. Some plants have retrofitted dampers just above the breech opening by fabricating the damper inside the stack rather than cutting the stack to install a modular damper.

Regarding balloons, Anderson said they are used effectively at many plants, but typically for keeping the gas path dry during layups of a few days or more rather than for overnight shutdown. In his experience, for a balloon to be useful for overnight shutdown a crew of two must be standing by to deploy the balloon immediately upon GT shutdown, and again to retrieve the balloon immediately before startup. Given the shrinking number of employees at most plants today this may not be practical.

The editors contacted duct-balloon expert Gary Werth for an update on a system capable of remote balloon deployment/retrieval (Fig 1). He said a system is in beta testing and has operated successfully. Anderson noted that the cost of installing a door in the stack and modifying or adding new stairs, ladders, and platforms for balloon deployment and retrieval might cost more than the balloon. Mindful of this possibility, Werth is developing a simpler design (Fig 2).

One final note: Balloons can be installed in the stack and in the GT inlet. Both locations require thoughtful administrative and/or physical interlocks to prevent accidental operation of the gas turbine when the balloon is deployed. CCJ

# Oil firing comparable to gas at 501F peaking plant

Most equipment-oriented technical papers presented at industry conferences, and articles that appear in electric-power publications, are based on supplier input and typically discuss expectations for new or improved systems and components rather than field-demonstrated experience. CCJ ONsite and CCJ (print) focus on the latter, to the degree possible. Many of the editors' daytime hours are spent in the field and on the phone learning from their network of sharing users to provide you actionable information.

A case in point is the dual-fuel retrofit of two W501FC gas turbines at the privately held Termocandelaria peaking facility near Cartagena. In 2006, the Colombian government promulgated a regulation that directed thermal plants unable to negotiate firm natural-gas contracts to guarantee their energy obligations with the electrical market by using fuel oil in a firm contract base.

Plant management responded to this requirement by converting Termocandelaria's gas-only, dry low-$NO_x$ engines to dual-fuel diffusion-flame combustion, with water injection for $NO_x$ control.

**1. Delivering fuel oil to Termocandelaria** at full capability reveals four trucks at the unloading station, several others in the queue to the left of the large oil tank, and several others in the parking lot at the top center of the photo

Mitsubishi Power Systems (today Mitsubishi Hitachi Power Systems Americas) was awarded the contract and completed work in only 11 months (November 2007) to satisfy project requirements. "Dual-fuel retrofit assures strong balance sheet," published by CCJ in 2Q/2009, presented design details, commissioning experience, and expected performance (access by scanning


**2. Termocandelaria staff is split into teams to manage logistics** and unloading operations efficiently. Pictured at top (l to r) are Abraham Turga, José Rosa, Robinson Quesada, Marjourie Maloof, Miguel Perez Ghisays, Policarpo Batista, Maria Alejandra Ruiz, Arnulfo Rojas, and Elias Sierra. At right are Elver Villero, Mariel Matute, Jairo Ballesteros, Shirley Romero, and Fabio Mendoza the QR code with your smartphone or tablet).

The modified units can burn either oil or gas; they are not arranged for co-firing (simultaneous combustion of both oil and gas). Gas is the fuel of choice and usually available.

In 2009, the editors asked Plant Manager Miguel Perez Ghisays (today General Manager) when he was interviewed for the first article to share operating experience with his colleagues worldwide when there was significant oil firing experience to report. That finally happened this year when the country's hydroelectric resources were diminished by El Niño weather patterns and the market required baseload dispatch of Termocandelaria and other thermal powerplants on oil (Fig 1).

**Data in hand, Perez Ghisays c**ontacted the editors from the office of Scott Cloyd, MHPSA's general manager of gas turbine service engineering, during a recent visit to Orlando. Also on the call was Termocandelaria's Operations Manager Policarpo Batista, who was a shift supervisor when the plant was converted to dual fuel.

Cloyd began the discussion with a review of design goals for the retrofit combustion system. At the top of the list: High starting and operational reliability on oil. This goal, Cloyd said, was enabled by the systems designed and supplied by MHPSA which recognized the benefits of diffusion-type combustors for fuel-oil operation and the value of the company's enhanced nozzle design and control philosophy to eliminate flow dividers.

The second most important design goal: Satisfy the fuel-consumption demands of the gas turbines during continuous baseload operation. Cloyd noted that each engine burns about 200 gpm of distillate at rated capacity. This requires the ability to unload three to four oil tank trucks per hour and enable continuous fuel treatment to clean the oil and reduce the potential for contaminants that could harm turbine components.

**The El Niño weather pattern** lasted from December 2015 until April 2016. During that time, Unit 1 started a dozen times on oil and ran 1113 hours on liquid fuel; Unit 2 had eight starts and ran 1269 hours. Both engines were dispatched by the system administrator about 90% of the time at their nameplate ratings. Starting reliability on oil for both engines was 100%. Reliability and availability of both engines exceeded 98% on oil, just as they had on gas.

Both "regular" distillate and ultra-low-sulfur oil were burned during El Niño. No problems were encountered with either fuel during unloading,

**3. Four trucks unload** simultaneously at Termocandelaria in the evening


**4. Unloading station is high-tech** at Termocandelaria. Heavy video monitoring is in evidence to ensure safe operations. Lines painted on the deck ensure exact positioning of trucks to facilitate the connections of the trucks to the unloading skids. In the unlikely event that a spill occurs, it will be directed to the trench under the grating which connects to the oil/water separator. Coalescing and particulate filters serving adjacent unloading stations are arranged in parallel and able to process oil from two unloading skids. Note, too, trucks must be certified "clean" before handling oil

treatment, forwarding, and combustion. Results of borescope inspections before and after the oil run revealed no degradation of hot-gas-path components. $NO_x$ emissions were maintained below the World Bank standard of 88 ppmvd on oil (66 ppmvd on gas) with correction to 15% $O_2$. CO emissions are not regulated; continuous emissions monitoring is not required.

The logistics of operating on fuel oil delivered by truck compared to pipeline supply of gas was a daunting challenge. Plant personnel had to closely monitor deliveries, fuel quality, and fuel processing. Perez Ghisays and his staff responded by splitting into teams to manage logistics and unloading operations efficiently (Fig 2).

**Discharging cargo** from four tanker trucks of up to 12,000-gal capacity simultaneously was successful (Figs 3, 4); no downstream issues were encountered. Oil was sampled randomly and all samples met specifications. The original unloading plan developed during fuel-oil commissioning accomplished all operational and technical requirements. Termocandelaria received oil from three terminals, two within about five miles of the plant and the third about 65 miles away.

The transport contractor guaranteed the number of trucks necessary to satisfy baseload operational requirements. At times, 16 would be in the queue to permit the unloading of 72 trucks in a day to fulfill the dispatch. No technical difficulties were encountered while unloading the 2800 trucks required to accommodate the El Niño phenomenon.

In wrapping up the interview, Perez Ghisays reflected on the decision to perform the fuel conversion with MHPSA, "It was the right decision in 2006 and is still the right decision in 2016." CCJ

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- Suggest a topic for inclusion in the program.
- Make a short presentation on best practices, lessons learned, generator upgrade, outage profile, O&M history, etc. Can be 5, 10, or 15 minutes, or longer.
- Bring a thumb drive to the meeting with a couple of photos describing a problem at your plant and ask your fellow users for suggestions on a solution. Think of this clinic as free consulting by those who walk in your shoes.

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**Email Vice Chair Ryan Harrison (ryan.harrison@atco.com) with your thoughts/ideas today.**

# Proper steam temperature control reduces operational risks

**By Jacob Bartol,** HRST Inc

**1. Bowed tubes** were caused by overspray

**2. Probe-type desuperheaters** in cycling units are prone to fatigue failure

**3. Cracking of steam-pipe wall** was caused by desuperheater spray water that was not evaporated according to design

Final steam-temperature control in combined-cycle and cogeneration facilities can be a complex issue with many variables. An increasing number of F-Class HRSGs are experiencing problems stemming from any combination of the following: poor steam-temperature control, desuperheater overspray, leaking desuperheaters, blocked valves or nozzles, desuperheater control-valve "hunting," etc.

Low-load operation is also an area of concern for many units because of the reduction in steam mass flow and simultaneous rise in GT exhaust gas temperature (with some GTs). In some HRSG designs, ones with unbalanced superheat and reheat surfaces, spraying to saturation (overspraying) at low loads is unavoidable.

When the foregoing issues cannot be resolved by making adjustments to the control system, more sophisticated control philosophies can be deployed both to mitigate the problems and extend the lives of HRSG components, and to boost performance (power output). Poor steam-temperature control can damage downstream equipment (Fig 1) and increase plant heat rate.

Steam-temperature control functions have not changed much over the years; however, as the HRSG fleet ages some of these problems are starting to reveal premature failures and damage in some units (Fig 2). A typical control system uses the steam temperature at the turbine inlet, steam-system pressure, and steam temperature at the desuperheater outlet to calculate the required desuperheater cooling-water flow.

Although this control-system arrangement works to inherently supply steam at the required temperature, it does not have the ability to reduce other HRSG-related issues or to accommodate a cyclic load profile. Recall that the design basis for many combined-cycle plants originally was a baseload configuration.

It is also a very common practice for operators to lower steam-temperature set points to reduce the risks of high-temperature excursions and alarms. The intentions are good, but this then will increase attemperator spray-water flow, possibly causing overspray damage; plus, it also will negatively impact unit power production.

One of the benefits of most modern control systems (especially distributed control systems) is that a design can be implemented and tested prior to deployment as a controlling medium. Control philosophies can be implemented to precisely regulate steam temperature throughout a plant's load profile.

## Component impacts

Desuperheater overspray can lead to several problems in HRSG components and external steam piping. Typically when an overspray condition occurs the piping and components downstream of the spray nozzles are thermally quenched. This can cause ID-initiated cracking and potential premature failure of the components (Fig 3).

Desuperheater probes, liners, and steam piping are most susceptible to thermal quenching. Keep in mind that pipe in the high-pressure superheat and reheat systems often is high-chrome steel, like P91, which can be expensive, challenging to repair, and have a long procurement lead time.

Superheater and reheater tube panels downstream of desuperheaters are also at risk of thermal shock damage. HRST often sees tubes that are bowed or deformed longitudinally, as shown in Fig 1. This damage stems from overspray in many situations.

**4. Tube-to-header weld failure** was attributed to thermal quenching

Excessive tube stress as a result of tube-to-tube temperature difference can put tube-to-header weld joints at greater risk of failure because of fatigue damage at these joints (Fig 4).

## Issue mitigation

Although the desuperheater issues are not always completely resolved by controls-only solutions, control systems can help mitigate damage using basic thermodynamic calculations. These calculations perform an energy balance across the desuperheater using existing instrumentation and curve-fit data in the DCS to control spray-water flow rates more accurately.

The system can be built into existing control functions and act as a bias signal to alleviate excessive spray flow to a certain extent. Alternatives include the QuenchMaster® air injection system to help mitigate this and other steam temperature control issues related to overspray at low loads (Fig 5).

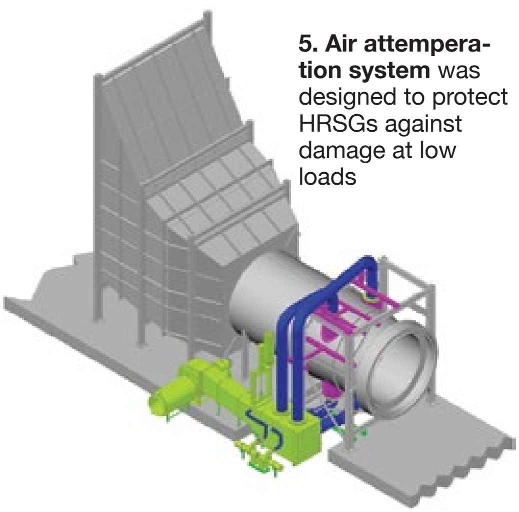
Desuperheater control- and block-valve arrangements that allow water to leak into the system can also cause thermal quenching of the associated components downstream of the desuperheater. Many control valves are not designed to operate in the lower range (<5%) of their travel because of turndown constraints as damage to the valve trim can occur.

Valve manufacturers typically suggest a block-valve arrangement upstream of the spray-water control valve to prevent this condition. HRST recommends a block-valve arrangement and a control philosophy that closes the block valve when the spray-water control valve position is <5% open. DCS alarm signals can be implemented to inform when a system is not operating optimally and is at risk of damage.

