$15
4Q/2013
www.ccj-online.com

CCJ COMBINED CYCLE Journal

User Group Reports

7F Users Group.................................58
Workshops important to professional development, borescope clinic, proper staking critical, Bigfoot mod can cause twisting of stator vanes, tip-shroud creep, clashing, HRSG performance thieves, NDE for boiler inspections, crack repair, fuel-nozzle flow testing

Western Turbine Users 69
Jim Hinrichs, depot presentations, The Axford Report, benchmarking aero performance, awards, social events

CTOTF™ aggregates its coverage of aeroderivative gas turbines..............76
Coordinated programs for Pratt & Whitney, Rolls-Royce, GE, and Solar engines will benefit users by sharing information across product lines

Buyers Guide 81
Connect with equipment/services providers directly from the pages of the CCJ by scanning quick-response (QR) codes with your smartphone or tablet

Remembrances, pp 3, 72

Business Partners 89
GTs turn 75, ACC Users pick San Diego, 7F Users form STUG, automation retrofit improves reliability, CCUG to meet in San Antonio, Crackfit facilitates assessments of defects, Calpine has a good 2013, USEA honors Lew King, ABMA President Rawson passes

Features

Fleet-wide M&D puts 'Big Data' into practice 6
Jason Makansi

ASME Power: FAC/LDI, agile HRSG, integrate solar tower with combined cycle, condenser retrofit 16
Patricia Irwin, PE

Generator inspection first step in avoiding failures attributed to dry stator-winding ties.............. 28

Lubricant varnishing and mitigation strategies................................... 34
Peter Dufresne Jr, Matthew Hobbs, Glen MacInnis

Partial discharge generally not well understood at the plant level.... 42
Donald Selkirk, PE

Problems experienced with modern generators 48
Clyde V Maughan

Register now for upcoming user group meetings

7F USERS GROUP
2014 Conference and Vendor Fair
May 19 – 23
Sheraton Wild Horse Pass Resort & Spa
Phoenix, Ariz
Contact: Sheila Vashi
sheila.vashi@7Fusers.org
www.7Fusers.org

D5-D5A Users
18th Annual Conference
June 1 – 5
Ritz-Carlton Key Biscayne
Miami, Fla
Contact: Gabe Fleck, gfleck@aeci.org
www.501D5-D5Ausers.org

Frame 6 Users Group
2014 Conference and Vendor Fair
June 23 – 26
Sanibel Harbour Marriott Resort & Spa
Ft Myers, Fla
Contact: Wickey Elmo
wickelmo@carolina.rr.com
www.Frame6UsersGroup.org

CCUG
2014 Conference and Discussion Forum
August 11 – 13
Westin Riverwalk, San Antonio, Tex
Contact: Sheila Vashi
sv.eventmgt@gmail.com
www.ccusers.org

STUG — STEAM TURBINE USERS GROUP
2014 Conference and Vendor Fair
August 19 – 21
Omni Richmond Hotel, Richmond, Va
Contact: Sheila Vashi,
sv.eventmgt@gmail.com
www.stusers.org

CTOTF™
2014 Fall Conference & Trade Show
September 7 – 11
Rancho Bernardo Inn
San Diego, Calif
Contact: Wickey Elmo, info@ctotf.org
www.ctotf.org

INDEPENDENT VOICE OF THE GAS-TURBINE-BASED GENERATION SECTOR

IN TEXAS WE LIKE TO SAY...

YOU DON'T ALWAYS HAVE TO BE FIRST.

BEING BEST IS A WHOLE LOT BETTER.

Heat Recovery Steam Generators | Waste Heat Boilers | Fired Packaged Watertube Boilers | Specialty Boilers

WE DIDN'T BUILD THE FIRST BOILER.

But in all your born days, you won't find a manufacturer today that makes a boiler that performs better than a RENTECH boiler. It's no yarn. Each of our boilers is custom-designed by RENTECH engineers and built in state-of-the-art facilities to operate efficiently in its unique application in a variety of industries. Our innovative, cost-effective technology will add value to your day-to-day operations with lasting benefits for the competitiveness of your business. Don't wait another day, call us about your next boiler project.

WWW.RENTECHBOILERS.COM
325.672.3400

RENTECH

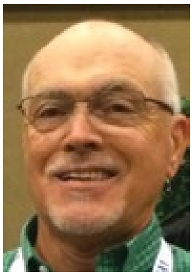
BOILERS FOR PEOPLE WHO KNOW AND CARE

GT users lose two champions in one week

Gas turbine users lost two dedicated supporters within a one-week period at the end of April:

- James M Hinrichs, 63, VP western operations for Veresen Inc, a diversified energy infrastructure company which owns and operates generating plants powered by gas turbines, among other assets.
- Charles Darwin Pond, 60, senior staff engineer, PAL Turbine Services LLC, which provides a wide range of field engineering services to owner/operators of GE steam and gas turbines and generators.

Both men were very capable engineers who served in the same sector of the electric power industry, but wore different hats. Their personalities also were quite different. One can only assume they at least knew of each other.


Hinrichs

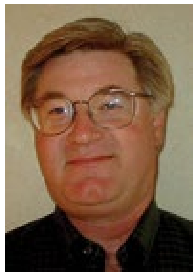
Hinrichs is best known for his contributions to the development of the Western Turbine Users Inc, today the world's largest user group serving owner/operators of aeroderivative gas turbines; also, for serving as the all-volunteer organization's first president—a term that wound up running 17 years. It wasn't easy. He had challenging "day jobs" during that period, managing generating assets at the beginning of the deregulated era for such companies as PurEnergy LLC, LS Power, and Dynegy Inc.

Hinrichs was a rock-solid professional with nerves of steel—a personality befitting a Roman infantry commander. But he had a soft side and knew how to laugh and enjoy himself. In fact, only a month before his untimely death on April 28, Hinrichs organized and participated in the tennis tournament at the 24th Annual WTUI Conference. He did that every year. In early April, Hinrichs went skiing. A few days later he checked into a hospital for back surgery. There were complications.

It is often said of the dead: He (or she) will be missed. He will most certainly be *remembered* for as long as there is a Western Turbine Users organization—a group which has grown from a few plant managers trading experiences over lunch in a break room, in the late 1980s, into a three-day, world-class technical meeting with more than 1000 participants.

Every leader, every organization, has a "defining moment" when circumstances create a situation that can go only one way: success or failure, win or lose. That moment came for Hinrichs and the Western Turbine officers and directors many years ago with a change in leadership at the OEM.

The way an "old-timer" tells it, GE's representatives considered WTUI competition and wanted to take over the group. A forceful "no way" was the user organization's reply. Various threats reportedly were made, but Hinrichs and the Board didn't flinch. The outcome: GE stopped providing technical support to the group, figuring it would fold without the company's involvement. But Hinrichs got the depots to assume responsibility for the meeting's technical aspects and WTUI not only survived, it improved and grew. A few years later, the misguided executive was removed and GE returned, without the swagger.


Pond

Pond was the restless sort—a cavalry officer ever riding to the sound of the guns. He graduated from the Univ of Illinois with a BS in Aeronautical Engineering and Industrial Education in 1975. Certifications as an Airframe and Power Plant Mechanic and as a Flight Instructor were achieved at roughly the same time. Pond was a flight instructor until joining GE as a field engineer in Overland Park, Kans, in 1977. Next stop was GE Schenectady, where he prepared engineers for field assignments. In 1985, Pond moved to TWA as a test-cell engineer, later promoted to master propulsion engineer. VP Engineering for Turbine Technology Services Corp was the next step, in 1991. As the millennium knocked, Pond started Pond and Lucier LLC with Dave Lucier. That gig lasted until 2008 with the formation of PAL Turbine Services LLC and Pond's unquenchable desire to return to field service work as a senior consulting engineer for PAL.

His close associates considered Pond the best mechanical field engineer in the business for GE Frames 5, 6, and 7B-EA and, perhaps, the industry's top instructor. Many others agree. The editors have listened to him disassemble a 7EA in two hours without ever referring to a note, without ever skipping a beat, without ever taking a break except possibly for a sip of water.

Among his social skills was that of a practical joker par excellence.

CCJ
COMBINED CYCLE Journal

Editorial Staff

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

Kiyo Komoda
Creative Director

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

Patricia Irwin, PE
Consulting Editor

Clark G Schwieger
Special Projects Manager
702-869-4739, clark@psimedia.info

Editorial Advisory Board

Robert W Anderson
Competitive Power Resources

Robert D Threlkeld
Plant Manager, Tenaska Lindsay Hill and Central Alabama Plants
Tenaska Operations Inc

J Edward Barndt
VP, Rockland Capital

Gabriel Fleck
Supervisor, Gas Plant Operations
Associated Electric Cooperative Inc

Dr Barry Dooley
Structural Integrity Associates Inc

Business Staff*

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

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

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

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

To cancel or change your subscription, write scott@ccj-online.com

Comprehensive Pump Support
Reliable & Responsive Service

Engineered Pump Rebuilding

Since 1969, Hydro has built its worldwide pump service organization by bringing a high level of engineering expertise and quality service to the pump aftermarket. We work with our customers to evaluate and understand the root causes of pump degradation or failure and to provide unbiased engineering analysis, quality workmanship and responsive field service for improved plant operation.

Turnkey, Field Service and 24/7 Emergency Response

Hydro's Field Service team has extensive knowledge of pumps from most major manufacturers and provides turnkey service, installation / start-up supervision, field machining, vibration analysis, laser alignment, pump system troubleshooting and emergency field response 24 hours a day, 7 days a week.

Hydro's Worldwide Network of Pump Aftermarket Service Centers

U.S. Service Centers

Hydro, Inc.
Headquarters
Chicago, IL
800.223.7867
www.hydroinc.com

HydroAire, Inc.
Chicago, IL
40th Street Facility
Madison Street Facility

Hydro East, Inc.
Philadelphia, PA

Hydro South, Inc.
Atlanta, GA

Evans Hydro, Inc.
Los Angeles, CA

HydroTex Dynamics, Inc.
Houston, TX

HydroTex Deer Park, Inc.
Deer Park, TX

HydroTex Golden Triangle, Inc.
Beaumont, TX

Hydro Pump Performance Test Lab, Inc.
Chicago, IL

Hydro Parts Solutions, Inc.
Houston, TX

Pump Parts

When you require a part and are facing a long lead time, Hydro can meet your needs in a reduced time frame through our reverse engineering, patternless casting, and integrated manufacturing processes. Hydro's engineers review and evaluate all parts to offer important upgrades and apply new technologies that will reduce wear and improve reliability.

Pump Testing - Managing Risk

Ensure your pump will perform as required. Hydro's 5000HP Performance Test Lab is compliant to API610 and Hydraulic Institute standards and can test horizontal, vertical, and submersible pumps.

Training

Hydro teaches practical solutions and troubleshooting techniques for common pump problems and offers specialized hands-on training programs. View upcoming courses online at www.hydroinc.com.

For more information about Hydro's comprehensive pump services for combined cycle plants, please contact John Francis at jfrancis@hydroinc.com or call 713-890-2117.

Hydro®

International Service Centers

CW Hydro
Incheon Metropolitan, Korea

Hydro Australia
Morwell, Australia

Hydro Scotford
Edmonton, AB, Canada

Hydro Middle East
Dubai, United Arab Emirates

Hydro Pump Services
Kuala Lumpur, Malaysia

Hydro Vietnam
Ho Chi Minh, Vietnam

Safe-T Hydro
Port Coquitlam, BC, Canada

Hydro Richier
Saint-Chamond, France

Fleet-wide M&D puts 'Big Data' into practice

Jason Makansi, Pearl Street Inc

1. NV Energy Monitoring and Diagnostics Center, one of the most recent to become operational, exemplifies an arrangement to foster collaboration, a goal of all M&D centers. About 100,000 information points from 50 separate generating units at 10 powerplants are collected and modeled to support production, asset management, and engineering

Many large and mid-size utilities and independent generating companies have installed fleet-wide monitoring and diagnostics (M&D) centers (Fig 1). While the practice began more than a decade ago, in many ways, it is now poised for even greater expansion, thanks to breathtaking growth and declining cost of backbone digital chip technology, cloud computing, wireless sensors, mobile and hand-held digital devices, and robust algorithms and analytics.

However, the digital architecture of fleet-wide M&D is likely to change over the next decade. Technology promises to pose fewer challenges than optimizing how technology fits into organizations. As one example, the notion of "aggregating" the digital signals and human specialists in one centralized location is somewhat specious, given that the data can be, and often are, made available anywhere on most any digital device (within security limitations of course). Likewise, collaboration can take place anywhere too, with a camera and a microphone on the computer, or over mobile hand-held devices.

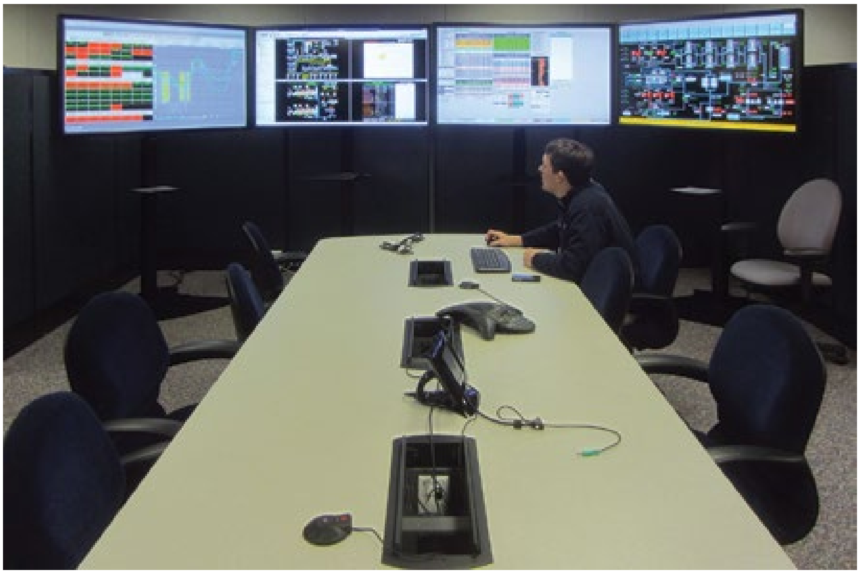
In short, the concept of a "center" may be an artifact of an industry focused on centralized utility grids. The concept of a "cockpit," though, may have more staying power, as it implies face-to-face collaboration, perhaps more vital during emergency and upset conditions, to ensure all of the available expertise—human and automation—is being brought to bear in coordinated fashion.

Some perspective

Before the industry had 1300-MW coal-fired units, there were (and still are) 1300-MW coal-fired *stations* comprised of five to 10 individual units. At one time (circa 1950s), such a plant might have been built with two control rooms, each serving a bank of units. In an earlier time, each *unit* might have had its control/monitoring room, with much of the actual control localized at the equipment.

Today's remote M&D center is simply part of this evolution, made possible by wired and wireless data networks and telecommunications. Also, in an earlier time, many plants had a "results" engineer responsible for calculating and monitoring performance—especially heat rate. Maintenance was performed largely on a preventive basis, machines routinely disassembled, inspected, and re-assembled, and components replaced based on an operating-hour schedule.

Being a fully regulated, cost-plus, assigned rate-of-return industry completely focused on reliability helped maintain this status quo until deregulation and competition became more than glints in the eyes of financial engineers by the 1990s. More recently, combined-cycle plants became more and more similar as they were built



2. Duke Energy's M&D center is evolving towards "Smart M&D"—a strategy incorporating data signals from thousands of new remote wireless sensors. Unlike other utilities, Progress Energy's (now Duke) monitoring program began with its combustion turbines in 2004. Today, the center monitors 265 individual gas turbine, fossil, hydro, and pumped storage units. It employs 6500 data models based on 65,000 individual data points. M&D technology is called a "force multiplier to leverage fewer specialists analyzing fleet critical equipment"

around standard gas turbine, steam turbine, and HRSG modules from OEMs. With a far more homogenous fuel than coal (natural gas), comes greater commonality in plant design, which allowed for more distributed expertise to manage these assets.

The enablers

On the technology side, the enablers of fleet-wide M&D include the following:

- Distributed digital control systems (DCS) progressively installed at powerplants beginning in the late 1980s.
- Data historian and storage technology capable of taking the data from a proprietary DCS and converting them into a standard format usable by software applications.
- Data highways and data networks employing standardized communication and routing protocols, including over the Internet, allowing further propagation of plant data.
- Computer hardware and software operating on non-proprietary desktop and PC operating systems.
- Inexpensive liquid crystal displays (LCD) and digital displays in larger and larger flat-screen formats, and in the other direction, ever-more-capable mobile devices and tablets that have essentially become handheld computers.

Whether a bricks-and-mortar "central" facility exists or not, the remote M&D concept is driving the integration of digital powerplant assets.

Behind the dashboard

Though you'll find a veritable suite of software applications from different vendors at the typical M&D center (Fig 2), the two "anchor tenants" are thermal performance monitoring and advanced pattern recognition (APR) to calculate efficiency and detect equipment anomalies and deviations.

Online heat-rate calculations using real-time data from the DCS have been going on for decades. At coal-fired plants, the calculation has been limited by a lack of real-time data for fuel analysis. However, for gas plants, hour-to-hour or day-to-day fuel variability has far less impact. According to at least two M&D center managers, what is different today is that real-time heat-rate values are being used for capacity dispatch into electricity markets.

Strange as it may seem, many plants still are dispatched based on heat-rate calculations from annual or periodic performance tests. Today, leading fleet owners dispatch on real-time calculation—taking into account

3. At Luminant's Power Optimization Center, predictive analytics is "without a doubt" the highest-value application. One desk/PC workstation is dedicated to long-term reliability issues, another to current operational issues across the fleet, and a third to trends governing major equipment from the data historian software

ambient conditions, current equipment condition and performance, cycling and less than design load, and other factors. M&D center specialists can alert plant staff about controllable losses, and changes they can make to maintain or improve unit efficiency, much earlier than without real-time performance monitoring.

Use of APR technologies is more diverse than heat-rate monitoring. At their core, all of these software solutions trend data points (or tags)—individual data points from the DCS through the historian, taken at high frequency (called data resolution). For example, one package popular at M&D centers trends data taken every 10 minutes (Fig 3). By comparing and correlating real-time versus historical trends on selected parameters for a given piece of equipment or system, deviations or anomalies from known patterns can be detected.

In their simplest form, APR techniques provide warnings and alerts much earlier than would be annunciated by the control system. Plant operators typically don't have the time, and/or aren't trained, to detect such anomalies. They are more focused on making sure things are running smoothly, not long-term issues.

One M&D center specialist, reporting at the 2013 conference of the Combined Cycle Users Group (www.ccusers.org), showed how the APR model detected a 2× shift on all of the generator proximity and seismic probes of a gas turbine/generator. Normal vibration levels are less than 1 mil. During the last run before an outage, the APR showed trending up to 1 to 2 mils. Learning of this, the plant staff removed a porthole and found that both generator J-straps were damaged. Subsequently, the plant repaired the damage in the field. Had this condition gone undetected, the probability of a J-strap failure during the next season's run would have been high.

At a more sophisticated level, M&D center specialists build models for specific components based on known or suspected failure conditions (often incorporating machine fleet experience) or after a failure has occurred, so that the precursors to that failure can be detected the next time. Specialists at several M&D centers, for example, report that they can anticipate when the combustor liners in their gas turbines are about to fail.

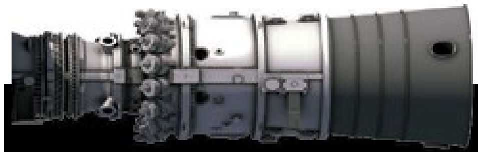
When the capability goes beyond an early warning, diagnostics jumps into the realm of prognostics. This simple analogy explains the difference: Diagnostics says you have cancer, prognostics says you have six months to live. In practice, prognostics capability accompanies early warning with some assessment of risk or time to failure—some sense, anyway, of how much time you have to deal with the deviation.

The crux of APR technology implies the need for large data sets at steady-state operation. After all, the steadier the operation has been, the easier it is to detect deviations from the patterns. This poses a conundrum for gas-turbine peaking and combined-cycle plants, which typically are cycled, dispatched, and start/stop frequently.

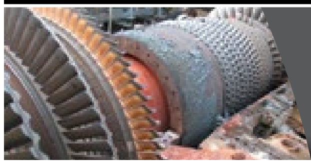
Most of the APR models have been built and proven for base-load and intermediate-load duty. Though the experience base is not as robust, GT/CC operators have prevented catastrophic equipment wrecks by diagnosing faulty bearings, generator J-strap failures,

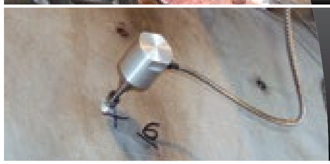
MISTRAS | TRIPLE 5 INDUSTRIES

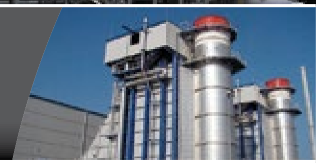
Combined Cycle ASSET PROTECTION

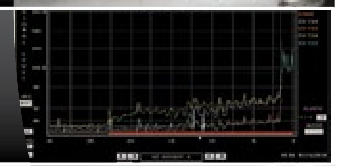


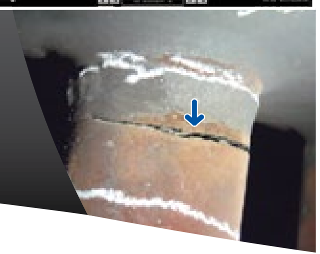
ACTMS™ On-line Stator Vane Crack Detection		AMS™ HRSG Leak Detection
• Cracking/liberating vane through turbine • Stationary airfoil cracking • Rubbing, loosening and blade clash • $7 to 10 million per incident	**PROBLEM**	• Tube stub weld leaks at the SH & RH headers • Tube leaks at the SH and RH Drains • Inability to locate area of the leak
• Non-intrusive sensors • After-market install • Complete forward compressor coverage	**IN SERVICE**	• Non-intrusive sensors • After-market install • 24-7 real time monitoring • Total HRSG coverage or in areas of most concern
• Defect source location • Graphical displays • Local and network alarming	**REAL TIME**	• Trend severity and progression of leak • Locate area of leak before unit removed from service • Local and network alarming
• On-line detection of vane cracking • Insight to unknown condition • Optimize remaining life • Early warning to prevent failure	**RESULTS**	• On-line tube leak detection • Early warning to prevent failure • Manage market exposure and risk • Tube leak repair during planned outage or period of low demand











www.mistrasgroup.com

Systems | Software | Monitoring | Services | Instrumentation

HRSG attemperator failures, nozzle issues following hot-gas-path (HGP) overhauls, blade rubs, and other anomalies by applying APR.

One way to address the challenges posed by transient operation is to take more data within shorter time intervals. At least one APR product designed for GT startup periods, for example, takes data every second, compared to the company's standard product which takes data at 10-min intervals. This capability allows you to compare one "startup signature" to another. Several M&D centers report using or testing this product but not necessarily getting enough value from it.

Another issue with GT applications is to make sure the models are properly tuned. As one M&D center specialist put it, "tuning a model at 70F ambient temperature is not the same thing as tuning it at 90F."

Feed me data

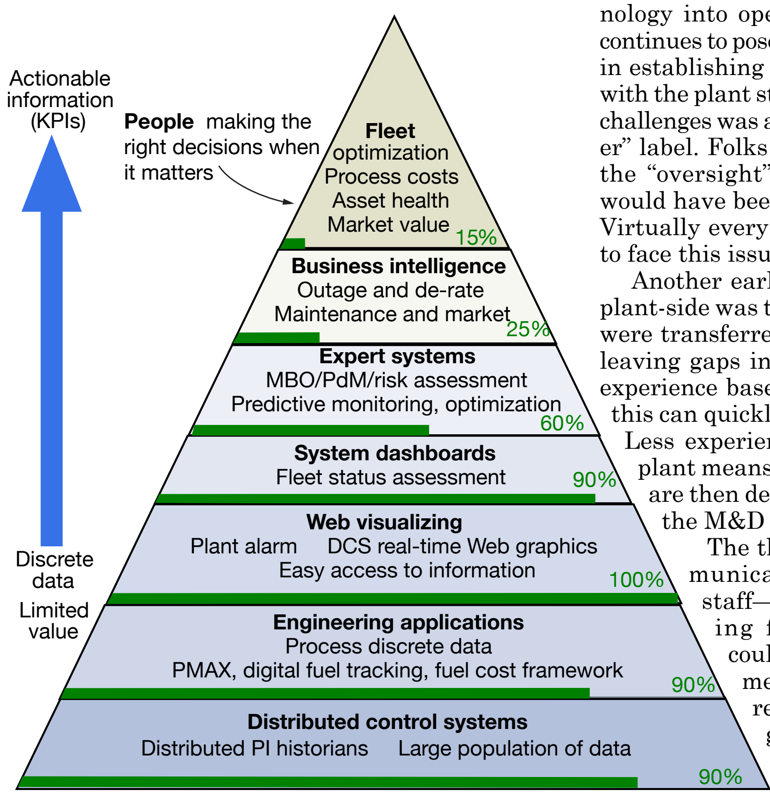
If APR and thermal performance are the core monitoring technologies, the data historian and data network are the backbone that makes the M&D center possible. The leading provider of this system has trending tools as well, although in general, most users report they are not as easy to use, or as robust as the customized software applications which pull from the data repository.

In a typical setup, data from the plant DCS is pulled through a firewall into the plant local-area network (LAN). From here, the data historian server pulls data from the LAN. This involves tens of thousands of "tags," not all of which are actual measured variables, but include tags for data quality, performance equations, manual entry, data conditioning, notifications, and others.

Each plant data historian server in turn feeds the owner/operator corporate wide-area network (WAN), usually over the Internet. Corporate IT receives data, monitors the status of the servers, stays abreast of security patches, and reviews signature files. Process data are directed to the M&D center.

Instrumentation is one of the big technical challenges with APR. This is especially true at gas-turbine-based generating facilities. It has been true for decades that the majority of reliability issues at GT plants, especially starting reliability, are associated with I&C. A representative of one owner/operator who recently started up an M&D center notes that instrumentation issues comprise 50% of the advisories.

In fact, identifying over 500 instrumentation issues across the fleet



4. Transformation of raw plant DCS data into actionable information available to those with a need to know is evolutionary, despite the market rhetoric around "big data"

proved to have value on its own. Many of these issues were known by the plants but considered low priority because they involved monitoring and not control. For other owner/operators, I&C related advisories have been reported to be as high as 70%, especially in the early phases of building and training models.

No 'big brother' here

One of the prevalent justifications for M&D center investments is a solution, at least a partial solution, to the "brain drain"—although the great recession probably has made this less of an issue. Management sees talented, experienced human resources spread across multiple plants, supported by advanced technology, as a means of reducing personnel costs without sacrificing, and hopefully improving, on standard performance metrics of efficiency and reliability.

Another driver is having at least a more consistent version of the truth. Aggregating the data and knowledge makes it easier for everyone to share, avoiding silos of knowledge, and ensuring that experienced people who leave or retire don't take the keys to the O&M kingdom with them.

Integrating remote M&D technology into operating organizations continues to pose challenges, especially in establishing trust and cooperation with the plant staff. One of the earliest challenges was avoiding the "big brother" label. Folks at the plant resented the "oversight" of what in the past would have been their responsibility. Virtually every M&D center has had to face this issue in some way.

Another early complaint from the plant-side was that the best operators were transferred to the M&D center, leaving gaps in the plant talent and experience base. It's easy to see how this can quickly spiral out of control. Less experience and talent at the plant means more problems which are then detected and resolved by the M&D center staff.

The third challenge is communicating with the plant staff—in particular, avoiding false positives that could inundate them with meaningless emails and reports which generally get in their way rather than ease their work lives. All M&D centers now strive to thoroughly validate and vet all indications before notifying the plant. In fact, many of these facilities are no longer called M&D centers. Instead, they have names like operations support, performance optimization, and performance center.

One M&D facility faced these challenges squarely by drawing a bright line between responsibilities and redefining the mission. If an indication is one with potentially an O&M impact within the next 24 hours, it is the responsibility of the plant; if longer, it is the responsibility of the M&D center. The mission, therefore, is about reliability and long-term condition-based monitoring, *not* day-to-day operations.

The struggle to balance human resources with technology continues, however. One specialist reports that building accurate models would have been far more difficult if they hadn't hired a vendor startup engineer. The best practice here is obvious: couple an equipment expert with a data and modeling expert. Other specialists report that such equipment experts are in short supply and high demand today.

5. The owner/operator of this M&D center is pushing the integration of plant performance data with electricity market and cost figures harder than others. It certainly began such a program sooner

The ebb and flow of utility management decisions also weighs on M&D center staffing. Several M&D centers had experts deployed 24/7/365. Now, the staffing has been cut back, in one case to the daytime shift only. Another center reported that they no longer monitor unit startups, and that staffing with two specialists 24/7 had recently been cut to two specialists only during the day shift Monday through Friday.

The irony here is rich, because the less-experienced, less-talented off-shift operators probably need the support more than first shift. But the management logic is obvious, too: Most parts of the country are awash in capacity. Units out of service don't make as much of an impact as, say, five years ago. Executives at many utilities have shifted their focus to transmission construction, and away from generation.

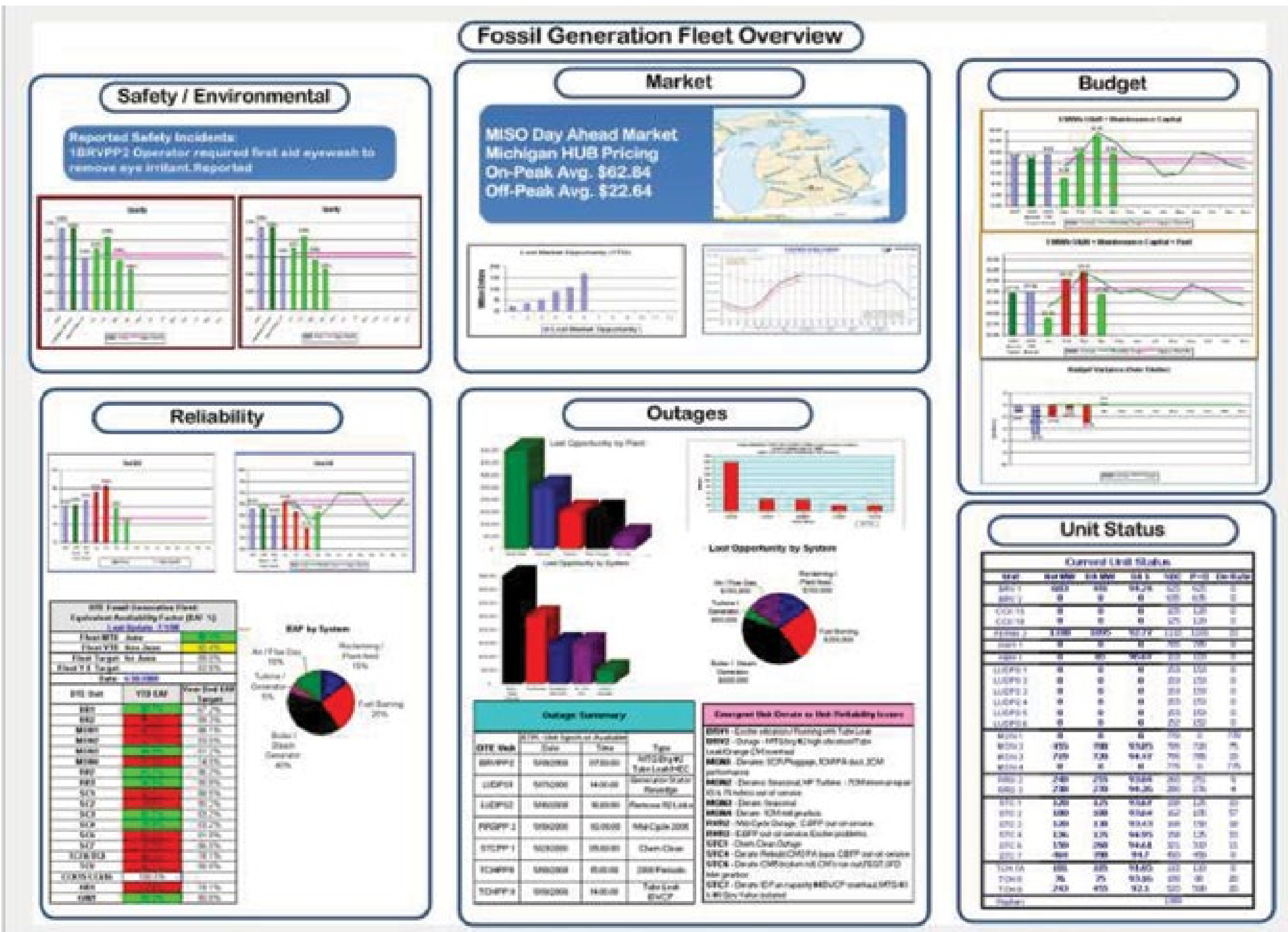
It is no surprise that the interface between M&D centers and plant staff proved a contentious subject during a session devoted to M&D centers at the CTOTF™ 2013 Fall Conference (www.ctotf.org). One seasoned operator asked whether such technologies "dumb down" operators. Others stress that, no, the idea is to make operators *smarter* by putting better information in their hands for making decisions.

Real-time financial management

The holy grail of fleet optimization could be called dynamic financial management. Imagine your plant's budget is no longer static, based on an annual review, annual capital spend, and O&M targets. Instead, your budget is dynamic, changing every day, maybe even every hour, based on the current condition of critical equipment. At the same time, all the operating costs are known (within some error bands) in real time, and that information is used to dispatch the entire fleet.

