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CCJ COMBINED CYCLE Journal

User Group Reports

Neutralizing amines and filming products are viewed by some of the industry's thought leaders as the next frontier in cycle chemistry. They offer the potential for reducing corrosion in heat-recovery steam generators, condensers, and steam turbines in plants not having the luxury of operating baseload and/or tight control of water/steam chemistry. Report brings you up to speed on a technology that promotes high plant availability and reduces maintenance costs.

HRSG FORUM WITH BOB ANDERSON

This year's event in Houston, like the HRSG Forum's inaugural meeting in Charlotte, addressed topics of immediate interest to HRSG experts and combined-cycle system owner/operators. There were spirited discussions before, during, and after the formal technical agenda. Participants networked freely within this consolidation of equipment details, operating trials and errors, and forward-looking ideas.

The world's largest conference supporting gas-turbine users attracted to Palm Springs in March more than 1000 attendees from 24 countries and 42 states. CCJ's coverage of this event begins with the best practices shared by in the following plants:

W.T.U.I. 1990 2018 Palm Springs 2018

■ Equus Power I, p 75 ■ J-Power Long Island Fleet, p 78 ■ Terry Bundy, p 76 ■ EVM I (Mexico), p 78 ■ Lawrence, p 80 ■ West Valley, p 82 ■ Pinelawn, p 84 ■ Shoreham, p 85 ■ REO Town Cogen, p 86 ■ Orange Grove, p 88 ■ Worthington, p 90 ■ Orange Cogen, p 92.

Compiled by Editor Clyde Maughan, a generator consultant of renown, and the steering committee of the Generator Users Group, this seminal work summarizing the presentations and discussions from the 2017 GUG conference was sponsored by Mechanical Dynamics & Analysis.

Best Practices Awards

Special Report

Features

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CCUG

2018 Conference and Discussion Forum
August 27 – 30
Louisville Marriott Downtown
Louisville, Ky

GUG GENERATOR USERS GROUP

2018 Conference and Discussion Forum
August 27 – 30
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CTOTF™

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MEETINGS
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2018

July 29-August 2, Ovation Users' Group, 31st Annual Conference, Pittsburgh, Westin Convention Center Hotel. Register for membership (end users of Ovation and WDPF systems only) at www.ovationusers.com and follow website for details. Contact: Kathleen Garvey, kathleen.garvey@emerson.com.

August 27-30, Combined Cycle Users Group (CCUG), 2018 Conference and Discussion Forum, Louisville, Ky, Louisville Marriott Downtown. Meeting is co-located with the Steam Turbine Users Group and Generator Users Group; some joint functions, including meals and vendor fair. Chairman: Phyllis Gassert, phyllis.gassert@talenenergy.com. Details at www.ccusers.org. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

August 27-30, Steam Turbine Users Group (STUG), 2018 Conference and Vendor Fair, Louisville, Ky, Louisville Marriott Downtown. Meeting is co-located with the Combined Cycle Users Group and Generator Users Group; some joint functions, including meals and vendor fair. Vice Chairman: Bert Norfleet, bert.norfleet@dom.com. Details at www.stusers.org. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

August 27-30, Generator Users Group (GUG), 2018 Conference and Vendor Fair, Louisville, Ky, Louisville Marriott Downtown. Meeting is co-located with the Combined Cycle Users Group and Steam Turbine Users Group; some joint functions, including meals and vendor fair. Chairman: Ryan Harrison, ryan.harrison@atco.com. Details at www.genusers.org. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

September 10-13, V Users Group, 2018 Annual Conference, Denver, Colo, Hilton Denver Inverness. Contact: Kelly Lewis, conference coordinator, kelly.lewis@siemens.com.

September 16-20, CTOTF Fall Conference & Trade Show, Chandler (Phoenix), Ariz, Sheraton Grand at Wild Horse Pass. Chairman: Jack Borsch, john.borsch@ihipower.com. Details/registration at www.ctotf.org. Contact: Ivy Suter, ivysuter@gmail.com.

October 8-11, ACC Users Group, Tenth Annual Conference, Colorado Springs, Colo, Cheyenne Mountain Resort. Details at www.acc-usersgroup.org. Registration/sponsorships contact: Sheila Vashi, sheila.vashi@sv-events.net. Speaker/program contact: Dr Andrew Howell, chairman, ahowell@epri.com.

October 7-11, 7EA Users Group, Annual Conference and Exhibition, Garden Grove, Calif, Hyatt Regency. Details/registration at http://ge7ea.users-groups.com.

November 13-15, Australasian HRSG Users Group, 2018 Annual Conference, Brisbane, Australia, Convention Centre. Visit conference website for details: https://www.eiseverywhere.com//ehome/ahug2018. Chairman: Dr R Barry Dooley, bdooley@structint.com. Submit abstracts for consideration directly to Dooley. Conference contact: Heather McDowell, heathermcdowell@meccaconceptconferences.onmicrosoft.com.