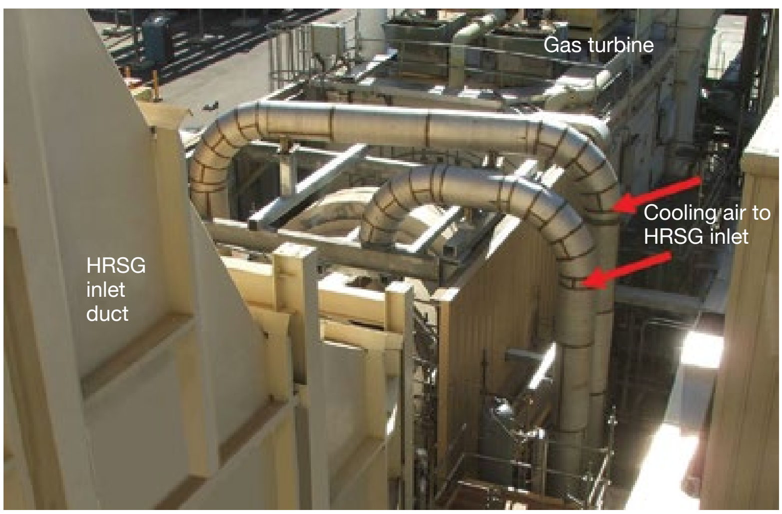
One of the most basic alarms is a comparison of calculated steam saturation temperature to actual steam temperature in a desuperheater system. This alarm ensures the process is not spraying down to saturation temperatures. HRST recommends desuperheaters maintain a minimum of 30 to 50 deg F of superheat to prevent thermal quenching of downstream components. A function similar to this also can be used to detect a leaking desuperheater spray circuit that allows water flow into the system with no spray-water demand.

## Initial design practices

Many of these issues are a direct result of control systems designed only for temperature control, or a plant originally designed as a baseload facility and now cycling. Many HRSG-related components often are overlooked during the design phase of a project, with other plant equipment believed "more important." In some cases, the designer is not as familiar with the impacts of other equipment (gas turbines, in particular) on the HRSG. CCJ



**5. Air attemperation system** was designed to protect HRSGs against damage at low loads



# Arrive early, stay late to maximize involvement, benefit

**W.T.U.I.**

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**2017 Conference & Expo**

**March 19 – 22**

**South Point Hotel & Casino**

For the latest information on technical and social programs, exhibit space, sponsorships, conference and hotel registration, etc, visit www.wtui.com.

To reserve exhibit space and sponsorships, contact
Bill Lewis: blewis@wtui.com, or
Alvin Boyd: aboyd@wtui.com

The 27th annual meeting of the Western Turbine Users Inc (WTUI) is only a few weeks away, March 19-22, 2017, at the South Point Hotel and Casino in Las Vegas. Make your reservations today at www.wtui.com. This is the organization's first conference outside of California since the 2007 meeting in Phoenix and the group's third trip to Las Vegas (1994 and 2001). Most people don't need an excuse to extend a business trip to Nevada's largest city by a day or two, but there's a good reason not to rush in and rush out this year: professionally beneficial social events.

They are critical to the success of user-group meetings, enabling attendees to meet in a relaxed environment and expand their networks for problem-solving. WTUI is hosting several "not-to-be-missed" functions as part of the organization's 27th annual conference. Most would not have been possible without financial support from the sponsors identified on signage in the exhibit hall, which will include Alan Mibab's AGTSI (ad, page opposite). Please thank them when you have the opportunity.

The headline events are profiled below. Keep in mind that several have a participant limit and a special fee, so the sooner you contact Conference Coordinator Charlene Raaker (craaker@wtui.com) the better your likelihood of success.

## Sunday, March 19

**Golf tournament,** 7:30 a.m. to 12:30 p.m., will be held at the Rhodes Ranch Golf Club, 15-20 minutes from the South Point. Golf Chairs Wayne Kawamoto and Jim Bloomquist consider this 6900-yard course, highlighted by several par 3s, "Las Vegas golf at its finest." The tournament is arranged as an 18-hole, four-man shotgun scramble (sometimes three- or two-man). Cost is $100 per player.

Golfers love their prizes: longest drive, closest to the center line, closest to the pin on several holes, plus team awards for low score. Last year, 26 awards were presented at the Monday luncheon, with two golfers receiving two each. Beware these "ringers" when you step onto the course this year: Janice Shogren, Beth Kallaene, Gabe Golden, Jay Dunkelman, Jeff Dietz, Zack Almont, Fred Keeler, Andy Stewart, Wes Knapp, Greg Jacobs, Mike Wayne, Ray Perez, Alan Hermann, Greg Atkinson, David Ehler, Brian Hulse, Vance Manning, Wayne Feragen, "Maddog" Kawamoto, Joe Jackson, Bloomquist, Jeff Martin, Tim Ahn, and Greg Young.

**Bowling tournament** at the South Point starts at 10 a.m., ends at l p.m. This is WTUI's first bowling contest; it was substituted for the tennis tourney this year given the hotel's huge bowling center. Bowling is limited to the first 30 participants to sign up at $20 each.

**Welcome hospitality** from 5:30 p.m. to 8:30 in the exhibit hall. This event, which includes the opening of the exhibition, is a very special function says WTUI Treasurer Kawamoto. All conference attendees and spouses/guests are invited.

## Monday, March 20

**This year's spouse tour**, 9 a.m. to 3 p.m., at $75 per person (including lunch), is billed as a once-in-a-lifetime experience (The Best of Vegas) for the up to 50 participants. The lid is still on the program so you'll have to check back at www.wtui.com for the agenda later. However, a better idea might be to sign up now; the Western Turbine all-volunteer organizers always "deliver." Bus transportation is provided, loading outside the South Point lobby at 8:45 a.m.

**Awards luncheon,** from noon to 1:00, salutes recipients of the golf and bowling awards.

**WTUI hoedown,** from 6:30 p.m. to 10 in the Grand Ballroom. Attendance is included in the conference registration fee. This is sure to be a good time and noisy, given the live entertainment by a boot-stomping band. Monday evening receptions and dinner at Western Turbine meetings are always fun.

## Tuesday, March 21

Two highlights on the Tuesday program are recognition awards and special technical presentations. The awards are presented at lunch—both for WTUI service and industry best practices. When the exhibition hall closes at 2:30, the technical presentations begin. There are three one-hour sessions in this part of the program, each consisting of three presentations conducted in parallel. Stay tuned to the Western Turbine website to get the details as they become available.

## Wednesday, March 22

Highlights of the Wednesday program—going-home day—are GE's hour-long new products update beginning at 10:45 a.m. and a special tour of the Hoover Dam powerplant arranged by WTUI Chairman Chuck Casey. Bus leaves the hotel at 1:30. The GE program offers a heads-up on developments that might facilitate operations, boost output, decrease emissions, and/


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PH: 561·994·0000
FX: 561·994·3600

or increase efficiency of your plant. The second, available only to 80 pre-registered attendees, certainly is worth staying for. There is no special fee for the Hoover Dam tour.

Built during the Great Depression in fewer than five years it was the largest dam of its time. Today, 80 years later, this National Historic Landmark is considered one of the "Seven Engineering Wonders of the Modern World." The engineering marvel, which enabled industrial development of the Pacific Southwest, forms Lake Mead behind the 72-story structure—said to be the largest man-made reservoir in the Western Hemisphere.

## LM2500

John Baker chaired his last LM2500 Breakout Session at the 2016 Palm Springs meeting, supported by Garry Grimwade who takes over in the front of the room at the upcoming Las Vegas conference. Baker needed a break to recharge his batteries, having led this group for nine consecutive years, perhaps more service time than any other breakout chair in the organization's history. He remains an active industry volunteer as a member of the steering committee for the Combined Cycle Users Group.

Both Baker's and Grimwade's day jobs are at Riverside Public Utilities' Clearwater Cogeneration Facility, a nominal 30-MW LM2500-powered 1 × 1 combined cycle in Corona, Calif. A proud Baker, the plant manager, calls it "the best powerplant in America."

The first breakout session, which ran for three hours Monday afternoon, kicked the meeting into high gear identifying/analyzing the findings in 2015 by Level 4 depots responsible for most major work on LM2500s. Air New Zealand Gas Turbines (ANZGT) was represented by Chris Martin, MTU Maintenance by Nico Brademann, and TransCanada Turbines (TCT) by Mico Madamesila.

Engine configurations covered by WTUI include the single annular combustor (SAC) and dry low emissions (DLE)—base engines as well as LM2500+/LM2500G4. These machines are used primarily to drive electrical generators and compressors, and to turn propeller shafts on naval and commercial vessels. The base LM2500 SAC dominates with about two-fifths of the units in service; LM2500+/LM2500G4 SAC account for another 30%, in round numbers.

**An important lesson learned** came out of the first case-history presentation and applies to all engine variations. Oversized compressor front frame (CFF) lower lug bores were found from the 4 to 8 o'clock positions. This is characteristic of some LM2500s installed onto Dresser-Rand packages, which use lower mounting lugs but have larger-diameter pin bores. The hole size is adjusted by reaming the CFF lugs.

In this case, the mod was made by the customer for its specific application. The mistake was in not letting the depot know about the custom mods. Had the shop repaired the lugs back to the OEM specific diameter without first checking with the customer, the overhauled CFF would have been incompatible with package mounts.

**High-pressure compressor** (base SAC and DLE machines). Heavy wear on mid-span damper pads on the first-stage blades caused an airfoil to liberate on one engine. The compressor had been borescoped beforehand with pad wear detected. Unfortunately, the owner decided to run the engine to the scheduled overhaul and failure occurred before the planned outage, putting a hard stop on the machine with damage to most all compressor parts as well as the combustor and first-stage nozzles. The old saying "pennywise and pound foolish" comes to mind.

Reminder: Periodic inspections are recommended every 4000 operating hours (refer to O&M Manual, Table 5-1) and damper pads on first-stage blades should be replaced at every depot visit.

**Stage-16 HPC blades** (SAC and DLE base and plus machines). Platform corner loss is a recurring issue on some engines with post SB-236 Inconel 718 blades. Stage-16 blades are known to have a resonance near the engine's operating range, causing high vibration which results in cracking, liberation, and/or corner loss. IND-236 specified the material change for improved durability against aeromechanical excitation, but while this has eliminated blade-tip corner cracking, platform corner loss is still an issue.

The OEM recommends Stage-16 blade platforms be checked during borescope inspections; when an engine is in the depot, NDT these blades. An investigation by GE resulted in a new blade design with cropped platform corners. The new design is said to have no impact on engine performance or operability.

**Vespel® strip de-bonding** (base SAC and DLE machines). Particles of Vespel strip have been found on the rotor air duct and inside the Stage 2 disk as the result of strip de-bonding from the HPC-rotor air duct. Loss of the Vespel strip may allow fretting wear to both the air duct and the second-stage-disk bore and could contribute to a change in the forward HPC vibration profile. A GE representative said the OEM is replacing the current epoxy adhesive with an alternative capable of operating at a higher service temperature.

A concerned user asked if this change would cause a step change in vibration. The OEM said it would and the level could go up or down—but as long as the engine is operating within GE's prescribed limits it should be fine.

**Broken inlet-guide-vane pushrod** (base SAC and DLE machines). During minor maintenance of this engine, three variable-stator-vane (VSV) pushrods were found broken and fully separated from the vane actuation lever below the spherical bearing housing on the threaded portion of each pushrod. Background facts: The unit is used for standby power, less than 50 hours/30 starts annually; compressor wash was semiannual.

Pay close attention to procedures the operator was told—specifically, proper cleaning and drying instructions in the O&M Manual. Also important is to ensure thorough hardware checks during periodic inspections and implementation of correct storage and preservation procedures when the engine is not in use.

**VSV torque-shaft wear** (SAC and DLE plus machines). Aft spherical bearings have experienced excessive wear on some engines post IND-169, -192, and -196. The latest thinking on the issue was published in IND-248 and -249 in July 2014. The first introduces an improved forward torque-shaft support, which consists of a new bearing bracket and a new shaft sleeve for the forward bearing. IND-249 introduces an improved aft torque-shaft bearing bracket. Another change: replacement of the slot-loaded spherical bearing to a full-contact one.

The depot speaker recommended that the latest configuration be installed in the field when the torque shaft is worn. Inspection should be to limits in WP 418. Bearings should be replaced once the radial clearances exceed the following: VSV torque-shaft forward bearing, 0.120 in.; aft bearing, 0.060 in.

**DLE baffle cracking** (an update for DLE base and plus machines). Baffle cracking has been discovered on disassembly of the post IND-181 design, which features profile and material changes. Speaker assured there was no impact on engine operation and no secondary damage has been found. Recommendation: Have the depot inspect and NDT DLE baffles upon exposure.