At least one fleet owner/operator dared to have this vision (Fig 4) more than seven years ago, and continues to work towards it, an effort anchored by its remote monitoring center (Fig 5). Over time, the effort incorporated recent wind-turbine additions, market information required by the ISO, and interfaces to the plant CMMS and enterprise business management systems (Fig 6).

The author saw a version of the Fig



6. One screen displays the performance dashboard for the entire fleet of a mid-sized electric utility. Getting to this point required integrating data and information from many "silos," both within and outside the organization, and accessing it with a common user interface

4 graphic six years ago. The percent-complete figures along the right side of the triangle are the same, except the one for system dashboards, which has risen to 90%. Similar to using real-time, heat-rate calculations for dispatch, making the transition to a truly data-driven fleet operator basing decisions on real-time cost-based key performance indicators (KPIs) doesn't happen overnight. "Big data" is evolution not revolution.

Glimpse into the future

A smarter or less-capable operator really isn't the issue. Automating repetitive tasks through technology has always been a persistent driver of change and cost management in industry. Getting the right information to the right people at the right time is the issue. One need only understand that airline pilots are essentially trained today as overseers of the plane's automation system.

Simple-cycle gas turbines are routinely started and stopped remotely and have been for decades. Combined cycles start up at the push of a button. Almost 20 years ago, the author visited a 1400-MW coal-fired plant in Australia that operated (and still does today, according to a recent report) with only two people onsite during the second and third shifts. Much of the monitoring and control was shifted to a central dispatch facility.

Fact is, M&D technologies can be more closely coupled to control systems so that they achieve "closed loop control," taking the human operator out of some decision loops. Although control-system suppliers are sensitive about taking deep dives into unmanned plant operation, they are ready to embed M&D and prognostics into their control-system architectures, hardware, and software.

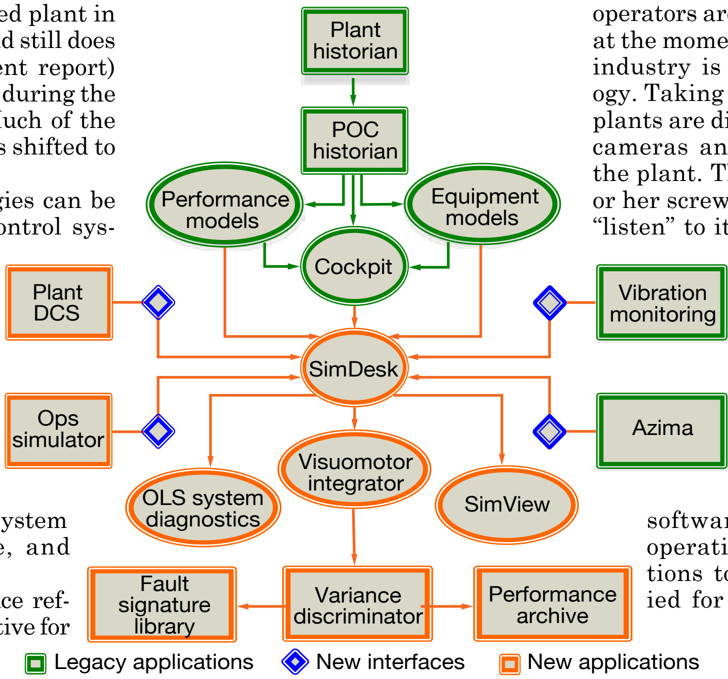
At the CTOTF conference referenced earlier, a top executive for a major control-system supplier focused his remarks on prognostic control, how sophisticated data analytics and big-data algorithms can be combined with super-fast simulation to inform real-time decisions. In this way, monitored variables are tracked and compared using multivariate techniques and the control system is run, in effect, in *fast forward* to predict how the plant will respond.

The latter is performed using a virtual model of the control system that runs in parallel with the real plant control system. Much of this capability can now be embedded in the controllers, avoiding separate systems pulling from an independent data historian. In another paradox, such capability may ultimately obviate the need for a remote M&D facility.

The application of wireless sensors is clearly the next front in M&D and prognostics. Specialists at one M&D center say they plan to add thousands of wireless sensors for vibration, temperature, electromagnetic interference (EMI), and other variables across its large regional footprint of assets, as well as build at least 1000 new APR and prognostics models to use the data.

At another facility, one full screen is dedicated to trending and displaying the data from remote wireless monitors across the fleet. According to users, wireless sensors cost as little as a few hundred dollars each. A typical combined cycle could have 300-400 new monitored points, a simple-cycle GT 50-60.

Consider how inexpensive direct measurements can also change the architecture of M&D. One of the reasons APR techniques became so popular was because direct measurements at power stations were limited. Supervisory systems for gas-turbine plants provided by the OEM, for example, are expressly intended to prevent catastrophic failures, not provide 24/7 indications of deviations, faults, equipment condition, etc. APR does a great job with the available measurements, but a machine more intimately instrumented for 24/7 diagnostics and trending may no longer require opaque black box algorithms for trending and correlations.



7. Vision for this M&D center is to have a simulation desk, in parallel with the M&D cockpit, running future operating scenarios

The upshot is the human-technology equation may flip again. With more of the right data from inexpensive sensors, it may make more sense to locate specialists at the plants, or consider them roving with no home base. Let's face it, the data aren't at the plant or an M&D center; they're in the "cloud." No reason why the equipment specialist, the plant operator, maintenance planner, OEM representative, and others can't meet virtually and discuss the issues.

A third piece of technology promises to facilitate such meetings: 3-D visualization. Owner/operators today can laser scan the as-built plant environment, convert the scans into virtual digital models, and reference all of the data about the equipment through standard points and clicks. We're not talking about crude 3-D models used in graphics packages, but high-resolution, high-fidelity graphics of the as-built environment—almost as clear as photographs.

Only a few powerplant owner/operators are moving in this direction at the moment, but the petrochemical industry is embracing the technology. Taking this a step further, some plants are discussing mounting video cameras and audio devices around the plant. The operator can't put his or her screwdriver on a machine and "listen" to it, as in the old days, but such surveillance would help detect leakage, changes in sound, and other ambient conditions.

Finally, integrating simulator capability is another coming wave. Already, some plants are equipped with M&D software that allows previous operating intervals and conditions to be replayed and studied for improvements. For the future, control-system vendors are promising fast-forward capability, the ability to run the simulator, essentially with a high-fidelity replica of the control system, *in parallel with* the DCS. This is tantamount to sending a spy to survey the landscape before you commit forces to battle.

Specialists can play "what-if" scenarios with control parameters to see how equipment/systems respond, not in real time, but ahead of time. In one configuration, a simulation desk complements the M&D center cockpit (Fig 7). CCJ

A cornucopia of ideas for combined-cycle users

Analytical thinking a common thread through presentations on HRSG damage mechanisms, faster steam production, repurposing of steam-plant condensers for combined-cycle service, integration of solar tower/thermal energy storage technologies into combined cycles

What's eating up your LP evaporators: FAC or LDI?

Most O&M personnel at combined-cycle and cogeneration plants powered by gas turbines are aware that tube/pipe-wall thinning attributed to flow-accelerated corrosion (FAC) is a frequent cause of pressure-part failures in the low-pressure section of heat-recovery steam generators (HRSGs).

Less common, but also of concern, is damage caused by liquid droplet impingement (LDI), say David Moelling, James Malloy, Marc Graham, Mark Taylor, and Andreas Fabricius of Tetra Engineering, an independent consultancy with offices in the US and Europe. Boiler and power-piping inspection and failure analysis are among the company's specialties.

An evaluation of "Design Factors for Avoiding FAC Erosion in HRSG LP Evaporators" was presented by this group of Tetra engineers at the ASME 2013 Power Conference, last summer, in Boston. The following is an overview of that presentation. Get the details by ordering the meeting proceedings from ASME and reading POWER2013-98255.

Recall that FAC involves the accelerated dissolution of the protective magnetite layer that forms naturally when carbon steel is oxidized in water or in a two-phase water/steam mixture. While extensive research over the last four decades has led to a good overall understanding of the essential damage mechanism—that is, dissolution rate depends on local water chemistry, temperature, and fluid velocity—work continues on understanding the relative importance of the individual parameters on wear rates and on improving the accuracy of predictions.

FAC can occur in both single- and two-phase flow conditions. The latter can accelerate FAC progression, principally by increasing the flow rate of water near the metal surface. It is possible in some cases to differentiate between the surface appearance of a pipe or tube subjected to single-phase FAC and one experiencing two-phase FAC.

Surfaces exposed to single-phase FAC are usually ascribed an "orange peel" appearance, with pits resembling many horseshoe prints, all oriented in the same direction (Fig 1). Surfaces exposed to two-phase FAC can have a wider range of appearances—from the so-called "tiger stripe" pattern to a black and shiny scoured surface to an "orange-peel" pattern very similar to single-phase FAC (Fig 2).

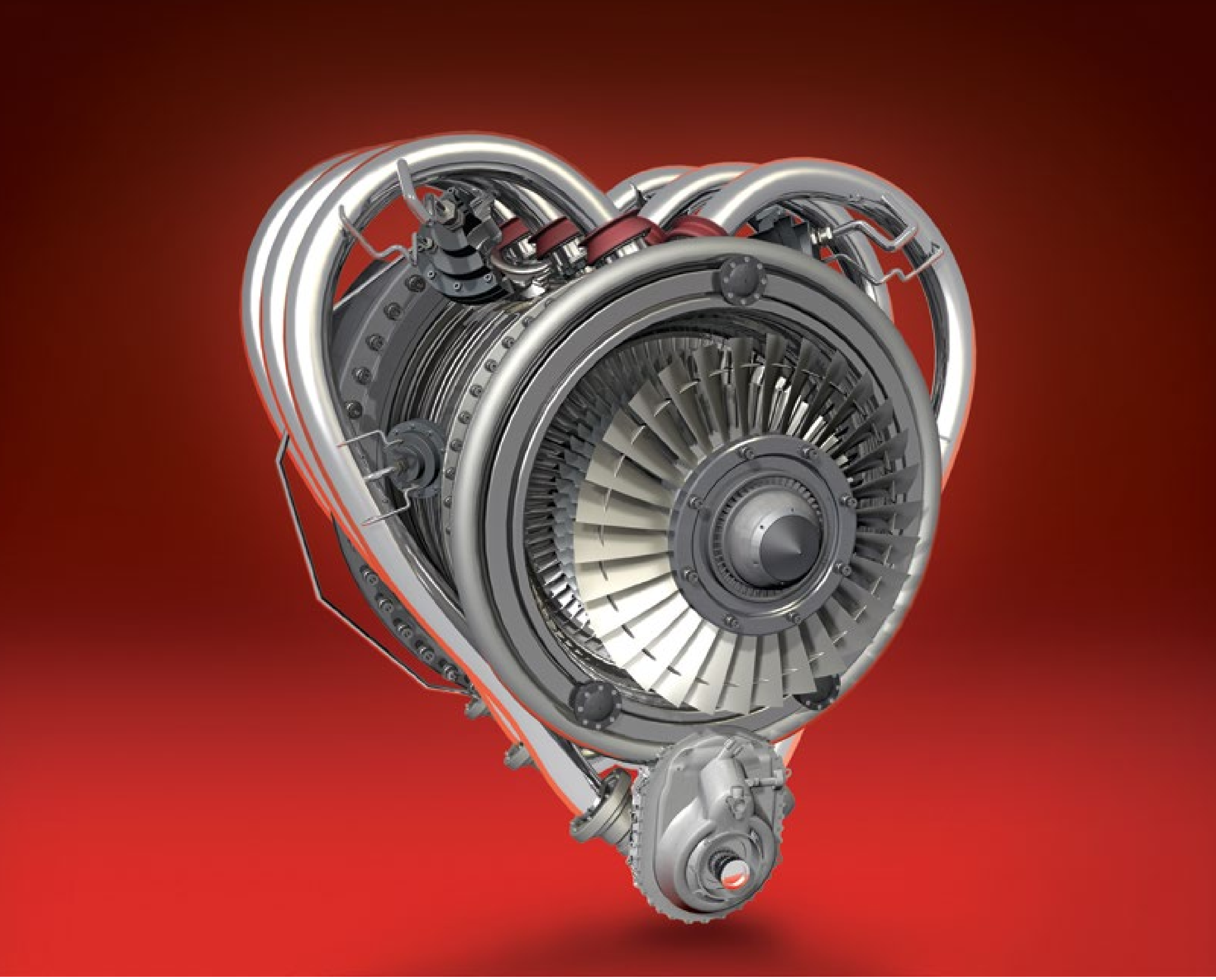
Mechanical erosion, like FAC, can lead to thinning of steel components. Water at high velocity can erode even the hardest materials—including diamond and tungsten carbide. The mechanism of interest in LP evaporator circuits is LDI. It causes material loss through the repeated impact of high-velocity droplets on a tube or pipe wall surface.

Common locations for LDI are in bends or near obstructions in piping carrying wet steam. Water, in the form of droplets or high-velocity liquid in the two-phase stream does not follow the contour of the pipe; their inertia causes them to stay on the original trajectory and impinge on downstream surfaces. This explains why LDI thinning is typically found in the "line of sight" of the original flow trajectory.

Damage caused by LDI is characterized by a rough surface, similar to cavitation pits, with little or no surface oxide. The wear rate attributed to LDI

1. Single-phase FAC as seen in an HRSG tube

2. Worn belly plate was removed from an LP drum exposed to two-phase flow



in a given material depends on several factors, including these:

- Impact velocity.
- Droplet size.
- Impact frequency.
- Liquid density.
- Vapor density.
- Viscosity (temperature).

The effect of impact velocity has been assessed by researchers. The resulting empirical formulations, which identify a threshold velocity below which no mechanical erosion occurs and can predict wastage rates by a power law relationship to velocity. There is disagreement on the exact velocity dependence of LDI and a considerable disparity on the value ascribed to that threshold velocity, ranging from "several tens of meters per second" to more than 100 m/sec (330 ft/sec).

Whereas FAC can be mitigated, if not eliminated, by keeping the water chemistry (pH and oxidation reduction potential) within the appropriate control band, the effects of LDI cannot. Only a change to flow geometry and/or local process conditions can lower the rate of surface loss.

As local flow velocities in a pipe or tube increase, the relative contribution for material loss transitions from FAC to LDI erosion, which first acts on the protective magnetite surface and later on the base metal once the oxide has been removed. For this reason, some have found it useful to divide LDI into LDI erosion and LDI corrosion. The former refers to purely mechanical wear at high flow rates; the latter encompasses mechanical erosion coupled with the corrosive action characteristic of FAC.

The notion that FAC and LDI could act in a complementary fashion is fittingly described by the term erosion/corrosion, which had been used to describe the range of flow-related mechanisms that could cause pipe thinning.

FAC, LDI in LP evaporators. FAC, and to a lesser degree LDI corrosion, is known to occur in HRSG LP evaporator circuits, at times requiring extensive repairs and even full-module replacements. Single-phase FAC can occur in any area where there are high local flow velocities exist—such as tube bends at the lower header and feeders, and connecting piping between header and downcomer. There is a noticeably higher amount of thinning of the tube walls at locations just above the feeder pipes entering the header.

Two-phase FAC has been observed in tube bends at the upper header (Fig 3), the inside surface of the upper header, risers and drum internals such as separator plates. LDI wear is potentially possible in the same areas if flow velocities are high enough (Fig 4).

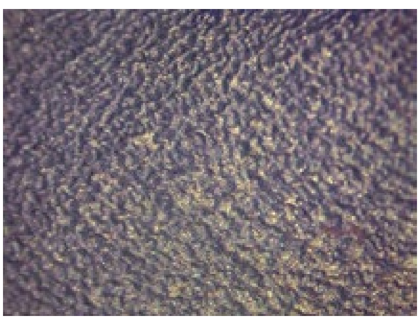
Tubes near the edge of the bundle adjoining the casing or center baffles may show accelerated thinning because of higher local gas temperatures which increase boiling rates, and hence local flow rates. The higher temperatures occur when hot gas bypasses upstream tubes along channels, such as the one formed by the gap between the casing wall and the edge tube.

Avoiding FAC and LDI. HRSG design and water chemistry play important roles in determining susceptibility of the LP evaporator circuit to FAC. Operating parameters such as water chemistry (pH and dissolved oxygen) can be adjusted, whereas the design, once in place, cannot. The emphasis here is on identifying the principal design factors that would render a HRSG more resistant to both of these degradation mechanisms.

Process conditions (flow velocities and flow regimes) in the LP evaporator are sensitive to small changes in heat transfer and load conditions. This is particularly true in units with very low pressures in the boiling zone—such as those making LP steam only for deaeration. Low pressures mean that there is a high void fraction in the two-phase region.

LP evaporator process conditions will vary with changes in HRSG steam production, which is impacted by gas-turbine load and (if installed) operation of supplementary firing. Therefore, progression of FAC and LDI wear can depend on the HRSG load profile over the operating life of the unit.

3. Two-phase flow at bend in LP evaporator tube caused this failure



4. Rough surface features characterize FAC and LDI erosion

Not everyone agrees liquid droplet impingement is a unique damage mechanism

Liquid droplet impingement (LDI) is a phenomenon whose existence, while believed by some to make sense, has not been fully vetted by the scientific community in the minds of at least a few of the world's leading authorities on powerplant water chemistry and HRSG damage mechanisms.

One of the presenters at the 2013 International Conference on FAC in Fossil, Combined Cycle/HRSG, and Renewable Energy Plants told the editors, that in his opinion, there was "nothing robust in the literature about LDI." He said the topic was raised at the conference and the consensus opinion was that everything thought to be LDI turned out to be "just old FAC occurring at a high rate" when analyzed under a microscope by experts.

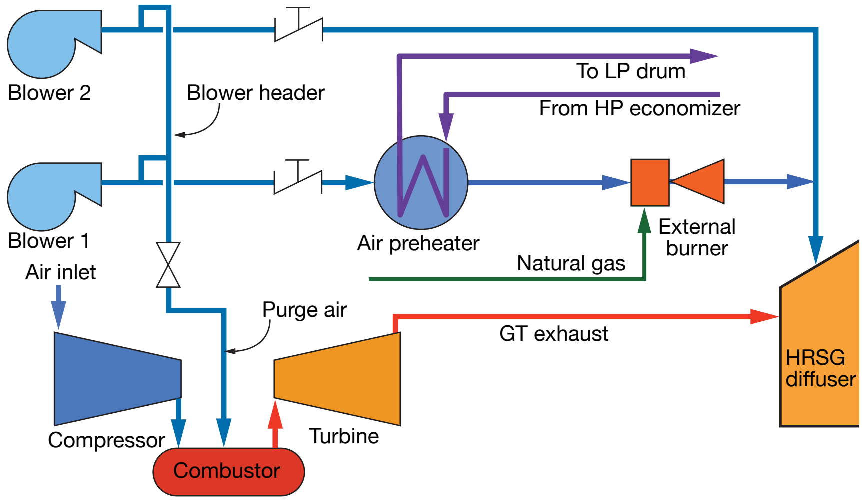
The chemist/metallurgist believes LDI might be one of those "stories" that circulates around the industry, developing a life of its own, but with no real basis in science—a Bigfoot or Loch Ness Monster of sorts. Everything mechanism-related, he continued, points to very high rates of FAC in two-phase environments; the droplets just increase the rate of mass transfer.

More to come on this topic in future issues. If you want to join the dialog, write bob@ccj-online.com.

Modifying a combined cycle to improve operational flexibility

Michael Radovich of URS, Princeton, NJ, described in his presentation, "Agile HRSG" (POWER2013-98255), a design enhancement for conventional reheat heat-recovery steam generators intended to enable faster startups. The modification might also be suitable for existing HRSGs. The operational flexibility provided by Radovich's design could help a plant improve its dispatch position and revenue stream, particularly where a grid operator is looking for reliable generation to back up must-take intermittent renewables.

The mod also would allow a combined-cycle plant to operate its HRSGs as standalone auxiliary boilers, and its



5. Modifications to improve the operating flexibility of a conventional combined cycle include addition of blowers, air preheater, and external burner

gas turbines in the simple-cycle mode without the need for bypass stacks. The only additional equipment required to make such operational improvements a reality, according to Radovich, are external blowers, a preheater, and a burner connected to each boiler's diffuser (the transition piece connecting the GT exhaust duct to the HRSG). The preheater uses water from the HRSG's HP economizer to raise the temperature of ambient air prior to combustion (Fig 5).

When GTs are shut down, this auxiliary equipment is placed in service; it provides enough flue gas to allow the HRSGs to operate as small auxiliary boilers. The steam produced pressurizes the drum, heats the steam lines, provides sealing steam for the steam turbine, and allows a vacuum to be maintained in the condenser. Sufficient steam would be available to synchronize the steam turbine, Radovich said.

The external burner system also can be used as a duct burner. During hot weather, it can provide the HRSG with additional heat to increase steam production.

When inspection and/or maintenance of Rankine cycle equipment is required, the plant can be lined up this way for simple-cycle operation: The HRSG, condenser, circulating-water system and steam turbine are shut down, and the boiler is drained. The blowers then are turned on and inject tempering air into the GT exhaust stream. Ambient air reduces the exhaust temperature to that required by the SCR for optimal NO_x control. Important to note is that the temperature of the ambient air/flue gas mixture does not cause distress to the uncooled HRSG heat-transfer surfaces.

Equipment specs. The two blowers incorporated into each GT/HRSG string should be sized to temper the diluted exhaust stream to about 780F; Radovich considers this the ideal temperature for good SCR performance. The combustor, he says, should be able to heat air flow from *one* of the blowers to about 900F, which is consistent with the desire to operate the steam turbine at low load.

A work in progress. Radovich acknowledged that his proposed cycle enhancement might be difficult to retrofit on some existing combined cycles because of the space required to install the external burners and heat-exchanger skids. Other possible sticking points that should be considered, he said, are listed below. All suggest the need for engineering analysis.

- HRSG drums might not be suitable for the low-pressure steam flows produced by the external combustion system.
- Low stack temperatures may cause ammonium bisulfate to deposit on preheater heat-transfer surfaces.
- The HRSG may not be able to handle the additional tempering-air flow.
- The steam turbine may not be capable of operating for extended periods at the low steam flows and pressures associated with the external combustion system.

In wrapping up his presentation, Radovich said the design described in his paper probably could be improved. For example, it may be more economical to fire an external duct burner with one of three 33% tempering air fans rather than one of two 50% fans.

A rigorous economic analysis also is necessary. The work presented at the ASME Power meeting did not address costs and auxiliary loads required by the modifications. A candid Radovich also revealed that "at this stage, we have not identified a vendor willing to bid the external heat exchanger/duct burner and blower modification. As we have also not identified the pressure drop through the heat exchangers and dust burner, we are not able to size the fans, except for mass flow."

To dig deeper, review the paper. It includes relevant Markov diagrams—graphical representations of all states and transitions that an individual train (one GT and its dedicated HRSG) can experience—as well as heat balances simulating normal operation in the design condition and auxiliary boiler operation in the off-design condition.

Retrofitting a steam-plant condenser for combined-cycle service

There are substantial differences in design between condensers for conventional steam plants and ones for combined cycles. These differences should be understood to guide appropriate modifications before repowering steam stations with gas turbines, stressed Dr Ranga Nadig of Maarky Thermal Systems Inc, Cherry Hill, NJ, at the 2013 ASME Power Conference. Nadig's paper, "Considerations in Converting a Dual-Shell or Dual-Pressure Coal-Fired Plant Condenser into a Combined-Cycle Plant Condenser" (POWER2013-98062), can be accessed in the meeting proceedings.

Steam surface condensers for large generating plants usually are of the dual-shell or dual-pressure type. Recall that:

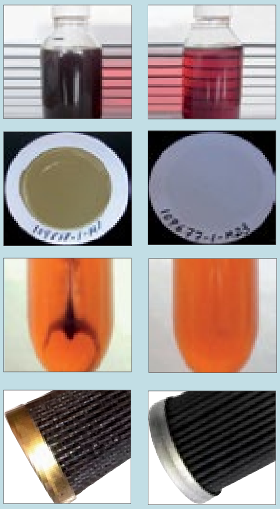
- A dual-shell unit consists of two identical shells operating at the same pressure; the hotwells and the steam domes of the two shells are connected (Figs 6, 7).
- In a dual-pressure condenser, the two shells operate at different pressures (Figs 8, 9). Circulating water enters the LP shell and, upon exiting, enters the HP shell. Cycle efficiency is improved by partially heating the condensate from the LP shell in the hotwell of the HP shell.

Condensers for large steam plants generally are equipped with feedwater heaters in the condenser neck, extraction piping, an external flash tank, and a large number of vents and drains. By contrast, combined-cycle condensers do not have integral feedwater heaters or extraction piping. Plus, they have no external flash tank and the number of vents and drains is minimal.

Although their operating principles are the same, Nadig told attend-

Varnish below MPC 5 - Always - Guaranteed!

The only system that works without chemicals and shows when the inserts are full!



Before** & **after
installation of a
CJC™ Varnish Removal Unit
VRU

Benefits

- Increase turbine reliability and availability
- No valve sticking of e.g. lifting or tripping system
- Prolong lifetime of your oil
- Low maintenance costs
- No system flushing

Varnish on journal bearing, gas turbine

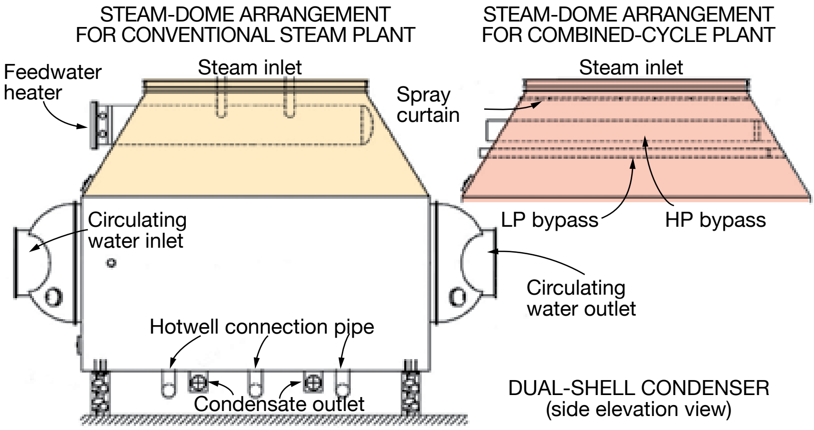
Varnish on valve spool

Varnish on plate heat exchanger

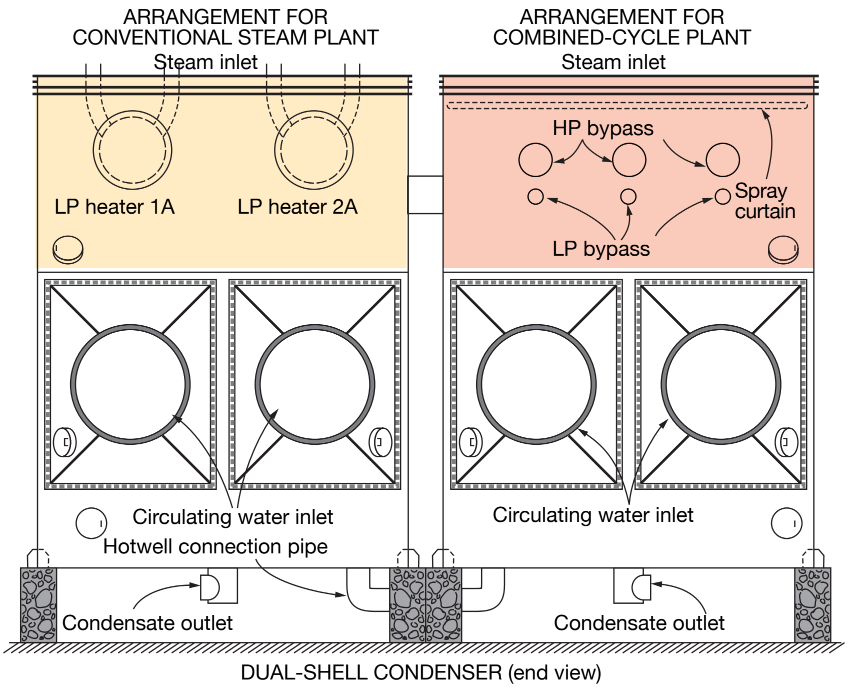
Install a
CJC™ Varnish Removal Unit
- for Gas & Steam Turbines
and avoid
Turbine Trips!
Contact us - today

Clean Oil - Bright Ideas

C.C.JENSEN Inc. | Georgia GA 30265 | USA
+1 770 692 6001 | ccjensen@ccjensen.com | www.ccjensen.com



6, 7. Differences between *dual-shell* condensers for conventional steam and combined-cycle plants focus on the transition section (steam dome) connecting the LP turbine outlet to the condenser steam inlet



ees there are substantial differences in the design and construction of condensers for conventional steam plants and combined cycles—including these:

- Combined-cycle plants have higher turbine exhaust-steam flow rates and often are required to operate for a short, or extended, period in bypass mode.
- Coal-fired plants have pressurized deaerators to remove oxygen from condensate; in combined cycles, condensate is deaerated in the condenser.
- Combined cycles in cogeneration service dispatch a portion of turbine extraction steam for heating purposes. In such arrangements, an equivalent quantity of makeup water is introduced and deaerated in the condenser.
- In conventional steam plants, vents and drains often are admitted to the condenser via a flash tank. In combined cycles, the vents and drains often discharge directly to the condenser.

Design features common to dual-shell, dual-pressure condensers

Heat-transfer surface, support-plate spacing. The heat-transfer surface in the existing condenser should be sufficient to meet the combined cycle's performance requirements; the existing support-plate spacing should be less than that needed for the repurposed turbine's exhaust-steam flow rate. Because the combined-cycle condenser will be operating in bypass mode periodically, it is prudent to increase the wall thickness of tubes in the impingement zone.

If possible, Nadig said, the top two rows of tubes in the impingement zone should be replaced by two rows of 14-BWG carbon-steel dummy tubes to help prevent tube failures and protect impingement-zone tubes from wear and tear during normal and bypass operation.

Feedwater heaters in the condenser neck are removed when repurposing a conventional steam-plant condenser for a combined cycle. The presenter stressed exercising care when extracting the heaters and their supports, to protect condenser internals (especially the tubes) against damage. Openings in the steam-dome plate to accommodate the feedwater heaters must be closed with an adequately stiffened cover plate, he said, to withstand the shell-side design pressure.

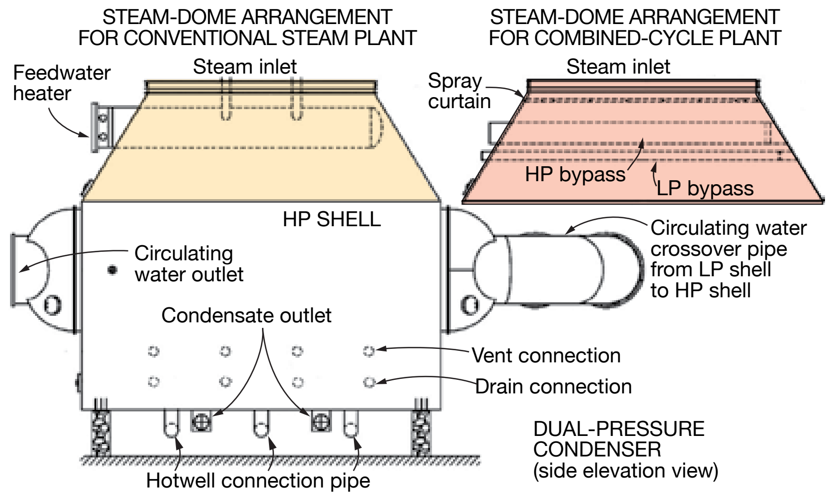
Also, extraction piping from the steam turbine must be removed and the open ends capped. Best practices: (1) Install drain connections on the end caps and rout them to the condenser hotwell. (2) Stiffen the ends of the extraction piping.

In a combined-cycle plant, the condenser must accept steam from the HRSG pressure-reducing desuperheating (PRD) valve when the steam turbine is not in operation. This typically is referred to as bypass operation and requires installation of bypass headers—HP, IP, and LP—in the steam dome (refer again to Figs 6, 8). Each HRSG is equipped with dedicated HP, IP, and LP bypass headers. To avoid excessive pressure variations, the bypass steam from each boiler must be split evenly between the condenser shells.