December 4-6, 501G Users Group, Mid-Year Meeting, Orlando, Fla, Hyatt Regency Orlando International Airport. Contact: Steve Bates, chairman, steven.bates@dynegy.com.

2019

February 17-22, 501F Users Group, Annual Meeting, Paradise Valley (Scottsdale), Ariz, DoubleTree Resort by Hilton. Chairman: Russ Snyder, russ.snyder@cleco.com. Details/registration at http://501f.users-groups.com when available. Contact: Tammy Faust, meeting coordinator, tammy@somp.co.

March 17-20, Western Turbine Users Inc, 29th Anniversary Conference and Expo, Las Vegas, Nev, South Point Hotel and Spa. Visit www.wtui.com end of summer for more information about the conference and registration. Contacts: Charlene Raaker, conference registration coordinator, craaker@wtui.com; Wayne Kawamoto, conference executive director, wkawamoto@wtui.com.

April 28-May 2, CTOTF 44th Spring Conference & Trade Show, St. Augustine, Fla, Renaissance World Golf Village. Chairman: Jack Borsch, john.borsch@ihipower.com. Details/registration at www.ctotf.org when available. Contact: Ivy Suter, ivysuter@gmail.com.

May 20-24, 7F Users Group, 2019 Conference & Vendor Fair, Schaumburg, Ill, Renaissance Schaumburg Hotel and Convention Center. Details/registration at www.powerusers.org when available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

July 22-24, HRSG Forum with Bob Anderson, Third Annual Conference, Orlando, Fla, Hilton Orlando. Details/registration end of summer 2018 at www.HRSGForum.com. Contact Alan Morris, amorris@morrismarketinginc.com.

September 15-19, CTOTF Fall Conference & Trade Show, Rancho Mirage, Calif, Westin Mission Hills. Chairman: Jack Borsch, john.borsch@ihipower.com. Details/registration at www.ctotf.org when available. Contact: Ivy Suter, ivysuter@gmail.com.

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Film-forming substances: The next frontier in cycle chemistry

By Steven C Stultz, Consulting Editor

If you've been in the power-generation business for a couple of decades—and made your bones at baseload, coal-fired, water-cooled plants, in particular—you may believe you know all there is to know about Rankine-cycle steam/water chemistry. Perhaps that's true, for that type of facility.

But with coal-fired plants being shuttered in increasing numbers you may find yourself transitioning to a combined-cycle facility starting one or more times daily and equipped with air-cooled condensers and designed for zero liquid discharge. This is a new ballgame with respect to chemistry. You can almost forget what you know; in any event, positively embrace re-education.

Neutralizing amines and filming products are relatively new to many in the industry because their potential for reducing corrosion in heat-recovery steam generators (HRSGs), condensers, and steam turbines was not of great importance to personnel at traditional steam plants operating baseload with tight control of chemistry.

In these days of must-take renewables they warrant consideration. If you attended either of the first two meetings of the *HRSG Forum with Bob Anderson* (www.hrsgforum.com) you likely are aware of how amines and filming products have benefitted some users.

EPRI's Steve Shulder provided a backgrounder on how these products work at the first conference. "Protect equipment against corrosion with neutralizing amines, filming products," co-authored by Shulder and colleague Mike Caravaggio, is a good primer on the topic and will answer many of your basic questions (CCJ No. 51, Fourth Quarter 2016).

Next, access online at no cost, the IAPWS (International Association for the Properties of Water and Steam, www.iapws.org) Technical Guidance Document (TGD) "Application of Film-Forming Amines in Fossil, Combined Cycle, and Biomass Power Plants" (TGD 8-16). This is said to be the first such public document published for the industry on the subject. It was developed under the leadership of Dr Barry Dooley of Structural Integrity Associates Inc, who serves as the executive secretary of IAPWS.

Dooley's presentation at the first HRSG Forum (2017) included information that he would share at the *First International Conference on Film Forming Amines and Products* in Lucerne, Switzerland, two months later. The well-respected chemist and metallurgist chaired both the Lucerne and second (Prague, Czech Republic, Mar 20-22, 2018) topical meetings. The 2019 conference will be held in Athens, Greece, next March.

It's probably fair to say that the chemistry of amines and filming products is somewhere in the middle stage of development: Some things are known, but there's a lot more to learn despite the use of some products for decades. In fact, even the generic name associated with these chemicals has changed recently.

Dooley told the editors that feedback from the 2017 Lucerne meeting indicated much confusion regarding the various terms used for film-forming substances—for example, film-forming amines (FFA), film-forming amine products (FFAP), film-forming products (FFP), and others.

So IAPWS used its leadership position in the international scientific community to adopt the term "film-forming substances (FFS)" shortly before the Second International Conference on Film Forming Amines and Products and then changed the name of the meeting to the *Second FFS International Conference.* It attracted about 70 participants from 30 countries, illustrating the increasing interest worldwide in understanding and applying FFS.