A GE investigation revealed the cracking initiates and propagates by high-cycle fatigue (HCF), starting at the bolt head. The OEM is working on an enhancement—the addition of a stiffening ring—to raise the resonant frequency above the combustor's acoustic range.

**Combustor burning** was identified on the inner liner of a base SAC machine at eight locations during borescope examinations. The burning, which worsened over time, was found near the inner rivet band at the inner liner, cowl, and dome-band joint. The user was concerned about the rate of wear.

Here's the machine history pertinent to this issue: Combustor overhauled and installed in November

2012; burning noted during borescope in July 2013 (4137 hours after overhaul); more burn holes noted in second borescope in November 2013 (hours not available); no significant change in damage found during the third borescope in May 2014 (10,727 hours after overhaul); degradation forced combustor removal and shop visit in December 2014 (15,398 hours).

Other important facts:

- Engine runs on gas with no water or steam injection; however, the combustor is configured for water injection and has no thermal barrier coating on the inner and outer surfaces of the liner.
- Burn holes were spaced relatively evenly around the combustor.
- Temperature spreads were within limits.
- Contaminant buildup on parts was found during the shop inspection, but this was not believed to cause the burning observed.
- Poor fuel filtration was suspect, but data provided to the depot were good.

A user asked the OEM representative in the meeting if the gas inlet pressure fluctuated and, if so, could that have affected the flame. Reply: Unstable pressure could have affected the flame which could have caused acoustic issues resulting in cracking/damage to the combustor.

However, with no specific gremlin identified, the depot's recommendation to this user going forward was to monitor combustor condition in accordance with the O&M Manual, and review site conditions—including fuel, filtration, fuel nozzles, etc—and maintain a watchful eye on them.

**First-stage nozzle air seals** (SAC base and plus machines). Seal tabs oxidized and cracked in operation, causing a potential risk for domestic object damage to the HP turbine airfoils. Vane design was found to cause overheating and oxidation of adjacent tabs. The fix: Installation of new inner and outer seals on affected machines. Another improvement: The number of tabs has been changed from 72 to 64 to match the number of vanes. Plus, the redesigned indexing tab is conducive to correct assembly and it avoids circumferential movement of seals.

**Turned/broken cooling-air tubes** (SAC and DLE base and plus machines).

Damage was found on second-stage blades on various engines. Plus, damaged/mission/rotated cooling-air tubes (spoolies), retainers, and spring washers were identified with missing parts/fragments fund inside nozzle segments. Side notes:

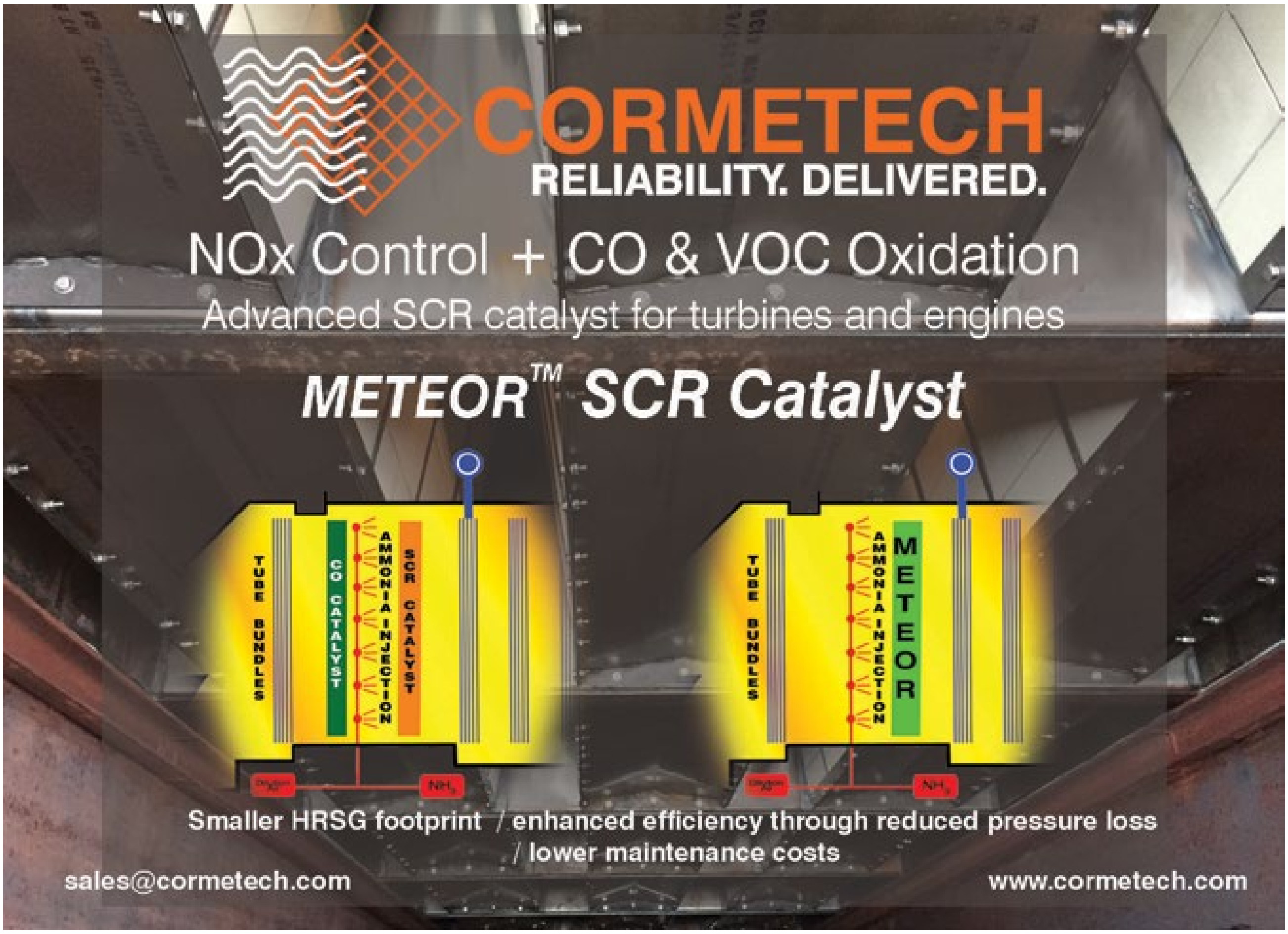
- Rotation of the cooling tube allows spring washer to cut into the tube releasing debris that can migrate into the flow path. This is conducive to domestic object damage of second-stage blades and nozzles.
- Vibration and the temperature difference between nozzles and HPC cooling air are thought to cause cooling-tube rotation.
- Rotated spoolies do not seem to have any effect on nozzle airfoil degradation.
- The spring washer has been eliminated, and removed from the IPC. Tube length and OD have been increased for a press fit to stop relative motion and wear. See IND-254 Rev 1 for details.

Recommended actions:

- Inspect cooling-air tubes periodically to monitor their condition.
- Implement IND-254 at the next hot-section exchange.

## LMS100

Breakout Chair Jason King, O&M manager at CPV Sentinel Energy LLC's eight-unit peaking plant in North Palm Springs, Calif, reminded users in his opening remarks of this fleet's strong commitment to information-sharing for driving continuous performance improvement. To support this commitment, the LMS100 users have established and strongly endorse these two communications channels:




- Monthly conference call, conducted the first Wednesday at 1 p.m. (Pacific). Contact King via the www.wtui.com website for dial-in number and participant passcode.
- Yahoo LMS100 Users Group (http://groups.yahoo.com/group/LMS100UG). Intent is to keep users current on the various technical and logistical issues challenging the fleet. It is facilitated by Karl Maier of SPS®.

Tripp DellaVilla of SPS made the first formal presentation of this breakout, focusing on LMS100 reliability and availability performance metrics and downtime contributors compiled from the company's ORAP® database. Here are a few of the points made by DellaVilla:

- Participation by LMS100 owner/operators in ORAP, now representing 67% of the 55 operating units in the fleet, should be higher to provide greatest value.
- ORAP Analytics™ Portal, recently released, allows users to view their plant's data via an Internet-based, on-demand business intelligence interface highlighting the specific KPIs of interest.
- Less work for plant personnel, more accurate information. ORAP Asset Insight™, recently commercialized, is an automated data-collection solution designed to tie into the plant's PI historian, via the Cloud, to collect without human intervention 85% of the data required by ORAP. The remaining 15%, concerning outage-event details, still requires a personal touch.

Next GE presented on fleet stats. Excerpts from those presentations follow:

- Fleet consists of 55 operating units (at the time of the 2016 meeting), as mentioned earlier. In addition, three units are being installed in California, two in Texas, and two in Argentina. A dozen orders were book in the year leading up to the 2016 conference: Five each in California and Arizona, two on the East Coast.
- Fleet operating hours totaled 434,000 operating hours/43,864 starts, with the high-time engine at 43,824 hours.
- Twenty-eight units have reliabilities of more than 98%.
- Fleet availability was said to be 98.2%.

Another presentation, one highlighting the various "field events" forcing an outage of 24 hours or more between October 2015 and February 2016, revealed nothing out of the ordinary: high-pressure-turbine first-stage blade cracks; HPT second stage blade foreign object damage; power-turbine FOD event, VSV system issue, failure to start, etc.

A later OEM presentation on asset management identified spares available to customers. Highlights:

- Lease program has six PA supercores, with two currently available.
- For the PB, one supercore is available.

The rotable module menu:

- Five high-pressure turbines.
- Three intermediate-pressure turbines.
- Six power-turbine (PT) rotor/stator modules.
- Three booster rotors.

A lengthy discussion of user experiences moderated by Chairman King touched on the following subjects, attesting to the breath of coverage:

- Chafing of jacking-oil lines which can lead to line failure. Easy to inspect for using a borescope, the floor leader said. He referred the group to SB-134 for guidance.
- Booster vane-ring replacement (SB-144). King did this at his plant and the job went well; he even showed a video to prove it.
- Loose PT23 sensor. Easy fix; see SB-179.
- Variable stator vanes held audience interest for significant time. SB-177 and SB-184 were focal points of the discussion.
- Fuel-hose leaks. Most such problems are resolved by proper installation and tightening of joints.
- Debris in oil filtration system. CCJ

# Evaluate use of reclaimed wastewater for your combined cycle

**By Gary Engstrom,** U.S. Water

Reclaimed municipal wastewater continues to gain attention as powerplants evaluate options to reduce their dependence on freshwater for steam generation and cooling. According to the EPA, thermoelectric power generation accounts for nearly half of US freshwater withdrawals (QR 1). The lion's share of this water is used for cooling.

QR 1

Recent regional water shortages have highlighted the importance of finding alternative, sustainable water sources for power generation. Water rationing or limits on freshwater use can have a crippling impact on plant capacity and operations.

So-called municipal reclaim wastewater (MRW) often can be used to relieve some of the pressure on freshwater supplies while providing a reliable, sustainable water source (QR 2). MRW as plant makeup can be successfully designed into new and existing facilities. The critical success factors and the components of primary concern are the same for both, but cost-effective options available to address them vary between new and existing facilities.

QR 2

This article identifies several of the key factors requiring evaluation before deciding on MRW for combined-cycle applications. Plus, it reviews the alternatives available to address/mitigate the performance-related issues MRW may create.

## MRW quality

Reclaim wastewater is subject to the same variability in the common-source water constituents plant operators are accustomed to monitoring and addressing in the day-to-day operation of their cooling-water and boiler-pretreatment systems.

**1. Characteristics of effluent from typical large municipal wastewater treatment facilities**

| Constituent | Range |
|---|---|
| Flow, mgd | 189-358 |
| Suspended solids, mg/l | 30-69 |
| BOD, mg/l | 69-105 |
| Oil and grease, mg/l | 10-17 |
| Nitrate (N), mg/l | NA-0.19 |
| Nitrite (N), mg/l | NA-0.14 |
| Ammonia (N), mg/l | 24-30 |
| Phosphate (P), mg/l | NA-3.35 |
| Turbidity, NTU | 22-51 |

NA = Not analyzed

These include the common scaling components (calcium, magnesium, barium, strontium, iron, and silica), alkalinity, suspended solids, and corrosive ions (chloride, sulfate) found in waters nationwide. The specific ion levels and their variabilities reflect regional differences in surface water, industrial makeup, and aquifer source—as well as seasonal changes, which can have a significant impact, particularly for surface waters.

However, overall MRW quality is determined in large part by the National Pollution Discharge Elimination System (NPDES) permit which controls the type and level of various contaminants that may be discharged. Acceptable contaminant levels depend on the receiving body of water and vary widely depending on the location, characteristics, time of year, and volume of the stream or surface water body.