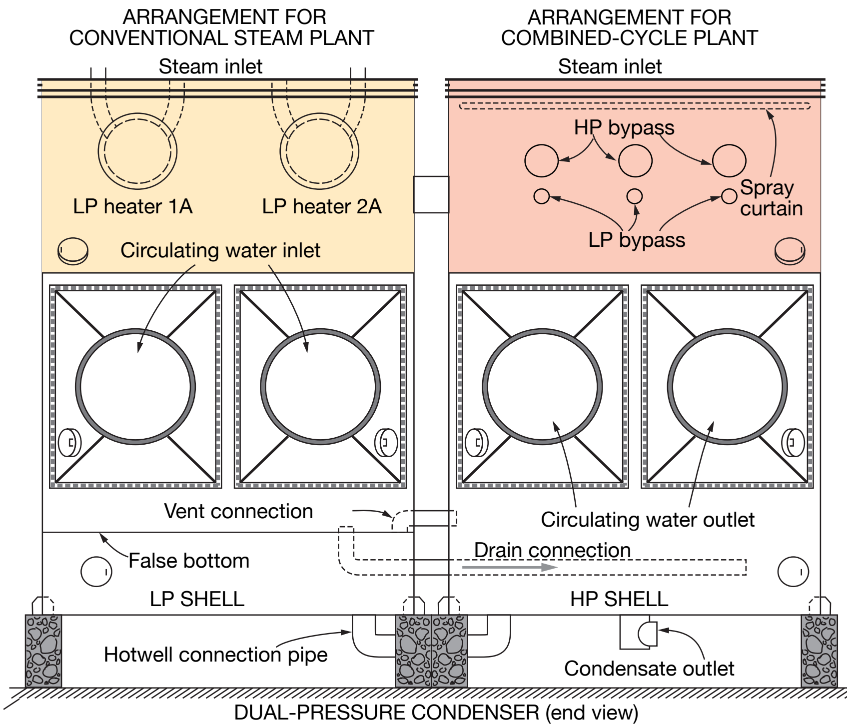
Bypass headers from multiple HRSGs can be manifolded into a single header, but this could cause pressure variations in the header during periods of partial bypass flow. To assure proper distribution of steam in the condenser, locate the centerline of the bypass header at least 6 ft above the topmost tubes.

Extend bypass headers along the length of the tubes to distribute steam evenly along the entire tube bundle. Nadig recommended that the bypass header be equipped with the smallest possible orifices—typically 0.25 in. diameter. They should be installed along the length of the header and oriented sideways, he added, so flow is not directed at turbine internals or the condenser tubes.

Nadig also suggested that the bypass admission design be in accordance with EPRI Report CS2251, "Recommended Guidelines for the Admis-



8, 9. Differences between *dual-pressure* condensers for conventional steam and combined-cycle plants also focus on the transition section (steam dome) connecting the LP turbine outlet to the condenser steam inlet



sion of High-Energy Fluids to Steam Surface Condensers," with appropriate corrections. He recommended sloping the bypass header along the length of the tubes and installing a drain connection with an impingement plate at the far end of the header to assure positive drainage.

The PRD valve should be designed and operated to assure that only dry steam is sent to the condenser, the speaker continued, and be sure the valve fails in the closed position. Nadig stressed carefully monitoring the temperature of bypass steam admitted to the condenser and establishing alarm settings for lower- and upper-bound temperatures. Proper control of steam temperature is critical to trouble-free bypass operation.

Caution: During bypass operation, some high-temperature steam may migrate into the turbine exhaust. A spray curtain can protect turbine internals and the expansion joint against excessive temperature. Installing the curtain just below the expansion joint is recommended. The nozzles should spray cold condensate in a fine mist covering the entire cross section of the turbine exhaust.

Vents, drains, flash tank. When retrofitting your steam-plant condenser for combined-cycle service, blank off discontinued vents and drains. Also, if a flash tank is installed, review its design with the new arrangement of vents and drains to assure its suitability for combined-cycle application. Nadig recommended that your analysis consider, among other things, the operating pressure in the flash tank, the loop-seal design for the condensate drain to the condenser hotwell, and the orifice-plate design for the condenser vent.

Design features particular to dual-pressure condensers

A false hotwell bottom is installed in the LP shell about 18 to 24 in. below the lower-most tube. It is not designed to handle the shell-side design pressure or the loads encountered during a shell-side hydro. The welds between the false bottom and the shell walls, and those between the false bottom and the hotwell support pipes, must be carefully examined for cracks. Failure to find and repair cracks can lead to performance loss as leaks tend to equalize the pressure between the two shells.

After completing the mods necessary to repurpose an existing condenser for combined-cycle service, conduct a shell-side hydro. Because the false bottom is not designed to withstand the pressures associated with a hydro, install manways to permit the free flow of water in the spaces above and below the false bottom.

Draining condensate from the LP to HP shells. Condensate collected in the space above the false bottom in the LP shell is drained into the hotwell of the HP shell, as shown in Fig 9. Because the LP shell operates at a lower pressure than the HP shell, provide sufficient head in the drain pipe to permit positive flow under all operating conditions.

Insufficient head can cause condensate to back up in the LP shell above the false bottom, submerging tubes and leading to an increase in LP-shell pressure. Condensate from the LP shell should be drained into the HP shell at a minimum of three to four locations along the length of the shell.

Venting considerations. Vent the steam space below the false bottom in the LP shell to the HP shell at a minimum of three to four locations along the length of the shell (refer again to Fig 9). Insufficient venting can lead to problems in hotwell level control because of the difference in levels between the hotwells for the LP and HP shells.

Circ-water crossover piping. When calculating the overall tube-side pressure drop for dual-pressure condensers, be sure to include the delta p in the crossover piping between the LP and HP shells, in addition to the tube-side pressure drops for each shell. It is important that the design of the circ-

water crossover piping be evaluated to ensure satisfactory performance in combined-cycle service.

Design features particular to dual-shell condensers

A dual-shell condenser is much simpler in design compared to a dual-pressure condenser. As mentioned earlier, the former consists of two identical shells connected in the steam-dome and hotwell locations. An important design point is to be sure the ducts connecting the two steam domes are large enough to equalize the pressure in the two shells under all operating conditions. Special attention should be given to the removal of debris from the piping connecting the two hotwells.

Benefits of integrating solar towers with combined cycles

Countries committed to reducing CO_2 emissions may incentivize utility and industrial power producers to build renewable generation assets characterized by low carbon intensity. With operators looking for the most cost-effective power-generation option, the integration of renewable energy sources with existing assets, or in new hybrid plants, may be appealing.

Renewable energy technologies, such as concentrating solar power (CSP), have made significant progress in the last decade with regard to efficiency and cost. However, in Australia and some other countries, when making investment decisions without including external costs for fossil fuels or government incentives for renewable electricity, the current economic climate favors natural-gas-fired simple- and combined-cycle plants over CSP installations.

To lower the specific investment cost of CSP and prepare for the expected increase in natural-gas prices, some Australian engineers see value in retrofitting existing gas-turbine plants with concentrating solar power as well as in designing plants from the ground up with a CSP component. This would create both environmental benefits—such as a reduction in carbon intensity—and economic benefits, including less-expensive CSP installations and renewable energy certificates.

An area of current interest is the retrofit of solar towers to reduce cost and allow independent operation of the combined-cycle and CSP components. Most existing integrated solar/combined cycle (ISCC) plants use parabolic trough systems with thermal oil to boost HRSG steam production. This is a well-established concept, acknowledged the authors of "ISCC Plants Using Solar Towers with Thermal Storage to Increase Plant Performance," presented at the ASME 2013 Power Conference (POWER2013-98121), but it limits the solar contribution and requires both plants to operate simultaneously.

Authors of the paper are the following: Juergen H Peterseim, Univ of Technology Sidney; Dr Amir Tadros, Aurecon Australia; Prof Udo Hellwig, ERK Eckrohrkesse GmbH; and Prof Stuart White, Univ of Technology Sidney.

Depending on the load profile, the ISCC could operate with or without storage capability. Thermal storage would be valuable to provide solar-generated electricity during periods of peak demand, such as the early evening hours. However, today's high cost for thermal storage—about \$90/kWh (thermal) makes it difficult to justify this investment without a premium on power dispatchability.

Australia and suitability

ISCC seems to be a suitable technology for reducing the carbon intensity of Australia's power-generation portfolio. The country has vast natural-gas reserves and abundant locations with excellent direct normal irradiance (DNI). But gas prices are expected to increase significantly if new LNG facilities come online over the next several years as anticipated. The CSP component also would benefit from current and expected increases in electricity prices.

From an economic perspective, ideal locations for ISCC facilities in Australia are remote load centers—such as the mining areas in the West. Electricity prices are higher there than along the East Coast, where a grid distributes large quantities of low-cost electricity from coal-fired powerplants.

Of particular interest are locations where GTs already are installed, because conversion costs would be comparatively low. Several operating plants known to the authors would qualify for ISCC conversion. They also recommended investigating the ISCC option for plants in the planning stage. Where the DNI is sufficiently high, the developer should at least reserve area for a future plant conversion.

Typically, an average daily DNI of more than $20MJ/m^2$ is required for a standalone CSP plant. However, the cost-reduction benefits of ISCC facilities made possible by the joint use of plant equipment (such as steam turbine and condenser) suggests that areas with a DNI above $17MJ/m^2$ should be considered as well.

ISCC plants in operation

Several ISCC plants are now operating—including ones in the US, Egypt, and Morocco. The largest, rated 75 MW, is the Martin Next Generation Plant in Florida. The authors said that all ISCC plants in service at the time of the ASME meeting relied on the mature parabolic trough technology, with thermal oil providing saturated or slightly superheated steam to the heat-recovery steam generator. In the HRSG, superheat is added to match steam-turbine requirements. This concept is well proven in several ISCC plants; the solar contribution typically is less than 15% of the total plant capacity.

The use of parabolic-trough technology with thermal oil limits steam temperatures to less than about 735F because the heat-transfer fluid degrades very quickly above 750F. To increase the steam enthalpy provided to the host plant, other working fluids, such as molten salts, must be used. A 5-MW prototype parabolic-trough plant using molten salt and thermal storage was retrofitted to the Priolo Gargallo combined-cycle plant in Italy; its steam temperature is nearly 1000F.

Solar-tower ISCC

With more solar-tower plants operating and under construction worldwide (including Gemasolar in Spain, and Ivanpah and Crescent Dunes in the US), the technology becomes increasingly mature and bankable. Significantly higher steam conditions (more than 1000F and 1600 psig) compared to parabolic troughs with thermal oil, facilitate CSP's integration into the CCGT's high temperature/pressure steam cycle.

The benefits of all ISCC plants are cost savings through the joint use of equipment—such as steam turbine, condenser, and feedwater system. However, solar-tower ISCCs have the potential additional benefit of sharing building infrastructure—for example, the stack could be modified to support the solar receiver.

The thermal-storage capability of solar-tower plants cited in the literature extends up to about 15 hours of full-load operation, twice that for a parabolic-trough system. Implementing thermal storage has the potential to maximize the CSP contribution but it strongly depends on the financial value of energy dispatchability. CCJ

SPECIAL REPORT

Generator inspection first step in avoiding failures attributed to dry stator-winding ties

Indiscriminate cost-cutting and/or inattention to detail during equipment manufacture, installation, operation, and/or maintenance are conducive to forced outages and unbudgeted expenses. Generally speaking, unrealistic expectations are to blame, not the individuals charged with doing their jobs faster and at lower cost.

That's simply the way it is in today's competitive generation business. How many times have you seen contracts let on the basis of merit rather than cost? Asset and plant managers take the rap when availability and generating capability go south, so it's in their best interest to share information on emerging issues. User groups are critical to this timely communication. Why should multiple plants be forced out of service for the same reason?

Manufacturers and services providers have a role to play as well, by keeping the industry and their customers informed about what is not performing as planned and how to correct the underlying issues. A case in point is the generator failure described by a user at the 2013 meeting of the Combined Cycle Users Group (CCUG). Access this case history by scanning the QR code with your smartphone or tablet, or go to http://www.ccj-online.com/3q-2013/generators/.

The idea that a failure of this magnitude would occur in a generator less than a year after COD caught CCUG attendees by surprise, judging from facial expressions. It's important to note that this was not a "one-off" failure. The other two generators coupled to gas turbines at this 3 × 1 combined cycle also were on the verge of failure. However, their repairs were relatively straightforward because the problem was identified before serious damage was done.

An objective of the presentation was to encourage owner/operators to pay close attention to OEM advisories, inspect their equipment accordingly, and take corrective action as necessary. The editors considered it unusual for a large generator made by one of the world's leading manufacturers of these machines to fail in the manner described—especially so because no one else in the meeting room seemed aware of the incident or its cause.

The following report, compiled from non-OEM industry sources, attempts to explain what likely happened and why. Your thoughts on the subject are welcome and will be held in confidence; write bob@ccj-online.com. Alternatively, you can reach out to industry colleagues by communicating via the CCUG users-only forum hosted at http://ccug.users-groups.com.

The downside of cost-cutting. Over the last three decades or so, electric power producers have put increasing pressure on generator manufacturers to reduce the cost of their machines. Particular focus has been on indirectly cooled generators common in combined-cycle plants.

A result of cost-cutting initiatives is a trend toward generator designs with increased reliability concerns. Examples include widespread use of the global vacuum pressure impregnation system for stator windings, generators built without isolation between core and frame, and an increase in stator-winding vibration issues attributed to high electromagnetic force (EMF).

Cost pressures also have resulted in numerous, more subtle modifications in construction that may show up as problems in unpredictable formats. An example is the "dry-tie" issue associated with some large indirectly cooled generators built by GE since about year 2000 and described in the article referenced above. The term "dry ties" commonly refers to the use of banding tapes to tie endwindings and connection rings.

Stator-winding vibration, it seems, always has been a leading cause of generator problems. Historically, endwindings were tied with cotton cord, then with glass cord, and then with resin-impregnated materials. This evolution occurred as EMF increased in the endwindings and connection rings.

The resin-impregnated tape commonly used on today's generators is a dry-tie material. Important variables enter into the tie process when using this material, including these:

- The tape is inherently non-lubricating, negatively affecting the ability to tighten the tie.
- The tape manufacturer may, without notice, change the amount of resin within the tape, or make subtle changes to the resin, thereby affecting its bonding and curing properties.

Banding tapes ordinarily are used to make high-strength insulated bands—such as those securing the armature windings on relatively low-speed rotating machines. In manufacturing these bands, the tape is machine-applied with controlled and substantial tape tension. The tape may be heated as it is applied. Significant consolidated



1, 2, 3. Dusting is indicative of early-stage vibration in endwinding


4, 5. Early-stage vibration of connection rings is identified by dusting


6, 7. Insulation wear on two rings in different phases is clearly problematic

8. Arc damage was caused by failure of connection-ring insulation

9. Questionable blocking of connection rings was in evidence on a winding that failed in service

cross-sections are built up which make the need for high resin content unnecessary. Plus, resin with high bonding strength is not necessarily required in these applications.

By contrast, making a reliable structural tie with such dry tapes introduces important inherent concerns, including the following:

- Obtaining a consistently tight tie using manual tensioning of a cold, non-lubricating tape.
- Assuring an adequate amount of resin required to obtain tie integration and structure component bonding.
- Assuring that the resin has consistent properties for obtaining high-bond-strength capability.

Generator endwinding support systems designed by GE over the last half century are considered "highly reliable" by at least some sources. This performance is attributed, in part, to a design philosophy which has incorporated a "wet tie." In making a wet tie, many strands of glass roving (fibers) are drawn though a liquid resin as the tie is made.

Wet ties largely eliminate the issues associated with dry ties. They allow the generator manufacturer to assure the purchaser that (1) the resin has a high bonding strength, (2) sufficient resin is applied with the tie to assure a high-contact bonding area, and (3) the tie is made extremely tight by use of tightening leverage and by taking advantage of the inherent lubricating characteristic of a wet resin.

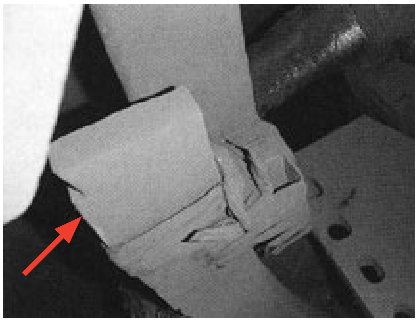
But in making the wet tie, shop personnel are handling a liquid resin in awkward positions involving a large amount of resin contact with hands and arms. Thus, making the wet tie is an uncomfortable and somewhat tedious process; there is considerable incentive to use an alternative process. The dry-tie material is one possible solution, but its application has led to reliability concerns on some GE generators.

Gallery. Figs 1, 2, and 3 show dusting as evidence of early-stage vibration in an endwinding; Figs 4 and 5 reflect vibration of connection rings. Early-stage dry-tie vibration illustrated in these five photos is relatively simple to repair—that is, to remove the dry ties and replace them with wet ties as recommended by the OEM. Even where insulation wear is significant (Figs 6 and 7), depending on depth and location, it may be possible to repair and retie. An alternative is a stator rewind.

Fig 8 shows a failure location on connection rings. It illustrates the amount of physical damage that can be caused by a failure arc, which persists for several seconds after the breaker trips as field current decays. The photo also shows the relatively weak integration of the tie between ring and support: The ring is connected to the support only at an edge of the ring rather than on a wide face. If the tie and bond are not exceptionally strong, the bond will fail and vibrations and wear can begin.

For the support in Fig 9, note that

10. Arc damage was found at the joint between the stator bar and connection ring



11. Dummy ring supports active connection ring in this design

12. Arc damage resulted from copper fatigue failure of a connection ring

the ring is contained on the faces but it does not fill the opening provided. Thus the ring is retained only by bonding of the faces and if that bond is broken by differential-expansion forces of cyclic loading, the ring will be free to vibrate.

Some configurations of connection-ring blocking can leave the blocks poorly integrated with the ties and rings. In such cases, the blocks themselves may disbond from the rings and ties. The loose block, or blocks, then can vibrate in a contained space and wear completely through the insulation of both adjacent connection rings. Since adjacent rings likely will be in different electrical phases, this condition is an invitation to electrical flashover and massive arc damage.

The damage in Fig 10 probably resulted from the arc of a phase-to-phase short circuit between two locations of bared conductor caused by vibration. In the event of a line-to-line failure, the minimum repair likely would involve full stator and field rewinds and extensive core, frame, and cooler cleaning. In a worst case, stator replacement could be required.

A few designs include a dummy ring in parallel to the active connection rings (Fig 11). These generators appear particularly vulnerable to vibration and wear. As shown, the ties are not doing a good job of joining the dummy ring to the support. Keep in mind that the dummy ring is made of a composite material having a significantly different expansion coefficient than copper. During cool-down from bake, and with cyclic loading, the dummy ring tends to disbond and become free to vibrate, shift position, wear the ties, and contact and damage connection-ring insulation. Early failure of the winding may result.

Typically, when dry-tied windings experience severe damage or failure, the cause is from insulation wear as seen in Figs 1-7. However, there is also the possibility that disbonding of ties and blocking can result in increased levels of component mobility and/or vibration natural frequencies drifting into resonant situations. These changes can result in much faster insulation wear, but they may also result in high-cycle fatigue and fracture of the copper conductor (Fig 12). Each of these conditions, insulation wear and copper fatigue, is extremely dangerous to winding integrity.

Fleet. About 450 generators of the 7FH2 type were manufactured between 2000 and 2011. Of those inspected, roughly 15% reportedly exhibited dusting; four with the dummy-ring design showed wear. Recall that the dust generated will appear as a blackish "grease" if the unit is oily. A significant number of 324, 330H, and 390H generators also have been inspected. A few were found with problems ranging from light dusting to serious insulation wear and exposure of copper. These problems focus on the connection rings and the OEM has recommended urgent action on inspecting these specific classes of generators in its advisories. A few that the editors were made aware of include these:

- Technical Information Letter (TIL) 1764, "324 and 330H Consolidated Dry-Tie Connection Ring Insulation Abrasion," February 2011.
- TIL 1792, "7FH2/7FH2B Consolidated Dry-Tie Connection-Ring Insulation Abrasion," May 2011.
- Electronic Technical Correspondence (ETC) 129, "Generator Stator Endwinding Dusting," September 2004.

It is difficult for the OEM, or for the owner, to predict which specific generators in the 7FH2, 324, 330H, and 390H lines may be experiencing difficulty. Reason is that there are numerous, sometimes unknown, variables that can contribute to vibration problems. These variables include the following:

- Electromagnetic forces differ from design-to-design and kVA rating within that design category. These forces have a strong correlation to mechanical duties.
- Variations in winding design, particularly for the connection-ring support structures.
- Tie-material properties are not accurately known to the OEM and may vary somewhat randomly from generator to generator.
- Workmanship may vary from generator to generator, and from bar to bar within a given machine. Such variation depends on the skill and motivation of the individuals performing the work. Fig 1 illustrates this: Some bars are vibrating, others are not.
- Deterioration depends on kVA output and the amount of load cycling, and this information is not readily available to the OEM.

It is clear that among individual generators of the classes noted above, there are unknown interactions of design, materials, workmanship, EMF, and operating duty. In general, then, it is unlikely that one can predict with accuracy which generators are vulnerable to damaging wear. However, there are exceptions that are said to have been made clear to the owners by the OEM. One example is the dummy-ring class of generators.

The OEM has issued recommendations related to inspection, stocking of materials, and the repair of any problems relating to the dry tie that are found. Repair is relatively simple if issues are identified before failure occurs. After a failure involving line-to-line flashover, repair can be very costly and include a long outage.

The bottom line: Unless your generators already have been inspected and found vibration-free, consider at least a cursory inspection of each machine as soon as possible. At a minimum, the initial inspection should focus on the connection end; it involves only removal of the upper outer and inner end shields, and the manhole covers of the non-connection end. But in every case, advice of the OEM should be considered carefully and this advice factored into your investigation and maintenance plans. CCJ

Lubricant varnishing and mitigation strategies

By **Peter Dufresne Jr, Matthew G Hobbs,** and **Glen MacInnis,** EPT

Nearly 10 years ago, GE reported that approximately one in three large industrial gas turbines showed signs of oil varnishing. Because this condition affects the availability and reliability of GTs, the OEM recommended the use of varnish removal systems. Despite the recommendation, varnish-related turbine outages remain a significant issue for the industry.

The primary reason varnish is an ongoing problem: The mechanism by which varnishing occurs is poorly understood by many turbine owner/operators. Thus, strategies aimed at correcting or mitigating varnish-related problems often are misdirected, resulting in less than ideal outcomes. The goal of this article, based on a presentation by the principal author at the 2013 Conference of the Frame 6 Users Group, is to improve understanding of varnish by discussing its specific cause and how various mitigation alternatives work to minimize operational impacts.

Varnish formation

Lubricant varnish generally is defined as a thin, hard, lustrous, oil-insoluble deposit composed primarily of organic residue. It is most readily defined by color intensity and is not easily removed by wiping.

While this definition provides an adequate description of varnish at the end of its life cycle (Fig 1), it must be expanded as follows to account for the remainder of the varnish cycle: Varnish begins its life as a soluble degradation product before converting to an insoluble particulate form. The process responsible for the deposition of particulate varnish is reversible.

This expanded definition reveals that varnish is a shape-shifter; it can be insoluble (conventionally recognized particulate form) or dissolved (soluble) in the fluid. An understanding of lubricant solvency is the key to understanding the mechanism by which varnish deposits are formed and, more importantly, the mechanism by which they can be removed.

1. Varnish is shown here in its insoluble form

Lubricant solvency

Under normal operating conditions, turbine lubricants are subjected to oxidation, which produces polar molecules (varnish precursors) from non-polar ones (lubricant mineral-oil base stocks). These polar species represent the starting point of the varnish life cycle. As a result, lubricants in service are a complex combination of base stocks, additives, and contaminants.

A lubricant's solvency is defined as its ability to dissolve these distinct components. Everything in the oil has a finite solubility, which is affected by numerous variables (molecular polarity, contaminant levels, temperature, etc). This solubility determines if a particular molecule is soluble in the fluid or if it will precipitate from the fluid to form a potentially damaging deposit.

When the solubility of a molecule is low, the lubricant cannot dissolve it and will actively release it, producing deposits. However, when the solubility of a molecule is high, the lubricant will have a high capacity to dissolve it, avoiding the formation of varnish deposits.

Factors affecting lubricant solvency

The following factors play a major role in determining the solubility of varnish precursors in lubricants:

Molecular polarity. The polarity of a molecule refers to the distribution of positive and negative charges within it. In some molecules, these charges are well separated (like the poles of a bar magnet); such molecules are said to be polar. In others, there is little or no separation of charge; these molecules are said to be non-polar.

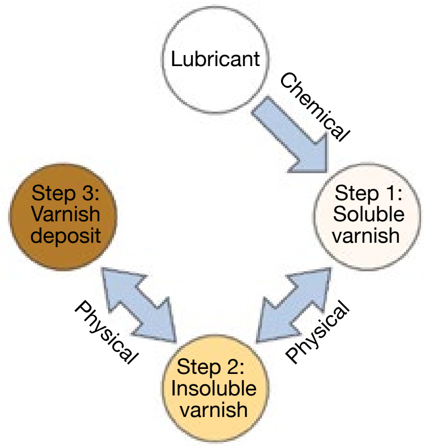
Molecular polarity is not simply black and white. The polarity scale incorporates shades of gray. Because polarity depends on the specific structure of every molecule, it is possible for one polar molecule to be more, or less, polar than another. The corollary for non-polar molecules is also true. The most basic axiom of solvency is that "like dissolves like."

This accounts for the fact that polar alcohol will dissolve fully in polar water while polar water will not dissolve in non-polar mineral oil. Although the varnish precursors produced by oxidative degradation of mineral oil base stocks are polar, they are much less so than water. Consequently, these somewhat polar degradation products have some finite solubility in a lubricant's non-polar mineral-oil matrix. Degradation products that are more polar will be correspondingly less soluble.

Contaminant levels. A lubricant has a finite capacity to dissolve other molecules (additives, contaminants, varnish precursors, etc). As the oil degrades and oxidation products accumulate, the solvency of the fluid decreases accordingly. Beyond a certain point (known as the saturation point), the fluid can no longer dissolve additional varnish precursors formed by continuing oxidation and varnish will begin to precipitate from solution in the solid form.

Temperature. Oil temperature

directly affects the solubilities of all the species dissolved within it. As temperature decreases, so does the solubility of varnish and its precursors. In the sugar industry, hot solutions of table sugar are cooled to decrease the sugar's solubility. As the sugar's solubility falls, crystalline table sugar is deposited from the solution. This same process is responsible for the precipitation of varnish deposits in cooler regions of a turbine's lubricant circulation system. Because metals are more polar than the lubricant's base stock, the precipitated polar varnishes prefer to adhere to the metal and form potentially damaging deposits. When the level of varnish precursors in a lubricant is at (or near) the fluid's saturation point, varnishing in cooler regions is very likely to occur.



2. Varnish formation cycle is summarized in three steps

The varnish cycle

The typical varnish formation cycle in a gas turbine involves these three steps (Fig 2):

1. Oxidation is a *chemical reaction* between the lubricant base stock and oxygen present in the air surrounding it. Oxidation is unavoidable and begins to take place the instant that a new fluid is exposed to air for the first time, regardless of whether or not the fluid is put into service. Like all other chemical reactions, the rate of oxidation is bound by the Arrhenius equation, which states that the rate of reaction will double for every 10-deg-C (18 deg F) increase in temperature.

Once a new fluid is put in service, it is exposed to higher temperatures and experiences a concomitant increase in the rate at which it oxidizes. Even when operating temperatures are a typical 125F, bearings may reach temperatures in excess of 300F; the rate of oxidation at the bearing in this instance will be more than 1000 times greater than that in the cooler regions of the system. As a result, oxidation typically occurs wherever hot spots are found.

Oxidation products build up in the lubricant over time, but remain dissolved at operating temperatures unless they exceed the fluid's saturation point.

2. As the oil moves from hotter regions within the system to cooler ones (hydraulic lines supplying high-pressure oil to engine geometry control, for instance), the fluid temperature falls and the solubility of any varnish precursors present decreases. These precursors begin to precipitate from solution in the form of particulates. Like water freezing to form ice, this precipitation of varnish is a *physical change* and not a chemical reaction.
3. Once formed, varnish particles agglomerate and form deposits, preferentially coating metal surfaces. These deposits are often the cause of unit trips or fail-to-start conditions. Like precipitation in Step 2 above, agglomeration and deposition are *physical changes.*

This model of varnish formation is widely accepted and reasonably well understood. Less well-understood is the fact that once varnish deposits form, they can be reabsorbed, if the solvency of the lubricant is increased. While the chemical changes that lead to the formation of varnish precursors (Step 1) are irreversible, the physical changes (Steps 2 and 3) which lead to the formation of varnish deposits are reversible. Successful varnish mitigation strategies use this fact to their advantage.

Testing for varnish

As a result of the potential for costly turbine downtime associated with varnishing, it is imperative that a lubricant's propensity to form varnish deposits be determined. Most turbine users test their lubricants for varnish potential using widely adopted techniques including QSA® (quantitative spectrophotometric analysis) and the standardized test MPC (membrane patch colorimetry, ASTM 7843). Proprietary (non-standardized) varnish test methods are not recommended, as they are not widely used and cannot be readily corroborated. Other collaborative analyses, like patch weight, may be helpful in substantiating oil health.

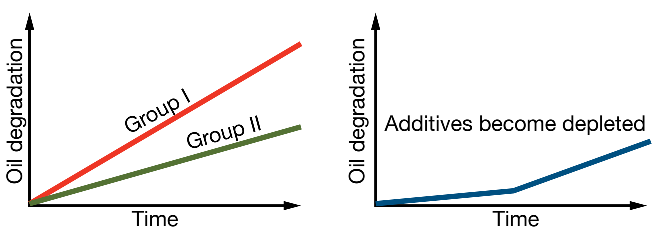
Both of the above varnish measurement methods can produce results which vary significantly depending upon the length of time during which the oil sample was "aged." Indeed, longer sample aging periods produce higher MPC values, suggesting that degradation of lubricants continues in the sample bottle. For this reason, the ASTM MPC method suggests all samples be incubated at room temperature for 72 hours after being heated to 140F for 24 hours. This well-defined and standardized aging time has provided inter-laboratory consistency and improved repeatability.

Increasing MPC and QSA values during sample aging occur as a result of the continuing propagation of oxidation reactions that were likely initiated when the lubricant was in service. Oils that continue to degrade in a sample bottle will also continue to degrade in a lubricant reservoir. This highlights the necessity of using varnish removal equipment on a continuous basis. In the absence of varnish removal equipment, lube-oil reservoirs with accumulations of dissolved break-down products can continue to form varnish when the turbine is not operating.

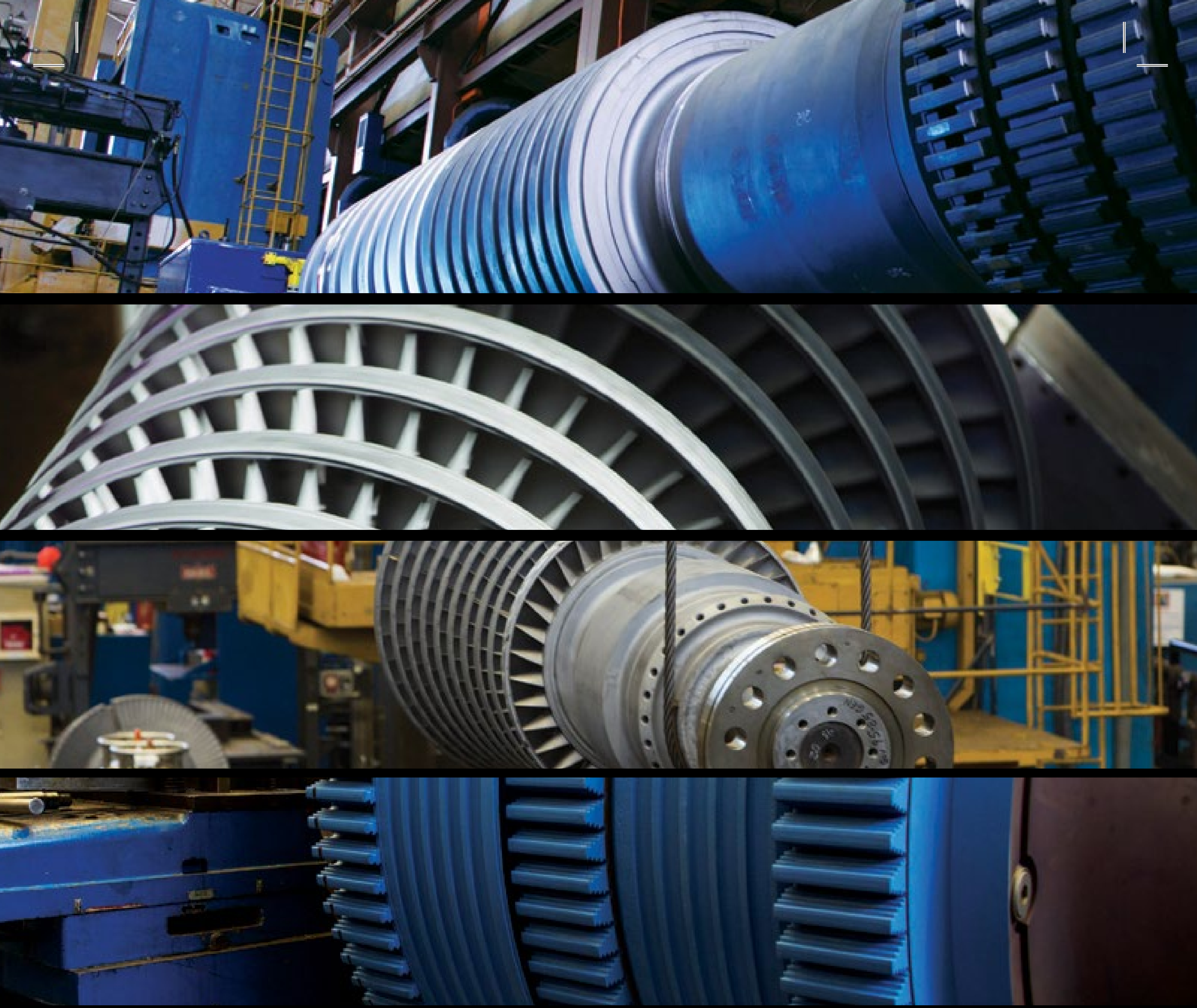
Strategies to combat varnishing

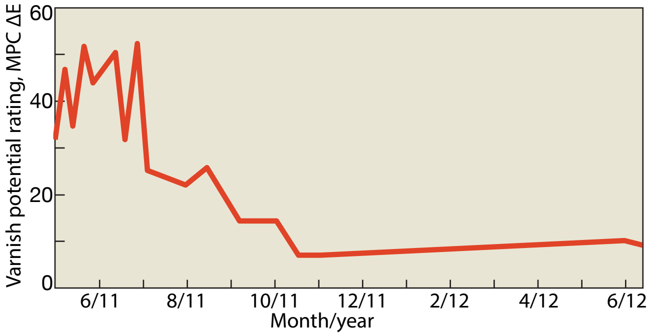
Most modern turbine lubricants are made with API (American Petroleum Institute) Group II mineral-oil base stocks, which contain an anti-oxidant additive package. The chemistry of Group II base stocks makes them more oxidatively stable than the traditional Group I base stocks that they generally have replaced in turbine-oil applications (Fig 3).