Under the FFS umbrella are two subsets of the technology: amine-based substances (FFA and FFAP), and non-amine-based FFPs.

The second international meeting provided a highly interactive forum for the presentation of new information and technology related to FFS, case studies of plant applications, and open discussion among users, equipment and chemical suppliers, university researchers, and industry consultants. The key messages from that conference:

- If everything is working well at your plant then consider really hard whether using an FFS will make any improvements. If not, consider that the application could cause problems.
- One clear case for application: If the shutdown frequency of the plant is going to increase, FFS can (perhaps) greatly improve offline protection.
- If you are considering use of an FFS for any application, be sure to read Section 8, "Operational Guidance for the Continuous Addition of an FFS," of the IAPWS technical guidance document referenced above. It will help you avoid mistakes and potential problems.
- Before applying an FFS to your plant, be sure its chemistry is well understood. Do not hesitate to hire one or more experts for advice before making a decision. Perhaps the biggest challenge facing users in FFS selection is the proprietary nature of these formulations. Suppliers typically are unwilling to disclose "what's inside." Don't inject anything into the steam/water circuit that you are not completely comfortable with.
- Get a thorough work-up on system chemistry before adding an FFS, this to develop a baseline condition for comparison purposes later.

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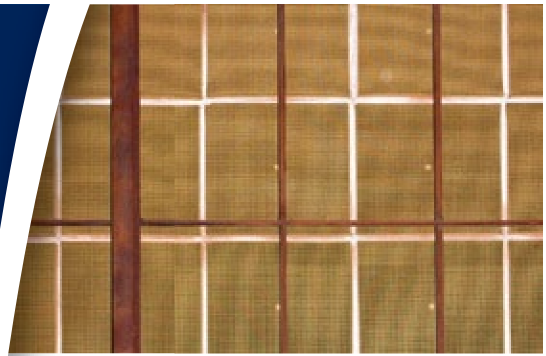

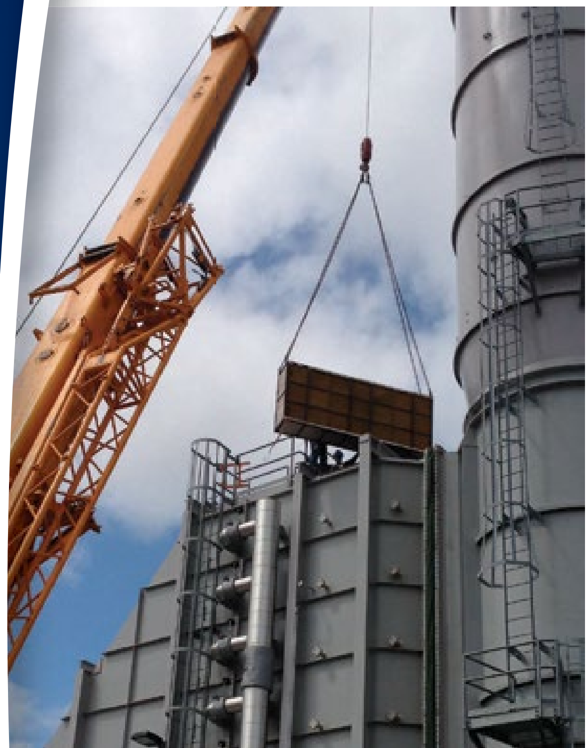

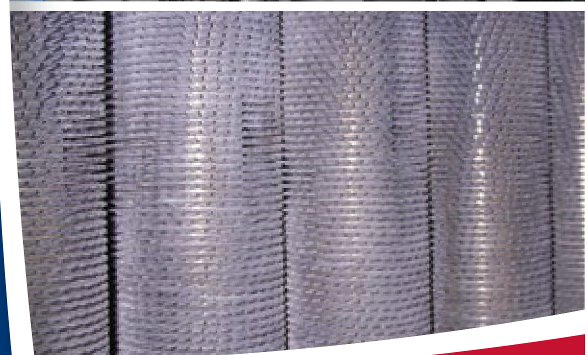

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FFS 2018 allowed plant owner/operators to get answers to many of their questions relating to the use of film-forming substances from the assembled community of international experts. A panel session focusing on key questions and uncertainties about FFS got "two thumbs up" from several attendees.