Wastewater discharges contain some important constituents that can have a significant impact on corrosion, deposition (scaling/fouling), and the potential for microbiological growth not typically encountered at significant levels in the more familiar fresh makeup waters. These include nutrients such as ammonia/ammonium ($NH_3/NH_4^+$), nitrate ($NO_3^-$), nitrite ($NO_2^-$), phosphorus/phosphate ($P/PO_4^{-3}$) and organic loading expressed as biological oxygen demand (BOD) or total organic carbon (TOC). These compounds are a direct result of the biological processes used to treat wastewater.

QR 3

Table 1 summarizes the typical quality of municipal wastewater from four large treatment facilities (QR 3). The constituents listed in the left-hand column are typical of the parameters included in an NPDES permit. Note that several of these constituents were not routinely analyzed at some of the facilities surveyed—likely because they were not regulated.

Keep in mind that many of the constituents of interest in cooling- and boiler-makeup water applications for scaling and corrosion potential usually are not regulated individually and not

**2. Effluent quality with various levels of wastewater treatment**

| Treatment | BOD, mg/l | TSS, mg/l | Total N, mg/l | Total P, mg/l | E.coli, organisms per ml | Oil and grease, mg/l |
|---|---|---|---|---|---|---|
| Raw wastewater | 150-500 | 150-450 | 35-60 | 6-16 | $10^7$-$10^8$ | 50-100 |
| Primary treatment | 120-250 | 80-200 | 30-55 | 6-14 | $10^6$-$10^7$ | 30-70 |
| Secondary treatment | 20-30 | 25-40 | 20-50 | 6-12 | $10^5$-$10^6$ | <10 |
| Nutrient removal | 5-20 | 5-20 | 10-20 | <2 | | <5 |
| Disinfection | | | | | $<10^3$ | |
| Advanced treatment | 2-5 | 2-5 | <10 | <1 | $<10^2$ | <5 |

**3. Ammonia limits for copper alloys**

| Alloy | Maximum ammonia (as $NH_3$), mg/l |
|---|---|
| Copper | None |
| Copper/zinc (Admiralty) | None |
| 90/10 copper/nickel | 10 |
| 70/30 copper/nickel | 20 |

always analyzed on a regular basis.

This information gap is relatively common when evaluating potential reclaim water sources and highlights the importance of collecting data over an extended period of time. Comprehensive data collection also has the advantage of capturing seasonal variations, which occur in most regions. With MRW, this variation is even more exaggerated and can be day-to-day or even in day-to-nighttime cycles with regards to flows and composition.

The wide variation in the ranges for the individual parameters shown in Table 1 is a direct result of the level of treatment represented by the different facilities. Municipal treatment facilities have a minimum of secondary biological treatment, with many either using or transitioning to nutrient (N, P) removal and tertiary or advanced wastewater treatment systems. Table 2 summarizes typical effluent qualities that can be expected from various levels of wastewater treatment (QR 4).

QR 4

The foregoing information assures high-quality MRW can be produced if the appropriate treatment processes are in place. In fact, water produced by an advanced wastewater treatment system is on par with most natural waters currently used.

When evaluating MRW for makeup, be sure you understand the treatment processes in operation and the variabilities that can be expected over time. This information, along with the volumes available, then must be matched to your plant's equipment specifications in terms of materials of construction, operational requirements, and chemical treatment programs employed.

## Important considerations when using MRW

The most important thing to consider when using MRW in power applications is the impact the unique wastewater chemistry and its variability will have on corrosion, and on the deposit-forming potential, of the system when combined with the normal cations and anions encountered in conventional water sources. Conventional makeup water composition is routinely factored into treatment schemes, equipment/materials of construction, and system design. This has not been done with the same level of experience for most unconventional water sources.

For example, phosphorus (phosphate) can be found in wastewaters at levels much higher than those encountered in well or surface waters. As mentioned previously, this will depend on the NPDES permit and is normally expressed as P rather than $PO_4$. Phosphate is an excellent mild-steel corrosion inhibitor and widely used in the treatment of cooling systems. Many cooling-water programs using MRW rely on this natural phosphate source for corrosion inhibition.

High levels of phosphate, combined with its variability, can create significant scaling issues in the system when higher hardness and/or temperatures are present. This can be aggravated by low flow conditions in critical heat exchangers.

Phosphate also is a nutrient that can stimulate microbiological growth and fouling, which is conducive to microbiologically influenced corrosion (MIC). Accelerated microbiological growth potential often is disregarded by powerplant operators, but it can have a major impact on the selection of cooling-tower fill and on biocide selection. High-efficiency fill, for example, can act as a high-surface-area substrate for microbiological growth. Fill plugging can result—possibly even collapse, caused by excessive weight when combined with high total suspended solids (TSS) trapped by the biofilm.

The presence of ammonia in the reclaim wastewater can have a detrimental effect on the corrosion rates of any copper alloys contained in the system—including stress corrosion cracking (SCC). Copper ions introduced into the water from accelerated corrosion also can have a negative impact on mild-steel corrosion rates because of copper plating and the resulting galvanic corrosion/pitting cells that may be formed. Table 3 lists the maximum ammonia levels that can be tolerated by various copper alloys.

### 4. Austin, Texas City municipal water/reclaim water analyses

| Parameter | City water | Reclaim water |
|---|---|---|
| pH | 9.3 | 7.3 |
| Conductivity, µmho | 330 | 900 |
| Alkalinity (as $CaCO_3$), mg/l | 56 | 60-90 |
| Total hardness (as $CaCO_3$), mg/l | 98 | 100-250 |
| Calcium (as $CaCO_3$), mg/l | 29 | 100-135 |
| Magnesium (as $CaCO_3$), mg/l | 69 | 100-140 |
| O-Phosphate (as $PO_4$), mg/l | 1.5 | 5-15 |
| Silica (as $SiO_2$), mg/l | 6 | 9.5 |
| Chloride (as Cl), mg/l | 48 | 110-150 |
| Sulfate (as $SO_4$), mg/l | 31 | 120-170 |

These levels are exceeded by many reclaim waters not subject to consistent nitrification (Tables 1 and 2). This is a major concern for existing systems where ammonia may not have been factored into the original design. New plants should address these issues during the design phase and in the materials-of-construction selection process.

Ammonia and nitrate, like phosphate, are nutrients that can stimulate microbiological growth and fouling along with the resulting corrosion. As with phosphate, this can also impact design and operational parameters—such as the selection of cooling-tower fill and the microbiological control program. The latter is particularly important because ammonia reacts with most halogen-containing oxidizing biocides.

With high ammonia levels in the reclaimed wastewater, the use of gaseous chlorine or sodium hypochlorite and breakpoint chlorination becomes unrealistic. The facility must look to alternatives such as chloramine or chlorine dioxide with the associated cost and cost/performance sacrifices.

Other wastewater parameters, such as TSS and chloride and sulfate levels, must be analyzed carefully over time—even when the starting levels in the original source water are acceptable.

TSS can be affected dramatically by increased system flows during rain events as a result of inflow and infiltration (I&I) in the wastewater collection system. The higher flows impact influent solids as well as settling and clarification in the treatment process. This can be further aggravated in older infrastructure where combined sanitary and storm water sewers still exist.

Chloride and sulfate levels in the wastewater returned to the treatment plant can be significantly higher than were present in the initial distribution water. This is the result of water-softener regeneration discharges, cycling up effects from industrial users, addition of wastewater treatment chemicals at the municipal facility, and, in some coastal areas, I&I of brackish or seawater into the collection system. The author has seen chloride levels of <35 mg/l in the distribution system with returned levels of >200 mg/l in the reclaim wastewater discharge.

Representative analyses are presented in Table 4 (QR 5). It shows chloride and sulfate levels in MRW for this example can be three to five times greater than in the original water. In some cases, the levels for both of these ions can exceed recommended levels for corrosion of specific metallurgy or materials of construction in cooling systems operating with relatively low cycles of concentration (COC).

QR 5

Chloride can cause stress corrosion cracking (SCC) of stainless steels. Table 5 lists suggested chloride limits for various stainless steels as a function of temperature. The recommended chloride levels would be exceeded at very low cycles of concentration for any of the less noble stainless-steel alloys used in heat exchangers operating on MRW. This would require upgrading the metallurgy for new plants during design, or retrofitting upgraded heat exchangers in an existing plant.

In addition to elevated chlorides affecting materials, elevated sulfates in reclaim water can impact the type of cement used in concrete in contact with the water (tower basins, for example). The American Concrete Institute (ACI) has established guidelines defining cement limitations as a function of sulfate in ACI 318 (Table 6, QR 6).

There are many locations where groundwater sulfate levels exceed 1200 mg/l. These levels would be significantly higher in the MRW and could have detrimental effects on concrete used in the system when cycled during normal cooling-tower operation. This often is addressed in the selection and application of appropriate coatings.

QR 6

The higher levels of total dissolved solids (TDS) found in MRWs alone may impose additional limitations on cooling-tower design and operating parameters. When cycled, high-TDS water may leave the system as drift. This can produce air emissions in violation of PM10 standards. Even with excellent drift eliminators in place, the author has seen towers restricted on cycles because of TDS rather than other conventional indices.

Even though MRW may be highly treated for removal of soluble organics, it may still contain higher organic loadings than most freshwater sources. This loading usually is expressed as BOD or TOC. The carbon source, combined with the nutrients previously described, create the food source necessary for increased microbiological growth and the resulting fouling and

### 5. Suggested chloride limits for stainless steels

| Metal alloy | Chloride as $Cl^-$, mg/l | |
|---|---|---|
| | 80F | 140F |
| 304 | 200 | 150 |
| 304L | 300 | 200 |
| 316 | 600 | 400 |
| 316L | 1000 | 800 |
| 317 | 1200 | 1000 |
| 317LMN | 1800 | 1500 |
| 904L | 3000 | 2000 |
| AL6X | 7000 | 5000 |
| AL6XN | 20,000 | 15,000 |

### 6. ACI-318 cement-type requirements for exposure to sulfate

| Cement exposure classification | Dissolved sulfate ($SO_4^=$) in water, mg/l |
|---|---|
| S0, No restriction | $SO_4^=$ <150 |
| S1, Type II* | 150<$SO_4^=$<1500 |
| S2, Type V* | 1500<$SO_4^=$<10,000 |
| S3, Type V plus pozzolan or slag cement* | $SO_4^=$>10,000 |

*With other exceptions (see code)

corrosion problems that occur in the cooling-water environment. Increased attention must be paid to microbiological control when employing this makeup water source.

The TOC levels of MRW make it difficult to use in very-high-purity applications—such as makeup for high-pressure boilers. Many of the low-molecular-weight organic constituents are very difficult or expensive to remove and will generate organic acids in the boiler. New and existing plant designs rely on potable water and conventional demin treatment trains for makeup to these systems.

## Lessons learned

There have been several important lessons learned regarding the use of MRW in combined-cycle plants that merit consideration when developing new projects or converting existing plants to this makeup water source for cooling-water applications. They include the following:

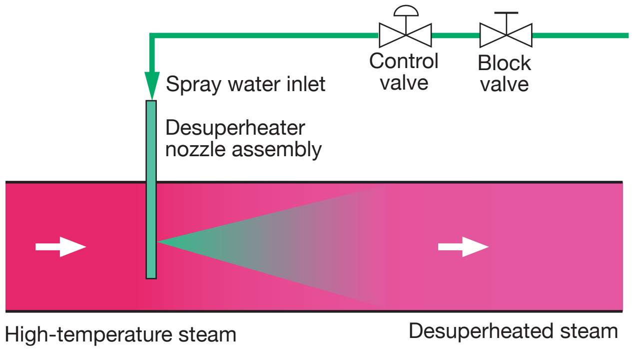
- Municipal plants that practice nutrient removal, advanced wastewater treatment, or tertiary treatment of their effluents provide water of sufficiently high quality to at least mitigate many of the problems described in the preceding discussion. These treatment plants may produce water of a quality at or near current fresh surface-water supplies.
- At a minimum, the wastewater treatment facility should practice a high level of nitrification to reduce the significant performance and cost issues associated with ammonia in the water.
- Many municipal providers of reclaim water are either upgrading their existing treatment facilities (now called water reclamation plants) or are constructing satellite treatment facilities to provide higher quality "designer" waters to meet the operational specifications for various industrial plants—including power production facilities. There may be multiple grades of these waters available.
- BOD, P ($PO_4$), and $NH_3$ levels must be clearly defined and understood because of the significant impacts they can have on microbiological control programs and chemistry. The microbiological-control portion of the chemical treatment program warrants greater attention than for most conventional makeup water sources.
- Water constituent analysis data must be complete and cover extended periods of time to capture annual, seasonal, and daily variations. The analyses must encompass standard water ions of interest for conventional cooling-water program applications, as well as the unique wastewater components described earlier.
- Cl, $SO_4$, TDS, and TSS levels in the reclaim water will be higher than in the corresponding municipal potable water and may impose operational, design, and materials-of-construction limitations on the system. These must be evaluated and mitigation options considered. Reducing cycles, upgrading materials of construction, changing tower fill, or modifying chemical-treatment programs all may provide benefits. Drift may pose an air-emissions limit not normally encountered in conventional applications.
- Flow variations in the wastewater facility resulting from the typical day/night cycle may require a storage buffer to ensure sufficient makeup water on a 24/7 basis. This is particularly important if the water requirement represents a significant portion of the total wastewater plant effluent.