Anti-oxidants usually are added to the lubricant as a built-in varnish mitigation strategy. These additives generally are comprised of two classes of chemicals: phenols and amines. Although both have anti-oxidant



3. API Group II base stocks generally are more oxidatively stable and degrade at a slower rate than Group I base stocks (left). Anti-oxidant additives reduce the rate of oxidative degradation in a base stock until they are consumed (right)





4. Varnish potential decreases over time following SVR installation. Multiple data points are required to make a proper assessment

activity on their own, they function more efficiently in concert with one another. While the specific identities and amounts of the anti-oxidants employed varies with different lubricant formulations, the mechanism by which they enhance fluid lifetime remains the same.

These chemical additives are sacrificial and will oxidize more readily than the lube-oil base stock. As a result, the oxidation rate of the oil itself is decreased, while anti-oxidants are present. Unfortunately, both phenols and amines become consumed as they oxidize; the phenols tend to deplete more quickly. Once the additives are consumed, the rate of fluid degradation accelerates, returning to that of the non-additized base stock (Fig 3). Anti-oxidants limit the rate of oxidative degradation and, therefore, delay varnishing, but they cannot prevent it.

Since anti-oxidant levels deplete continuously, it is important to monitor them to ensure that your lubricant is protected from excessive degradation. Methods for monitoring additive depletion include voltammetry (RULER testing ASTM 6971), Fourier transform infrared (FTIR) spectroscopy, and high-pressure liquid chromatography (HPLC). Regardless of the monitoring method employed, the fluid should be replaced when all anti-oxidant additives have been consumed.

While the anti-oxidant additives included in most turbine-oil formulations are an essential tool in the fight against varnish, as noted above, they can only limit oxidative degradation, not prevent it. When the lubricant inevitably oxidizes and varnish precursors are formed, varnish removal systems are necessary to prevent degradation products from accumulating to the point where varnishing occurs. There are two main types of varnish removal systems: those based upon the removal of suspended (insoluble) particles and those based upon the removal of soluble varnish and its precursors.

Suspended-particle removal systems. Depth filtration, Balanced Charge Agglomeration™, electrostatic oil cleaning, or combinations of these techniques are advanced forms of particulate removal. These techniques remove fine particulates that are suspended within the fluid, including insoluble varnish particles. As particulate removal technologies, these systems must wait for insoluble varnish particles to form before they can be of value.

Since solvency decreases at lower temperatures (favoring the formation of insolubles), the maximum benefit obtained using these systems is achieved when the turbine is not operating and the lubricant is at ambient temperatures. Suspended particle removal systems are, therefore, of more use when employed periodically, during outages; they are less effective when used continuously during turbine operation. When used in the manner described above, these systems are incapable of removing soluble varnish and its precursors.

In an effort to overcome this limitation and enable continuous use, oil coolers can be used on the inlets of these systems to accelerate the varnish formation cycle and precipitate insolubles from the lubricant immediately before it passes through the varnish removal system. This form of varnish removal is referred to as "temperature-induced varnish removal."

However, the magnitude by which the oil can be cooled is limited: Cool oil is more viscous and difficult to pass through the particle removal systems. Because of this limitation, the oil cannot be cooled to the temperatures required for complete removal of all of the soluble varnish present. Result: The lubricant's solvency is never improved to the point where varnish deposits already present elsewhere in the system can be re-dissolved into the fluid.

Moreover, the soluble varnish and soluble varnish precursors, which cannot be removed from the fluid, return to the turbine where they may plate out on metal surfaces. As more varnish is deposited, the lubricant becomes perpetually saturated and further varnish removal is impaired. As varnish continues to build up, the suspended particle removal system often will be unable to keep up.

Soluble varnish removal (SVR™) systems use specialized Ion Charge Bonding (ICB™) ion-exchange resins that contain billions of polar sites capable of adsorbing soluble varnish and its precursors. This adsorption relies on a preferential molecular interaction between the polar varnish molecules and the polar sites present within the resin. Just as polar varnish prefers to coat polar metal surfaces, so too it prefers to adsorb on the polar sites of the ICB resin.

Conventional ion-exchange resins function by exchanging one chemical for another. Unlike these resins, which exchange one contaminant for another, ICB resins are engineered to adsorb the entire contaminant without returning any others to the fluid.

A key benefit of the ICB adsorption principle is that harmful oxidation products can be removed at any operating temperature, meaning that SVR systems can be used continuously. The continuous removal of soluble varnish and its precursors ensures that degradation products do not accumulate in the lubricant, eliminating the risk of varnish formation during normal turbine shut down cycles. Moreover, the continuous removal of soluble varnish produces a lubricant with extremely high solvency.

Since the *physical changes* that resulted in the formation of insoluble varnish particles and deposits are reversible, the high solvency of the SVR-treated lubricant forces insoluble varnish already present on turbine surfaces back into the soluble varnish form where they can be adsorbed and removed. With all the remaining oxidation byproducts removed, the varnish formation cycle is completely stopped.

Fig 4 illustrates the usual trend in MPC values for one year following the installation of an SVR system. There are two distinct phases in this example. The first is the "restoration" or "clean-up" phase. The second is the "stability phase." As SVR treatment is initiated and the restoration phase begins, the MPC value increases initially. For many users, an initial increase in the fluid's varnish potential following the installation of an SVR is concerning; however, such an increase is typical and, indeed, demonstrates that the SVR is accomplishing its goal.

As previously insoluble varnish deposits are cleaned by the lubricant, which now has the solvency required to return them to the soluble state, the level of soluble varnish increases

resulting in higher MPC measurements. This restoration phase typically lasts for three or four months, but longer durations are possible, depending upon the level of contamination present.

When a system is relatively clean and contains few or no varnish deposits, the fluid's varnish potential begins to drop immediately following SVR use. Once MPC values decrease below 10, the lubricant enters the stability phase. In this state, the oil contains minimal levels of oxidation products/varnish precursors and has a high solvency. Turbine operation under these conditions is ideal, as the high lubricant solvency and low concentrations of soluble varnish precursors prevent varnish from forming under the variable operating temperature and pressures conditions employed in most turbines.

Soluble varnish removal

Varnish particles and deposits are created from reversible *physical changes* that begin with soluble oxidation products and end with insoluble deposits. For these changes to be reversible, the chemistry of the deposits has to be similar to the chemistry of the lubricant from which the deposits originated. Normally, once fluid solvency has been increased (by removing soluble varnish at normal operating temperature), deposits will simply dissolve back into the fluid and be removed.

However, when one lubricant is replaced by another type, it can impair the ability of deposits or remaining varnish particles to return to their soluble form. An immediate oil change can, therefore, result in significant amounts of varnish being left on turbine surfaces. For this reason, old reservoirs should be cleaned prior to oil changes. The ICB process can be used to restore fluid solvency, allowing deposits created by the lubricant to return to their soluble form and be removed. In this manner, the reservoir can be cleaned and readied for new oil without ever having to drain it.CCJ

About the EPT authors
Peter Dufresne Jr, (pdufresne@cleanoil.com), director, and his father, Peter Sr, have championed the use of resin-based technology for lubricant purification for years. Matthew G Hobbs (mhobbs@cleanoil.com), senior chemist, has a PhD in synthetic chemistry. Prior to joining EPT, he was GM of a national oil analysis laboratory. Glen MacInnis (gmacinnis@cleanoil.com) has a master's of science in chemistry and previously managed R&D at EPT.

CCUG

2014 Annual Conference

August 11-13
Westin Riverwalk
San Antonio, Tex

A relaxing venue for open and meaningful discussion on topics of importance to combined-cycle owners and operators

Conference program features in-depth presentations and open discussion forums on the following subjects, among others:

◆ Cycle chemistry ◆ Leadership/management ◆ HRSG drains issues and mods/upgrades ◆ NERC lessons learned ◆ Generators and transformers ◆ HP and RHR valve issues and repairs ◆ Plant safety ◆ Fast-start/fast-ramp experience ◆ Attemperator leakage and failure prevention ◆ Predictive maintenance ◆ Inlet air filtration ◆ Impacts of cycling/load swings on equipment and associated costs ◆ Workforce challenges ◆ Knowledge sharing and training ◆ Plant benchmarking and lessons learned ◆ New technologies ◆ Ageing equipment: the role of operators and technicians

Plus, presentation of the 2014 *Professional Achievement Awards* to leading individuals for significant contributions to combined-cycle technology, design, construction, and/or O&M. Nominations accepted online until April 1 at www.ccusers.org.

CCUG
COMBINED CYCLE USERS GROUP
An independent user organization

Details on program topics, awards nominations, sponsorship opportunities, registration, etc., are at www.ccusers.org.

Questions? Please contact Sheila Vashi, conference manager, at SV.EventMgt@gmail.com.

Online forum hosted at http//ccug.users-groups.com

PD, common in air-cooled stator windings, is not well understood at the plant level

By Donald Selkirk, PE, SaskPower

According to IEEE Standard 100, partial discharge (PD) is "An electric discharge which only partially bridges the insulation between conductors, and which may or may not occur adjacent to a conductor." IEEE 100 goes on to say "Partial discharges occur when the local electric-field intensity exceeds the dielectric strength of the dielectric involved, resulting in local ionization and breakdown."

In simpler terms, PD is an electrical discharge or spark that occurs within a high-voltage insulation system. The discharge bridges only part of the gap between two energized surfaces, or an energized surface and ground, thus it is only a *partial* discharge.

While lightning is not a form of PD, comparing the two phenomena can shed some light on PD. For a lightning strike to occur, there has to be a voltage differential between the clouds and the earth large enough to breakdown the dielectric—in this case, the air between the clouds and the earth. When the voltage becomes large enough, it ionizes the air, forcing the air molecules to release electrons. These electrons then move, en masse, in the direction dictated by the voltage. This net movement of negatively charged electrons is, by definition, a current flow, which is seen as a lightning strike.

The lightning metaphor breaks down in one respect; a lightning strike is not a *partial discharge* because it completely bridges the gap between the two conductors (the clouds and the ground). In order to restore the value of the lightning example and make it more like PD, imagine these two things:

- The cloud-to-ground voltage never gets high enough to ionize normal air. In this manner our *normal* air becomes like the generator's insulation system.
- There is a small bubble of unusual air in the atmosphere that is more easily ionized than normal air and therefore has a lower dielectric strength than the normal air. This bubble is like a flaw in a generator's insulation system. Then imagine that if a significant voltage were applied to the unusual bubble of air, you might get a small lightning bolt within the bubble. This is a partial discharge.

How does PD occur in a stator winding?

In a generator stator winding, voids occur when there is a small air pocket within the insulation system. The dielectric strength of solid insulation can be as much as 100 times greater than air. As one would expect, manufacturers of electric machinery and equipment go to great lengths to avoid this problem.

Unfortunately there is no such thing as a perfect insulation system. Air pockets can result from defects in the manufacturing process, mechanical damage to the insulation (often caused during bar installation), contamination, insulation system delamination, and ageing. PD activity in insulation voids often occurs within the slot portion of the stator winding, because the energized copper conductor is very close to the grounded stator core. This type of PD is commonly referred to as "slot PD."

PD activity also can occur in other locations, like in the end winding, where bars of significantly different voltages are too close together. Another common PD location is at the exit of the stator-core slots, if voltage grading is not properly applied.

What's the difference between PD and corona?

In the industry, the terms PD and corona are commonly used interchangeably; however, this is not correct. Both corona and PD are electrical discharges that occur in high-voltage equipment when the strength of the applied electric field is great enough to cause ionization. But the IEEE Standards define corona as "A luminous discharge due to ionization of the air surrounding a conductor caused by a voltage gradient exceeding a certain critical value."

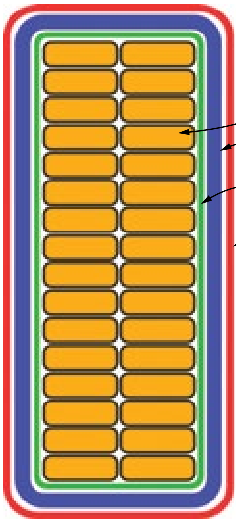
PD is not necessarily luminous or visible. Further, PD may not occur adjacent to an energized conductor and need not occur in air or gas. Additionally, a corona discharge may bridge the entire gap between energized conductors; PD is a localized phenomenon.

What is the difference between PD and vibration sparking?

The term "spark erosion" (SE) must be used with caution: Most often it refers strictly to vibration sparking; occasionally to both vibration sparking and PD. This article uses SE to refer to vibration sparking.

Before proceeding with an analysis of vibration sparking, some background information is in order. When modern mica ground-wall generator bars are constructed, copper strands are Roebeled together to form the bar (Fig 1). Note that Roebel transposi-

1. Copper strands are Roebeled together to form modern mica ground-wall generator bars tion is a process for making stator bars in which the individual conductors that make up the bar are twisted together such that each individual conductor occupies every position within the bar at least once. This is done to reduce circulating currents within the bar.



2. Stator bar cross section shows inner and outer corona protection

The bar usually is wound with a layer of semi-conductive tape to provide inner corona protection. Mica-based, ground-wall tape then is applied. This tape creates a wall between the energized bar copper and the grounded stator core and frame. A second layer of semi-conductive tape is applied on top of the ground wall to provide outer corona protection.

In the end region of the bar, near the slot exit, a voltage grading tape is applied in order to reduce the electrical-stress gradient at the end of the slot grounding tape in the end winding near the slot exit (Fig 2). The outer corona protection provides a path to ground for any charge that builds up on the surface of the bar and thus, by design, current flows through this layer from the surface of the bar into the stator core.

Vibration sparking occurs when the current in the outer corona protection layer, flowing into the stator core, is interrupted because movement of the stator bar open-circuits the current path. This phenomenon is similar to the sparking that occurs when an electrical contact that is carrying current opens.

Vibration sparking only can occur when the stator bars are vibrating, such that there is relative movement between the stator bars and the stator core. Further, stator-bar vibration also can abrade the ground wall to the extent that a ground fault occurs. Given that the resistance of the outer corona protection is not less than 300 to 2000 ohms per square, the sparking damage should be prevented.

Damage caused by PD versus vibration sparking

Generally speaking, PD deterioration of mica-based ground-wall insulation in the slot is a very slow process. Even a stator winding suffering from severe PD may last many decades before a rewind is necessary (provided that ozone levels are not beyond acceptable limits).

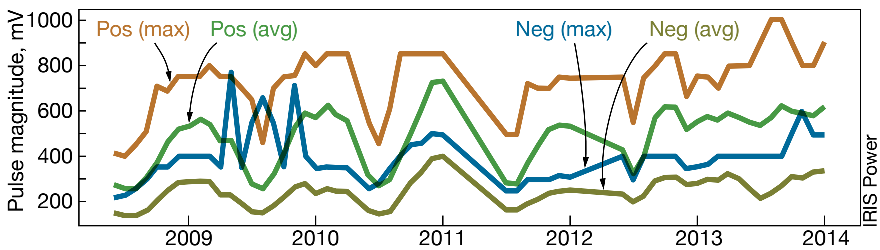
Vibration sparking is much more serious and has been known to cause winding failure in as little as three years. But, if the stator bars are kept tight in the slots, vibration sparking cannot occur.

If a generator is suffering from severe PD—to the extent the packing material that keeps the bar tight in the slot deteriorates—bar vibration could begin. PD also deteriorates the outer corona protection, which causes an increase in its resistance, which would resist the flow of current and, one might assume, reduce the severity of sparking. However, this has not been the case. Industry experience shows that PD and vibration sparking seem to grow together. In any case, it is best to ensure that a machine suffering from PD is kept securely wedged so that bar vibration cannot begin.

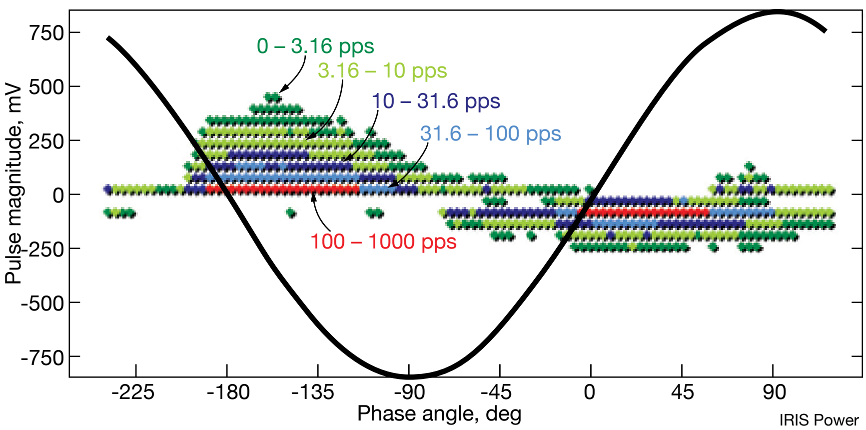
How to detect PD and vibration sparking

When diagnosing vibration sparking versus PD, it can be difficult to ascertain whether one phenomenon, or the other, or both are taking place. It should be noted that PD can only occur on the high-voltage bars in the winding, but vibration sparking can take place at any voltage, including neutral.

There are several ways to detect PD. They can be broken down into two primary groups: online and offline detection. Online PD detection is done either by using a radio-frequency current transformer (RFCT) to measure electromagnetic interference (EMI) or by measuring and analyzing the PD voltage pulses (referred to as PD detection). Both systems have been in use for decades.



3. Two-dimensional trend plot gives plant personnel a general indication of the level of PD in a stator winding



4. Three-dimensional plots can provide the user with information on the nature of the PD in the stator winding

Electromagnetic Interference Method. EMI is generated as a byproduct of energy conversion from power frequency to radio frequencies at the site of an electrical defect. EMI data are collected by applying an RFCT to the generator-neutral lead or to the generator-frame ground.

EMI monitoring can provide information on PD within a stator winding as well as condition-based information on the stator, rotor, bearings, oil seals, exciter, bus, and associated electrical systems. Potential drawbacks to EMI monitoring with an RFCT are that specialists are required to perform the data collection and analysis. Also the equipment is installed temporarily, so long-term data logging is not possible.

PD Detection Method. Online PD detection via pulse measurement is done by installing capacitive coupling devices in or near the generator. These devices filter pulses into PD monitoring equipment. PD detection is concerned with these four characteristics:

- Magnitude, which relates to the size of the insulation voids.
- Pulse count, which relates to the number of insulation voids.
- Polarity, which relates to the location of the voids within the insulation system.
- Position relative to the phase-to-ground voltage, which relates to whether the PD activity is driven by phase-to-ground or phase-to-phase voltage.

PD detection can provide simple, two-dimensional PD monitoring and data logging accessible to plant personnel, or three-dimensional PD monitoring done by trained technicians using specialized equipment. The former delivers PD pulse-height analysis plots, which provide plant personnel with a general indication of the level of PD in the stator winding, and data trending that indicates whether any changes have taken place in the amount of PD in the winding (Fig 3).

Three-dimensional PD monitoring delivers pulse-height analysis plots and phase-resolved plots of stator winding PD activity and can provide the user with a great deal of information about the nature of the PD in the stator winding (Fig 4). It also can provide information on the location of the PD (slot, end winding), relative size of the worst insulation defects, quantity of insulation defects, and whether the PD may be related to vibration sparking.

The advantages of PD monitoring are that a permanent installation provides continuous two-dimensional data logging and the ability to do more in-depth, three-dimensional data logging without taking the unit out of service. In addition, PD analyses via voltage pulse measurements have a longer track record in the industry. The disadvantages include the need to take equipment offline to install and calibrate the system and not having the ability to monitor other conditions.

Whether using EMI detection or the traditional PD voltage pulse monitoring, online monitoring provides only an indication of the health of the insulation system—not an absolute measurement of remaining life. Further, the most valuable PD data are historical data for the machine of interest.

Therefore, it is best to start PD monitoring programs early to have good data available for comparison purposes. Offline testing and visual inspections are strongly recommended when online testing indicates a developing problem.

Ozone resulting from PD

Ozone is created by electrical discharges in air. It exists naturally in the upper atmosphere, where it helps block harmful UV radiation from the sun. Low levels of ozone also exist naturally at ground level, in concentrations of 0.020 to 0.035 ppm.

Ozone is created by PD in generators, too. This is a problem because it is dangerous to humans even at low concentrations. And, levels of ozone in powerplants can be quite high (sidebar). In one case, ozone production at a 225-MW powerplant was so high that a blue haze could be seen in the generator room. Measurements taken inside the generator enclosure showed steady-state concentrations of 40 ppm of ozone—400 times the OHSA limit for an eight-hour time-weighted average.

To solve the immediate problem, air in the enclosure was circulated through a carbon filter, which reduced the level to 2 ppm. A visual inspection of the machine showed widespread deterioration of the slot's outer corona protection and substantial corrosion of ferrous parts and rubber components, confirming significant levels of PD.

Since research has shown that ozone levels directly correspond to PD levels, testing for ozone is a good indicator of PD, but it must be done properly. Review the path of the cool-

Ozone exposure

OSHA regulates ozone in the workplace based on the following time-weighted averages:

- 0.2 ppm for no more than two hours exposure.
- 0.1 ppm for eight hours per day of exposure doing light work.
- 0.08 ppm for eight hours per day of exposure doing moderate work.
- 0.05 ppm for eight hours per day of exposure doing heavy work.

Ozone at ground level can decrease lung function, aggravate asthma, cause throat irritation and coughing, chest pain and shortness of breath, inflammation of the lung tissue, and higher susceptibility to respiratory infection. Ground-level ozone is one of the five major air pollutants that the EPA uses to calculate the Air Quality Index.

ing air and accessibility when determining locations for measurement. The objective is to take air samples as close as possible to the source of discharge.

Ozone levels of 0.020 to 0.035 ppm, the range of normal ground-level concentrations, indicate no PD. Levels of 0.030 to 0.040 ppm would be considered moderate; 0.060 to 0.090 ppm, high. As is the case with online PD monitoring, being able to compare ozone levels over time is the most valuable approach, so it is best to start ozone monitoring programs early.

Long-term effects of PD

Besides the production of ozone, the long-term effects of PD include the (1) possibility that it may morph into vibration sparking and (2) continued decay of the outer corona protection in the slot and in portions on the end winding.

As discussed above, vibration sparking is a dangerous condition that can abrade the ground-wall insulation and cause a ground fault between the stator core and the energized stator bar. Typically, utility generators are high-resistance-grounded, meaning that a current-limiting resistor is installed between the generator neutral and ground. This circuit will limit current to the range of 3 to 10 amps. In the case of a single line-to-ground fault (SLG), the current path for the fault current is from the stator bar, into the stator core to ground, through the neutral-grounding resistor (NGR), back through the winding, and to the source of the fault.

The presence of the resistor limits current to a very low value, so damage to the stator core is highly unlikely. If the voltage across the NGR is high enough, ground-fault protection will operate and trip the prime-mover fuel supply and generator excitation. The greater worry is the possibility of a second ground fault occurring before the protection operates.

If vibration sparking is widespread throughout the machine, then much of the ground-wall insulation may have deteriorated. When the first ground fault occurs, current flow through the NGR causes a voltage drop across the NGR. This, in turn, causes the neutral voltage to rise from zero to the line-to-ground voltage.

The increase in neutral voltage elevates the phase voltages from line-to-ground to line-to-line values. The deteriorated ground-wall insulation is now exposed to a higher voltage and is very likely to experience a second failure. Further, because the common ground-fault protection reacts to the voltage across the NGR (or in some cases, current flow through the NGR), it will not react to a ground fault very near the neutral; the fault does not create enough voltage across the NGR to cause the protection to operate. So, there may already be an existing ground fault.

If two ground faults occur almost

simultaneously, either because one fault already existed or because the elevated voltage punctures another weak location in the insulation, there is now a double line-to-ground fault (DLG). In the case of a DLG fault, the presence of two faults short circuits the NGR and the current flow through the fault is limited only by the resistance of the faults and the stator core. This resistance is typically very low and can easily result in tens of thousands of amps of current flow. Result: Substantial damage to the stator winding and core, which will almost certainly result in the need to rewind the machine and restack the core. The rotor may be affected as well.

At minimum, generator owners should confirm correct settings and operation of existing ground-fault protection and may also wish to consider the addition of a ground-fault protection scheme that provides 100% winding protection.

Unfortunately there is very little that can be done to eliminate PD in the stator slots short of a rewind. Options that often are considered are the injection of conductive silicon to restore the outer corona protection and reversal of the generator neutral and high-voltage terminals. Injection of conductive silicon is often rejected because it is very difficult to remove should a future rewind be necessary. Also, increased heating is likely to occur because the silicon can block the ventilation ducts in the stator core.

It is possible that if PD is occurring only in a few localized areas, and those areas can be located by testing (ozone, corona probe, lights-out test), that a local injection of conductive silicon would both eliminate the PD and not cause the problems associated with widespread silicon injection.

Reversal of the high-voltage and neutral ends of the machine is another option, but involves reconfiguring the high-voltage and neutral terminals. The advantage is that the high-voltage bars, where PD has damaged the semiconductor, become the low-voltage bars, where PD doesn't occur. Therefore, the low-voltage bars, undamaged by PD, become the high-voltage bars. This solution is commonly considered but rarely implemented because of the cost and complexity of reconfiguring the generator.

Corona in the end windings often can be cleaned up and repaired by painting on new outer corona protection. In many cases these repairs result in a reduction in PD level when the machine is returned to service. But when the repairs no longer result in a PD reduction, it may mean that slot PD has become the dominant source. CCJ

Problems experienced with modern generators

By Clyde V Maughan, Maughan Generator Consultants

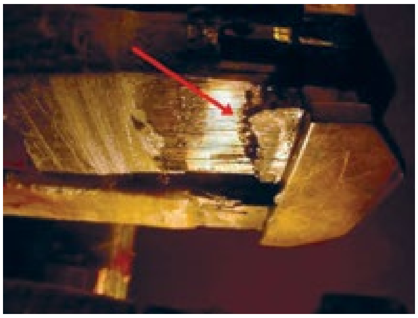
The generation sector of the electric-power industry has undergone many changes in its 100+ year history, both in technologies and in government influences. Relative to generator technology, for example, the evolution of cooling methods has included (1) open-flow air cooling, (2) closed-flow air with coolers, (3) hydrogen-atmosphere cooling, and (4) direct hydrogen and/or water cooling.

Because power generation is resource-intensive and covers large geographic areas, government involvement in the industry was inevitable. Nevertheless, for many years the market was controlled, to some extent, by the original equipment manufacturers. Profit margins were generous and generator OEMs had the resources to make quantum leaps in rating and design sophistication while generally producing a quality product.

In the early 1970s, government began forcing the industry in the direction of increasing competition. The cost pressures associated with this transition have had significant negative impacts regarding generators, including: (1) Increasingly lower quality of new machines and (2) increasingly lower capability of technical support for addressing the inevitably high rates of in-service problems.

Quality has suffered as new designs pushed duties to higher and uncharted levels and as these designs incorporated less costly materials and procedures to allow faster manufacturing. Technical capability has suffered as OEMs have greatly reduced the number of engineers in their organizations and as institutional knowledge has been lost to retirements.

The industry impact associated with quality issues has been profound, and appears increasingly so. The goal of this article, which is based in part on a presentation by the author at the 2013 Conference of the Combined Cycle Users Group, is to help owner/operators better understand some of the major technical and business issues concerning generators today.



1. Broken bar was caused by absence of series blocking on an endwinding

2. Several inches of copper burned away on a stator bar as a result of endwinding resonance

3, 4. Vibration sparking is a fast-acting destructive phenomenon as evidenced by bar damage at left and side-packing damage at right

Premature failures

Historically, utility-size generators were made with considerable margin in load capability. But with powerful computers and increased competition providing both the capability and motivation, the latest generator designs have increased mechanical, electrical, and thermal duties to the point where little margin remains.

Generators rarely exceed specification parameters today. The result is a fleet of machines that increasingly requires major maintenance long before the historic target of 30 years for stator windings and 20 years for field windings. Examples are cited below.

Stator endwinding vibration has been an ongoing issue for large generators. Problems have been exacerbated as engineers designed to accommodate higher vibration driving forces while simplifying support systems. A case in point is the elimination of series blocking on the endwinding in Fig 1, which caused the broken bar in the photo. Local endwinding resonance resulted in the failure shown in Fig 2.

Protection against such failures probably is best obtained by being sure a thorough bump test is performed on new and reworked windings. Resonant values should be outside the 115-140-Hz range (for 60-Hz generators).

Stator-bar slot vibration. Large, indirectly cooled generators typically have many stator slots and tall, narrow bars. This design approach maximizes the area for transferring heat through the groundwall insulation. But it also may allow the tall, narrow bar to vibrate sideways in the slot, probably driven by core vibration. Such vibration causes vibration sparking, a fast-acting destructive phenomenon (Figs 3, 4).

Designers believed side filler would prevent side vibration. However, packing of incremental thickness cannot fully fill a continuously varying space, and vibration can occur. If deterioration is significant, corrective action probably requires a rewind to remove the fatally degraded bars and allow installation of side pressure springs.

Dry endwinding support ties. The integrity of endwinding support systems on some generator designs relies heavily on bonding of the ties to the support structure, connection rings, and stator bars. Some OEMs have used a *wet* tie to make this bond as strong as possible. For cost

5, 6. Dry ties generally have not performed well in endwinding support systems. At left is dust generated where ties have failed; at right, bare copper is exposed from wear associated with dry ties

and simplification reasons, a changeover was made to *dry* ties, which have not performed well and have led to numerous problems (Figs 5, 6).

Note that *wet* means the glass for making the tie is drawn through a resin of high bonding strength as the tie is being made; *dry* means the glass is pre-impregnated with a resin that is dried, slightly cured, to allow for ease of application.

Experience indicates that after a few years of operation with dry ties, heavy insulation wear may be in evidence at several locations, leaving significant exposure to an extremely damaging phase-to-phase fault. The scope of repair depends on the amount of damage. If the insulation is intact, simply replacing the dry ties with wet ties may be all that's necessary. Were a phase-to-phase fault to occur, stator and field rewinds along with extensive cleaning are likely to be required, and in worst case, replacement of the generator might be necessary.

To learn more about dry ties and the problems associated with them, read "Generator inspection first step in avoiding failures attributed to dry stator-winding ties," p 28.

Bolted connections have been used in the electric-power industry since its infancy. Safely carrying current through a bolted joint requires two primary conditions: clean non-oxidized surfaces and high local contact pressure. Meeting these two conditions for high-current applications is something of an art, one dependent upon passing known skills down from generation to generation of skilled personnel. If this knowledge is lost, the result can be joints that begin to destructively overheat (Fig 7).

A joint similar to one shown in Fig 8 was made up with bolts of stainless steel, which has a propensity to gall. In this case, the nut-to-bolt galling absorbed the torque of the wrench and left some bolts loose, but with apparent proper torque. The result was joint failure, massive arcing, extensive contamination, and a stator and field rewind—plus weeks of frame, cooler, and core


MITSUBISHI HITACHI POWER SYSTEMS
Pulling Ahead
as ONE

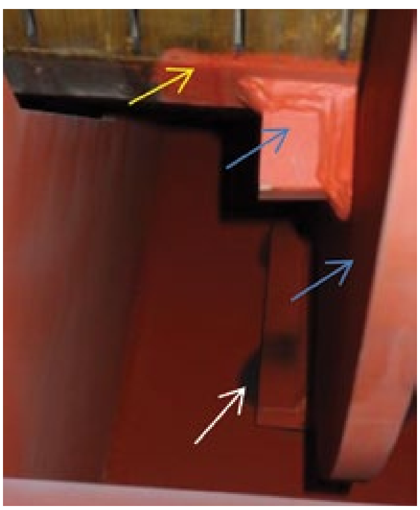
7, 8. Bolted connections improperly made can destructively overheat. Failing flexible lead above connected an HV bushing to isophase bus; HV joint failure at right was caused by loose bolting

cleaning.

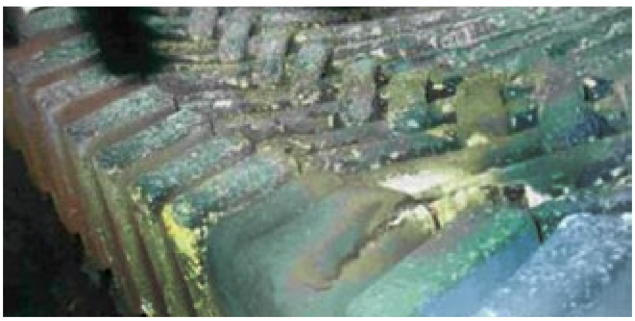
Prevention of bolted-joint problems involves being certain of the following:

- Connecting surfaces are properly plated.
- Surfaces are clean.
- Selected torque values are correct.
- The nut/bolt torque is not influenced by galling or other friction conditions.