Other conference highlights included the following:

- Updates were presented on recent experiences at fossil, nuclear, and industrial plants worldwide. The experience at nuclear plants has been with octadecylamine (ODA), whereas a wide range of FFS is being applied to fossil and industrial plants. The experience of FFP on condensate polishing, and methods for determining FFA on surfaces, were discussed.
- Attendees shared ongoing research activities at different international organizations concerning decomposition products of FFA, distribution of FFA, measuring/quantifying the concentration of FFS in cycle water, adsorption kinetics of film formation, and the effects of FFS on flow-accelerated corrosion (FAC).
- Extensive discussions reviewed the possible benefits of using FFS. They also identified many problems still occurring worldwide in plants using FFS without the detailed knowledge suggested by Section 8 of the IAPWS TGD. However, there wasn't much open discussion on these problems. One of Dooley's goals for the next meeting is to dig deeper into specific experience issues.
- Two main conclusions from the conference: (1) Hydrophobicity does not always equate to protection, and (2) FFS cannot be quoted as "reducing" FAC simply by indicating a reduction in monitored iron levels. Regarding the second point, there should be before/after data for any application, with supporting photos if possible.
- The need for adapting sampling and monitoring concepts to the specific FFS chemistry applied was recommended.
- Gaps in knowledge and topics for further research were identified. For example, fundamental work remains to better understand the mechanisms at play with FFS. This includes film formation kinetics, equilibrium and stability, film structure (that is, thickness or number of layers), how absorption is affected by other amines, and the correspondence to the reduction in corrosion rate.
- Work is required to understand the mechanism of the interaction between FFS and surface oxides. This was discussed as "interfacial science" and should involve the interaction of the FFS film with existing surface to include, initially, Fe_3O_4, Fe_2O_3, FeOOH, CuO, and CuO_2. Also needed is work on the interactions that occur under feedwater conditions up to about 575F, where magnetite is soluble.

First international conference, presentation summaries

The principal goals of proper system-wide water chemistry are to limit deposits, reduce corrosion, and prevent carryover of impurities into steam turbines and downstream equipment. Driven by new flexibility demands on combined-cycle units, a fast-growing concern is HRSG component corrosion, especially during reduced-load operation or when offline.

Managing HRSG corrosion

Corrosion protection for HRSG internal surfaces traditionally has focused on a proper (high) pH level, typically maintained by adding ammonia (NH_3) and perhaps neutralizing amines (NH_3 derivatives). Some plants have embraced oxygenated treatment (OT) with condensate polishers and other controls to force a protective hematite layer on the metal surfaces.

More recently, some owner/operators have adopted various film-forming substances to enhance the effort and extend protection during shutdown.

As this experience grows, a possible new horizon in system treatment is coming into focus. Most users know that ammonia helps control pH, and specific pH can help combat FAC. They now want to know if a film-forming substance can both help control pH and coat the metal as a barrier, both online and offline, against corrosion. Perhaps this is too simplistic, but it states the overall question (the exact details of which can be left to the chemists).

In sum, O&M personnel want to protect as many metal surfaces as possible, whenever possible. The expectation (hope) is that FFS can create a barrier between metallic surfaces and the working fluid (water and steam) to prevent corrosion from occurring. Such treatment can also protect against all-too-familiar oxygen pitting when offline.

Interest is expanding because of cycling, but these products also show promise in more general areas: corrosion protection in continuous operation, reduced corrosion-product transport, and maintaining clean and smooth heat-transfer surfaces (steam turbine and condenser included).

Some industry observers believe this could be the next big step in power-station water chemistry. But it won't happen quickly. IAPWS was just the first professional organization to recognize the current limits of industry and scientific knowledge about FFS compounds, products, processes, benefits, and potential risks.

IAPWS/SCPWS

As mentioned in the opening section, IAPWS published the first international guidance for FFS—TGD 8-16—in August 2016. Only eight months later, it and the Swiss Committee for the Properties of Water and Steam hosted the first international topical meeting on film-forming amines and products in Lucerne, organized by Dooley and SCPWS President Marco Lendi of Swan Analytische Instrumente AG.

Operators, chemists, and researchers from utilities, suppliers, and laboratories were on hand to hear 30 presentations over three days and to discuss the trials, theories, and outlook for this new frontier. Attendees represented 20 countries.

Dooley pointed out that previous innovative and landmark cycle-chemistry changes all were backed by volumes of good scientific information. For FFS, such knowledge quantity and quality have not yet been achieved.

IAPWS and others have provided ongoing guidance for "the conventional treatment methodologies of volatile (AVT and OT) and solid alkali (PT and CT)," stated Dooley. Alkalizing amines have been applied worldwide as extensions to these methods, or as standalone treatments. More recently, film-forming substances have been introduced into the market and their use continues to increase.

"Unfortunately," explained Dooley, "there has been much misunderstanding and confusion for the owner/operators of exactly what these chemicals can achieve when applied." Guidance is also needed on "misapplication," he stressed.