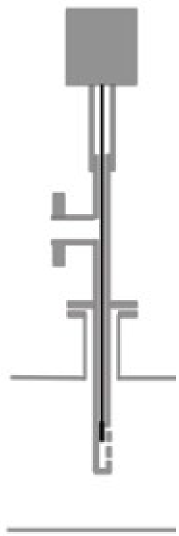
  The powerplant discharge must meet permitting requirements after cycling. You cannot assume that an industrial facility will have discharge limitations similar to those of the municipal facility on an NPDES permit for direct discharge.
- Many powerplants send their effluents back to the municipal treatment facility for treatment and discharge under the current permit at an incremental cost. TDS cycling and potential water-quality degradation is not normally an issue if the water flowing to and from the powerplant represents a relatively small percentage of the overall wastewater treatment plant capacity. The effects of cycling must be evaluated if this is not the case.
- The powerplant and the MRW supplier should have a clear understanding and realistic specification for the water being provided—including constituent ranges. Ranges are critical because they provide the basis for system operational and chemical-treatment program guidelines. These, in turn, impact performance and system reliability. The agreement should be documented in a written contract. Alternatives also must be identified for periods when the water is not in-spec or when the systems are out of service for scheduled or unscheduled maintenance. CCJ

# HRSG enemy No. 1

There were three breakout sessions on the afternoon of GE Day at the 25th annual 7EA Users Group meeting, Nov 1-3, 2016, in Hershey, Pa. CCJ editors attended the combined-cycle workshop, which offered presentations and discussion on heat-recovery steam generators, steam turbines, generators, and control systems.

Michelle York, an HRSG application engineer who came to GE when it acquired Alstom, wanted to focus her comments on topics of greatest interest to the 20 or so users in attendance so she asked them where they were suffering the most pain in their HRSGs and steam systems.



**Key elements** of a typical desuperheater used in combined-cycle service are identified in the left-hand side of the illustration; details of a probe-type attemperator are shown at right. Care should be taken to prevent throttling of the block valve which would result in premature wear and leakage

To get the discussion flowing, York put up a list of common issues which included the following: deterioration of tube restraints, flow-accelerated corrosion, removal of gas-side deposits, the life of pressure parts, duct-burner maintenance, and attemperator failures. Everything on her list got a lukewarm response except for the last item. Attemperators were the near-unanimous source of pain at the plants represented.

The editors thought this surprising. CCJ's coverage of attemperator issues goes back to the first issue, published in fall 2003. "Steam-turbine bypass systems" was co-authored by Robert W Anderson, then manager of combined-cycle services for Progress Energy Inc, and Henk van Ballegooyen, then president of Gryphon International Engineering Services Inc (now CHA Engineering Service), a Canadian consulting firm.

On the road to the quarterly's 50th issue—the one you are reading—attemperators have been featured in many articles. It's probably safe to say that CCJ has published more editorial pages on attemperators over the last 13 years than any other periodical serving the generation sector of the electric power industry.

And Anderson, now an HRSG/steam-system consultant and member of the magazine's Editorial Advisory Board, has had a hand in several. You can access many CCJ articles contributing to the industry's collective knowledge on attemperators by using the keyword search function on the periodical's website at www.ccj-online.com.

**The editors called Anderson** shortly after the 7EA conference to ask why attemperators continue to be a problem, what is being done to mitigate the issues, possible new designs on the drawing board, etc. The first thing he said was "Attend the first annual 'HRSG Forum with Bob Anderson,' Feb 28-Mar 2, 2017, in Charlotte. Problem-free steam attemperation is one of the hot topics on the discussion program." For more information, see p 83.

Commercial complete, Anderson got down to business and commented on the informal survey conducted by York in Hershey. In today's post-regulated industry, he said, no comprehensive database exists to quantify which HRSG system or equipment causes plant operators the most problems. Anderson's experience based on review of owners' operating data, and from listening to users at various HRSG conferences worldwide, suggests that inter-stage and terminal attemperators are at the top the list.

During the late 1990s and early 2000s, the "bubble" years, he continued, many of the HRSGs supplied for F-class combined cycles were equipped with an attemperator in which the spray-control-valve trim was located inside a "mast" or "probe" that extended into the steam flow path (figure).

**The probe-type attemperator** works this way: The valve trim moves up and down inside the mast, sequentially turning on or off individual spray nozzles. Note that this arrangement uses fixed-area orifices as nozzles, as the detail in the figure illustrates. It provides the relatively wide range of spray-water flows required at a competitive price. However, exposing the moving parts of the close-tolerance valve trim to thermal cycles—heat soaking in the steam pipe when not spraying and thermal quenching when spraying begins—caused erratic trim movement, cracking of the nozzle assembly, and, in the extreme, liberation of the nozzle assembly.

When the nozzle assembly fractures or liberates, water impinges on the inside wall of the steam pipe. A typical result is cracking on the internal surface of the pipe and of girth welds.

Anderson said his findings on consulting assignments, comments from owners at user-group conferences, and discussions with boiler and attemperator manufacturers suggest that most "internal-trim" attemperators in F-class combined cycles have been replaced with more reliable equipment and have not been installed in new HRSGs for several years.

Good news, correct? No; at least not in Anderson's experience. You might think the frequency of attemperator-related failures would decrease as better equipment is installed, he said, but that does not seem to be the case.

**Thermal transients.** Anderson went on, "Barry Dooley [a senior associate at Structural Integrity Associates Inc] and I conduct what we call Level I HRSG surveys. These one-day asset examinations focus on identifying damaging thermal transients, evaluating the effectiveness of the plant's cycle chemistry program, and determining in which locations within the HRSG flow-accelerated corrosion (FAC) may be active.

"A key means of identifying undesirable thermal transients during these surveys is an informed review of historical operating data. Very few operational errors—or poor performance of key systems like superheater drains, attemperators, steam-turbine bypass systems, etc—result in immediate equipment failure.

"Rather, most operational errors or oversights produce transients that cause accelerated incremental accumulation of thermal-fatigue damage. If the transient is repeated often enough, failure will occur. If you know what to look for, evidence of these transients can be found in the plant's historian and corrective actions taken to mitigate or eliminate additional damage."

Anderson said that he and Dooley have conducted more than 50 thermal-transient surveys on HRSGs supplied by 16 different manufacturers and incorporating many different models of attemperators. "Along the way," the consultant said, "I've formed some opinions about attemperator problems, what causes them, and how to avoid them."

Causes include one or more of the following (in combination):

- Insufficient maintenance.
- Ineffective control logic.
- Leaking spray water.
- Overspray.
- Defective hardware (nozzles, thermal liner, valves).
- Defective design (straight run of steam pipe upstream and downstream of the attemperator too short, no steam pipe drain or ineffective drain, inferior hardware).

Attemperators operate in very severe thermal and differential-pressure environments. Even the best hardware requires routine inspection to identify and replace worn or broken components before they damage steam pipes, headers, and tubes. Of the more than 50 plants Anderson and Dooley have surveyed, only one-fifth have a routine attemperator inspection program in place, leaving plenty of room for inexpensive improvement.

Rapid and large changes in gas-turbine exhaust temperature during startup, and high exhaust temperature characteristic of low-load operation, can make it difficult for the attemperator to maintain superheater/reheater outlet steam temperatures within design limits and also avoid overspray conditions. Many HRSGs built during the "bubble" used a simple feedback loop for steam-temperature control, resulting in poor attemperator performance.

This encouraged some operators to manually manipulate the attemperator set point, often causing severe overspray conditions. The use of well-tuned cascade control logic can achieve acceptable automatic attemperator performance for most HRSGs without operator manipulation.

**If spray water leaks** from the attemperator nozzle during periods when steam flow is low, or zero, it will fall onto the internal surface of the steam pipe and cause thermal-quench damage, and significantly increase the quantity of water that must be drained during the next startup.

Anderson says he often sees evidence of leaking during a review of operating data. "Sometimes the cause is insufficient inspection/repair of the block valve, but mostly it's due to the use of *master* control valve/*martyr* block valve control logic. In my view, it's not possible or necessary to maintain tight shutoff at the control-valve seat if the block valve maintains long-term tight shutoff.

"Master control valve/martyr block valve logic causes many unnecessary block-valve open/close cycles and virtually ensures both valves will leak after only a few runs. You can prevent leakage by arranging the logic to open the block valve only once during startup—when exhaust temperature increases to around 950F—and to close only when the exhaust temperature decreases below 950F during shutdown."

**Overspray occurs** when more water is injected into the steam than can be evaporated before reaching the thermocouple located downstream of the attemperator. If the steam temperature downstream of the attemperator decreases to within 30 deg F of saturation, damage to pipes, headers, and tubes may result. Control logic should be arranged to prevent the control valve from opening any further when this overspray limit is reached.

Most attemperators in use today use spring-loaded variable-area spray nozzles which provide good atomization over a wide range of flows; however, they depend on free movement of a poppet to work properly. Oxidation of the poppet stem or guide and fouling by debris in the spray water can cause nozzles to stick open or closed.

Attemperator manufacturers have worked to eliminate oxidation issues by changing materials. Most now recommend installation of a strainer upstream of the block valve to prevent valve and nozzle fouling. Routine inspection of nozzles is important. When in doubt about a nozzle's condition, replace it with a new one and send the suspect nozzle to the manufacture for refurbishment.

**Thermal liner.** Most desuperheating stations also incorporate a thermal liner to protect the steam pipe from spray-water impingement. But liners can crack, warp, or slide down the steam pipe, making routine inspection important. Lesson learned: Small cracks might be monitored via frequent inspections, but if left too long may result in liberation of parts, or all, of the liner, disrupting steam distribution to downstream heating surfaces or risking FOD to the steam turbine if from a terminal attemperator.

A few units suffer from attemperator steam pipes that are too short to permit spray water to evaporate before it impinges on downstream pipework. In some cases, the pipe may be just long enough that replacing the existing attemperator with one that produces better atomization, hence faster evaporation, may solve the problem. In severe cases the pipe must be made longer. CCJ

# Propane and ethane: Abundance drives options with questions

The US is blessed with an abundance of natural gas, thanks lately to surging shale-gas extraction from the Marcellus and Utica formations. The US is now a net exporter of energy. So what do we do with this surplus?

New projects might point to one option, while perhaps raising new questions. The US Virgin Islands is converting to LPG (liquefied petroleum gas or propane). A new plant in the US will fire both ethane and natural gas. Santa Catalina Island is supporting its microgrid with propane-fueled microturbines.

"Green Duba," Saudi Arabia's first integrated solar/combined cycle (ISCC) plant, now under construction in the Arabian Gulf region, will take full advantage of the country's domestic wet gas resources and burn condensate in F-class gas turbines (Fig 1).

Jeffrey Goldmeer, manager of gas-turbine combustion and fuel solutions at GE Power, and the person responsible for the OEM's strategic development of gas-turbine products for emerging fuel applications worldwide, co-authored and presented "Enabling ethane as a primary gas- turbine fuel: An economic benefit from the growth of shale gas" at PowerGen International in 2015.

He and his co-authors set the stage. "The rapid increase in US propane and ethane production, coupled with the development of new infrastructure and export terminals, is pointing to power generation from propane and ethane both domestically and internationally."

**1. F-class GE turbines** can be equipped to burn non-methane components from gas fields (above)

**2. Virgin Islands infrastructure improvements** include greater transmission capacity (left)

## US Virgin Islands

Traditionally used as a fuel for cooking, heating, and transportation, propane is now seen as a practical energy resource for power, especially in locations with high fuel costs (or a strong desire to reduce current emissions).

Such is the case with the US Virgin Islands (Fig 2).

At last year's Caribbean Energy Security Summit in Washington, DC, Vice President Joe Biden complimented the Virgin Islands Water and Power Authority (WAPA), stating "They're combining renewable energy with propane to lower costs and secure their supply, saving ratepayers 30% on utility bills."