Core/frame structure. On 2-pole generators, the core must be isolated from the frame by a flexible attachment. Otherwise the inevitable *vibration* of the core outside diameter, typically about 2 mils, may transmit intolerable



9, 10. Core-to-frame support structure at left is for the generator at right. Welded method of attachment without vibration isolators increases the susceptibility of the generator to frame and foundation cracking



11, 12. Inadequate clearances at phase-to-phase locations difficult to insulate are conducive to failed connections (left). At right is copper burning caused by a non-mica connection insulation failure

vibration and noise to the frame. While the term *vibration* is commonly used, the condition actually is deformation of the core caused by the magnetic pull of the field flux on the core.

The core-to-frame support structure for the Fig 10 generator is shown in Fig 9. The core (yellow arrow) is attached directly to the keybar/bore ring fabricated structure (blue arrows), which is welded directly to the frame outer wrapper (white arrow). This configuration eliminates the cost of isolation components, but leaves the generator vulnerable to noise levels approaching 116 dB(A), and the prospects of possible frame and foundation cracking. Operation may be acceptable if the noise levels can be tolerated and frame and/or foundation cracking do not occur. Otherwise, this condition may not be correctable without stator (or generator) replacement.

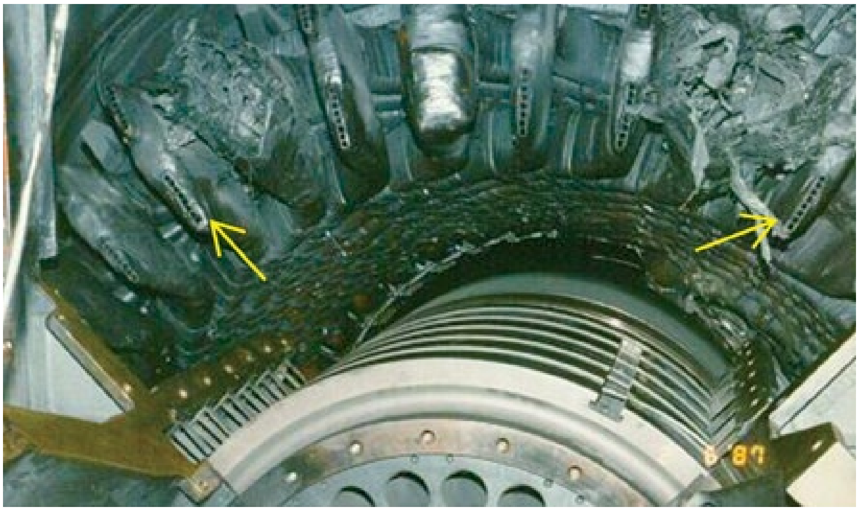
Series and phase connection insulation. These connections are difficult to insulate with mica tapes. Thus for many years, there has been widespread use of a much faster and lower-cost insulating method: A non-conducting box filled with non-mica potting compound.

This is perfectly adequate at the low voltage difference between series connections. But if air- gap clearances are less than about ⅜ in. at phase-to-phase locations, partial discharge can occur. Figs 11 and 12 were photographed at one such line-to-line phase break. Designers now typically use potting compound on the series connections, but insulate the phase connections with mica tapes.

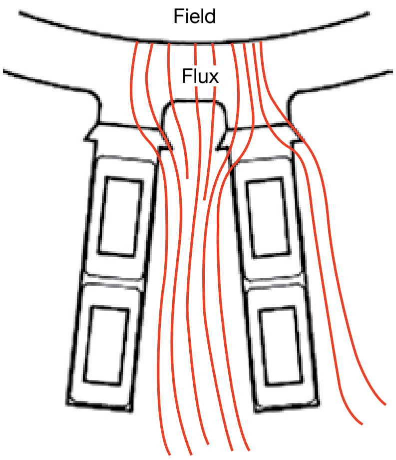
However, it is impossible to fully insulate the connections on direct-gas-cooled stator windings—because access for gas flow must be permitted. Numerous massive winding "ring-of-fire" failures have occurred on machines with heavily contaminated insulating surfaces and air gaps. Contamination that led to the failure in Fig 13 was the result of an arc from a broken bar or connection. For stators manufactured with bared conductor, your first line of defense against failure, and possibly the only one, is to assure no gross contamination occurs.

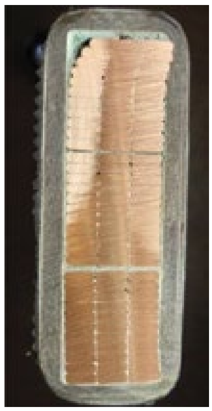
Global vacuum pressure impregnation. VPI of *individual* stator bars with asphalt began a century ago. Stator-bar VPI with thermoset resins started in about 1949 and has been used successfully to make high-quality stator windings since.

In the 1960s, global VPI was identified as a fast and inexpensive method of making a stator. The process involves putting the *entire* stator, wound with "dry" coil insulation, in a large VPI



13. Ring-of-fire failure occurred at this stator endwinding. Arrows identify typical bare-conductor locations





15. Where the top of the top bar in Fig 14 is deep in the slot, the air gap flux essentially all transfers into the iron; no flux cuts the copper and there is no side EMF on the bar (left)

16. If the bar is shallow in the slot, air-gap flux cuts the top strands of the top bar and displaces them (right)

tank, where it is impregnated in a single operation. GVPI was first used on motors and small generators. In the mid-1970s it became popular with some OEMs for making large generators—even ones rated more than 400 MVA. But these windings have been subject to some maintenance issues, including the following:

- Slot partial discharge and possibly vibration sparking, which seem to be related to a slip plane between bars and core.
- Difficulties in performing a rewind, which are related to the VPI process bonding stator bars into the slots. It is difficult-to-impossible, and time-consuming, to remove the winding to allow a rewind. Where a rewind is performed, the process is slow and the core is vulnerable to damage. On a GVPI generator, for quality and outage time considerations, stator replacement may be preferable to the rewind option.

Notwithstanding these limitations, because of the major advantages to GVPI, this process will remain popular for large generators.

Step-down at end of core. High design uprate of modern generators involves greater step-down of the iron at the ends of the core. Because this puts the top of the top bar above the core iron, there is high air-gap flux cutting the copper strands at the top of the top bar and a significant sideways electromagnetic force (EMF) on the top bar.

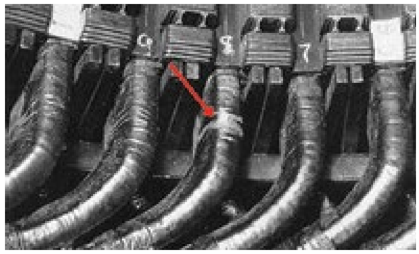
Apparently, this causes sideways vibration of the bars at the end of the core (Fig 14); however, this condition may be relatively benign, and placing side pressure springs on the side of the bar to apply force in the same direction as the EMF may stop the vibration.

But there is another, perhaps more important, concern. Back into the slot a foot or so from the core end, the top of the top bar is deep in the slot. At that depth, the air gap flux has essentially all transferred into the iron (Fig 15). No air gap flux is cutting the copper and thus there is no side EMF on the bar.

But in these new designs, the top of the top bar is above the core tooth iron (refer back to Fig 14). If the bar is shallow in the slot, as it is in hydro generators, there is air-gap flux cutting the top strands of the top bar and you can get the condition shown in Fig 16.

Thus there becomes the worry that

14. Side forces on the top bar likely caused the vibration that led to dusting



17. Modern thermoset windings prevent tape separation (so-called girth crack) identified with pre-1960 asphalt windings

18. Small coil-wound generators made with inappropriate asphalt material post-1970 reintroduced the failure mechanism illustrated in Fig 17. In photo, the remaining groundwall measured 20% of original thickness

19. Slot partial-discharge activity is in evidence on this modern air-cooled generator

this strand-movement phenomenon may occur on modern 2-pole stators—perhaps a greater worry because the top of the bar is completely out of the top of the slot and exposed to full (reduced) air gap flux and corresponding EMF. End-of-slot concerns are relatively new, and assistance of the OEM should be obtained for assessing the scope of possible problems and corrective options.

Tape migration on stator bars. This was a highly destructive deterioration mechanism on asphalt windings for pre-1960 generators rated more than about 40 MW (Fig 17). This condition was eliminated by use of thermoset windings. But the problem has recurred on post-1970 small (less than 20 MW) coil-wound generators that were made with an inappropriate asphalt material (Fig 18). The generator shown had been in service 20 years. The winding failed during a power factor test at line-to-neutral voltage. Repair of such a failure likely would involve a stator rewind.

High electrical stress on stator windings. Historically, the electrical stress across the stator-bar groundwall has increased very slowly over time. This is because electrical duty increases at about a ninth power of stress—volts/mil (vpm). On asphalt/mica windings, design stress was about 45 vpm.

For the polyester/mica systems introduced in the 1950s, stress was increased to around 54 vpm. With the introduction of epoxy/mica systems in the 1960s, stress initially went into the 60-65-vpm range; now designs above 80 vpm are being produced. Note that the increase from 65 to 80 vpm is large—650% (divide 80 by 65 and raise the result to the ninth power).

To date, generators rarely have failed because of electrical duty, but expect that as stress levels increase, pure electrical failures will appear.

There is another condition on generators that is less benign. Specifically, these increased stresses are no doubt related to the increase of partial discharge (PD) activity being seen on modern air-cooled generators (Fig 19). It is unlikely that PD activity will fail the winding, even after many years of service. But ozone generation can be high, and this alone may force a stator rewind.

Rotor problems

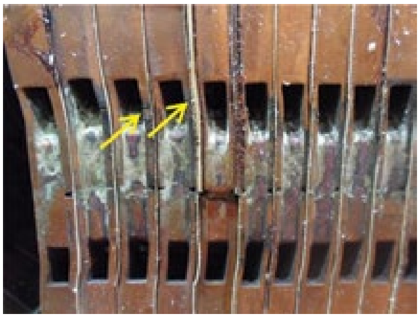
Problems with field windings—such as grounds, distortion of and shorts in turns and coils, migration of coils and slot and turn insulation, as well as broken turns and connections—continue to occur frequently, as they have for years. Interestingly, design margins in fields have not been impacted as greatly as those for stators, largely because fields never were engineered with much margin. But also, since copper's mechanical properties are inherently marginal, there has not been much opportunity for cost reduction and increase in duty on fields.

The design temperature of fields fortunately has been slow to evolve upward. High-temperature insulation materials are available, but copper has poor mechanical properties, even at room temperature—properties that degrade rapidly above about 265F.

Direct cooling has been the best uprate tool for fields: It reduces the average copper temperature, as well as hot-spot temperatures. However, direct cooling can bring problems when contaminated atmospheres are allowed to foul generator internals. Turn shorts sometimes are associated with cleanliness issues (Fig 20).

Complex and mechanically weak gas-entry locations are another chal-

20. Strand shorts in a direct-cooled field are caused by contaminants entrained in cooling air



21. Direct cooling presents challenges at coolant entry locations. Mechanical weakness combined with brazing in those areas is conducive to cracking of the copper

lenge presented by direct cooling. Brazing in those areas can make turns vulnerable to cracking of the copper (Fig 21) and winding failure.

Historically, field forgings generally have not been associated with catastrophic failures; less so today, because of improvements in the quality and consistency of forgings over the years. The primary remaining quality/cost issue on forgings remains the many 18/5 (18% manganese, 5% chromium) retaining rings still in service.

Recall that this alloy is vulnerable to stress corrosion in the presence of moisture; several have failed catastrophically in service. For generators still operating with 18/5 rings, it is vital that the rings not be exposed to water—in particular on the inside diameters of the rings.

About 25 years ago the replacement 18/18 alloy was developed for retaining rings. Although not subject to stress corrosion, it can crack in the presence of severe conditions—for example, an extremely aggressive atmosphere, torsional resonance, etc. One OEM recommends a ring inspection every 12 years; required tests can be conducted without removing the field.

The talent conundrum

Cost pressure undoubtedly is the primary cause of failures in modern generators. It has contributed to a reduction in design margin and has seriously reduced the capabilities of OEM design, manufacturing, and service organizations.

Generator issues also can be traced to the inability to effectively transfer lessons learned/best practices from experienced design and service engineers to new hires. Much of the knowledge on how to build and repair a generator is, in a real sense, *art*. Failure to pass on this know-how in an organized and effective manner repeatedly has led to the "reinvention" of old problems. The sections above having to do with dry ties and improperly made-up bolted joints clearly illustrate the point.

Given existing industry conditions, it simply is not possible to maintain the numbers of skilled engineers and technicians required to design, manufacture, and maintain generators to satisfy customer expectations. Budgets aside, there are other contributors to the loss of talent. Three come to mind:

- Power generation is no longer a "glamor" business for attracting the top talent demanded for design and manufacture of the complex generator.
- Today's design engineers are spread thin and it is difficult for an individual to become highly skilled in any one discipline.
- The advent of computer-aided design has reduced the "feel" for the machine that came from using a hand calculator and slide rule.

Impact of an inadequate RCA

Historically, diagnosis of new and complex generator failures was done by OEM factory engineers because accurate problem assessments can be aided significantly by a technical education background and by generator design experience. The staffing reductions noted earlier translate to fewer engineers with diagnostics capabilities being available for problem investigation and root-cause analysis.

RCAs of generator failures can be difficult. Consider the following:

- Generators are mechanically complex and generator operational theory is challenging. While the design and operation of most plant equipment are somewhat intuitively obvious to an experienced engineer, there is little about a generator that is obvious to even those with the best intuition.
- Generators can fail in many ways. Most plant personnel have heard an OEM engineer say, "We haven't had this kind of failure before." This typically is greeted with skepticism. However, there are so many ways a generator can fail, this comment may be accurate on occasion.
- Powerplant O&M personnel typically are much more familiar with gas and steam turbines, and I&C, than with generators and HV equipment.
- Generator failures often involve major destruction to the failure location because of burning and arcing damage. This may require that the root cause of failure be decided by implication.
- Even with the best generator monitoring instrumentation available today, plant records often shed little light on the failure root cause.

Misdiagnosis of the root cause of a generator failure can be exceptionally costly (tens of millions of dollars and perhaps in the 100s with loss of generation costs included), while leaving the machine vulnerable to a repeat of the same failure. Here are some recent experiences:

- A ring-of-fire stator winding failure on a 900-MW water-cooled winding was incorrectly attributed to the internal piping arrangement. Had the correct design error not been identified by further consultation, repeat of the massive stator winding failure would have been inevitable (refer back to Fig 13).
- A stator winding failure on a 200-

MW generator was incorrectly attributed to "lightning." Corrective action taken was based on this misdiagnosis. The unit failed again several months later at the same location for the same reason—partial discharge (refer back to Figs 11, 12).

- On a 250-MW generator, dust accumulation on a core end-package was believed caused by minor stator-bar vibration and no corrective action was taken. The root of the problem actually was local core looseness. A few weeks after return to service, the winding failed to ground: Stator-bar insulation wear was caused by pieces liberated from core laminations.
- Core discoloration at the location of stator winding failure was judged "insignificant" after inspection and a deficient ElCid test. This 80-MW stator was rewound without correcting the core-iron condition. Shortly after return to service, the new replacement winding failed: Core iron melted in the same location.
- An asphalt stator winding was incorrectly diagnosed as having "destructive migration of the groundwall" (refer back to Fig 17). An inexperienced OEM engineer and an inexperienced independent consultant each recommended immediate stator rewind to avoid "catastrophic service failure." Their recommendations were vacated by a more experienced engineer, and this stator winding continues to operate safely many years later.

Concluding observations

There are no easy answers to the dilemma of marginal equipment and inexperienced service personnel. Generally, a deficient design does not leave margin for modification to a lower-duty design, and there seems no ready solution to the problems relating to technical personnel limitations. Apparently, the current difficulties and challenges will remain until such time as owners transition from a first-cost to a lifecycle-cost mentality regarding equipment purchases.

Until that utopian condition arrives, generating-plant personnel might consider following the four initiatives below for dealing with generator challenges:

1. Monitor your generator with state-of-the-art instrumentation.
2. Maintain monitoring equipment in good operating condition.
3. Record and retain all information gathered by diagnostic instrumentation.
4. Should your generator suffer a failure, assure that the investigation and RCA are thorough and the information provided by the OEM and/or independent consultant is both plausible and reasonable. If not, quickly enlist additional technical support to prevent the loss of information and valuable time.

Consider that a "we don't know" conclusion by the investigative team is acceptable when the cause of the failure cannot be determined with a high degree of accuracy. As the bullet points immediately above attest, inaccurate conclusions can be very costly. **CCJ**

Clyde V Maughan is president of Maughan Generator Consultants, Schenectady, NY. He has more than 60 years of experience in the design, manufacture, inspection, failure root-cause diagnostics, and repair of generators rated up to 1400 MW from the leading suppliers in the US, Europe, and Japan. Maughan has been in private practice for the last 27 years. He spent the first 36 years of his professional career with General Electric Co.

Workshops critical to professional development

Open discussion sessions at 7F Users Group meetings are invaluable for keeping owner/operators informed about emerging issues, providing guidance on how to identify the onset of these problems, and suggesting action to take if you see something you were hoping not to find.

Workshop sessions, ranging from about an hour to half a day at the organization's annual conferences, afford attendees the opportunity to come up to speed on technologies that can help make them more effective in their daily activities. With the minuscule staffing at most plants today, it's difficult to find adequate time to expand your technical knowhow on the job. Take advantage of all the professional-development opportunities available to you at each user group meeting.

Last issue's 7F report focused on discussion session topics from the 2013 conference, this article summarizes a few of the important workshop sessions. The material presented is generally applicable to all combined-cycle plants, not just those with 7F engines.

Borescope clinic

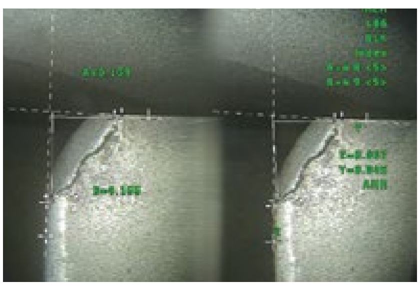
Mike Hoogsteden, field service manager for Advanced Turbine Support LLC, reminded 7F users that the intelligence gathered during periodic borescope inspections is critical to getting top performance from their engines. About half of the O&M personnel attending the 7F User Group's annual conference were first-timers and benefitted considerably from Hoogsteden's review of (1) what Advanced Turbine Support's inspectors are seeing in the field and (2) several important Technical Information Letters (TIL) released by the OEM for this fleet.

Hoogsteden began with a review of the latest borescope and nondestructive examination (NDE) tools available. They enable experienced technicians, with deep knowledge of the engine model being examined, to identify potential problems and evaluate the findings faster than previously possible. High-definition (Fig 1) and large field-of-view (Fig 2) are two attributes of modern top-of-the-line inspection equipment.

So-called stereo technology provides the borescope technician (1) a simple, accurate method of measuring linear dimensions in an image (Fig 3), (2) distance information between two points and a perpendicular line drawn to the line created by the two points, (3) the difference in height between points on two different surface planes, (4) a way to determine the surface area of a defect, and (5) the capability to measure the length of a non-linear defect or feature.

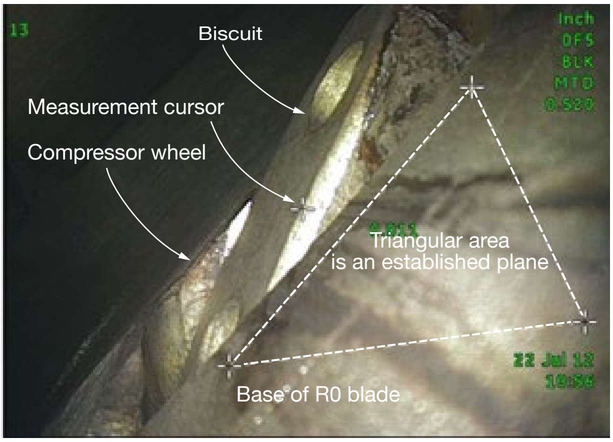
Hoogsteden next described 3D Phase Measurement (PM)—a new full-screen, on-demand optical measurement technology—as an "exciting breakthrough" for borescope inspections. He said it scans the part surface and creates a 3D map that allows tech-

1, 2. Clear, bright photos (left) and a large field of view (right) are produced by high-definition, top-of-the-line inspection equipment



3. Stereo technology allows fast, accurate measurements

4. Measurement of blade clearances is possible only with 3D PM



5. A simple machining step allows borescope access to the biscuit area for precise measurement of rotation

nicians to perform all measurements and views right on the 3D surface. This technology also allows technicians to determine turbine blade clearances (Fig 4).

Top technicians supported by state-of-the-art diagnostic equipment and the capability to perform some critical maintenance remotely (including the removal of protruding shims close to liberation, minor blending, etc) permit the plant manager to track concerns with confidence, thereby allowing cost-effective condition-based maintenance planning.

Be sure your stake is well done. TIL 1870R1 (Mar 5, 2013) requires owner/operators to check for first-row blade migration on F-class compressors that received an R0 re-installation between January 2008 and January 2013. Concern is that there may be insufficient interference between the stake marks and the blades, and that the airfoils may have moved forward. A small population of turbines reportedly has had migration events related to improper blade installation.

This technical information letter is a sequel to TIL 1796 (Apr 25, 2011) which required 7F owners to check for forward migration of R0 blades both visually and physically. The latter is defined a simple "lift and tug" on each blade (not a hard yank) to confirm axial restraint. Blades that do not pass this test must be restaked.

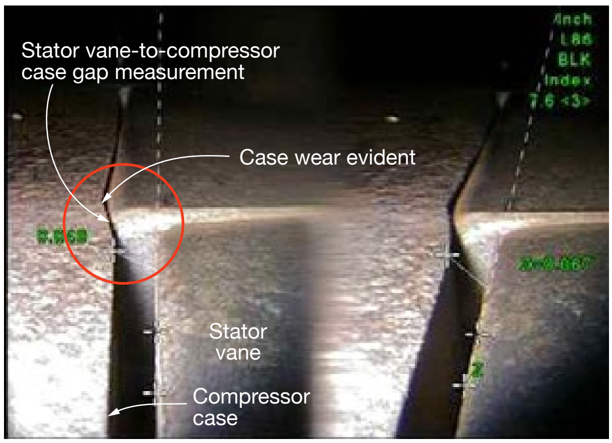
Reasons blades might migrate: (1) Stake marks are undersized and unable to prevent the blade from moving forward. (2) The radial gap between the blade dovetail and slot bottom is excessive, allowing the blade to slip over the stake marks. In the extreme, axial movement is conducive to compressor blades rubbing against the casing bellmouth, damaging both the blade and the rub ring.

Improper depth, diameter, and/or height of stake marks, and improper use of feeler gauges for gap checking, are the root causes of most blade migration events. Coincidentally, an insurer reporting at another user conference said that three-quarters of all powerplant losses had a worker component—including ineffective training, supervision, etc.

Hoogsteden told the 7F users that TIL 1870R1 goes beyond TIL 1796 by requiring owner/operators to check for biscuit rotation where this blade retention solution has been installed. It also calls for verification of staking measurements and radial gaps during major inspections when the bellmouth can be jacked up to permit access for inspection.

For those users not familiar with biscuits, Hoogsteden explained that after several blade installations there may not be sufficient room along the edge of the slot bottom for staking and an insert (biscuit) is inserted into a cut-out in the first compressor wheel to perform the same function as peening. A problem associated with biscuits can be

6, 7. Effects of twisting following a Bigfoot mod are easy to see at the left; close-up is at right



their rotation, generally precipitated by improper staking.

If you are not familiar with TIL 1870R1, contact your GE representative for a copy. It explains how the biscuit should be staked and how much rotation is permissible. In the TIL, the OEM suggests the use of a mirror to facilitate visual inspection of the biscuit. The speaker said Advanced Turbine Support believes the mirror is not a sufficiently comprehensive aid for this purpose and might result in drawing erroneous conclusions. The company is validating an alternative approach introduced by a customer that with simple machining allows borescope access to the biscuit area for precise measurements of rotation (Fig 5).

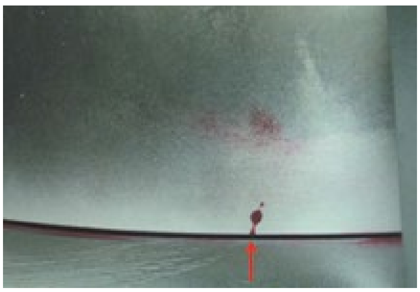
Rocking solution conducive to stator blade twisting. TIL 1769 (Dec 1, 2010) instructs 7F owner/operators on how to inspect their gas-turbine compressors for stator-vane rocking in stages S14 through S16. Much has been published in the CCJ on the subject of vane rock attributed to worn hookfits, with many affected users opting for pinning of the individual square-based vanes into segments to promote rigidity and prevent the release of vanes into the air stream. This solution, developed by Rodger Anderson of DRS-Power Technology Inc, has proved effective over the years.

One of the OEM's solutions for dealing with vane rock is its so-called Bigfoot mod which involves onsite machining of the casing to create a new hook fit for the vanes. Inspections by Advanced Turbine Support of stages S14-S16 following implementation of the Bigfoot mod indicates twisting of stator vanes in some cases. Such twisting is conducive to casing wear and tear because the Type-409 stainless steel compressor vanes are harder than the cast steel casing (Figs 6 and 7). Hoogsteden suggested that users experiencing twisting might want to trend the casing wear over time.

The editors asked a compressor expert what impact twisting might have on performance. A back of the envelope calculation assuming a nominal 2.5-deg twist could cost from 0.5 to 1% in compressor efficiency.

Wait, there's more. Hoogsteden pre-

8. Compressor rotor blade exhibits rolled metal



9. Rotor-blade tip cracks are easy to spot with dye penetrant

10. Protruding stator vane shim should be machined flush with the platform or removed

sented thumbnails and offered experienced commentary on several more TILs during his presentation. Here are excerpts from the editors' notes:

- 1509R3 addresses R0, R1, and S0. It recommends annual visual inspection for R0 root cracking, R0/R1 tip discoloration, rolled metal (Fig 8), and/or tip loss. The TIL provides detailed recommendations if any of those deterioration mechanisms are identified. Example: For S0 stator vanes, inspection personnel are urged to look for trailing-edge cracks; if found, immediate replacement is recommended.

    Advanced Turbine Support is not in complete agreement with the OEM's recommendations. It believes that annual visual inspections are not sufficiently comprehensive and have the potential to miss small or tight indications that could result in blade liberations and a catastrophic failure. The company's inspection experts have identified multiple rotor-blade tip cracks (Fig 9) with visible dye penetrant that were not seen during unaided visual inspections.
- 1562 suggests monitoring the condition of compressor shims and the corrective actions necessary to mitigate the risks of migrating shims on both E- and F-class machines (Fig 10). There are 20 possible shim locations in the first five stages (R0 through R4) of 7F units and they are spaced approximately 60 deg apart from each other.
- 1638 addresses, among other issues, F-class R1 case-off ultrasonic inspections for dovetail distress below the blade platform. The testing interval is 8000 fired hours or 150 fired starts, whichever occurs first. This recommendation is modified for peaking units performing more than 150 annual starts to just before and following the peak season. Inspectors have found four such cracks to date.

    Advanced Turbine Support recommends users heed caution and opt for in-situ inspections at more frequent intervals. In the case of the last in-situ discovery, Hoogsteden believes there was a high probability of major damage before the next OEM-recommended inspection interval, potentially leaving LTSA customers at risk.

11. Extent of damage to a second-stage bucket tip shroud is measured

- 1858, 1859, and 1863 concern the inspection of second-stage buckets on the 7FA.03 (7241+e, enhanced compressor). The first advises users to perform the inspections recommended in the document for second-stage buckets of original and modified design to mitigate the risks associated with tip-shroud creep (Fig 11). The second alerts users of the potential need for increased borescope inspections when installing second-stage buckets of original or modified design. The third TIL alerts users of the potential need for increased borescope inspections if the unit operating profile is changed.
- 1884 addresses clashing on bottom half of 7EA compressors, but Advanced Turbine Support has growing concerns with F-class units as they have discovered increasing evidence of clashing in the field including one such finding in the top half of the compressor.

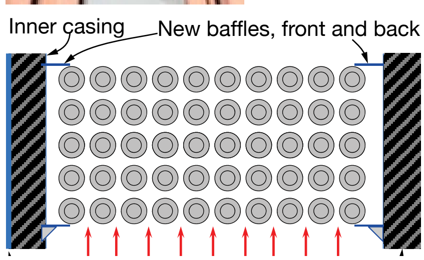
Boost HRSG performance, improve the bottom line

The performance thieves lurking in many heat-recovery steam generators sometimes can be eliminated with relatively little effort and at low cost, Lester Stanley, PE, told owner/operators attending HRST Inc's half-day HRSG workshop at the 7F Users Group conference. The boiler expert focused on the following performance thieves during his opening presentation:

- Gas baffling.
- Gas-side fouling.
- LP economizer recirculation.
- Buoyancy instability/vapor locking.

Baffles force turbine exhaust gas through the tube bundles, maximizing heat transfer and performance. Even gaps of only 2 in. between adjacent tube panels, between tube panels and the inner liner, and between headers in the crawl-space area, can cause significant losses, Stanley told the group. Baffle integrity in evaporator and economizer sections is particularly important, he said.

12. Failed baffle was designed to prevent turbine exhaust gas from bypassing heat-transfer surface by flowing between adjacent panels



13. Sidewall baffles, relatively easy to install, prevent gas from taking the path of least resistance between the tube bundle and inner liner

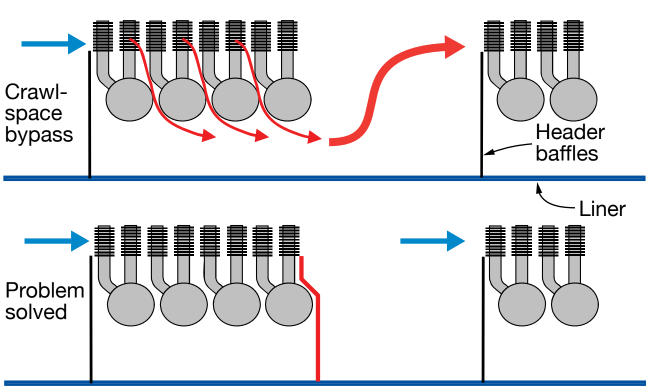
Damaged or missing baffling is easy to identify during a gas-side inspection (Fig 12) and relatively easy and inexpensive to correct with standard carbon-steel components and conventional welding techniques (Figs 13, 14). Perhaps the most costly component of baffle repair and/or replacement is the installation of scaffolding. Therefore, it makes good sense to do this work when cleaning tube panels, which also requires scaffolding.

Stanley noted that thermal performance loss is not the only adverse impact of ineffective baffling; it has been known to contribute to flow-accelerated corrosion (FAC) as well. Also, when baffles in the firing-duct area are not in good condition, duct-burner flames can be disrupted and tubes and the SCR can suffer thermal damage—all in addition to performance loss.

Though baffle work is relatively simple to do, if your unit has excessive gaps in many locations, the plant maintenance budget might not be able to swallow the whole refurbishment project in one gulp. Stanley discussed one such case where performance modeling provided justification and prioritization of the work.

Some gap locations create more performance decrease than others, he said. In the real-world example described, Stanley said that the annual benefit of coil-to-coil baffle fixes in all six access lanes of an F-class HRSG was about $1 million. However, baffle restoration in only two of the lanes produced 60% of that benefit making the investment decision an easy one. In this case, the plant reported a 2 MW increase in output after repairs were made.

Gas-side fouling, as most attendees knew, can be caused by one or more of the following: rust, ammonia salts, sulfur compounds, and liberated insulation. They also were aware that the consequences of fouling include an increase in gas-turbine backpressure, a thermal-efficiency penalty, and the release of particulates up the stack, especially at startup.



14. Header baffles stop hot gas from bypassing the tube bundles via the crawl space

But many were not sure of the financial impact of fouling. Stanley worked up a short calculation that showed gas-turbine power production decreased by 0.105% for each 1-in.-H_2O increase in backpressure. For a 7FA with a nominal rating of 183 MW at ISO conditions, this translates to a "de-rate" of 192 kW. In addition, fouling reduces HRSG thermal efficiency because it reduces heat transfer and steam production.

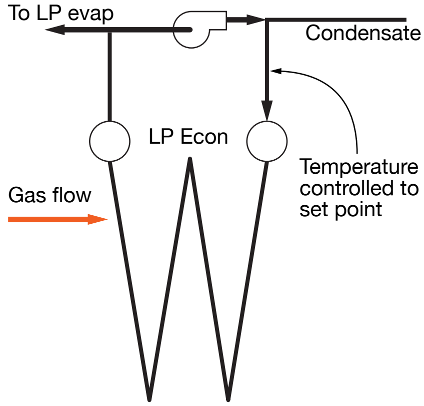
Someone asked about the optimal time for cleaning fouled heat-transfer surfaces. Stanley said this was an economic decision and could be different for every plant. He added that high backpressure often drives the decision, to avoid the consequences of an unnecessary turbine trip. Next, the boiler expert suggested that plants develop their thermal-performance and backpressure yardsticks to determine the optimal time for cleaning.

Stanley pointed out that rust is relatively easy to remove, SCR ammonia salts not so. Regarding the latter, he warned about the difficulties in cleaning tube bundles after they had bridged over—that is, totally packed to the fin OD with ammonia salts. "Clean before crisis," Stanley urged.