The specific contents of most film-forming substances are considered proprietary by their manufacturers. With many new compounds in development, there is limited experience in their handling, feed requirements, performance issues, and measurement. Steam applications are a relatively

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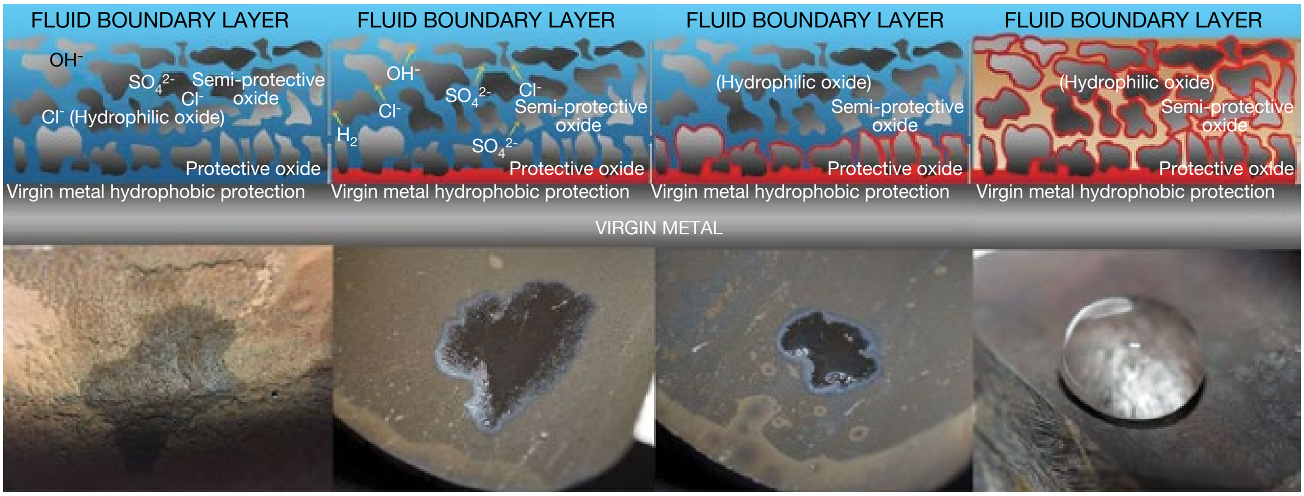


No protection
All oxide layers hydrophylic

Stage 1
Anodamine permeation to base metal
Cycle clearance
Limited visual oxide hydrophobicity
Virgin metal protection and hydrophobicity

Stage 2
Cycle clearance decreases
Partial semi-porous protective oxide hydrophobicity
Virgin metal protection and hydrophobicity

Stage 3
Semi-porous protective oxide free of inorganic contaminants
Cycle clearance completed
Complete hydrophobicity

1. Non-amine product was selected by a Dutch combined-cycle facility based on its hydrophobic properties, stability to at least 1112F, and non-toxic chemistry

new area, as is the targeting of specific surfaces for corrosion protection (versus bulk protection).

In presentations by chemical suppliers, end users, and others, measurement methods and procedures, along with trials and errors, were discussed in detail. Among methods reviewed at this inaugural event were gas chromatography, electrochemical impedance spectroscopy, photometry, direct photometrical measurement, and others. But the conclusion was that no viable online measurement method is currently available (yet will be required for proper monitoring).

Added to this, one presentation stated that the organic agents can be classified into five categories, although this does not fit all compositions used. Many of the products available on the market are multi-component proprietary mixtures containing constituents in more than one of these categories:

- Alkalizing amines.
- Oxygen scavengers.
- Chelants.
- Dispersants.
- Film-forming amines.

A startling conclusion was reached: "Mathematically we have a minimum of 480 different variations, and in real application the number is even higher."

Operating plant trials, results

Several operating plant trials and methods were discussed in detail as outlined below:

A Dutch combined cycle depends on immediate availability and faces daily stops and starts, as well as weekend shutdowns. Its operating range is between 50% and 100% of baseload.

Since commissioning in 2009, the facility has dedicated a great deal of time and effort on its cycle chemistry, with positive results. It began with OT (VGB guidelines), yet within a year had FAC indications in the LP drums. Chemistry was then adjusted in line with IAPWS guidelines and results improved. But they wanted to do "even better," to move "from good to excellent."

The owner/operator considered options for two-phase FAC control:

- Additional ammonia.
- Solid alkalizers.
- Neutralizing amines.
- Film-forming amines.
- Other.

Simply increasing ammonia (to achieve pH 9.8) was ruled out because of local wastewater restrictions. Solid alkalizers also were nixed (Benson HP and feedwater attemperation). The amines being used at the time gave better pH control but were breaking down, leading to organics and phase-transition-zone (PTZ) concerns in the steam turbine.

The plant selected a non-amine product based on its hydrophobic properties, stability to at least 1112F, and non-toxic chemistry (Fig 1). Some positive results have been experienced and these have contributed to the following significant long-term expectations: 1- to 1.5-hr faster cold starts, no steam sparging requirement during shutdown, effort and expense savings for layup, and reduced valve damage caused by corrosion products. Results are preliminary; the trials continue.

Three Belgian plants were examined, all facing what are now common challenges: flexible operations and standby readiness.

This presentation began with the familiar owner/operator dilemma:

- Start date, unknown.
- Stop date, unknown.
- Outage period, unknown.
- Standby for grid, yes.