Local conditions encourage the renewables. Solar will soon expand to about 18 MW and biomass will grow to 7 MW. But traditionally the bulk of VI's power has been supplied by gas turbines firing No. 2 diesel and No. 6 fuel oil. So to reduce emissions and lower rates to its customers, WAPA and GE are converting several gas turbines to multiple-firing capability: propane, LNG, and oil.

Propane will be the major fuel source, and a complete infrastructure is being prepared to support the independent power grids on St. Thomas and St. Croix. Propane comes from the Vitol Group under a long-term agreement that includes much of the new infrastructure.

WAPA's Executive Director Hugo V Hodge Jr says, "This major undertaking of the LPG conversion project with far-reaching effects on the economy of the Virgin Islands and WAPA's customers, and has become a source of much attention by energy companies and utilities not only in the Caribbean but across the world."

Commissioning of the plants started earlier in 2016 and is expected to continue through the fourth quarter.

## Ethane for power

Also by tradition, ethane is a feedstock for the petrochemical industry. But supply is outpacing demand, and development of new petrochemical cracking capabilities takes time. This opens a door to both domestic power generation and fuel export.

Ethane for power generation in the US will be validated by a new powerplant located near the fuel source in the Marcellus and Utica shale plays. This first-of-a-kind combined cycle will be fueled by both ethane and natural gas in conventional GE turbines. Being located near the shale formations provides access to low-cost gas from numerous suppliers. The plant will supply the PJM grid and help offset closures of regional coal plants.

Fuel flexibility (Fig 3) is often a local decision, says Goldmeer. "In this case it's the abundance of shale gas with higher hydrocarbons. If there's a process plant that is stripping off an abundance of higher hydrocarbons near an existing or a planned powerplant, perhaps there is a gas-turbine fuel option at a reasonable cost." Owner/operators and developers should review their local options first, he suggests. The exact percentage of the compounds available from processing and fractionation lies locally within the source.

**3. On-site fuel blending facility** was developed by GE

As the GE authors state, "If ethane continues to be processed at or near the cost of natural gas, then there is the potential for the landed costs of exported ethane from the US to be less expensive than LNG in some parts of the world. In this scenario, ethane could be an ideal export candidate for power generation."

**4. Saudi Electric's Power Plant 12** in Riyadh is equipped with 7FA.05 gas turbines capable of burning Arabian Super Light crude oil

## Saudi Green Duba

Along the northeastern edge of the Red Sea, Saudi Electricity Company (SEC) has begun construction of the Green Duba ISCC Power Plant, marking the first use of condensate as a gas- turbine fuel in the Kingdom. Duba 1 is also the first integration of a concentrated solar thermal power station (CSP) with a combined-cycle plant. But most of the power will come from the combined cycle.

"The gas field has some significant non-methane components, also known as condensate," explains Goldmeer. "You can turn these into feedstocks, but in this case there is no convenient home for them. So they decided to burn them in an F-class turbine. And that's where combustion technology comes in."

GE is supplying a 7F.05 gas turbine to operate on condensate, and a 7F.03 to operate on natural gas. Both also can burn Arabian Super Light (ASL) crude. The CSP solar field is expected to add 50 MW, bringing Green Duba to 600 MW. Says SEC CEO Eng Ziyad M Alphiha, "We expect the plant to provide cost efficiencies over its lifecycle, along with the fuel flexibility and solar capabilities needed to support the Kingdom's fuel conservation and renewable technology initiatives."

Similar GE 7F.05 units are operating at Power Plant 12 in Riyadh, also able to fire ASL (Fig 4).

## Fuel evaluation

In the design of new combustion equipment, or selection of a new fuel source, it is essential to have a thorough knowledge of the fuel and compare this to operating data accumulated over time. Step One is knowing the fuel source, the type of fuel, potential fuel pre-treatments, and transport logistics.

"For ethane and propane," says Goldmeer, "it is important to understand if it would be pure or another commercial grade." HD-5 propane, for example, can be 90% propane with up to 5% propene (also known as propylene) and 5% other hydrocarbons.


**5. Marcellus shale ethane** is now exported from Marcus Hook

Therefore, a detailed listing of each constituent gas (percent by volume) is needed to determine the fuel's heating value, interchangeability (Modified Wobbe Index), and contaminant risk. Testing can then proceed.

Regardless of the fuel, the configuration of a combustor for a heavy-duty gas turbine must provide stable operability characteristics while meeting plant emissions. Other critical factors are turndown capability, transient response, and fuel flexibility. Operability factors include blowout, combustion instability, auto-ignition, and flashback.

The increased reactivity of ethane, for example, may lead to poor combustion dynamics (resonant pressure oscillations) or flashback, and potentially higher $NO_x$ emissions. "These constraints are not independent and cannot be optimized separately," explains Goldmeer.

In a lean, premixed combustion system (DLN), flashback can occur if the flame moves from the combustion zone to the premixer or fuel nozzle, potentially affecting metal temperatures. Any resulting flame holding can have the same impact. Goldmeer explains, "GE determines the risk of flashback by examining the behavior during a forced ignition event. This information is used during the project and equipment development cycle to reduce risk."

Small changes in fuel/air concentrations also can impact the flame's heat-release rate, and this potential can be higher in DLN systems. To mitigate these risks, says Goldmeer, various strategies are available to decouple the feedback loop between flame and fuel flow rate, which are then evaluated.

GE's OpFlex™ AutoTune, for example, is designed to accommodate such changes. Goldmeer explains, "This includes an adaptive real-time engine simulation that has been in operation for more than nine years, has been installed on more than 300 gas turbines, and has accumulated more than 1.5 million operating hours."

Emissions can also be affected, especially with a high level of ethane and increased flame temperature.

## Infrastructure and horizons

The increased availability of non-methane fuels is leading to new infrastructure projects for both propane and ethane.

The US became a net exporter of propane in 2011; shipments have been increasing to both Europe and Asia. Propane exports are also active in Canada (for example, AltaGas Ltd's LPG to Asian markets via Astomos Energy Corp of Japan).

The first dedicated ethane export terminal in the US is now operational at Marcus Hook near Philadelphia, capitalizing on the Marcellus and Utica formation activity (Fig 5). A second ethane export terminal is operational in Texas on the Houston Ship Channel (Morgan's Point) and in 2016 completed its first transatlantic shipment to Norway.

What remains on the power-generation side is project economics and justification, based on various models including annual fuel cost and the levelized cost of electricity.

In North America, with the shale-gas contribution surging, local end users are considering the possibilities, and asking the necessary questions. It's GE and other OEMs that will provide the answers.

As Goldmeer puts it, "We love educated customers. We love customers who are thinking ahead, who are challenging us to be better or to have better solutions, to help them create more value for their company and their shareholders.

"Ultimately," he continues, "every one of us buys electricity, so by interacting and asking questions we all help ourselves." CCJ

# Reno, February 2017: Four OEMs among the 100 vendors vying for 501F business

Participation in the 501F Users Group annual meeting at the Peppermill Reno (Nev) early next year (Feb 19-23, 2017) is highly recommended for owner/operators of these gas turbines (GTs). The players in the service business are changing and their product/services offerings are evolving—oftentimes faster than you might think (Sidebar 1). It's virtually impossible to do the job company management expects unless you keep up with what the suppliers are doing, particularly the OEM and its major competitors.

The user organization, chaired by Cleco Power LLC's Russ Snyder, has been serving owner/operators for nearly two decades, with the 2017 meeting promising to be the most important since the group's founding (Sidebar 2). There will be special closed-session, in-depth presentations to users by industry heavyweights Siemens Energy, Mitsubishi-Hitachi Power Systems Americas, Ansaldo Energia's PSM, GE Power, and Sulzer. Snyder told the editors, "All owners of 501F equipment will certainly leave the conference with a better understanding of their options in the marketplace for maintaining their equipment."

**This will be GE's** first participation in the conference, made possible by its license from PSM for pre-2016 501F components and technology. The company aims to impress, a conclusion drawn by the editors from GE's presentation during the recent Siemens F-class roundtable at CTOTF's™ Fall Turbine Forum chaired by Rich Wallen of Oglethorpe Power Corp.

There Jim Masso, GE's engineering leader for non-OEM GTs stressed two goals for this business unit:

- Operating intervals of more than



## 1. Competition for 501F parts, services heats up as OEMs reshape their companies

If you're a relative newcomer to gas-turbine O&M, you might not be aware that Westinghouse and Mitsubishi collaborated on the development of the 501F gas turbine—that is, until Siemens purchased Westinghouse in 1998.

Mitsubishi, at the time a virtual unknown in the North American electric-power community, responded to market demands by launching Mitsubishi Power Systems Americas (MPSA) in 2001 with six employees. Installation of world-class manufacturing facilities followed, and a merger of the thermal power generation businesses of Mitsubishi Heavy Industries Ltd and Hitachi Ltd in February 2014 created what today is Mitsubishi Hitachi Power Systems Americas (MHPSA)—an entity that includes MPSA, Hitachi Power Systems Canada, Mechanical Dynamics & Analysis (MD&A), and Hitachi Power Systems America. MHPSA has more than 2000 employees.

On a somewhat parallel path, PSM, which formed in 1999 and was purchased by Calpine Corp at the end of 2000, began developing replacement hardware for its owner's fleet of 501Fs. A few years later the company started selling parts to other 501F owner/operators.

OEM Alstom purchased PSM in 2007 and grew the latter's parts and services business dramatically. In April 2014, GE announced its intention to purchase Alstom. After reviewing the proposed acquisition for more than a year, the US Dept of Justice and the European Union announced in September 2015 that GE could buy Alstom, but it could not own PSM.

The highly regarded parts/services provider was then ring-fenced in a separate organization, with an independent manager to oversee its business as GE and Alstom completed their negotiations. From Sept 8, 2015 through Feb 25, 2016, PSM technically was owned by GE/Alstom, but those companies had no involvement in PSM's business during that time. On February 25, Ansaldo Energia, an Italian gas-turbine manufacturer, purchased PSM from GE, retaining the entire catalog of intellectual property for its product portfolio.

As part of the antitrust rulemaking, GE received a license limited to certain historical PSM intellectual property related to aftermarket services for Siemens and Mitsubishi gas turbines—not PSM's solutions for GE engines. Thus today, Ansaldo Energia's PSM retains all intellectual property, documentation, people, and assets to support its 501F and 7FA customers and the company continues to offer all products, services, and technologies previously available.

The bottom line: In only 15 years, 501F owners went from having two suppliers of capital parts and major shop services to five, with Sulzer developing its own line of 501F offerings independently.

32,000 hours for F-class units. Getting to 32k intervals with HGP hardware is not really the challenge, attendees were told. The proverbial fly-in-the-ointment comes from an auxiliaries' perspective. According to Masso, with the equipment currently installed in the fleet, the 32k interval is not likely achievable. Upgrades are necessary to make gas control valves, compressor bleed valves, etc, more robust.

- Total combined-cycle support for equipment and remote monitoring. At the mid-September CTOTF meeting, GE was said to be monitoring remotely six 501Fs; eight more units will be added to that list in 2017.

The company reported it was spending significantly on non-OEM products and services—one of GE's largest investment areas over the next several years. Today, it has over 300 engineers dedicated to non-OEM engines. The speaker said the company has purchased several Siemens gas turbines and has repaired three 501F engines thus far, and acquired a significant amount of hardware to meet its market objectives.

Looking ahead, GE says it plans to offer in 2018 a 501F Advanced Gas Path (AGP) upgrade solution similar to the one it has for the 7FA. The company already has nailed down casting slots to ensure a well-established supply chain. New parts for the 501F hot gas path (HGP) will be available next year.

Additional topics likely to be included in GE's presentations at the 501F meeting are parts health management, rotor life extension, and Aeropac rewinds. Regarding parts health management, the company is rapidly gaining commercial operating experience with LifeSight, a wire-free strain/creep sensor permanently affixed to the surfaces of parts—such as compressor blades—which indicates strain beneath the sensor. Data are retained for trending.

**With hours and starts** piling up on 501F engines, owner/operators of units about 15 or more years out from COD become concerned about rotor mortality. What to do? Chairman Snyder told the editors the board of directors is encouraging discussion of rotor-shop service options in Reno by the industry heavyweights identified above so users can compare vendor offerings.

To assist owner/operators, one 501F board member compiled the table of rotor service options on p 111 based on presentations by the major players to these users over the last few years. This is particularly valuable for 2017 conference-goers because they can pencil in changes during the meeting and have an up-to-date reference before returning to their plants.

Of course, attendees will have to add GE information, this being its first 501F meeting. And PSM information might have changed some since last year. The company's acquisition by Ansaldo Energia was not completed until after the 2016 conference and updates are likely on the location of the rotor disassembly shop, high-speed balance capability, structural weld repairs, etc. The presentations referenced are available to 501F users on the organization's website at http://501f.users-groups.com.