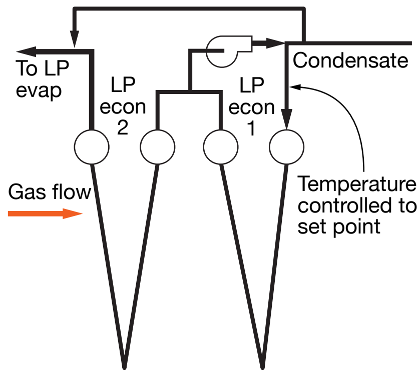
The next 10 minutes or so was dedicated to a review of the types of cleaning, the effectiveness of various media, and the advantages of so-called deep cleaning—a process developed by HRST Inc. Stanley said that, in general, best results in the cleaning of fouled finned-tube surfaces have been achieved using CO_2 and compressed-air blasting, perhaps in series. Water deluge or hydroblasting can do the job in some instances, he continued, but waste collection and disposal would likely militate against the use of water.

The next performance thief Stanley discussed was LP economizer recirculation. Bryan Craig wrote in a recent issue of HRST's *Boiler Biz* that recirculation often is used to raise the temperature of condensate entering the LP economizer above the turbine-exhaust dew point to minimize corrosion of panels in the back end of the unit.

However, this comes with a cost. Recirculating water flow to increase the inlet temperature reduces overall output from the HRSG in a small, but measurable way, he stated. The



15. Corrosion is controlled in some LP economizers by recirculating a portion of the water exiting that heat exchanger back to the inlet to stay above the dew-point temperature

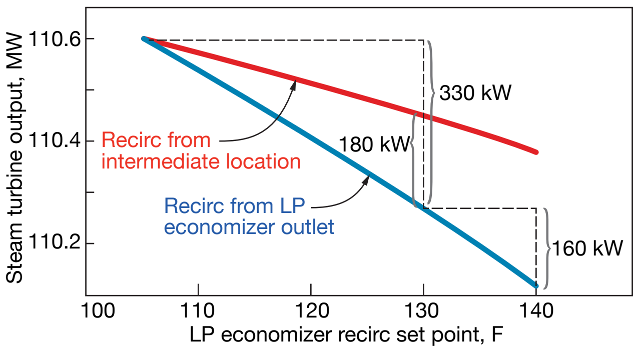


16. A more efficient recirculation scheme is to recirculate warm water from an intermediate header, if installed

amount of performance reduction depends on the water-temperature set point, and also the location from which the recirc flow is taken.

Some LP economizers recirculate a portion of the flow from the economizer outlet back to the inlet to achieve temperature control (Fig 15); others recirculate from an intermediate point within the economizer, design permitting (Fig 16). HRST engineers have concluded that if recirc must be used, it is more efficient to take the flow from an intermediate point than from the economizer outlet. The temperature set point also comes into play: Reducing the set point improves efficiency.

Craig used Fig 17 to illustrate this point. The chart is based on a typical F-class HRSG with a 12-row LP economizer and a condenser hotwell temperature of 105F. If recirc flow is taken from the economizer outlet, reducing the temperature set point from 140F to 130F increases steam-turbine output by 160 kW. Assuming the plant operates 5000 hr/yr and is paid $50/MWh for the electricity it produces, the 10-deg-F reduction in the set point is worth $40,000 yearly. For



17. The output penalty associated with recirculation may be such that replacement of a corroded harp is the more economic approach

the 130F set point, extracting recirc flow from the midpoint of the economizer increases steamer output by another 180 kW, more than doubling the annual revenue gain to $85,000.

Eliminating recirc altogether, and allowing cold water to enter the LP economizer, increases steam-turbine production by 330 kW, which is worth about $82,000 per year. This suggests it may make sense to forego recirculation and plan on replacing the last one, two, or three rows of LP economizer surface every eight years or so, give or take a couple of years. Also worthwhile considering: The first time you replace the back-end surface, switch to an alloy material suitable for the wet environment and eliminate the need to do it a second time.

Buoyancy instability. Stanley began the final segment of his presentation by reviewing the performance loss caused by buoyancy instability in panelized economizers. Nearly all economizers have some down-flowing tubes, he said; most have down-flow in half the tubes. Buoyancy instability causes flow to stagnate in some of the down-flow tubes, or to reverse direction. When water does not flow as designed, the effective heat-transfer surface is reduced and heat absorption decreases.

Also, stagnant and reverse-flow tubes become hotter than neighboring tubes increasing the level of stress. The risk of this happening is greatest at low loads. Hundreds of thermal cycles can occur within a day, leading to fatigue failures in less time than you might think. Modification of flow circuitry can correct the issue.

If a performance assessment advises that buoyancy instability is a problem early in the life of a unit, changing the location of splitter plates in the upper header should be considered to optimize the flow pattern. Stanley said the relocation of splitter plates is not as difficult as it might appear. In some cases, he said, it can be easier than plugging economizer tubes.

Buoyancy instability in return-bend economizers causes water in some circuits to flow very slowly or not at all, others to flow quickly. If the gas temperature is above the saturation temperature, stagnant tubes will vapor-lock—that is a steam bubble trapped in the return bend will block flow, generally until unit load is high enough to clear it. It is difficult to modify existing systems to correct this problem.

Go beyond visual inspections

Boiler expert Bryan Craig, PE, urged users to consider going beyond the "standard" visual inspection of their heat-recovery steam generators. Unit age, cyclic operating history, and findings during previous inspections are among the variables that should be factored into your decision, he said.

Craig acknowledged that a simple walkdown of the gas side is all you need to find problems such as liner/insulation damage in the hot-gas path, fouled catalyst and heat-transfer surfaces, tube damage, leaking penetration seals, etc, but suggested a lot more could be going on internally that you'd want to know about. One of the speaker's objectives was to familiarize owner/operators with some of the inspection techniques at their disposal and explain how these technologies are capable of helping them.

Desuperheaters were Craig's starting point. A great deal has been written about them in the last 10 years—the probe type, in particular. Craig said probe-type desuperheaters on HRSGs cycling once a week or more should be inspected annually. Look for cracking or distress on the desuperheater assembly, check nozzles for looseness and plugging, verify springs are intact. Also, use a borescope to assure liner integrity and the absence of pitting/wear at the downstream elbow. If DCS data suggest overspray, check piping for cracking.

Borescopes were offered as good screening tools for HRSG inspections—qualitative, not quantitative. Examples: Find evidence of FAC; check condition of superheater, evaporator, and economizer tubes and headers to the extent possible (access often limited). One suggestion was to install borescope ports in headers to improve access.

Tube sampling is a destructive inspection option for users. This has to be done selectively—perhaps based on borescope findings—because of the expense involved. Tube deposits and failures are two reasons for sampling. But identifying the optimum sampling location can be challenging, Craig noted. He suggested removing 3 ft of a degraded or failed tube for laboratory analysis—including alloy verification, hardness, dimensional checks, and deposit/scale/oxide analysis and measurement.

Magnetic-particle and dye-penetrant testing were cited as the best/most practical methods for identifying surface cracks in suspect areas, including these:

- Tube-to-header joints in the economizer inlet pass, at all pressure levels, after 500 cycles.
- Superheater and reheater tube-to-header joints, if warped tubes get worse over time.
- At or near welds in the base tube material.
- Vent and drain lines.

Craig told the group dye penetrant testing has several advantages and a few negatives. On the plus side: Flaws are very visible, technicians generally can be trained quickly (although experience is valuable), cost is low. Disadvantages include the following: Proper cleaning of the suspect area is required, fumes can be toxic in confined spaces, results can be misinterpreted by inexperienced personnel.

Magnetic-particle testing typically is used to find fatigue cracks in ferritic materials that have been in service for a few years, the speaker said. Advantages over dye pen include speed, ability to perform in damp environments, use in areas with poor ventilation. It is not recommended for components with complex or tight geometries.

Ultrasonic thickness testing finds greatest use in tracking flow-accelerated corrosion (FAC) and external corrosion. Discussion of UT flaw detection followed, with Craig explaining both the shear-wave and phased-array techniques and illustrating how welds are examined. He warned that it takes time and experience to get meaningful results with shear-wave UT. Phased-array UT is much faster.

Most attendees were familiar with UT because of its extensive use in gas-turbine inspections. The volumetric technique, like radiation, is capable of subsurface flaw detection; but UT has none of the safety hazards associated with radiation. Its ability to determine the depth of a crack, for example, is particularly valuable to owner/operators. Depending on geometry, a high level of skill and experience may be required to properly interpret the data and get meaningful results. Mockups sometimes are required to calibrate the test. Craig suggested that owner/operators make sure the technician assigned to their jobs has a Level 2 certification—at a minimum. Also, that you receive a "scan plan" before work begins.

Positive Material Identification capability is valuable when conducting HRSG inspections. If questions arise, PMI can quickly determine the chemical composition of metal surfaces. A hardness tester is another screening tool you should have, particularly if P91 material is installed in your main and hot-reheat steam systems. Hardness testing looks easy, but keep in mind that bad data are easy to get. Replication is a technique that creates an image of a metal's grain structure; it supplements hardness testing in the evaluation of P91 condition. This inspection work should be done by a qualified and experienced metallurgist.

Thermal imaging (thermography) is valuable plant-level technology for detecting and quantifying hot spots, areas of missing insulation, exhaust as leaks, etc. Finally, Craig suggested to attendees that careful review of DCS data often can pinpoint problems and that trending of data is valuable for monitoring solutions. Issues that can be identified by reviewing DCS data include the following: poor control of feedwater flow, improper schedule for steam drains during startup, fluctuating drum level, desuperheater cycling, spraying to saturation, etc.

Quickly repair cracks in liners, perf plates

The third segment of the 7F HRSG workshop, presented by Stanley, included useful maintenance tips on inlet and firing ducts. He began with the basics. HRSGs typically are insulated internally using a floating liner, Stanley said. Outer casing is of carbon-steel plate, separated from the floating sheet-steel inner liner by ceramic-fiber blanket insulation. The casing provides a gas-tight seal, he continued, and supports the liner. Insulation protects the casing from high exhaust-gas temperatures—thereby minimizing heat loss and casing thermal expansion, and allowing the use of carbon steel for both the casing and structural members. The floating liner keeps insulation in place and allows for thermal expansion of hot-face components.

Next, Stanley ran through the details of liner construction and repair. He used essentially the same material for this segment of his presentation as colleague Ned Congdon, PE, had shared with plant personnel at the Western Turbine Users Inc meeting two months earlier. Stanley discussed inlet-duct problems as Congdon had done, acknowledging that while the exhaust stream from the 7FA is not as turbulent as that from the LM6000, it still demands respect.

He stressed not tolerating any rattling or spinning parts, or exposed insulation. Gas-flow distribution devices were not part of Congdon's presentation, but Stanley covered material distress in turning vanes and the perforated plate. He suggested inspecting carefully for cracking of turning vanes and noting that cracked vanes often can be removed with no duct-burner effect, but a proper engineering evaluation is needed to support decision-making.

The perforated plate likewise must be inspected for cracking. If you find evidence of such, Stanley suggested that you begin planning to replace the plate with an upgraded version. Sometimes sections of the perf plate can be removed with no duct-burner effect, but make sure a CFD analysis agrees beforehand.

Stanley closed with a review of firing-duct oxidation and creep damage generally caused by improper specification or use of materials. Creep strength declines logarithmically with temperature, the speaker reminded, and offered the following limits on use of typical steels:

- Carbon steel, 700F.
- Cor-Ten, 1100F.
- Type 409 stainless steel, 1200F.
- Type 304 stainless steel, 1500F.
- Type 310 stainless steel, 1800F.

Fuel-nozzle flow testing

Sometimes you think you know something until you listen to someone who really knows that something, making you aware of how little you really know. Fuel-nozzle flow testing may be one of those things. Mitch Cohen of Orlando-based Turbine Technology Services Corp (TTS), a respected combustion-system expert, presented work on that subject developed by the Electric Power Research Institute (EPRI). Judging from the questions, there were some bona fide subject-matter experts at the 45-min 7F workshop for owner/operators, but there also were a few others at the opposite end of the knowledge spectrum.

Flow testing is a longtime key component of both the fuel-nozzle manufacturing and repair processes, even for diffusion and early DLN systems having NO_x targets of 25 ppm or higher. For these older systems, acceptable combustion performance could be achieved with a higher degree of combustor-to-combustor variation in the fuel/air ratio than today's more sophisticated combustor designs require. Consequently, methods used to flow test older model fuel nozzles did not have such stringent requirements for accuracy.

However, the evolution to advanced low-NO_x combustion systems—such as the DLN2.6—demands more accurate, reproducible, and repeatable measurements and tighter control of a nozzle's effective flow area. This accuracy and tighter control extends both to the absolute area of nozzles, which impacts the dynamic characteristics of the combustion process, and to the variation in area among sets of fuel nozzles and components, which impacts—most importantly—margin from lean blowout (LBO). Emissions and dynamics also are affected.

Cohen's presentation announced the availability of the EPRI technical update 1023970, "Fuel Nozzle Flow Testing Guideline for Gas Turbine Low-NO_x Combustion System," that he, Leonard Angello of EPRI, and Hans Van Esch of Turbine End-user Services co-authored to accomplish the following:

- Assist operators in the selection and qualification of fuel-nozzle repair/flow-test vendors.
- Provide a detailed methodology for obtaining accurate flow-test results, which discusses both equipment and flow-test procedures.
- Identify the steps involved in validating flow-test results.
- Provide guidance on both how to interpret flow test data and how to use that information to establish criteria for returning nozzles to service.

Cohen told attendees that optimal operation of 7FA DLN2.6 combustion systems requires the balancing of several competing requirements, including these:

- Maintaining NO_x emissions at less than 9 ppm.
- Preventing LBO trips.
- Maintaining the amplitudes of hot, cold, and chug tones within acceptable limits.
- Achieving the required load turndown while holding CO emissions within permit limits.

Tight control of fuel/air ratio is critical to these goals, he said, adding that exacting fuel-nozzle flow testing is required to assure this level of control can be achieved. However, the experience of TTS in troubleshooting DLN operational problems, Cohen noted, is that operations personnel sometimes are unaware of the basic requirements of flow testing or how to evaluate data they receive. In many instances, he added, operators are not even sure if they have received flow-test data for nozzles that are in service, and/or they are unable to locate this information. These findings helped provide the incentive to develop the EPRI guideline.

What is flow testing? Cohen began his tutorial by answering this question. He said, "It is the measurement of the effective flow area, or simply the 'effective area' of a flow passage, usually expressed in square inches." For a standard venturi nozzle measurement is relatively simple, but for more complicated geometries—such as a fuel nozzle—the effective area must be determined in a flow test rig. Cohen continued: "In a flow test rig, if we know precisely the mass flow and gas composition (dry air) we can calculate the effective area by measuring the upstream and downstream pressures and the temperature."

Flow testing is important, he said, to achieve equal (that is, as close to equal as technology allows) fuel flows through the respective fuel passages (PM1, PM2, PM3, Quat) of each combustor by minimizing the variation in effective area from can-to-can. Cohen pointed out that, for a given fuel manifold, each combustor sees the same pressure and temperature conditions and that any difference in fuel flow among the chambers is due solely to differences in effective area.

Another reason flow testing is important is that failure to operate at the design pressure ratio across fuel nozzles is conducive to combustor dynamics issues. Achieving the correct pressure ratio demands high accuracy in measuring the targeted effective area of the fuel nozzles. Cohen used this as a segue to discuss how the reliability of flow test results are validated. Accuracy, repeatability, and reproducibility of the data are vital to enable proper tuning of the engine. He defined those terms this way:

- Accuracy is the deviation of the measured effective area from the actual effective area.
- Repeatability is the ability of a measurement system—a flow test rig in this case—to reproduce a measurement while operating under an unchanging set of conditions.
- Reproducibility is the ability to reproduce a measurement under different conditions of pressure, temperature, and humidity, and at different points in time. It presumes the test rig has been broken down and rebuilt between measurements. Reproducibility also is an indicator of the consistency of the setup and testing procedure used by different, or the same, technicians responsible for measurements.

The EPRI guideline recommends these quantitative limits for each validation parameter:

- Accuracy within plus/minus 0.75% of a calibrated master standard part—defined as one whose effective area has been measured by an independent calibration lab using instrumentation traceable to the National Institute of Standards and Technology.
- Repeatability: Two standard deviations; less than 0.5% of the average measurement.
- Reproducibility: Two standard deviations; less than 0.75% of the average measurement.

Having valid measurements is only table stakes, however. How this information is used to develop test specifications and to qualify/reject fuel nozzles is the owner/operator's challenge. First step, Cohen said, is for the operator and vendor to discuss and agree on the limits for can-to-can variation in effective area for each flow passage (PM1, PM2, etc). This typically is expressed as a limit of the percentage calculated by subtracting the minimum effective area from the maximum and dividing that by the average effective area. He added that many vendors offering flow-test services use this as the only qualifying criterion.

But that is a mistake, Cohen believes. For each gas passage, the average effective area also should be within a certain percentage of a specified target value, calculated by subtracting the targeted effective area from the average and dividing the result by the targeted effective area.

He went on to illustrate, by use of a series of charts available to users on the 7F Users Group website, how numbers written into a specification can appear correct but may be unsatisfactory for assuring proper tuning of advanced DLN combustion systems. The example presented showed two sets of PM3 assembly flow test data having the same average effective area and the same max-to-min range, 4.0% in this case. For the first data set, the variation from the average effective area was +2.1%, -1.9%; for the second set, +0.6%, -3.4%. Both sets of numbers satisfy the spec, but the second set does not meet the intent of the spec.

Here's one reason why: One combustor always will be the lowest flowing of the 14 and the first to flame out if operated too lean. Minimizing the variation in average effective area—at the low end in particular—will provide more margin from potential LBO. Another reason: High- or low-flowing cans can result in excessively high dynamics in only one or two combustion chambers and this can lead to high NO_x emissions when the entire combustion system is tuned to reduce the dynamics in the one or two affected cans. CCJ

Aero Nation still growing as 25th anniversary nears

Chuck Casey opened his first meeting as president of the Western Turbine Users Inc with the confidence and polish of a veteran leader. He began the 24th Annual Conference & Expo in Palm Springs, Calif, March 23-26, by announcing personnel changes in the WTUI leadership.

John Baker, who manages a 1 × 1 combined cycle for Riverside Public Utilities (RPU), completed his three-year term on the Board of Directors at the meeting, and Charles Byrom, a plant manager for the Anaheim Public Utilities Dept, resigned his director position because of impending retirement. Devin Chapin, Turlock Irrigation District, and Jermaine Woodall, Exelon Generation, were elected to fill their vacated seats.

All other officers, board members, break-out session chairs, and support personnel continue in their current positions. Specifics are available at www.wtui.com and in the previous issue of CCJ, p 81.

Casey, the utility generation manager for RPU, announced that this was the third meeting in the last five years with over 1000 attendees, including 347 owner/operators. More than 350 companies (users and vendors) were involved in the conference; their representatives came from 39 states and 11 countries (Canada, Australia, Netherlands, Tanzania, Brazil, Mexico, Argentina, UK, France, Belgium, and Ecuador). The 227 companies participating in the exhibition filled nearly 90,000 ft^2 of display space.

By show of hands, about one-third of the attendees were first-timers. At the other end of the spectrum, about 20% had been coming to Western Turbine meetings for 10 years or longer. A handful acknowledged having been around since the beginning—including APR Energy's Brian Hulse; WTUI Treasurer Wayne Kawamoto, plant manager, Corona Cogen; Mike Raaker, Raaker Services LLC; and the organization's first president, Jim Hinrichs, who passed suddenly April 28, a month after the meeting ended (pp 3, 72).

Following brief comments by Casey on WTUI's value proposition, how to extract maximum value from the meeting, introductions, program comments, etc, the president invited Kawamoto to the podium to deliver the Treasurer's Report. Finances were in order and positive, and accepted by voice vote. Kawamoto then reviewed plans for future meetings with the organization's 25th anniversary conference and expo at the Long Beach Convention Center, next March 15-18, at the top of his list. The group plans on returning to Palm Springs in 2016 and revisiting Las Vegas in 2017 (last there in 2001).

Depot presentations

Reports by each of the four depots—ANZGT (Air New Zealand Gas Turbine), IHI Corp, MTU Maintenance Berlin-Brandenburg, and TransCanada Turbines (TCT)—followed the business portion of the session.

ANZGT. Mal Waite, commercial manager, reviewed the company's capabilities and safety culture, capping off his talk with an entertaining film on safety in a beach setting. John Callesen, who manages the company's Bakersfield (Calif) shop, and Frank Oldread, GM of the US operation, were at the front of the room with Waite. Recall that Oldread was a member of the WTUI leadership team when he wore a user's shoes.

ANZGT offers Level 1 to 4 repair and overhaul services on LM2500 and LM5000 gas turbines out of its Auckland (NZ) depot and Level 1 and 2 repairs/services at its Bakersfield facility. Teams of field-service technicians are based at both locations and operate 24/7 for immediate mobilization. In 2010, the company became the sole LM5000 parts supplier to the world market and the depot repair facility for GE's LM5000 lease fleet.

IHI's Yoshio Yonezawa, VP energy and plant operations, reviewed the 161-year-old company's products and services, stressing its "Realize Your Dreams" motto. He mentioned IHI's expanding participation in the Level 2 depot in Cheyenne that it opened with Wyoming-based Reed Services Inc about two years ago.

Koji Hibino, SVP of the Cheyenne Service Center, followed Yonezawa at the podium and offered more detail on the US facility. It handles consulting inspections, engine/module replacement, HP and LP compressor airfoil repair/replacement, onsite maintenance and troubleshooting (up to Level 2), implementation of service bulletins, etc. Ken Ueda, well known to LM users, continues as the service manager in Cheyenne.

In Japan, IHI operates a Level 4 GE-authorized depot for the LM2500 and LM6000 from its shops in Kure and Mizuho and has a dedicated test cell for LM engines in Kure. Satellite repair facilities are located in Thailand and Australia. IHI has LM6000PC and PD machines available for lease also has a "remote witness" online monitoring center in Tokyo for abnormality detection analysis. The company's goal is to identify and resolve problems before breakdowns occur, thereby improving the performance and reliability of customer equipment.

MTU Maintenance's Burkhard Schulz spoke first for the company as he has for several years, but only briefly this time. Schulz returned for his 14th consecutive Western Turbine meeting to thank the organization and MTU customers for their loyalty over the years and to introduce Steffen Richter as the new business leader for industrial gas turbines (IGT). Schulz retires later this year.

Uwe Kaltwasser, director of sales and customer support for the IGT segment of the aerospace company and well known to many attendees, followed Richter. He began with a capabilities review of the Level 4 Ludwigsfelde shop, MTU's center of excellence for the repair of industrial gas turbines. A short video provided valuable perspective of the world largest shop licensed by GE. MTU is an authorized service provider for LM2500, LM2500+, LM5000, and LM6000 engines. The company and its affiliates operate Level 2 shops in Ayutthaya (Thailand), Mongstad (Norway), New Braunfels, Tex, and Brazil. It has nearly 700 employees and hosted more than 1000 shop visits in 2013.

MTU's test cell in Ludwigsfelde is designed to accommodate and test LM2500, LM2500+, and LM6000 gas turbines under actual operating and load conditions, thereby assuring that maintenance work is performed in accordance with best industry practices. LM5000s are tested on an aircraft-engine test bed.

TCT. President Dan Simonelli stressed the company's commitment to safety and described its HandSafe program. TCT has been recognized as one of Canada's safest employers; last year it ranked No. 2. Dale Goehring, well-known to aero users, followed Simonelli with a capabilities presentation. The company's new Level 4 Airdrie plant with state-of-the-art equipment and tooling is located about 20 minutes north of Calgary. It handles all models of the LM6000, as well as the LM2500 and LM2500+.

Recall that TCT is a joint-venture company between TransCanada Corp and Wood Group GTS. It employs 230 people worldwide and operates Level 2 "hospital shops" in Bakersfield, Syracuse, Houston, and Glasgow (Scotland). Ongoing employee training by the OEM is a requirement; all technicians get 50 hours of formal education annually.

Goehring also discussed TCT's test facility in the Airdrie facility, now fully operational. It enables the company to provide incoming engine testing, troubleshooting, and diagnostic services for all models of the LM6000. Load banks are used to dissipate the power produced during testing.

The OEM's team included Gabriel McCabe and Lance Herrington of GE Distributed Power and Cynthia Kantor of GE Power & Water. McCabe is responsible for customer partnerships (Americas) for the Distributed Power organization which aggregates aero GTs, Waukesha diesels, and Jenbacher engines for power generation, mechanical drive applications, mobile power, etc. The company's commitment to EHS, quality, delivery, cost, and productivity was discussed in prepared remarks as was the supplier's diagnostic monitoring center now tracking more than 400 units—undefined as to size, type of prime mover, purpose.

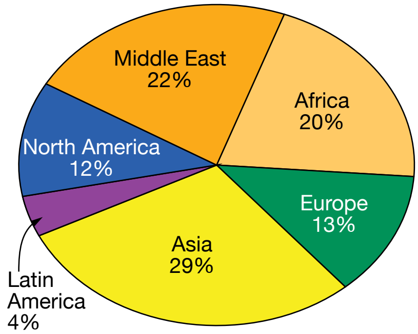
The Axford Report

Mark Axford, the Houston-based consultant considered by many to be the leading independent expert on gas-turbine (GT) markets, predicted that US orders for GTs would increase by 15% this year over the nearly 6 GW purchased in 2013. Worldwide, he expects a *decline* of 5% from the 61 GW booked last year. The Eurozone's lingering recession is a significant factor in the downward pressure on international orders (less 800 MW in both 2012 and 2013).

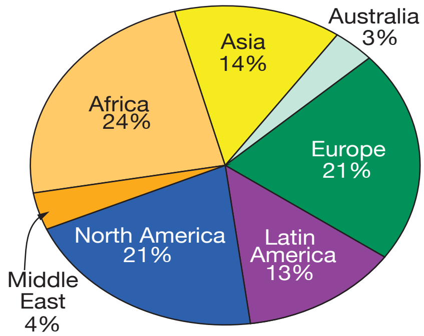
The Axford Report, as the annual presentation at WTUI has come to be known, traditionally opens the meeting on the second day of the event. It is highly regarded by conference attendees and always attracts a large audience. Axford's perspective and data help guide business decisions made by the more than 200 equipment and services providers that regularly participate in the world's largest meeting dedicated to aero engines in land and marine applications.

The market analyst began with a *mea culpa* for overestimating his *Ax*Spectations of 25% US growth in 2013 compared to 2012. The market surge predicted was, in his words, a "no-show," with actual orders down by about 5% from the total recorded a year earlier.

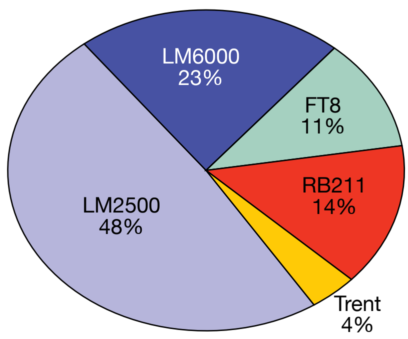
Worldwide, Axford had expected 5% growth and he nailed that within a few tenths of a percentage point. Geographically, 29% of the orders were from Asia, 22% from the Middle East, and 20% from Africa (Fig 1). Regarding Africa, the lion's share of its orders was committed to Algeria, which bought nearly 9800 MW in 2013. Interesting to note is that Algeria's generating capability at the end of 2011 was only about 11 GW.



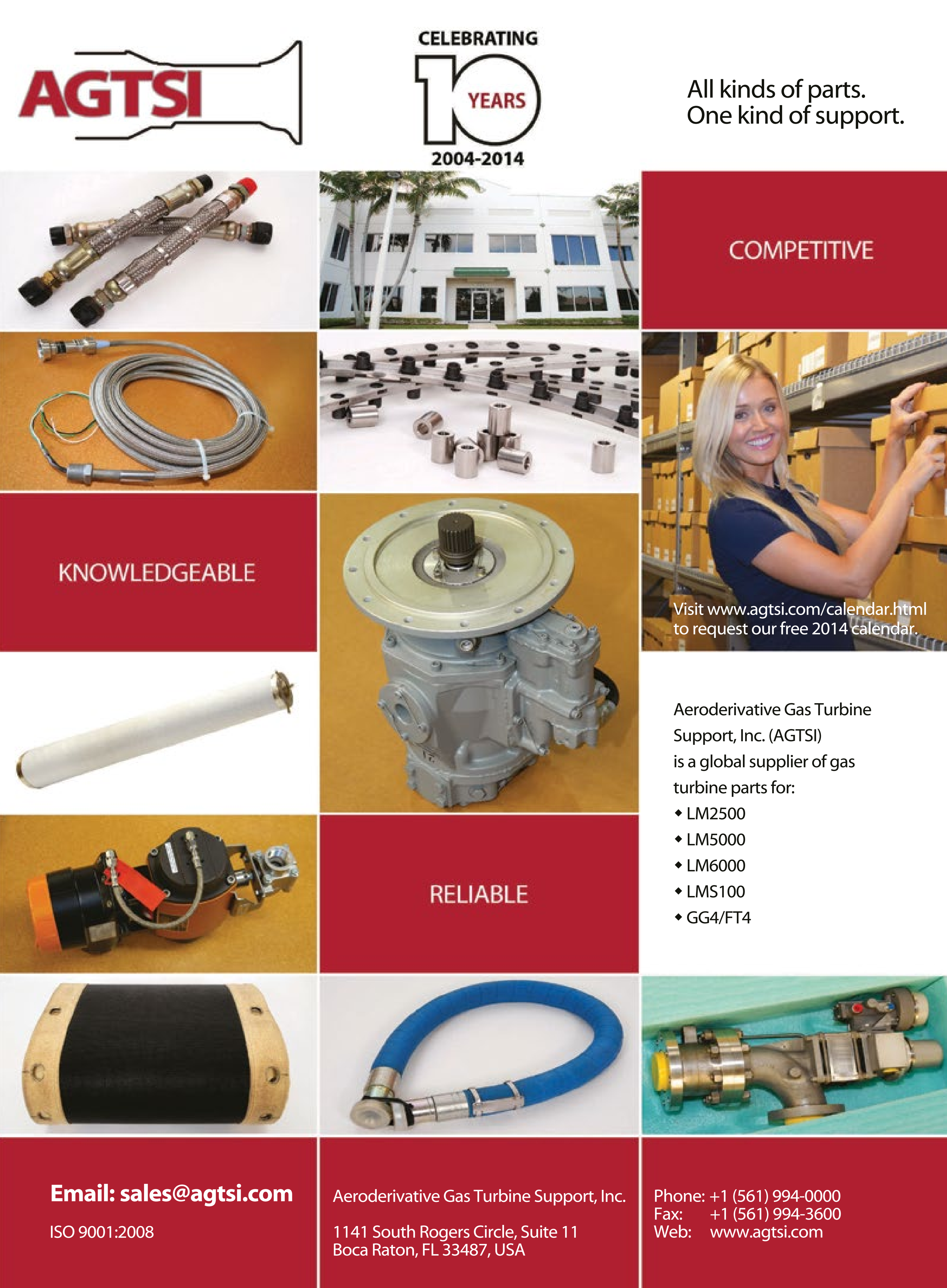
1. Orders for gas turbines worldwide in 2013 topped 60 GW, about 5% more capacity than was booked in 2012. The highest percentage of business came from Asia, which has been the norm for the last several years. Two points made by Axford, in his address before the Western Turbine Users: Highest-ever percentage for Africa; 87% of "Europe" orders came from the former USSR



2. Aero GT orders worldwide totaled nearly 8000 MW, up a couple of percentage points over 2012



3. LM6000s and LM2500s dominated aero orders outside the US in 2013, as they have for several years. No LMS100s or PW4000s were ordered internationally. Note that the LM2500 segment includes 20 LM2500+ mobile units, the FT8 slice 28 trailer-mounted engines


AGTSI
CELEBRATING
10 YEARS
2004-2014
All kinds of parts.
One kind of support.
COMPETITIVE
KNOWLEDGEABLE
Visit www.agtsi.com/calendar.html to request our free 2014 calendar.
Aeroderivative Gas Turbine Support, Inc. (AGTSI) is a global supplier of gas turbine parts for:
◆ LM2500
◆ LM5000
◆ LM6000
◆ LMS100
◆ GG4/FT4
RELIABLE
Email: sales@agtsi.com
ISO 9001:2008
Aeroderivative Gas Turbine Support, Inc.
1141 South Rogers Circle, Suite 11
Boca Raton, FL 33487, USA
Phone: +1 (561) 994-0000
Fax: +1 (561) 994-3600
Web: www.agtsi.com

OEM market share. Globally in 2013, Siemens and GE combined for 76% of the total order book for units larger than 10 MW, as they had a year earlier. However, in 2012 the split was Siemens 36%, GE 40%; this year Siemens captured only 29% of the market. GE's 47% share, its best competitive performance since 2002, was strongly influenced by success in Algeria where GE captured 80% of the 2013 orders, valued at $2.7 billion.

Mitsubishi Hitachi Power Systems finished a solid third with 16% of the market; in 2012 it booked 17%. With Mitsubishi, Hitachi, and the former Pratt & Whitney Power Systems merged into one entity, it's unlikely that any company will push MHPS out of the No. 3 position. More likely is that Mitsubishi Hitachi will grow its market share.