The Belgian owner/operators asked two key questions:

1. How can a system be both conserved and available for the grid at the same time?
2. What can we do when an outage is extended from days to months?

Traditional outage methods meant nitrogen blanketing, pH increase and oxygen scavenging, turbine and condenser dehumidification, and eventually full dry dehumidification.

To avoid these steps, two FFS strategies emerged:

1. For planned, long-term outages, film-forming amines would be injected two weeks before the outage.
2. For unplanned outages, the plants would apply continuous FFA injection with standard water treatment.

Trials to date have shown some hydrophobicity in the condenser and feedwater tank. But looking at the plant in general, the hydrophobic layer is not always present. The conclusion is that the FFAP improves conservation efficiency, but overall corrosion protection is not yet confirmed.

This discussion led to an important

comment during questions: "Plants need to be careful that just because they are dosing with an FFS, this does not mean that the whole plant is now protected. Such a view could pose a major risk."

Coal-fired units also were reviewed, seeking better layup and storage protection. The selected product for a two-unit conventional coal-fired station in the US was an FFP. The first treatment in 2012 was for offline protection. Full-time dosing began in 2013, after chemical cleaning (Fig 2).

Both units had a history of iron transport with heavy deposits resulting in boiler tube failures and frequent boiler cleanings. Many improvement steps had been taken prior to FFP dosing, significantly reducing deposition rate, tube failures, and cleaning requirements.

In January 2016, one unit suffered an HP feedwater heater drain-line failure from two-phase FAC. But evidence of minor wall loss was traced back to 1997, and damage might have been critical before the new dosing program began. Preliminary conclusion: There appears to be value in feeding the product to reduce metals transport, but more data are needed to confirm.

Nuclear PWR contribution. Although IAPWS TGD 8-16 is not intended for nuclear plants, operating experience at pressurized water reactors is an important part of the continuing study of film-forming amines and products. Presentations on the secondary side of these reactor systems further clarified some potential benefits, including:

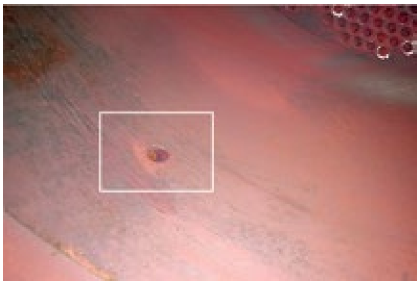
- Anti-corrosion properties and thermal stability of ODA film.
- The effect of ODA on removal rate of pre-existing magnetite deposits.
- The effect of ODA on ion-exchange resins and their regeneration.

ODA was being used in addition to ammonia/amine pH control.

In one thermal study, the ODA film was found to be stable. Also, ODA made the magnetite easier to remove. ODA application did not change the purification rate of ion-exchange resins.

In a second PWR presentation, anticipated long-term benefits include corrosion protection during transients, possible removal of tubing deposits, and enhanced heat transfer. However, effects on sensitive plant instrumentation as well as stringent regulatory requirements (changes that could impact licensing) were raised as cautions.

Nuclear plants typically are base-load stations. Shutdowns, however, can be lengthy. FFS applications for these extended layups are now being demonstrated at some plants. Nuclear compliance (regulatory) requirements will require rigorous testing and qualification. IAPWS members are participating in these initiatives, and a Technical Guidance Document is planned.



2. Hydrophobic surface in a coal-fired boiler. First treatment in 2012 was for offline protection; full-time dosing began a year later after chemical cleaning

Steam turbines

As plants continue to cycle, the steam turbine is affected by high alternating loads, and a shifting of the phase transition zone in the LP section of the turbine. This can lead to droplet erosion which causes damage on the turbine blade surfaces (areas of first condensate).

Steam-turbine discussions included washing and protection methods using ODA.

Faced with new demands for flexible energy production, a German plant was concerned with the increasing risks of LP-turbine deposits and corrosion. Standard cleaning methods were discussed, including turbine washing with ODA-treated wet steam after shutdown, and wet cleaning as the turbine was rotated through warm ODA-treated condensate by turning gear.

The preferred procedure was online cleaning by injecting ODA at full load either into the feedwater, into the condensate, or directly into the front end of the turbine.

Further turbine-related case studies were reviewed. One was treated with ODA in the condenser and also just before the turbine. Operators set a maximum ODA concentration of 2 ppm. This plant, in Hurth, Germany, had the online cleaning results shown in Fig 3. Stated the presenter, "Cycle treatment improved the corrosion protection during shutdown and had a positive effect on recommissioning at Knapsack 1.

"Total commissioning time was reduced from about eight hours to four. Time for reaching standard conductivity levels in steam during recommissioning was decreased from five to six hours to two to three hours." Also, no impact to the reliability of online measurement equipment was detected.