## Safety

Review of safe work practices never gets old; there's always something to learn. Over the last decade, safety has taken hold as a "religion" on the deck plates. Virtually no maintenance activities are undertaken today without a safety review—at US plants at least.

Evidence of safety's importance among owner/operators: Safety entries in CCJ's annual Best Practices Awards program often outnumber those in any other category. Plus, several user groups, such as the 501F, begin their meetings with a safety focus. And OEM sessions at user group meetings often

## 501F User Group rotor presentation summary

| Menu of options | Siemens | MHPSA | PSM | Sulzer |
|---|---|---|---|---|
| Shop service product | RCIE (Rotor and Casing Interval Extension) | CRI (Comprehensive Rotor Inspection) | LTE (Lifetime Extension) and LifeMod™ | CRDI (Complete Rotor Disassembly and Inspection) |
| 501F User Group presentations | 2015 Savannah | 2015 Savannah, 2016 San Antonio | 2015 Savannah, 2016 San Antonio | 2012 Tampa |
| Recommended timing for shop visit | 100,000 to 150,000 hours or 2500 starts (may be modified for specific unit issues) | Second major, or within 12 years depending on corrosion or other issues | Second major | Second major |
| Spare/exchange rotor | 501FC, 501FD2, and 501FD3 exchanges available | 501FC exchange with lead time, 501FD2 exchange available | 501FD2 exchange available | Brokered sales of repaired rotors |
| Disassembly shop | Charlotte, Houston (partial capability) | Savannah, Houston | Richmond (Alstom shop; alternative location in development) | LaPorte (Tex), Indonesia, Netherlands |
| High-speed balance | Charlotte | Savannah | Richmond (Alstom shop; alternative location in development) | Not offered; have been successful with low-speed balance |
| Component manufacture | All components | All components | All components | Bolting, fasteners (new manufacture), disks, etc (brokered sales of repaired parts) |
| Structural weld repairs | Submerged-arc capability in Charlotte (used in an emergency when replacement parts not available); air-separator axial length repair | Not offered | Rotor weld technology available in Richmond (Alstom shop); TBD for new location | Disk seal arms, seal lands on shafts, bearing journals |
| Options/upgrades | Compressor bolt/nut upgrade, belly bands, air separator | Compressor bolt/nut upgrade, belly bands, air separator, disk coating, R4 turbine root spring | Compressor bolt/nut upgrade, belly bands | Compressor bolt/nut upgrade, belly bands |
| Curvic-clutch machining | Charlotte | Savannah | Offsite shop | Not offered; has not been needed |
| Blade locking hardware | Inspect, replace | Inspect, replace | Inspect, replace | Inspect, weld repair of plates, replace hardware |

## 2. 501F Users Group: Serving owner/operators for nearly two decades

The need for users to share their collective knowledge on the 501F engine became evident to a few owners having their proverbial "skin in the game" as the sun set on the last millennium. O&M data were coming from the first 501F engines to enter commercial service (1993) at Florida Power & Light Co's Lauderdale Generating Station and closer examination of it and other fleet experience was warranted.

The first gathering of 501F users was conducted at Dynegy Inc's Houston headquarters building in 1999; about half a dozen interested parties attended. Host Bill Barras, director of parts and technical services for the independent power producer's gas-turbine fleet at the time (today he is associated with EthosEnergy Group), recalls that participants included Pete Sobieski, Craig Beers, and Jim Beckett—all with Calpine Corp then—and Paul Tegen of Cogentrix Inc. Barras says Dynegy and Calpine together had several dozen 501Fs on order, in construction, or in startup when the group met.

The second meeting, also at Dynegy, drew about 20 participants and was chaired by Barras and Tegen. Both also chaired the third meeting in January 2001 at Reliant Energy's El Dorado combined cycle in Boulder City, Nev (renamed Desert Star Energy Center by the current owner, San Diego Gas & Electric Co). Tegen remembers high interest in the 501F drew 75 or so users and more than a dozen Siemens reps to the relatively small conference room where attendees were sandwiched in elbow-to-elbow.

Tegen was elected chairman of the 501F Users Group and conducted the 2002 meeting at the Hilton in Walt Disney World. He continued to chair the organization until mid-2010, succeeded by the incumbent chairman Russ Snyder. Tegen continues his affiliation with the all-volunteer group as vice chairman (Sidebar 3). In 2014, Snyder spearheaded an initiative to incorporate the group as a 501(c)(6) non-profit. That was completed in May 2014.

The 501F Users Group grew quickly in both size and importance from that point on. Today it is among the largest user groups supporting owner/operators of gas-turbine assets. A typical meeting will attract 125 or more users, about 100 exhibitors, and approximately 50 vendor presentations in addition to the special sessions conducted by the OEMs and major third-party suppliers.

start with a presentation on the company's commitment to safety.

The last several 501F User Group meetings have begun with a nominal hour-long open discussion on safe work practices and accident avoidance. Chairman Snyder finds the safety discussion a good means for getting the meeting off to a fast, positive start. Every attendee can participate with either a question, or suggestion of a best practice adopted by his or her plant.

A little bit of preparation on the part of attendees can make the opening session a particularly valuable experience for all. Think about safety lessons learned, accidents avoided, near misses, best practices, etc, at your plant in the past year and make a couple of notes. When Snyder encourages participation from the floor, raise your hand, stand at your seat, wait for one of the meeting directors to hand you the portable microphone, and share your experience. No, you don't have to go to the front of the room and make a presentation. Just share facts, results, and positive actions.

One topic in Reno is almost sure to be slips, trips, and falls. Collaborative plant audits are valuable for identifying hazards. Ask a few experienced O&M personnel from neighboring plants to audit your facility. Fresh eyes are all it often takes to make your plant safer. After a while you may not realize you're stepping over hazards.

**The robust, interactive** safety session at last year's conference added to the group's best-practices experience. Some of what you read below may seem like "old school." If so, that's probably because of your industry experience. Important to keep in mind: Nominally half of the user attendees at every 501F meeting (by show of hands) in recent years were first-timers. For many of them, most of following ideas were new.

The session began with some attendees contributing safety incidents, including the following:

- Scaffolding knocked out of position by a bump during cleanup created an unsafe condition.
- Person from another site opened the compartment door without permission, got knocked down (air pressure was a contributing factor), and was seriously injured.
- LOTO signage was removed by a contractor involved in a valve test and not replaced. The violation was noticed by a plant employee and the job was shut down to re-educate the contractor's personnel.
- In a filter house, the grating between levels was removed to pass through replacement filters. It was never replaced and a worker fell to the next level.
- Contractor was moving material with the small hook of the turbine-hall crane but did not raise the main hook to a safe height. No personnel were injured but a truck was damaged.
- A user reported a rash of bumps by forklift operators who backed up into just about everything over the previous 18 months or so. Another attendee said his plant had a similar experience and that almost all accidents were backing ones. Discussion ensued with a couple of plants saying they have a spotter policy (shotgun person is on the ground, not sitting on the forklift). However, even with spotters some accidents occurred. Flags were said to help, but even they were not found to be foolproof.
- Reinforce the notion that "safety over all," environment second, everything else further down the list.
- A point was made that almost all accidents have a human-error component at some point in time.
- An interesting stat based on plant experience: More employees miss work from injuries at home than at work. Some plants conduct interactive sessions on home safety because of this.
- Proper fit-up of safety gear is important. One size doesn't fit all. Example: Eye injuries can occur from dust blowing under safety glasses. A demonstration revealed one person could put his finger between his face and the frame of his glasses while another had trouble putting a piece of paper under it. CCJ

### 3. 501F Users Group Board of Directors, Officers

**Chairman of the board and president:** Russ Snyder, GM southern gas fleet, *Cleco Power LLC*

**Vice chairman of the board:** Paul Tegen, chief CT/I&C engineer, *Cogentrix Energy Power Management LLC*

**Director and secretary:** Carey Frost, 501F program manager, *Duke Energy*

**Director:** Arlen Morris, principal engineer, *Florida Power & Light Co*

**Director:** David Lucas, managing director of gas plants, *PacifiCorp Energy*

**Director:** John Burke, O&M manager, LSP-Cottage Grove, *NAES Corp*

**Director:** Ramon Gonzalez Recio, main equipment engineer, *Falcon Group (Mexico)*

**Director:** Blaine Gartner, principal engineer for technical resources and compliance, *Xcel Energy*

**Director:** Jeff Parker, engineer, Desert Basin Generating Station, *SRP*

**IT officer:** Dave Gundry, turbine engineer, *Xcel Energy*

# PROFESSIONAL SERVICES

## Plus new/used equipment, tools, parts



## BUSINESS PARTNERS

### Recent release: Technical guidance documents on powerplant chemistry

The Power Plant Chemistry (PPC) working group of IAPWS (pronounced eye-apps), the International Association for the Properties of Water and Steam, released two technical guidance documents (TGDs) of value to powerplant owner/operators at its annual meeting in Dresden, Germany, September 11-16:

- "Application of Film-Forming Amines in Fossil, Combined Cycle, and Biomass Plants."
- "HRSG High-Pressure Evaporator Sampling for Internal Deposit Identification and for Determining the Need to Chemical Clean."

Both are available free-of-charge on the organization's website (www.iapws.org), where you'll likely identify several more useful TGDs.

The primary purpose of the annual IAPWS meetings is to connect researchers and scientists with the engineers who use their information. The free-flowing exchange provides researchers with guidance on topical industry problems and the engineers with the latest research results. Areas of technology addressed by IAPWS of greatest interest to electricity producers are powerplant chemistry, power cycles with $CO_2$ capture and storage, and combined heat and power systems—including district heating.

### Siemens update

**Panda Power Funds** and the OEM commissioned two H-class combined cycles in Pennsylvania this fall. The Liberty and Patriot projects each are rated 829 MW and consist of two single-shaft power blocks (SGT6-8000H gas turbines, SST6-5000 steam turbines, SGen6-2000H generators). A complementary service agreement includes parts, inspections, scheduled service/maintenance, and Siemens'

Power Diagnostics™ (remote monitoring and diagnostics).

**Siemens ships its first F-class** gas turbine for Iran's Bandar Abbas project—simple cycle today, combined cycle in the future. The two SGT5-4000F engines are equipped with SGen5-2000H generators. EPC contractor is the in-country MAPNA Group, which was awarded a license by Siemens for manufacturing gas turbines in Iran. More than 20 gas turbine/generators are planned for the country over the next four to five years.

**Argentina's Albanesi SA** orders seven SGT-800 gas turbines—two each for the Rio Cuarto and San Miguel de Tucuman powerplants and three for the city of Ezeiza. These units will be supplied from the company's Finspong (Sweden) factory, bringing the total number of SGT-800s sold worldwide to 300 since the engine was introduced as the GTX100 in 1997. The largest model in the SGT-800 series is capable of producing 54 MW at a nominal efficiency of 39%. In related news, the international energy group SoEnergy orders two Trent 60 machines for service in Argentina. They will be made in the US and Canada.

**Sudanese Thermal Power Generating Co** purchases five SGT5-2000E gas turbines with a combined generating capacity of 850 MW for commercial service by the end of 2017. SGen5-100A generators will be coupled to the GTs. Three of the simple-cycle machines will be located at the Garri Power Station north of Khartoum, the other two on the Red Sea coast. Fuel flexibility was critical to the OEM's success on this order: The units are designed to burn natural gas, heavy fuel oil, and light diesel.

## GE update

**GE inks Exelon** to a five-year contract to use the OEM's software to analyze and manage the utility's 91 US powerplants, which produce nearly 33 GW and supply more than 10 million customers. This is GE's largest such deployment in the power sector and one of the three largest sales of its Predix industrial operating system thus far. GE Power's Steve Bolze, was quoted as saying the company's technology has increased powerplant efficiency by 3% and reliability by 5%, while cutting O&M costs by 25%.

**Southern California Edison** announces it will install the world's first battery storage and gas-turbine hybrid. The LM6000 Hybrid EGT, scheduled for installation at two SCE sites in the coming months, involves installation of a battery energy storage system from Current, powered by GE, and upgrades to an LM6000 gas turbine to integrate the two systems. The solution, developed in collaboration with Wellhead Power Solutions LLC, qualifies for the CAISO's contingency-reserve tariff.

**Vattenfall Europe Warme AG** selects GE Power Services to overhaul and extend the operating life of two 130-MW steam turbines (COD 1963 and 1993) at the Wedel district-heating plant in Hamburg, Germany.

## Briefs

**Sulzer expands its capabilities** for the repair of steam turbines with the upgrade of facilities at the company's Piedmont (SC) shop. It is now equipped to carry out complete refurbishments of steam-turbine packages up to 750 hp in addition to the services already delivered—including balancing and governor overhauls.