Axford breaks out the aero stats for WTUI attendees. In North America, 2013 orders totaled 1630 MW, he told the group, with 85% of the order book going to GE. Slightly more than one-third of the total was purchased to serve as compressor drives for the oil and gas industry. Worldwide, aero orders in 2013 totaled nearly 8 GW, up slightly from 2012 (Fig 2). GE garnered more than 80% of the total aero business globally.

Fig 3 illustrates that aero orders outside North America were dominated by sales of LM2500 and LM6000 engines. By contrast, North American aero orders for electric generation service were a mixed bag: GE LM2500s, LM6000s, and LMS100s accounting for 5%, 15%, and 38%, respectively, of the total, and MHPS's FT4000™Swiftpac®, 7%. Aeros purchased as compressor drivers were 13 PGT25+G4s, accounting for 27% of the total, and two Rolls-Royce RB211s, 8%.

Global orders for the popular

Remembering Jim Hinrichs

Every engineer worth his salt wants to know how things work—and how to make them work better. For those whose job it is to keep a powerplant running and electricity flowing, it is critical that they know how to keep the turbine shaft turning. That's what Western Turbine Users Inc is all about, Jim Hinrichs told the editors in a recent interview. Jim knew. He was a founding member of WTUI and served as its president for 17 years.

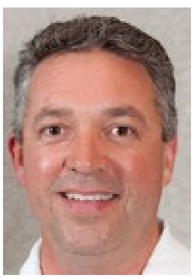
"When the first LM2500 packages were installed," Hinrichs recalled, "the guys at the plants were facing similar problems, but there was no mechanism for sharing solutions or even determining if your problem was one-of-a-kind." At the time, the OEM wasn't providing all the guidance needed, so the LM2500 pioneers decided to do it themselves.

Hinrichs continued, "At first we'd meet at the plants and sit around a conference table with one goal—to brainstorm, troubleshoot, share issues, and solve problems. Although GE had a service organization, these machines were brand new in land-based service and the OEM was on a learning curve just as we were." In 1991, the founders made the decision to incorporate with regular by-laws and membership procedures, and that decision set the tone for the future of the group. It started as an all-volunteer organization and still is.

Another turning point resulted from GE's temporary withdrawal of technical support for the conference, Hinrichs recalled. "That hole in our program was promptly filled by the licensed depots. The depots tackled the job of preparing detailed technical presentations to the users, a task central to the annual conference," he said. "Witnessing competing depot engineers sitting side-by-side editing each other's notes and PowerPoint slides is a phenomenal sight and a testament to the WTUI camaraderie," Hinrichs added.

Still, the heart and soul of WTUI is the dedicated users who understand that helping a fellow user is an investment in their own company and expertise because "what's Joe's problem today, could be mine tomorrow." Through the years, WTUI has grown beyond Hinrich's expectations, but it remains true to its focus: solve users' problems, period.

Some of the people who knew Hinrichs best share their thoughts below. Two, Wayne Kawamoto and Mike Raaker, also were founding members. Jon Kimble followed Hinrichs as WTUI president, Chuck Casey is the current president. Mark Axford and Sal DellaVilla, non-users, have been an integral part of the organization's activities since its first official meeting in 1991.



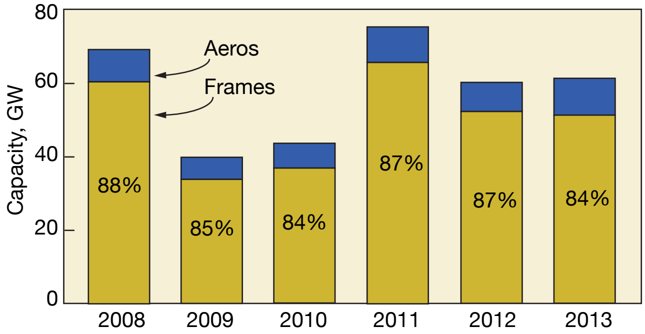
No one has done more to ensure my professional success than Jim Hinrichs. I was a plant I&E tech for only one year following learning experiences in the US Navy and GE, when Jim tapped me to manage PurEnergy LLC's Colton Power project—eight GE10B1 peaking units at two four-unit sites in California. That experience was a springboard to what has been an extremely rewarding career. I look forward to passing on to my grandchildren what Jim taught me.

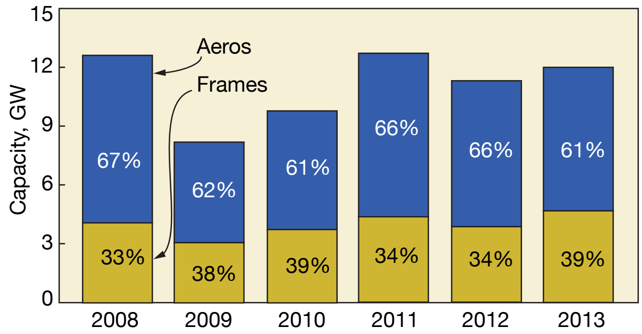
Chuck Casey, *Utility Generation Manager, Riverside Public Utilities; WTUI President*

I've known Jim since his appointment to fulfill WTUI's first president's vacancy back in 1992. Throughout his position as president until his retirement in 2008, I've gotten to know Jim as a great fellow associate, husband, and personal friend. We all looked up to Jim because of his friendly nature, ability to communicate well, and his cheerful personality to enjoy life. Both he and Susan have been the cornerstone in the growth of the WTUI. We will all miss him at our conferences.

Wayne T Kawamoto, *Plant Manager, Corona Energy Partners Ltd; WTUI Treasurer*

Jim Hinrichs was the soul of WTUI.





4, 5. Market share of aeros versus frames, worldwide, for all gas turbines larger than 10 MW is at left. For gas turbines rated between 18 and 65 MW, worldwide, aeros traditionally hold a 2:1 advantage in aggregate capacity (right). In 2013, the aero share dropped a few percentage points from the two previous years because a large order from Thailand for small combined cycles specified the Siemens SGT-800, a frame unit, rather than the LM6000 aero alternative

LM6000 totaled 32 engines in 2013 down 10 from a year earlier. Only two LM6000s were purchased by US generators; none were sold into the Eurozone. Sales of the LMS100 rebounded from two in 2012 to six last year—all for US service, including five in California. To date a total of 62 simple-cycle units have been ordered, 44 for the US. Industry sources have told the editors that the premium price for the LMS100 might make it unattractive to at least some international prospects.

Aeros versus frames. Fig 4 shows that the split between aeros and frames has remained relatively constant for the last several years, with the latter capturing 84% to 88% of the business. But aeros are the clear choice among users for gas turbines rated between 18 and 65 MW, which includes all the LM engines supported by WTUI (Fig 5).

Simple cycle versus combined cycle. About 71% of the gas turbines ordered last year for US service will serve in combined cycles, the balance in simple-cycle applications. This percentage is significantly higher than the 61% averaged over the last five years, based on Axford's numbers. Going back further in time, the market split was closer to 50/50, the consultant said. Perhaps the ability of the latest combined cycles to start faster because of equipment design improvements and better startup procedures make owner/operators more inclined to cycle these units and compete against simple-cycle engines for some business that in the past was almost exclusively theirs.

The SPS Report

CEO Sal DellaVilla and his team of engineers at Charlotte-based Strategic Power Systems Inc (SPS) trend the performance of gas and steam turbines worldwide, enabling owner/operators to benchmark their assets against peers. SPS data are held in high regard

All of the great things that WTUI has accomplished are due in large part to Jim's passion and vision: To create and grow an independent forum for aeroderivative gas turbine professionals. Other GT user groups have been set up to replicate WTUI but none have come close to reaching the platinum standard set by Jim Hinrichs.

Mark Axford, *Axford Turbine Consultants LLC*

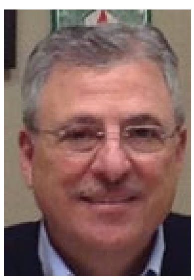
There are a lot of titles that come to mind when I think of Jim Hinrichs: manager, leader, professional, teammate, mentor, friend. I imagine anyone who worked with Jim would agree. I particularly admired his ability to communicate, his sense of organization, his energy and real love for what he was doing. Jim once described work in the power industry as "fun" and you could feel that when you were around him. I was honored when Jim recruited me to work with him as a member of the WTUI Board of Directors. I recall being surprised—overwhelmed—later, when Jim asked me to consider succeeding him as the organization's president. Those of you who knew Jim know he was persuasive, his zeal was infectious; I accepted. I'll always be grateful for his nomination.

Jon Kimble, *WTUI President Emeritus*

Everyone who knew Jim, knew him as a friend, and "oh by the way," he was president of WTUI. His sense of humor and inability to say anything negative about anyone, even me, made him a special guy and the right person to lead the organization. Our discussions over the years evolved from engines, schedules, contracts, regulations, etc, to wives, families, dreams, and plans for the future. I am very proud to say I was Jim's friend and sidekick for the last 30 years. Charlene, Ida, and I will miss Jim and the times we spent with him and Susan, especially our "not so quiet" lunches and dinners. In case you didn't know, Jim had a very infectious laugh. We were always the loudest table.

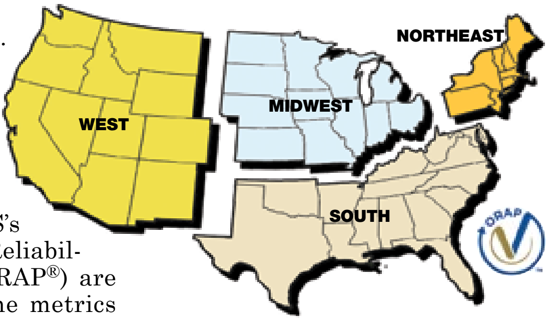
Mike Raaker, *Raaker Services LLC; WTUI VP Emeritus*

Today I received some very devastating and unbelievable news: the passing of a good friend, Jim Hinrichs. The mark of any man is how he has touched the lives of others. Jim touched so many others, and in so many ways, he will never be forgotten. WTUI is heading toward 25 years; Jim left his indelible imprint all over Western Turbine. Those of us who knew and worked with Jim know the measure of his contribution. Those who never had the opportunity to meet Jim, and today participate in WTUI, reap the benefit of his hard work. Rest in a well-deserved peace, Jim.



Salvatore A DellaVilla Jr, *CEO, Strategic Power Systems Inc* by WTUI and its members. While preparing for the 2014 conference, the company's experts compiled the following summary of aerounit performance over the last several years.

Data extracted from SPS's proprietary Operational Reliability Analysis Program (ORAP®) are presented in Table 1. The metrics presented—annual service hours and starts, service hours per start, service and capacity factors, availability, and reliability—were calculated using data gathered across the globe from plants that participated in the ORAP program in 2013, as well as during the 2008-2012 period used in the comparison.



The information is presented by duty cycle. Interesting to note is that for peaking and cycling units, annual service hours and starts, as well as service hours per start, increased significantly from the averages compiled for the 2008-2012 period to the numbers recorded in 2013. And as you might imagine, there is a reliability and availability penalty associated with increased operation. Availability and reliability numbers for both peaking and cycling units were slightly higher in the 2008-2012 period than in 2013.

One of the goals of the Western Turbine meeting is to help owner/operators recapture that lost performance. While past performance may not predict future performance, it does matter and should be understood because it sets market expectations and establishes the baseline for product improvements.

Regional impacts. To better understand how operating paradigms varied by region from 2008-2012 to 2013, SPS engineers compared ORAP capacity-factor and reserve-standby-factor data for the Northeast, South, Midwest, and West in Table 2. Noteworthy is that low gas prices, combined with the need to support intermittent renewables, increased the aggregate capacity factor for aeros in the middle of the country by 30% and in the Northeast by 25%.

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

Parameter	2013 Aero	2008-2012 Aero
Peaking units:		
Annual service hours	901	569
Annual starts	126	105
Service hours/start	7.2	5.4
Service factor, %	10.3	6.5
Capacity factor, %	8.5	5.7
Availability, %	92.8	93.9
Reliability, %	95.9	97.5
Cycling units:		
Annual service hours	2849	2241
Annual starts	178	161
Service hours/start	16.0	13.9
Service factor, %	32.5	25.6
Capacity factor, %	26.5	20.0
Availability, %	92.2	92.3
Reliability, %	96.5	96.7
Base-load units:		
Annual service hours	6045	6237
Annual starts	77	86
Service hours/start	78.2	72.7
Service factor, %	69.0	71.2
Capacity factor, %	58.5	59.9
Availability, %	92.6	92.0
Reliability, %	96.9	97.1

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

Parameter	2013 Aero	2008-2012 Aero
West:		
CF, %	22.0	28.5
RSF, %	62.7	54.0
Midwest:		
CF, %	9.0	6.9
RSF, %	78.1	82.1
Northeast:		
CF, %	18.4	14.7
RSF, %	72.0	71.1
South:		
CF, %	16.0	17.2
RSF, %	75.7	74.4

Note: West includes Alaska and Hawaii

Social events

Social events are critical to the success of every user group because they allow attendees to meet in a relaxed environment and expand their networks for problem-solving. There were five major social events on the agenda for the 2014 meeting, made possible, for the most part, by vendor contributions. Here are thumbnails:

- Sunday golf was at the Escena Golf Club, a Nicklaus-designed, 7200-yard championship course. Format: four-person, 18-hole shotgun scramble. Chairmen: WTUI Treasurer Wayne Kawamoto and VP Jim Bloomquist. There were 138 participants this year—far too many to mention (Figs 6, 7).
- Sunday tennis was at the Plaza Racquet Club. Only seven participants this year (Fig 8), perhaps because the sport is too strenuous (unlike golf, tennis players actually sweat).
- Jeep tour for significant others of the Palm Springs Indian Canyons focusing on the history, culture, and lifestyle of the Cahuilla Indians, whose ancestors lived there. There were more than 50 participants in this event (Fig 9).
- Evening reception at the Palm Springs Air Museum featured aircraft from WW II to present. Plus Top Gun Academy, the Andrews Sisters on the Bob Hope

6. Bumper cars. First car to the greens wins the tournament

7. Marginal golfers, but perhaps the best-looking foursome (l to r): Tripp and Sal DellaVilla, Strategic Power Systems Inc; Don Haines, plant manager, Panoche Energy Center, and LMS100 Breakout Chair; and Steve Wenger, Camfil Farr Power Systems

8. Champions all. Ladies (l to r): Svitlana Palona, CSE Engineering Inc (2013 champion); Tina Toburen, T2E3; and Susan Hinrichs. Men: Morgan Hendry, SSS Clutch Co; Corey Mullen, Clean Air Engineering; Jackson Chu, ST Aerospace (2014 champion); and Jim Hinrichs, Veresen Inc

9. Explorers. Jeep tour of the Palm Springs Indian Canyons

10. Reliving the air battles of WW II at the Palm Springs Air Museum

Stage, sidebars with volunteer pilot-historians who actually flew the planes (Fig 10).

- Evening reception alongside the huge Renaissance Hotel pool was sponsored by the depots and featured foods and adult beverages from the sponsors' countries—Canada, Germany, Japan, and New Zealand.

Awards

WTUI presents awards annually during lunch on the first two days of the meeting. At one, golf and tennis awards are the focus; at the other lunch, recognition is given for service to the organization. This year, the CCJ's Best Practices Awards to LM aeros was integrated into the program. Awards included the following:

Golf. The first place men's team was represented by Andy Stewart, A&I Component Support Ltd; Kevin Roller, AAF International; Jerry Weinle, GE Distributed Power; and Kyle Bryan, TurboCare.

Tennis. Jackson Chu, ST Aerospace, received the championship racquet.

WTUI Service Awards went to Directors Ed Jackson of Missouri River Energy Services, Charles Byrom of the Anaheim Public Utilities Dept, and John Baker of Riverside Public Utilities (Figs 11, 12).

Best Practices Awards went to the following plants:

- For Monitoring and Diagnostics, Panoche Energy Center, owned by Energy Investor Funds and operated by Wood Group GTS Power Plant Services (Fig 13). Plant staff implemented a real-time performance monitoring system to maximize plant efficiency based on contractual obligations, resulting in a substantial increase in variable revenue.
- For Monitoring and Diagnostics, Corona Cogen, owned by WCAC Operating Company and operated by CAMS (Fig 14). In-house development and implementation of a comprehensive interactive plant management system effectively streamlines regulatory compliance and plant maintenance. Benefits include lower operating costs, higher availability/reliability, and increased transparency.
- For Performance Improvement, Apizaco Cogeneration, owned by Procter & Gamble and operated by Wood Group GTS Power Plant Services (Fig 15). The plant continually experienced loss of power output because of compressor fouling from volcanic ash. A more aggressive regimen of offline compressor washing and installation of an upgraded IGV assembly provided the additional power needed to satisfy customer requirements. CCJ

Editor's note: Technical coverage of the 2014 Western Turbine conference will appear in the next two issues of CCJ.

11, 12. WTUI President Chuck Casey presents service awards to Ed Jackson (left) and Charles Byrom

13-15. CCJ Editor Bob Schwieger presents Best Practices Awards to Don Haines, plant manager, Panoche Energy Center; Wayne Kawamoto, plant manager, Corona Cogen; and Carlos Avalos, lead operator, and Karl Bryan, plant manager, Apizaco Cogeneration

CTOTF aggregates its coverage of aero engines

Only a few months away from its 40th anniversary, CTOTF™ never stops evolving to meet the industry's information needs. Perhaps that's why it's the most senior user group—by more than a decade—serving gas-turbine owner/operators. Jack Borsch, VP O&M at Colectric Partners, was not in the chairman's chair very long when he began making organizational adjustments. Recall that Borsch replaced Bob Kirn at the helm last fall, when Kirn retired from TVA.

One of the first things Borsch did was to build more structure into the aeroderivative portion of the organization's program, putting the various engines under one umbrella and assigning experts to guide the coverage for each of the four OEMs involved: Pratt & Whitney (now PW Power Systems), Rolls-Royce, GE, and Solar Turbines. Here's how the CTOTF Aero Roundtable team is arranged:

- Senior chair: Jim Riddle, production manager for CAMS-SEEDCO LLC.
- PWPS chair: Greg Dolezal, maintenance manager for Iberdrola Renewables' Klamath Cogeneration.
- Rolls-Royce chair: John-Erik Nelson, principal mechanical engineer, Braintree Electric Light Dept.
- GE chair: Dennis Oehring, director of field services and O&M for ProEnergy Services.
- Solar chair: William Chen, PE, operations engineer for the LA County Sanitation Districts' Calabasas Gas-to-Energy Facility.

The CTOTF spring meeting focuses on Rolls-Royce engines and the PWPS FT8; the fall meeting on the PWPS FT4, GE LM2500/5000/6000, and Solar GTs. If you are responsible for one or more of the thousands of Solar machines populating the electric-power and oil-and-gas industries and looking for an independent forum that encourages information exchange among users, this may well be your best option. Consider registering for the fall meeting today (see ad, p 79). The remainder of this article offers a flavor of a typical program for Solar engines, based on information shared at last fall's meeting.

There were three prepared presentations and a discussion forum


Riddle


Dolezal


Nelson


Oehring


Borsch

at the fall 2013 Solar Roundtable. Ken Mertz of AAF International reviewed the benefits of HEPA filtration for maintaining compressor efficiency while Marcus Bastianen, PE, Everest Sciences Corp, discussed the principles of hybrid inlet cooling for gas turbines to extract maximum power and efficiency from small- and medium-size engines. Finally, John Kyser, associate civil engineer for the East Bay Municipal Utility District, shared lessons learned in bringing East Bay's first GT into commercial service.

Users generally think HEPA filters are new to gas turbines in power generation service, but that's not so. AAF International, for example, installed its first HEPAs on a land-based GT (LM1600) in mid-1992. Earlier use was offshore. Mertz began by providing perspective on the quantity of particles captured by a HEPA filter that would penetrate a conventional fine-dust filter. Efficiency is what's reported, he said, but penetration is what's important.

The filter standard you're probably most familiar with is ASHRAE 52.2. It ranks particle capture capability using a MERV (Minimum Efficiency Reporting Value) rating from 1 to 16. The most efficient filters for preventing fine particles from entering the compressor are at the upper end of that scale. Your GT filters likely are rated MERV 14 or 15. The first removes from 75% to 85% of the particles in the inlet air between 0.3 micron and 1 micron; MERV 15 captures 85% to 95%. Both MERV 14 and 15 remove more than 90% of particles 1 micron and larger.

But an important point to keep in mind is that the particles of greatest concern regarding compressor fouling are smaller than 0.5 micron. This means any filter with a MERV rating could allow all particles smaller than 0.3 micron to pass through it and still meet the ASHRAE specification. The normal distribution of particles typically found in urban ambient air indicates that there are 100 times more 0.1-micron particles than 0.5-micron particles.

HEPA filters are rated according to EN1882 (a European standard), which is based on the minimum capture rate of the most penetrating particle size. MPPS, in plain English, is the particle size that has the lowest capture efficiency for the media tested. The defining size usually is in the range of 0.05 to 0.2 micron. The standard requires that MPPS particle capture be at least 99.5% for an E12 rarting. In the particle size range of greatest interest—up to 0.5 micron—a Univ of Michigan study showed that a new

E12 HEPA captured 200 times more particles than a new MERV 15

With the session focus on the Solar Mercury, Mertz offered a side-by-side comparison of two Merc 50s located about 10 miles inland from the coast and subjected to an occasional marine layer. One engine was equipped with MERV-13-rated cylindrical/conical-style inlet filters, the other E12 with pre-filter wraps. While the filter houses have pulsing capability, that feature is not used.

Test results based on 4500 operating hours were extrapolated to 8000 hours and the following conclusions were drawn:

- The E12-equipped engine produced 3.6% more power than the GT with MERV 13 filters.
- Heat-rate improvement favored the E12 engine by 2.32% over the unit with MERV 13 filters.

Mertz's presentation is available at www.ctotf.org.

Indirect/hybrid inlet cooling. Everest Sciences' air-inlet solutions are particularly well suited today to gas turbines up to about the size of an LM2500, a fact reflected by the more than 10 projects the company has in service. Bastianen offered case studies on three Solar machines given the session's focus: a Taurus 60 generating power in the Southwest, a Mercury 50 on the West Coast producing power from the combustion of landfill gas, and a Taurus 70 in pipeline compression service in the Northeast.

The speaker described the following three turbine inlet cooling systems available from Everest Sciences:

- ECOCool reduces the temperature of ambient air by evaporation in a high-tech crossflow heat exchanger. Cool air leaving the crossflow exchanger then is used to cool ambient air for combustion in an indirect air-cooled heat exchanger. The key point: Combustion air is cooled, and its density is increased, without adding moisture. Next, the combustion air passes through a wetted-media evap cooler before entering the compressor.
- ECOChill has the same first two steps as ECOCool—referred to as the Everest Cycle—but it uses a chiller instead of an evap cooler as the final step. Note that the chiller here is substantially smaller than one used in a conventional chilling system because some of the cooling already has been done by the Everest Cycle. The smaller the chiller, the more *net* power output and the higher the *net* engine efficiency.
- Hydro-FlexCool is a variant of the Everest Cycle (the first two steps in ECOCool). Its indirect evaporative heat exchanger uses brackish or reclaimed water and air as the first step in turbine inlet cooling.

Case study 1: For the Taurus 60, the *net* yearly economic value associated with using ECOCool for 11.2 months is more than half a million dollars. The engine produces an additional 3.1 million kWh (net) annually—roughly split 2:1 between off-peak and on-peak production. Average heat rate and emissions for the incremental power is 25% less than for the base case.

Case study 2: For the Mercury 50, the *net* yearly economic value is more than $350,000 using ECOChill for 10.2 months. The engine produces an additional 2 million kWh (net) annually, nearly 30% of that on-peak. Average net heat rate and emissions for the incremental power is 19% less than the base case.

Case study 3: For the Taurus 70, the *net* yearly economic value is more than $1.2 million using ECOChill for 6.1 months. The engine annually produces almost 3.5 million shp more with this inlet cooling solution. Average heat rate and emissions for the incremental power is 21% less than for the base case. Unlike case studies 1 and 2, here fuel costs are passed along to the customer, improving economics and enabling project payback in less than one year.

Commissioning a Merc 50. Kyser's 4.6-MW machine joined three 2.1-MW recips operating at the Oakland wastewater treatment plant since 1986. All generating units burn digester gas with a heating value of about 600 Btu/scf. About half the gas comes from sewage, the remainder from commercial wastes (winery, restaurants, etc) delivered by truck.

East Bay's treatment plant consumes about 4.8 MW in handling and treating the approximately 60-million gal/day of wastewater flow (dry weather), plus trucked wastes. The original diesel/generators together could only manage about 4 MW on average; power purchased from PG&E made up the shortfall.

With biogas available and being flared, the utility decided to increase its generating capability. A gas turbine was selected as the prime mover because of its emissions and reliability advantages over the diesel alternative. Design began in July 2007 and the turbine/generator entered commercial service in November 2011.

A new gas conditioning system, rated at 3000 scfm, was installed as part of the turbine project to serve all generating units. It removes siloxanes using activated carbon. Clean digester gas exiting the conditioning system at about 6 psig is compressed to 230 psig for the Merc 50, and moisture is removed. At full load, the Solar engine consumes about 1200 scfm of the 2000 scfm of biogas produced by the digesters. The balance is burned in the diesel/generators and excess power is exported to PG&E. A heat-recovery unit in the turbine exhaust stream is used to warm water for the digesters.

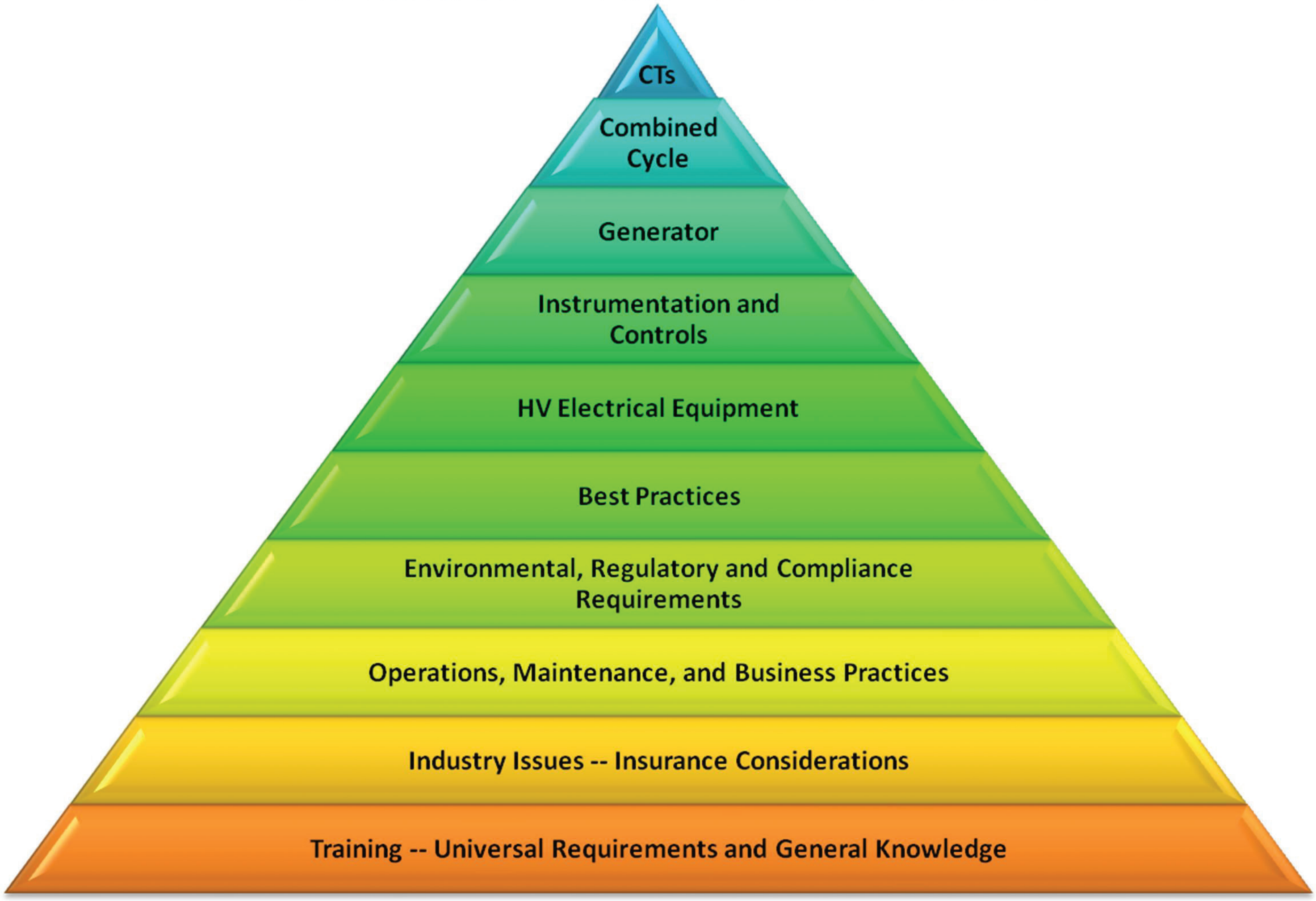
Operating a generating facility on biogas can be challenging because gas production varies with waste flows and energy content. One slide showed gross electric production during a two-week period in spring 2012. Average generation was about 6 MW over that time but there were a couple of days when the plant produced less than 4 MW and a few days when it generated more than 8 MW.

The most difficult problem facing East Bay during the Merc 50's first year of operation was ablation of fuel-injector effusion caps and collateral damage to turbine blades downstream. The issue was first detected during a routine inspection by the OEM in July 2012. A laboratory investigation at the end of August concluded that the injector damage was caused by exposure to high temperatures. The melting temperature of the effusion cap was 2400F, with the tip expected to operate at about 1600F. Laboratory tests found no evidence of corrosion or external contamination—from siloxanes, for example—in the combustion chamber.

Eight new injectors were purchased and installed; two of them were equipped with thermocouples behind their effusion caps. Data obtained revealed that temperatures reached from 1700F to 1850F during operation. The control system was programmed to trigger a shutdown at 1800F. Investigators believed that the original 6% pilot setting allowed flame too close to the injector tip.

That certainly contributed to the damage, but it was not the only cause. Engineering and testing over the next several months eventually solved the problem. During that period, injectors were replaced three times. Dialing back of the pilot to a 4.5% setting was one of the first corrective steps taken, but that fell short. The solution ultimately was an injector designed specifically for medium-Btu gas and a 1.5% pilot. Operating temperature of the upgraded injector is in the range of 1150F to 1250F. The new hardware had been in service for five months at the time of the presentation with no problems reported. CCJ

Consider Your Whole Plant



Participate in the 39th Annual Fall Combustion Turbine Operations Technical Forum™ and get it all

CTOTF™ and CT-Tech

September 7-11, 2014
Rancho Bernardo Inn
San Diego, Calif.

Registration information at www.CTOTF.org

Your direct connection to CCJ's Online Buyers Guide

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 backpressure, and long lasting. As the largest stocking distributor of industrial air filters in the West, AFC is equipped to meet your most urgent GT inlet filtration needs. Turnkey installation available.

Advanced Turbine Support

Has delivered unbiased fleet experience and superior customer service for more than a decade. Company provides users high-resolution borescope inspections, cutting edge ultrasonic and eddy-current inspections, and magnetic-particle and liquid dye-penetrant inspections in accordance with OEM Technical Information Letters and Service Bulletins.

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.

Allied Power Group

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

American Chemical Technologies

Provides state-of-the-art synthetic lubricants to the power generation industry. Founded more than 30 years ago in the US, ACT has grown to become an international supplier of value-added lubricants that provide superior benefits to equipment, the environment, and are worker-friendly.

ap+m

Largest worldwide independent stocking distributor of both aeroderivative and heavy industrial gas-turbine engine parts. As a stocking distributor of over 17,000 parts, ap+m provides internal and external engine parts as well as package parts to operators, end users, and depots worldwide.

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.

ATCO Emissions Management

With a full line of noise control products and the company's Balanced Design Approach™ to reducing installed cost, ATCO is a single-source pro-

ABOUT QR CODES

A wealth of data in the palm of your hand. Visit your App Store and download one of our suggested QR readers for your smartphone or tablet to access enhanced digital content and information.

Recommended, free, and easy-to-use apps:

- AT&T Code Scanner
- QR Reader for iPhone
- QR Reader for Android

vider of complete, cost-effective noise, emissions control, and heat-recovery solutions.

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.

Bibb EAC

Multi-discipline consulting engineering firm with a focus in the power industry, Bibb has participated in a variety of projects ranging from repowering existing plants to renewable energy.

Braden Manufacturing

Braden designs and manufacturers air filtration systems and filters, inlet cooling/heating, silencing, exhaust and inlet ductwork, diverter dampers, simple cycle SCRs, expansion joints, bypass stacks, and diffusers and plenums.

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 Co

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.

Cleaver-Brooks

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

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%.

Creative Power Solutions

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

CSE Engineering

Specializes in gas, steam, and hydro turbine control system upgrades, <ITC>® HMI replacement for GE Speedtronic™ MK IV and V, gas and steam turbine field services, Woodward parts and repairs. CSE is a *Woodward Recognized Turbine Retrofit Partner.*

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.

DeepSouth Hardware Solutions

Spent the last seven years stockpiling surplus Westinghouse WDPF, WEStation, and Emerson Ovation control systems. Many of the items we carry are cost-prohibitive or obsolete from the OEM. Our reputation is built on fast service, low prices, and quality hardware.

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.

DRB Industries

Leading supplier of gas-turbine inlet air filtration and cooling products along with turnkey installation. DRB also supplies cooling-tower parts and retrofits and evaporative media, and offers plant audits and inspections.