In a steam-turbine overview, Dooley emphasized that losses of up to 8% are associated with nucleation of moisture from superheated steam into the phase transition zone and the formation and release of liquid films on turbine-blade surfaces. This affects both reliability and efficiency.

He explained that these wetness losses are influenced by the size of droplets in the last LP stages of the turbine. The droplets, especially if large, impede thermodynamic equilibrium and can also lead to erosion damage in the blades and nozzles.

He then listed two methods of control: application of an electronic charge to introduce a corona and increase the nucleating ions, and (perhaps) by changing the surface tension in the turbine environment. The latter is a potential area for FFS.

Testing to date gives at least one summary: ODA is known to produce slight changes in surface tension and may improve steam-turbine efficiency. However, this benefit is limited to the LP turbine. Studies continue.

Polyamine conclusions

GE Water (now Suez) offered a recap based on 60 years of working with FFA compounds (the first ODA patent was issued in 1954). The company reported that it offers an FFS product for continuous dosing at preferred low

3. ODA treatment improved corrosion protection (condenser at left, last-stage turbine blades at right) during shutdown and had a positive effect on recommissioning at this steam plant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levels. For the past 15 years it has been working with new classes of chemicals for targeted corrosion protection and studying their corrosion performance, volatility, and decomposition. Work by several suppliers continues (Fig 4).

For system chemistry changes, there was strong caution to not simply "set it and forget it."

Meeting participants unanimously agreed that the starting point for any amine program must be a proper cycle-chemistry program, set according to international standards. IAPWS provides the guidance for such a program through its TGDs and other information available free-of-charge at www.iapws.org.

EPRI then wrapped up the technical sessions with a case study showing positive results using a stairstep or feathered approach. The example plant moved from conventional chemistry to a neutralizing amine (ethanolamine, ETA) treatment using less ammonia (1:5 ratio). This improved pH control, but iron levels remained too high. The plant then installed a temporary filming-amine feed station at the condensate pumps, and transitioned from ETA/NH_3 to FA/ETA (200-ppb active filmer). Fine-tuning adjustments followed.

Although testing and refinements continue, some conclusions have been reached:

Better pH control in the IP combats corrosion which minimizes HRSG inspections and repairs.

Filming can offer long-term surface protection; corrosion coupons showed effective beading and no detectable corrosion over 60 to 90 days.

The example process is believed by at least some as reasonable in cost.

Wrap-up

A recurring theme at the meeting was the list of possible benefits of FFS for fossil/HRSG plants, including the following:

- Low corrosion-product generation and transport.
- Shutdown protection under wet and dry conditions.
- Fewer tube failures from under-deposit corrosion and corrosion fatigue.
- Reduced or prevented FAC (single- and two-phase).
- Reduced or eliminated corrosion/FAC in air-cooled condensers (ACCs).
- Cleaner steam turbines; possible efficiency improvement.
- Shorter startup times.
- Optimum pH control in water and steam.
- Suitable for all-ferrous and mixed-metallurgy feedwater systems.

4. Testing of filming products has been ongoing for decades. The first ODA patent was issued in 1954

However, several problem areas, and many open issues, were identified, including these:

- Decomposition of added alkalizing amines.
- Elevated CACE (conductivity after cation exchange) in condensate and steam.
- Misidentification of real contaminants.
- Numerous proprietary mixes and blends.
- Incomplete analysis of product and amount to use.
- Increased boiler/HRSG evaporator deposition.
- Increased levels of deposits in tubes, headers, drums.
- No rugged application processes.
- Variable detailed documentation of FAC and ACC corrosion/FAC.

Plus, the unknowns are numerous. They include the ability to accurately measure filming products during operation, the exact impact on two-phase FAC in HRSG evaporators, and potential risks of under-deposit corrosion in evaporators.

There are more unknowns, but perhaps the best guidance dispensed is to study the IAPWS guidelines, then think carefully about the following meeting takeaways before launching a comprehensive program:

- Have a proper internationally recognized cycle-chemistry program.
- Know the exact chemical composition of any products you plan to add.
- Know the risks of FFS and dosing.
- Know the expected benefits, especially for plants forced into cycling operation.
- Know whether or not such a treatment program is appropriate for your particular plant.

Most importantly, know that there are still many unknowns.

Other topics discussed but not reported here included FFS application in the fertilizer industry, use in conventional industrial boilers, effects on aluminum (Heller cooling towers), use in distillation systems and low-pressure units, use in direct-contact geothermal plants, and specifics on laboratory analysis and measurement. CCJ

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Lube-oil cleanliness critical to long bearing life

By Brian Hulse, BDHulse Consulting Services LLC

"We have met the enemy and he is us."

Walt Kelly wrote those words for Pogo to speak in his comic strip, marking the first annual observance of Earth Day back in April 1970. He was making the observation that pollution of the planet was mankind's self-inflicted wound.