**Clark-Reliance Corp** introduces the Jerguson® LumaStar™ EPL-316 illuminator, which provides high-contrast, white LED light, to provide superior gage visibility day or night. LED lights essentially are maintenance-free and rated for approximately 100,000 hours of service.

**MTU Maintenance** extends its exclusive contract with Thailand's Rojana Power for the power producer's nine LM6000 engines. The 10-yr agreement covers both scheduled and unscheduled maintenance events as well as onsite services. Recall that MTU's Berlin-Brandenburg facility is a GE-licensed Level IV depot with one of relatively few test cells worldwide equipped to handle LM2500 and LM6000 engines.

**Alta Solutions Inc** releases its AS-7000 machinery protection system, which merges an API 670 fifth-edition MPS with Alta's real-time gapless data acquisition—thereby enabling the automatic capture of high-resolution machinery data for subsequent analysis.

**U.S. Water's** PhosZero™ chemistry was among the 2016 finalists in the R&D 100 Awards Program. The technology provides both scale and corrosion protection with reduced aquatic toxicity. It is designed to provide users a phosphorus-free cooling-water treatment that both achieves desired performance results while meeting regulatory requirements.

STUG

STEAM TURBINE USERS GROUP

# Fourth Annual Meeting

**Sheraton Grand at Wild Horse Pass, Chandler (Phoenix), Ariz**
**August 28-31, 2017**

**Please mark your calendar and plan to attend**
**Registration opens in April at www.stusers.org**

The STUG Steering Committee invites your input for the group's Fourth Annual Meeting. Here are some of the ways you can participate and make your attendance more productive:

- Suggest a topic for inclusion in the program.
- Make a short presentation on best practices, lessons learned, turbine upgrade, outage profile, O&M history, etc. Can be 5, 10, or 15 minutes, or longer.
- Bring a thumb drive to the meeting with a couple of photos describing a problem at your plant and ask your fellow users for suggestions on a solution. Think of this clinic as free consulting by those who walk in your shoes.

## The STUG Steering Committee

First row (l to r): Jay Hoffman, *Tenaska Inc;* Gary Crisp, *NV Energy*

Second row: Jess Bills, *SRP Desert Basin;* John McQuerry, *Calpine Corp;* Chair Eddie Argo, *Southern Company*

Third row: Jake English, *Duke Energy*

Top row: Lonny Simon, *OxyChem;* Vice Chair Bert Norfleet, *Dominion*

**Email Vice Chair Bert Norfleet (bert.norfleet@dom.com) with your thoughts/ideas today.**

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## at www.ccj-online.com/bg

Products and services from over 100 companies support new unit construction, retrofit and maintenance activities at existing facilities, and plant operations. Solutions span gas and steam turbines, HRSGs, pumps, valves, piping, cooling towers, condensers, etc

### AAF International

Global leader in the field of air filtration, meeting the most demanding conditions and the toughest environmental challenges. The company's filtration, noise abatement, and other turbine products are effective, durable, and crucial to greater efficiency and performance.

### ABB

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

### Advanced Filtration Concepts

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

### Advanced Indoor Air Quality Care

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

### Advanced Turbine Support

Has delivered unbiased fleet experience and superior customer service for more than a decade. Company provides users high-resolution borescope inspections, cutting edge ultrasonic and eddy-current inspections, and magnetic-particle and liquid dye-penetrant inspections in accordance with OEM Technical Information Letters and Service Bulletins.

### 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.

### AGTServices

Over 200 years of combined, proven OEM engineering, design, and hands-on experience; known in the industry for its schedule-conscious, cost-effective solutions with respect to generator testing and repairs.

### American Chemical Technologies

Provides state-of-the-art synthetic lubricants to the power generation industry. Founded more than 30 years ago in the US, ACT has grown to become an international supplier of value-added lubricants that provide superior benefits to equipment, the environment, and are worker-friendly.

### Apex Dry Ice Blasting & Industrial Services

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.

### ARNOLD Group

With more than 550 installed insulation systems on heavy-duty gas and steam turbines, company is the global leader in designing, manufacturing, and installing the most efficient and reliable single-layer turbine insulation systems.

### BASF Corp

Committed to providing customers with cost-effective solutions to the most complex emissions control problems; company is constantly developing new catalyst technologies to meet ever-more stringent emissions requirements.

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### Bearings Plus Inc

Provider of repairs and custom technology upgrades for turbomachinery. Designs and manufactures an integrated solution to meet specific requirements for every operating environment, applying the latest fluid film bearing and high-performing seal technology to legacy equipment to optimize performance.

### Bremco

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

### C C Jensen Oil Maintenance

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

### Caldwell Energy

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

### Camfil Farr Power Systems

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

### Chanute Manufacturing

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

### CLARCOR Industrial Air

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

### 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.

### Crown Electric Engineering & Manufacturing

Engineers, designs, fabricates, and installs isolated phase bus, large bus duct systems, and outdoor switchgear. Specializes in rapid response needs such as IPB for GSU change-outs, quick-ship fabrication, and emergency on-site service needs.

### CSE Engineering

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

### Cust-O-Fab Specialty Services

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

### Cutsforth

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

### DEKOMTE de Temple

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

### Donaldson Company

Leading worldwide provider of filtration systems that improve people's lives, enhance equipment performance, and protect the environment. Donaldson is committed to satisfying customer needs for filtration solutions through innovative research and development, application expertise, and global presence.

### Dry Ice Blasting of Atlanta

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

### EagleBurgmann Expansion Joint Solutions

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

### 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.

### Eta Technologies

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

### EthosEnergy

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

### Falcon Crest Aviation

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

### Federal Steel Supply Inc

Distributor of seamless HRSG high-energy pipe and power piping. Scheduled and heavier than scheduled walls in stock for headers, steam lines, etc. SA106 B/C and SA335 P11/P22/P91. Fittings to complement all pipe. Offering cut-to-length, custom fittings, specialty end preparation, supplemental testing, and emergency same-day shipments.

### Frenzelit North America

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

### Gas Turbine Controls

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

### Gas Turbine Efficiency

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

### GP Strategies

Provides training, engineering, and performance improvement services specifically designed for the power industry: The EtaPRO™ Performance and Condition Monitoring System and GPiLEARN+™.

### Groome Industrial Service Group

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

### GTC Services

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

### Gulf Coast Filters & Supply

Keep your filter house and evap coolers operating at peak condition. GCF provides comprehensive, personalized filter-house products, field service, and maintenance, emphasizing safety, professionalism, efficiency, minimal job-site disruption, quality products, and thorough testing and inspections.

### Haldor Topsoe

Our air pollution technology includes a series of unique catalysts for Selective Catalytic Reduction (SCR) systems for the control of nitrogen oxides ($NO_X$), and the reduction of carbon monoxide (CO) and volatile organic compounds (VOCs), from stationary and mobile sources.

### Hilliard

The HILCO® Division cost-effectively brings fluid-contamination problems under control and engineers a full-range of filters, cartridges, vessels, vent mist eliminators, transfer valves, reclaimers, coolant recyclers and systems, and membrane filtration systems.

### HRST

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

### Hydro

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

### Hy-Pro Filtration

Provides innovative products, support, and solutions to solve hydraulic, lubrication, and diesel contamination problems. Company's global distribution and technical-support networks enable customers to get the most out of their diesel, hydraulic, and lube-oil assets. ISO 9001 certified.

### Janus Fire Systems

Manufacturer of special hazard fire protection solutions. Designers of engineered clean agent and high- or low-pressure carbon dioxide systems composed of hardware and software tailored to the application.

### JASC

Engineers and manufactures actuators and fluid-control components for power generation, aerospace, defense, and research applications to improve operational capability and performance.

### KnechtionRepair Tools

Manufactures tools designed to make thread repairs to both the female and male ends of cross-threaded compression fittings. In most cases, the repair will be accomplished without removing the tube from the system. This saves the O&M tech time and avoids additional downtime.

### Kobelco Compressors America

Provides robust, high-efficiency fuel-gas compressors for use with all major types of gas turbines—including GE, Mitsubishi, Alstom, Siemens, Rolls-Royce, and Solar. Over 300 of the company's screw-type compressors have been supplied for gas turbines.

### Liburdi Turbine Services

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

### Mechanical Dynamics & Analysis

One of the largest turbine/generator engineering and outage-services companies in the US. MD&A provides complete project management, overhaul, and reconditioning of heavy rotating equipment worldwide.

## Membrana, a 3M company

Market-leading producer of microporous membranes and membrane devices used in healthcare and industrial degassing applications. The Industrial & Specialty Filtration Group manufactures Liqui-Flux® ultrafiltration and microfiltration modules as well as Liqui-Cel® membrane contactors.

## Mitten Manufacturing

Leading fluid system packager for numerous OEMs, EPC firms, utilities, and plant operators all over the world offering a number of value-added designs, spare parts management, and field services.

## NAES

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

## National Electric Coil

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

## NEM Energy

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

## Nor-Cal Controls ES Inc

Provides control-system consulting, engineering, and training solutions and services to the power generation sector. Cost-effective solutions are based on proven technology and open-architecture design, eliminating the need for service contracts at the end of the project.

## Parker Balston

Develops and manufactures nitrogen generators for all your power generation needs including boiler layup, gas seals, purging gas lines prior to service, blanketing demin water tanks, and LNG terminals.

## Parker Hannifin

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

## PetrolinkUSA

Provides high-velocity hot-oil flushing, EHC flushing, chemical cleaning, lubricant reconditioning, and auxiliary on-line filtration. Preventive maintenance services include equipment assessments and lubricant analysis.

## Praxair Surface Technologies

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

## Precision Iceblast

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

## Proco Products

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

## PSM

Full-service provider to gas-turbine equipped generating plants, offering technologically advanced aftermarket turbine components and performance upgrades, parts reconditioning, field services, and flexible Long Term Agreements (LTAs) to the worldwide power generation industry.

## PW Power Systems

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

## Real Time Power

Offers smart optimization solutions for power generation. Expertise spans machine learning, predictive modeling, diagnostics, and forecasting. Employs data scientists with unique domain knowledge of gas turbines to create realistic and practical algorithms, providing accurate predictions which improve plant operations.

## Rentech Boiler Systems

International provider of high-quality, engineered industrial boiler systems. Rentech is a market leader in providing HRSGs for cogeneration and CHP plants. It is in its second decade of designing and manufacturing high-quality custom boilers—including HRSGs, waste-heat boilers, fired packaged boilers, specialty boilers, and emissions control systems.

## Rotating Equipment Repair Inc

Specializing in high pressure multi-stage boiler feed pumps, RER provides its customers high quality engineering services, repairs, and parts for centrifugal pumps through the utilization of highly skilled professionals, cutting-edge technology, and proven work methodologies.

## Sargent & Lundy

Provides complete engineering and design, project services, and energy business consulting for power projects and system-wide planning. The firm has been dedicated exclusively to serving electric power and energy-intensive clients for more than 120 years.

## Siemens Energy

A leading global supplier for the generation, transmission, and distribution of power and for the extraction, conversion, and transport of oil and gas. Leadership in the increasingly complex energy business makes it a first-choice supplier for global customers. Known for innovation, excellence and responsibility, company has the answers to the sustainability, flexibility, reliability, and cost challenges facing customers today.

## Sound Technologies

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

## SSS Clutch Company

Clutches enable operators to disconnect generators from simple-cycle turbines for synchronous-condenser service. Clutches also find application in CHP plants and in single-shaft combined-cycle facilities where operating flexibility is beneficial.

## Strategic Power Systems

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

## Structural Integrity Associates

Powered by talent and technology, SI is a global leader in providing innovative engineering solutions. Using a multidisciplinary approach, our experts bring a fresh perspective and proven solutions for structural evaluation and repair.

## Sulzer

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

COMBINED CYCLE Journal
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# Index to advertisers



FIND A VENDOR, FIX A PLANT

## Taylor's Industrial Coatings

Highly skilled staff is trained and equipped with the latest tools and equipment necessary to complete coating projects on time and in scope with a commitment to safety, technical support, and quality workmanship.

## TEC-The Energy Corp

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

## 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.

## 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.

## TesTex Inc

World leader in electromagnetic non-destructive testing (NDT). We continually define the state-of-the-art for the testing of ferrous and non-ferrous materials and structures through applied research and development.

## Texas Bearing Services

Manufactures and repairs fluid film (babbitt) bearings and seals for turbomachinery including gas and steam turbines, compressors, generators, gearboxes, and more. Works with OEMs, distributors, and end-users all over the world and offer 24/7/365 emergency services for critical outages.

## 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.