Dresser-Rand Turbine Technology Services

Specializes in the service and repair of heavy industrial gas and steam turbines. D-R provides aftermarket solutions for combustion, hot-gas-path and stationary and rotating components for most major gas-turbine models and frame sizes.

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.

Electrical Builders Inc

Expertise is in isolated phase bus (IPB) installations, retrofit/modifications, inspection, testing, cleaning, and repair. Services include non-segregated and cable bus installation and maintenance, specialty welding, transformer and generator breaker change-outs, and 24/7 emergency response.

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.

Environmental Alternatives

The first company to utilize CO_2 for cleaning HRSGs, having introduced this technology to the combined-cycle power market back in the early 1990s. EAI offers the most experience in the industry for this type of work.

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.

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 its corrosion. ZOKmx is a power cleaner formulated to replace solvents providing exceptional cleaning without the health and environmental risks associated with solvents.

Flow Systems

Specializes in repair and overhaul of gas-turbine accessories and steam-turbine equipment, as well as rotating equipment, utilizing modern techniques, highly skilled personnel and a state-of-the-art service facility to deliver superior quality, feasibility, and delivery to meet customer demands.

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.

Freudenberg Filtration

Global technology leaders in the field of air and liquid filtration. The company's Viledon and micronAir brands are synonymous with high-quality filtration systems for industrial applications. Additionally, Freudenberg offers a wide-ranging service portfolio to ensure that its filter systems provide optimum benefit.

Fulmer Company

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

Gas Turbine Controls

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

Gas Turbine Efficiency

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

GEA Heat Exchangers

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

W L Gore & Associates

Focuses on optimizing gas-turbine performance via the application of hydrophobic, membrane-based, HEPA inlet air filters, which eliminate the need for off-line washes while dramatically reducing or eliminating the power-output and heat-rate degradations that result from turbine fouling.

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.

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.

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.

Industrial Cooling Solutions Inc

Offers complete cooling-tower services--including engineering and construction of new towers, repair services, and preferred pricing on parts. Company affordably brings existing towers to full functionality.

JASC

Engineers and manufactures actuators and fluid-control components for power generation, aerospace, defense, and research applications to improve operational capability and performance.

Johnson Matthey

Worldwide leader in the development and manufacture of catalysts for the reduction of NO_x, CO, VOC, NH_3, and particulate emissions from gas turbines, boilers, stationary reciprocating IC engines, and industrial processes.

Kipper Tool Co

Emerging global leader in providing custom tool solutions and asset management that will work in extreme environments—including natural disasters, power outages, and planned maintenance outages. Provides vendor-managed tool systems for warranty, maintenance, replacement, and upgrade.

KnechtionRepair Tools

Manufactures tools designed to make thread repairs to both the female and male ends of cross-threaded compression fittings. In most cases, the repair will be accomplished without removing the tube from the system. This saves the O&M tech time and avoids additional downtime.

Kobelco Compressors America

Provides robust, high-efficiency fuel-gas compressors for use with all major types of gas turbines—including GE, Mitsubishi, Alstom, Siemens, Rolls-Royce, and Solar. Over 300 of the company's screw-type compressors have been supplied for gas turbines.

Liburdi Turbine Services

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

M & M Engineering

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

Mechanical Dynamics & Analysis

One of the largest turbine/generator engineering and outage-services companies in the US. MD&A provides complete project management, overhaul, and reconditioning of heavy rotating equipment worldwide.

Mee Industries Inc

Pioneered gas-turbine inlet fogging technology more than 20 years ago. Ever since, MeeFog™ systems have set the standard for cost-effective power augmentation. MeeFog has been used by, or approved by, every major GT manufacturer in the world.

Membrana, a Polypore 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.

Moran Iron Works

Global fabrication company committed to providing efficient processes, flexibility, and adaptability to ensure projects are completed on schedule. Moran specializes in one-of-a-kind fabrication and replacement of critical turbine components.

NAES

The energy industry's largest independent provider of operations, construction, and maintenance services—including equipment retrofit and repair, onsite turbine inspection/overhauls, and staffing solutions.

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.

Natole Turbine Enterprises

Provides gas-turbine consulting to the utility, cogeneration, IPP, and pipeline gas-turbine markets. These services are directed toward component repair, rotor refurbishment, overhaul, upgrading, and reapplication.

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 applications.

Nooter/Eriksen

World's leading independent supplier of natural circulation HRSGs behind gas turbines and a single-source supplier of custom-designed heat-recovery systems. NE's annual sales volume includes HRSGs for combined-cycle powerplants whose output exceeds 8 MW.

On-Site Equipment Maintenance

Solid reputation in the power industry for decades as the industry leader in rebuilding critical and severe service control valves, AOVs, MOVs, and turbine valves. Company also specializes in boiler feed pumps, circ-water pumps, condensate pumps, fuel pumps, and rotating equipment.

Phoenix Turbine LLC

Provider of high-quality, cost-competitive light and heavy industrial gas-turbine combustion and hot- section refurbishment services from "B" technology through "F" class. Company is a leader in shroud-block manufacturing and components for mature Westinghouse 501 combustion systems.

Pneumafil

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

Powergenics

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

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.

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.

CUSTOM PLATFORM

Allows users to obtain the product and services information they need to make buying decisions, including the following:

- Search by category, company, keyword.
- Details of products and services available.
- Photos, references, custom links, white papers.
- Single point of contact.
- One-click emails and phone calls.

REGISTER YOUR COMPANY TODAY

At www.ccj-online.com/bg and benefit immediately from participating in CCJ's Buyers Guide. Scan the QR code at the right with your smartphone or tablet to go directly to the sign-up page. Questions? Contact Susie Carahalios at 303-697-5009 or susie@carahaliosmedia.com.

Proco Products

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

PSM—an Alstom company

Full-service provider to gas-turbine equipped generating plants, offering technologically advanced aftermarket turbine components and performance upgrades, parts reconditioning, field services, and flexible Long Term Agreements (LTAs) to the worldwide power generation industry.

PW Power Systems

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

Rentech Boiler Systems

International provider of high-quality, engineered industrial boiler systems. Rentech is a market leader in providing HRSGs for cogeneration and CHP plants. It is in its second decade of designing and manufacturing high-quality custom boilers—including HRSGs, waste-heat boilers, fired packaged boilers, specialty boilers, and emissions control systems.

RMS Energy Co LLC

Professional, nationwide construction and consulting firm with highly trained and experienced installation professionals who perform all aspects of isolated phase bus (IPB) duct removal, reinstallation, retrofitting, and testing.

Rockwell Automation

Helps power producers navigate the technological, engineering, and design challenges they face in implementing new or upgraded control systems. Company offers integrated control, power, safety, and information solutions in one open, scalable architecture for complete plant-wide control.

Sargent & Lundy

Provides complete engineering and design, project services, and energy business consulting for power projects and system-wide planning. The firm has been dedicated exclusively to serving electric power and energy-intensive clients for more than 120 years.

Sentry Equipment

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

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.

Stellar Energy

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

Strategic Power Systems

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

Structural Integrity Associates Inc

Leading engineering and consulting firm dedicated to the analysis, control, and prevention of structural and mechanical failures. Integrates full scope of services, from inspection and condition assessment, to monitoring and remaining life analysis, repair or remediation, and total risk management.

Sulzer Turbo Services

The leading independent and most technically advanced and innovative services provider for all brands of mechanical and electromechanical rotating equipment. The company also manufactures and sells replacement parts for gas turbines, steam turbines, compressors, motors, and generators.

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.

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 Controls & Excitation

TC&E is an engineering consultation firm focused on turbine and generator controls services. Services include emergency troubleshooting, maintenance support, and equipment upgrades on GE MK I-VIe controls, exciters, and LCIs.

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 Technics

Global distributor of parts and components for industrial and marine turbine engines, providing support for GE LMS100, LM2500, LM5000, LM6000 as well as P&W GG8/FT8, GE Frame 3/5/6/7/9, and Rolls Royce turbines.

TurboCare

Comprehensive product and service solutions for rotating equipment manufactured by all major OEMs—including component repair, equipment refurbishment, system retrofits, engineering, and replacement parts.

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.

URS

Leading provider of engineering, construction, and technical services offers a full range of (1) program-management; (2) planning, design and engineering, (3) systems engineering and technical assistance, (4) construction and construction management, (5) O&M; and (6) decommissioning and closure services.

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.

Wabash Power Equipment

Full range of power equipment and services including: packaged boilers, rental boilers, and electric generators; diesel/generators and gas and steam turbine/generators; pulverizers and accessories; auxiliary equipment; spare parts.

Wood Group GTS

Leading independent provider of services and solutions for the power and oil and gas markets. These services include powerplant engineering, procurement and construction, facility O&M, repair and overhaul of gas and steam turbines, pumps, compressors, and other high-speed rotating equipment.

Young & Franklin

Premier fuel control supplier for combustion turbines for both long-term hydraulic solutions and, more recently, innovative all-electric controls solutions. Product scope supports natural gas, liquid, syngas, and alternative fuels as well as providing air controls to provide proper fuel to air mixtures.

Zokman Products

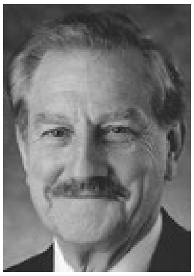
Distributor of ZOK27 and ZOKmx gas-turbine compressor cleaning detergents. ZOK27 is a single cleaner and inhibitor in one that cleans and protects the engine—and also inhibits corrosion. ZOKmx is a power cleaner formulated to replace solvents providing exceptional cleaning without the health and environmental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

BUSINESS PARTNERS

Gas turbines to celebrate 75th birthday

This coming Independence Day, a double birthday celebration is in order: the 238th for the United States of America and the 75th for the modern gas turbine (GT). Septimus van der Linden, president, Brulin Associates LLC, who has been involved in the development of GT power projects for more than half a century, called the CCJ offices to remind the editors that the first GT to generate power for an electric utility was successfully tested at full power on July 7, 1939.

Van der Linden is a volunteer technology historian always ready to help connect today's engineers and technicians with yesterday's equipment so they can better appreciate both how GT technology developed and the challenges that were overcome. The high-performance machines of today didn't "just happen."



Van der Linden

The first utility gas turbine to generate electricity, rated 4 MW, was developed by Brown Boveri & Cie (BBC) and installed in the town of Neuchâtel, Switzerland. The engine, an ASME Landmark, was restored by Alstom and relocated to the company's development and production facility in Birr, Switzerland, where it is on permanent display (Fig 1). Key to this engineering achievement, says van der Linden, was the successful demonstration of an efficient axial compressor, developed by BBC's Claude Seippel.

Continuing, van der Linden said both WW I and WW II, especially the latter, interrupted GT development. However, interest was rekindled after WW II because more-efficient power systems were required to burn expensive liquid fuels. Intercooled reheat recuperative designs led in innovation. Some burned heavy oil and were integrated into combined-cycle systems to maximize power density and efficiency.

Although Europe introduced the GT for power-generation and on-wing applications, it was the US that quickly exploited the technology, introducing better materials and coatings to allow the higher turbine inlet temperatures conducive to increased output and efficiency. The rapid advancement in GT technology has been described by some engineers as "incredible": In only 75 years, gas turbines have gone from 4 MW to the 470-MW Mitsubishi 701J, from 17% simple-cycle efficiency to more than 44% (GE's LMS100PB), and from compression ratios of 4:1 to 41:1 (LMS100PA).

The gas turbine's development reminds that "history is the bridge to the future." To dig deeper, van der Linden suggests the recently published "Gas Turbine Powerhouse," by Prof Dr-Ing Dietrich Eckardt, available through Amazon. The author has more than 40 years of experience in turbomachinery research and GT development (Alstom/ABB among others). Since 1992 he has been an honorary professor for the development of gas turbines at the Technical University Dresden in Germany.

Van der Linden says Eckardt's writing on the early development (prior to 1939) of gas turbines is based on "incredible" research into archives and written communications not previously published.

1. The world's first industrial GT on display at Alstom's facility in Birr, Switzerland

7F Users form STUG

Challenged by the time available to adequately address the technical concerns of gas-turbine owner/operators at its annual meetings, the 7F Users Group is transitioning its coverage of steam turbines and generators to a new forum—the Steam Turbine Users Group (STUG). The organization's website forum at www.stusers.org will support all steam turbines and generators used in combined-cycle plants and operate like the 7F forum at www.7Fusers.org. Register online today if your responsibilities include steam turbines and/or generators.

STUG's first conference will be held August 19-21 at the Omni Richmond Hotel, Richmond, Va, and focus on A-10 and D-11 steam turbines and their associated generators. The first day of the meeting will offer an in-depth review of Alstom's capabilities in the repair and overhaul of steam turbines and generators—including a shop tour. Day Two is reserved for user presentations, vendor breakouts, and a vendor fair. The third day is dedicated to presentations and a product fair by GE Power & Water.

Jay Hoffman, plant engineer for the 3 × 1 Tenaska Virginia Generating Station, powered by 7FAs, was elected the group's first chairman; Jake English of Tampa Electric Co is vice chair. Other members of the steering committee are Jess Bills of SRP, Gary Crisp of NV Energy, Brent Edwards of Southern Company Inc, John McQuerry of Calpine Corp, Bert Norfleet of Dominion Energy Inc, Lonny Simon of OxyChem, and John Walsh of Sundevil Power Holdings LLC.

While in Richmond, consider a working vacation, coupling attendance at the STUG meeting with some time off. There are plenty of fun things to do in the area—including, Bush Gardens, Virginia Beach, charter fishing, Revolutionary War and Civil War sites, Colonial Williamsburg, nearby Washington, DC, naval bases offering tours, etc.

CCUG to host 2014 meeting in San Antonio

Plant personnel often can't get to industry meetings because most are held in the spring and fall during the outage seasons. Dr Robert Mayfield, chairman, and the steering committee for the Combined Cycle Users Group, came up with a solution: Schedule the CCUG's annual meeting in summer at a vacation spot with plenty of things for the family to do while you're attending the conference.

The organization's fourth annual meeting will be held August 11-13 at the Westin Riverwalk in San Antonio (www.ccusers.org). CCUG conferences are dedicated to formal presentations and attendee-driven discussion sessions focusing on the design, construction, operation, and maintenance of the integrated plant. Additional topics addressed include NERC and other regulatory impacts on planned operations, environmental rulemakings, plant mods to achieve performance goals, safety initiatives, professional development, skills training, etc.

Mayfield

The upcoming program features sessions on the following topics, among others:

- HRSG inspection and maintenance, operational challenges and how to mitigate them, upgrades for ageing units, best practices for reducing outage cost.
- NERC rules from the plant's perspective—including audits, CIP, training, recent and upcoming regulations.
- Fast-start combined-cycle technology—opportunities for improving flexibility, what works/what doesn't.
- Challenges of modern control systems, and beyond. Discussion points include 3-D visualization, controls upgrades/retrofits, alarm management, HMI challenges and solutions, cybersecurity, mobile/portable devices.
- Upgrading, updating CC plants for improved efficiency and cost savings.
- Workforce challenges and changing paradigms.
- Water chemistry management/corrosion control.
- Performance software/diagnostic monitoring and assessment.

Local attractions are varied and many. Beyond the Alamo, the following, and others, await your visit: SeaWorld, Six Flags, helicopter tours, Riverwalk, Texas Ranger Museum, wine tours, wax museum, children's theatre, wildlife ranch, Natural Bridge Caverns, children's museum, zoo, stock show and rodeo, etc.

ACC Users Group to meet in San Diego

Howell

The Air-Cooled Condenser Users Group, chaired by Dr Andrew Howell, senior system chemist for Xcel Energy, announces that its sixth annual meeting will be held at the Sheraton San Diego Hotel & Marina, September 22-25. Registration is open on the website at www.acc-usersgroup.org. Questions related to the technical program can be answered by Howell (andy.howell@xcelenergy.com), those regarding sponsorships and other business matters by Sheila Vashi, (sv.eventmgt@gmail.com), the meeting coordinator.

Automation retrofit improves Frame 6 reliability

A complete automation retrofit by Metso on Lahti Energy's 1987-vintage, 50-MW Frame 6 gas turbine in Lahti, Finland, provided plant personnel a better view into the power generation process, enabling a shift in operating philosophy from reactive to proactive. Other benefits of the controls upgrade included higher unit availability and reliability, and safer operation.

Process Engineer Mikko Anttila said, "The turbine acts as a backup plant for the main plants, Kymijarvi I and II, at the same site. If one of those two goes down, and the GT is needed but will not start, we lose capacity. This is critical if the price of electricity is high at that time. Availability is particularly important to district heating customers in the winter when a forced outage with no backup translates to cold customers.

Project Engineer Jarmo Naukkarinen explained that an automation retrofit was necessary because the original control system had reached end-of-life and components were no longer available. In addition, personnel best qualified to maintain the system were retiring. Metso's solution included its GT control and protection system, machine monitoring, and information management.

Integration of the turbine controller

into a single plant-wide automation system benefitted Lahti Energy, which operates a network of smaller plants in the vicinity of Lahti. "An operator who knows how to operate one plant, and understands the process, is now able to run any of our plants," Naukkarinen noted. "There are fewer risks involved."

Operators also are able to carry out all functions and diagnostics through one system, significantly improving plant availability. Now that we have a single automation system, the project engineer continued, maintenance is simpler, as is training. Plus, plant staff can implement minor changes in software configuration.

Troubleshooting the Frame 6 is much easier today. All information from the turbine can be viewed in the Kymijarvi main control room on graphic displays having the ability to scroll back in time to examine events and process variables leading up to an alarm condition.

Direction of electric power generation in the EU uncertain

Houston-based consultant Mark Axford predicted flagging sales of GTs in the European Union this year, following a disappointing 2013 order book. His remarks on the soft EU market surprised at least some attendees at the Western Turbine Users Inc's 24th Annual Conference & Expo in Palm Springs, Calif, March 23-26 (see article elsewhere in this issue).

But a commentary by Netherlands Consultant Jacob Klimstra and Ing Giorgio Dodero of Italy's IPG Industrial Project Group Srl, following the Power Plant Flexibility Conference in Berlin, March 19-21, provided the explanation, pointing to the many challenges facing European power generators. Klimstra chaired the conference; Dodero was one of the speakers.

The two industry experts noted that the energy sector faced important decisions in the years ahead and that it was "not easy to foresee what will happen." They listed the following as having major impacts on generation planning, as well as the need for more information in these areas to support investments in new projects:

- Environmental protection.
- Impacts of renewables.
- Efficiency increase.
- Shale gas.
- Impacts of geopolitics.
- Economic recession in Western Europe.
- Globalization.

Many of the speakers and delegates attributed the fierce competition among alternative generation technologies to the impacts of renewables. Here are some of the takeaways from the meeting listed by Klimstra and Dodero:

- Conventional coal-fired units. Manufacturers expect to improve operating flexibility by achieving better coal pulverization.
- Combined cycles. Flexibility and efficiency improvements are in progress. The gas-turbine process could be changed.
- Reciprocating engines. High availability, fast start, and integration opportunities with energy storage may give recips new roles for improving grid stability and power quality.
- Nuclear plants. New roles for nuclear are under study. Adding flexibility to existing units is not easy.
- Integrated gasification/combined cycles. Gasification could have a role within "gas to liquids" plants, but their operating flexibility is considered poor.
- Energy storage is viewed positively for managing the integration of renewables into the generation mix.

Consensus was that it is not clear which of the foregoing technologies would achieve greatest market success in the future. Choice certainly will involve assessments of risks concerning gas supply (Germany gets

30% of its gas from Russia) and carbon capture and storage. CCS is expensive and does not cycle well.

Crackfit facilitates assessments of defects found during outages

Crackfit, a procedure and software solution developed by European Technology Development (ETD), Leatherhead, England, is designed to assess the remaining life of powerplant components with defects such as lack of fusion/penetration in welds, stress concentrations at sharp corners, emerging or embedded defects in straight pipes, etc.

David Slater (dslater@etd-consulting.com) business development manager at ETD, told the editors that the consultancy's personnel use Crackfit in their powerplant work. He said the user manual provided with the software should get you up and running; if not, training is available at additional cost. Slater added that NDE knowledge is not necessary for using this tool, but familiarity with defect-assessment codes and standards does help.

Previously available for sale only, the solution now can be leased for the duration of an outage. Several plants in the Middle East reportedly have used it to help decide if defects found during outage inspections must be repaired immediately or if work could be postponed to a more convenient time. A typical assessment using Crackfit takes only a few days. Previously it might have taken weeks and removed the opportunity for repair during the same planned outage.

As now configured, the software is mainly applicable for pressurized components in heat-recovery steam generators and other types of boilers, and piping. However, Slater believes that with some development effort, Crackfit's use likely could be extended to include turbine wheels, blades, and other components.

Calpine has a good 2013

Calpine Corp reported that in 2013 it achieved a record-low fleet-wide forced-outage factor of 1.6% and a starting reliability of 98.5%, thanks in large part to the company's ongoing preventive maintenance program. Fleet optimization enabled Calpine to deliver on customer commitments and commercial obligations, while maintaining strict cost management. One of the year's highlights was the announced acquisition of the 1050-MW Guadalupe Energy Center, a Texas combined cycle with two 2 × 1 power blocks.

Around the plants. Through December 2013, Calpine had completed the upgrade of 12 Siemens and eight GE gas turbines, adding 200 MW to its installed capacity. Four more units will be upgraded under this program. The company also began upgrading dual-fuel turbines in its North segment. Plus, it is evaluating opportunities to develop more than 1000 MW in the PJM market area that offer cost advantages—such as existing infrastructure and favorable transmission-queue positions.

Notable operational achievements in 2013 included the following: (1) Top-quartile safety metrics (0.88 total recordable incident rate); (2) 100% starting reliability by the Otay Mesa Energy Center and the Kennedy International Airport Power Plant.

Products/services

KnechtionRepair, a tool that repairs both internal and external threads of industrial standard two-ferrule-type compression tube fittings, is now offered for ¼-in. fittings. Previously, only ⅜- and ½-in. sizes were available (Fig 2; also see "Repair cross-threaded compression fittings quickly," 2Q/2013, p 129). The tool's unique holder and hollow-bore tap enables maintenance

2. Tool set for repairing cross-threaded compression fittings quickl

and shop technicians to repair damaged threads on compression fittings made by Swagelok®, Parker, Hy-Lok USA, Superlok®, Gylok, and others within minutes, as the video illustrates (access by scanning the QR code).

Tests to verify the effectiveness of KnechtionRepair (www.knechtion-repair.com) were conducted on three test samples of $3/8$-in.-diam stainless steel tubing with a wall thickness of 35 mils. In all three cases, no leakage was observed at the tube fittings, indicating a leak-proof connection—even with up to three threads removed from the fitting nuts. All test samples failed by rupture of the tubing wall at pressures in the neighborhood of 15,000 psig, which far exceeded the allowable design pressure.

Graver Water Systems (www.graver.com) engineers say that one of the ways power producers are managing operations to achieve peak performance is by optimizing steam-cycle water chemistry. They note that condensate polishing often was omitted from balance-of-plant requirements for combined cycles because of cost constraints. Many generating plants without polishers are experiencing flow-accelerated corrosion, longer-than-expected cycle starts, operational inefficiencies, and increased spending to replace damaged equipment.

Conversely, combined cycles with polishing have realized significant operational benefits beyond strict reliance on blowdown and chemistry treatment. Condensate polishing helps to safeguard expensive assets, stabilize cycle chemistry to achieve EPRI-recommended iron levels, prevent corrosion-product transport and deposition while optimizing unit start-up and operation. These benefits are especially pertinent to facilities with air-cooled condensers because of their high metal-oxide loads.

Graver offers the following options, among others, for asset protection:

- Precoat filter demineralizers use powdered resins to economically remove suspended and dissolved contaminants from the steam/water cycle. These systems often are installed after a plant is in service to improve its performance and availability.
- Disposable and backwashable filters trap suspended contaminants. While these short-term solutions do not remove dissolved contaminants, they are better than no treatment. Retrofit is relatively simple.

Oil Filtration Systems, Boerne, Tex, announces the availability of high-vacuum transformer oil purification (HVTOPS) and dielectric oil purification systems (DOPS) capable of improving dielectric strength to meet or exceed 40 kVA per ASTM D877 and interfacial tension to meet or exceed 40 dynes/cm per ASTM D971. Rental units are available.

Association news

American Boiler Manufacturers Assn. CCJ's editorial staff joins myriad others in mourning the passing of William Randall Rawson, ABMA President and CEO. Our association with Rawson goes back to 1988 when he joined the organization to back up Executive Director Russ Mosher and this editor was writing a 100-yr history of ABMA.

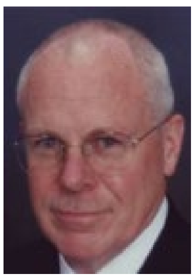
Interesting to note was that one of

the organization's primary reasons for forming was to establish standards for materials and workmanship to ensure boiler operational safety, which was a big concern at the time. ABMA's first materials specifications were adopted in October 1889, long before the ASME Boiler Code was formalized in 1915.

Rawson maintained safety and quality of workmanship at the forefront of ABMA's objectives throughout his tenure. The board of directors said "he aptly served to champion the mission of the ABMA and did so with integrity and utmost professionalism. His leadership and management of the organization help to foster the healthy, vibrant, and relevant association that continues after 125 years."

United States Energy Assn selects Lewellyn King, creator, host, and executive producer of "White House Chronicle," and founder and former publisher of Energy Daily, as the recipient of its 2014 United States Energy Award. USEA Executive Director Barry K Worthington said that King is honored for his role in support of the organization's mission and for his significant contributions to and promotion of energy issues globally.

Turbine Inlet Cooling Assn, Naperville, Ill, offers the following benefits to gas-turbine users at no cost:


Rawson


King

- Webinars on best practices for all turbine inlet-cooling technologies. Sign up at www.turbineinletcooling.org.
- TICA membership (offer good through June 30, 2014).
- An invitation to evaluate TICA information and services, and to give suggestions for the organization's future activities.

Executive Director Dharam (Don) Punwani encourages powerplant owner/operators to visit the TICA website to access a bibliography of TIC information, a database of TIC installations, and an online calculator for evaluating the performance of various cooling technologies.

Company news

Emerson Process Management Power and Water Solutions is selected by Union Power Partners, a subsidiary of Entegra Power Group, to replace turbine controls at Union Power Station in Arkansas, a 2200-MW facility having four 2 × 1 combined cycles, with its Ovation™ solution.

Alstom SA sells a portion of its steam power business to Triton, an investment fund. The sale values the unit that makes auxiliary components for air heaters and other heat-transfer equipment at about $1 billion.

Sulzer restructures, creating a new service division as part of a strategic move to focus the company's activities in three market sectors: power, oil and gas, and water. Integrating all services for rotating equipment into one division creates a leading role for Sulzer's HV coil production facility based at the Birmingham (UK) Service Centre.

Evoqua Water Technologies LLC is formed by AEA Investors LP after it acquires the municipal, industrial, and services water and wastewater treatment operations and assets of Siemens Water Technologies LLC.

NAES Corp finalizes the previously announced acquisition of E3 Consulting LLC, a nationally recognized independent technical and strategic business advisor to the energy industry.

PROFESSIONAL SERVICES

Plus new/used equipment, tools, parts

NV Energy announces the following manager responsibility changes at its Arrow Canyon Complex (Harry Allen, Chuck Lenzie, and Silverhawk Generating Stations): Forrest Hawman is named operations manager, Shane Pritchard maintenance manager, and Ron McCallum maintenance manager for outages and PdM for all three plants; David Hall continues as engineering manager for the complex. All report to Regional Director Steve Page.

Siemens AG announces a contract from Turkey's Enerjisa for the turnkey construction of Bandirma II. The 1 × 1 combined cycle is powered by an SGT5-8000H gas turbine, the 28th unit of this model series sold worldwide.

Sentry® Equipment Corp, Oconomowoc, Wis, is recognized by Bechtel Power for outstanding work on the EPC contractor's power projects.

Chromalloy, Palm Beach Gardens, Fla, renews its 10-yr agreement with Solar Turbines Inc to provide component repairs (turbine blades, nozzles, and cases, among other critical parts) and new production support for the manufacturer's engine sets.

NEM begins work on three once-through HRSGs for cogeneration units at the Shell Carmon Creek Project in Peace River, Alta. The supplementary-fired boilers will operate on exhaust gas from three SGT6-5000F(4) and be equipped with a diverter system and bypass stacks.

MHPS becomes a new acronym to remember as Mitsubishi and Hitachi complete JV Mitsubishi Hitachi Power Systems Ltd (www.mhpowersystems.com), a power generation systems company that combines the global fossil businesses of predecessors Mitsubishi Heavy Industries Ltd and Hitachi Ltd.

Cleaver-Brooks breaks ground for an expansion of its Lincoln (Neb) manufacturing facility. The addition is scheduled for completion in late 2014

The new company began operating February 1. MHI holds a 65% equity interest in the merged entity, Hitachi the remainder. The merged organization will deliver an expanded, broader portfolio of power generation products and solutions.

In related news, David M Walsh is appointed president and CEO of Mitsubishi Hitachi Power Systems Americas Inc with responsibility for all aspects of the company's business in the Western Hemisphere. Plus, MHPSA signs a contract with Grand River Dam Authority to supply a gas-fired M501J gas turbine/generator and an SRT-50 steam turbine/generator for the utility's new Unit 3 at its existing powerplant in Chouteau, Okla.

Foster Wheeler AG announces that it has entered into a definitive agreement with AMEC plc for the latter to purchase all FW shares issued and to be issued. AMEC offered for each outstanding share of FW common stock 0.8998 shares of its stock and $16 in cash. The transaction is expected to close in the second half of 2014.

Wood Group GTS is awarded a contract by the City of Austin to replace four obsolete and proprietary GE Millennium turbine control panels at its Sand Hill Energy Center. The new open-architecture Rockwell ControlLogix® platform will enable powerplant operators to modify turbine controls themselves to meet differing plant conditions.

ProEnergy is selected to continue the operation and maintenance of powerplants in Elgin and Gibson City, Ill, recently purchased from Ameren Corp by Main Line Generation LLC, a wholly owned subsidiary of Rockland Power Partners II. Elgin is a 460-MW simple-cycle facility powered by four Siemens W501D5A gas turbines; Gibson City, a 234-MW peaking plant, has two D5As.

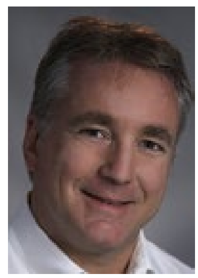
Platts announces the availability of the 2014 *UDI Directory of Electric Power Producers & Distributors,* which contains profiles of more than 4000 electric utilities and energy services providers in the US and Canada (www.platts.

com). The weighty tome also includes the names/titles of 17,000 energy executives, listings for 280 associations, power pools, and independent system operators, plus 150 agencies and commissions. Purchase options include hardbound book, mailing list on CD-ROM, statistical profiles on CD-ROM.

People

Phoenix Turbine LLC announces the addition of James Coyle as director of metallurgy and advanced technology to support the development of advanced repairs for gas-turbine parts. Coyle, who has a post-graduate degree in metallurgical engineering, has more than 30 years of experience in superalloy repairs and parts life extension.

ProEnergy announces the appointment of Mike Brady as SVP Energy Services, with responsibility for the day-to-day leadership and business activities of the unit. He brings to the company nearly 25 years of industry experience—including engagements at TAS Energy, where Brady was president/COO, Pratt & Whitney, and GE.


Brady

Index to advertisers

501F/G.... 93
AAF 17
ACC Users Group.... 87
ACT Independent Turbo Services 19
Aeroderivative Gas Turbine Support Inc 71
AGTServices Inc.... 97
AP+M.... 77
Braden Manufacturing LLC 43
Bremco Inc 61
CAMS 97
CCJ Buyers Guide.... 85
Cleaver-Brooks.... 15
Combined Cycle Users Group 41
Conval Inc 11
CTOTF 79, 88
Cust-O-Fab Specialty Services LLC 44
Cutsforth Inc.... 7
Donaldson Company Inc.... 57
Dresser-Rand Turbine Technology Services 29
Eagle Burgmann USA Inc.... 45
ECT.... 52
Environmental Alternatives Inc 31
Esco Tool.... 65
Frame 6 Users Group 98
Fulmer Co.... 49
Gas Turbine Controls Corp.... 47
Generator Technical Forum 95
Graver Technologies.... 62
Haldor Topsoe 33
Hillard Corp 55
HRST Inc 96
Hydro Inc.... 4-5
Hy-Pro Filtration 40
IPG-Industrial Project Group SpA 90
Industcards.... 91
JASC, JASC Installations 27
C C Jensen.... 21
Kobelco/Kobe Steel Ltd 13
Knection Repair.... 39
Liburdi Turbine Services Inc 65
Mechanical Dynamics & Analysis, Ltd.... 53
Membrana Filtration 64
Mistras Group Inc.... 9
Mitsubishi Hitachi Power Systems.... 50-51
NAES Corp 96
National Electric Coil 68
Natole Turbine Enterprises Inc 96
NEM Energy.... 63
NRG Energy Services.... 37
Ovation Users Group.... 94
Phoenix Turbine LLC 60
Platts 92
Praxair Surface Technologies.... 46
Precision Iceblast Corp 25
Rentech Boiler Systems Inc 2
Roblicorp.... 52
Structural Integrity Associates Inc.... 59
STUG-Steam Turbine Users Group.... 67
Sulzer Turbo Services.... 99
Victory Energy 23
Wood Group GTS.... 100
X Subs 97
Young & Franklin Inc.... 35