Listening to a presenter at the Western Turbine Users' 2018 annual conference talk about bearing failures in General Electric LM engines (aeroderivatives) and how root causes are difficult to nail down because of the extensive damage suffered in these events, I couldn't help but hear Walt's/Pogo's prophetic and accurate words in my head. Sadly, about nine times out of 10 we kill our bearings with the same thing Pogo was lamenting that day so long ago—trash.

LM bearings are designed for a service lifespan of approximately 28-billion revolutions (about 50,000 operating hours) in a very harsh environment. To successfully make that journey, they have to be (1) free from manufacturing defects, and (2) operated and maintained as designers intended.

A manufacturing problem usually shows itself within the first 10% of the design service lifespan (about 5000 operating hours in this case). Bearing designers call this L10. If a bearing survives its L10, statistically it has made it out of the "infant mortality" window, is presumed free of manufacturing defects, and should be capable of meeting the full design lifespan.

Assuming an LM bearing fails after the 5000-hr threshold, an operations and/or maintenance oversight is likely the cause. If we make one more assumption—that the engine has not been transported recently—thus eliminating the possibility of mechanical damage to the bearings, we've almost guaranteed that.

Important to the discussion is that GE aeros use internal air pressure to help offset shaft thrust in the machine. That air pressure, combined with the mechanical load-carrying capacity of a single ball bearing, balances the thrust loading of the shafts. Air-pressure balance must be monitored and, from time to time, as engine seals degrade through normal wear-and-tear, the air pressure must be adjusted. Failure to perform this maintenance task will usually result in bearing failure.

If we have operated the engine properly and within all limits, are out of the bearing infant-mortality window, haven't transported the engine recently, have been monitoring recoup curves, and then had a bearing failure, it's highly likely the cause is a trash problem, or more appropriately in the tribology vernacular, *contamination.*

How could this have happened? Lessons learned over the years point to these Top 10 ways contamination can kill your bearings:

No. 10, Mixing lubricants

Most plants store their lubricants in one place. Any one or more of the following factors could lead to a mixing event—possibly one with serious repercussions: an inattentive moment, a reshuffling of the drums, similarly painted drums, lack of or poor quality of training, poor lighting at night, colorblindness, the pressure of time.

No. 9, New-oil contamination (Part 1)

Although the number of confirmed events is low, it does happen. Metal wastage from the drum manufacturing

1. Bearing wear and tear is attributed to trash nine times out of 10

2. Poor housekeeping in the drum storage area can be a potent contamination source

3. Using one set of tools—funnels, containers, etc—for transferring oil from its storage location to the point of use can lead to oil degradation through mixing over time

process, fill process, and other steps can sometimes leave hard particles in a fresh drum of oil. Most plant facilities do not have filters on their drum pumps or whatever means they use to draw oil from their drums.

No. 8, New-oil contamination (Part 2)

Oils typically are delivered to powerplants in drums. Some facilities have covered drum storage areas, some do not. Even with a cover, rainwater, dust, etc, can collect on the tops of drums. If the drum top is not cleaned prior to opening, when the bung is cracked in it goes. Once a drum is opened and in use, this scenario can play out ever more easily. Keeping the drums and surrounding area clean is an ongoing battle, and the fighting is relentless.

No. 7, Planned/unplanned major maintenance

One of the major strengths of LM machines is their ability to facilitate major maintenance onsite. Whether a combustor change-out, a hot-section exchange, or a TMF (turbine mid frame) replacement, the work can be done at the plant. However, these maintenance activities also expose the bearing cavities and bearings, and can allow contaminants to enter the system. The need for vigilance during maintenance cannot be overstated.

No. 6, Routine maintenance

Filter-element replacement? Leaking hose? Damaged fitting? Checking finger screens? Any one of these routine tasks can introduce contaminants into the system and, ultimately, cause bearing failure. Anytime the system is cracked open, a cleanliness plan should be thought out and implemented to ensure protection against contamination.

No. 5, Filter-element selection (Part 1)

There are several filter-element suppliers in the marketplace, and they offer a wide array of alternative selections that may physically fit in the housings supplied by your packager. Although most supply-chain folks would argue, cheaper is not always better. Understanding the ins and outs of filter specifications and capabilities are a technical minefield, and changes in suppliers or supplier part numbers should be made only under engineering advisement from your team. Trusting the supplier is not enough: Keep those honest folks honest.

No. 4, Filter-element selection (Part 2)

From time to time, gas turbine OEMs (GE for LM aeros) will provide guidance via a service letter or product bulletin, or some other established vehicle, regarding filtration requirements. Keeping abreast of OEM guidance is critical to successful operation and maintenance of these machines. You may think you have all your ducks in a row and are on your "A" game, but the only thing that is constant is change and things can (and do) change quickly with these engines.

No. 3, Poor or no system flush after an event

When a bearing failure does occur, debris is washed into the system. Thus, prior to starting a replacement machine, it is imperative that a thorough flush of the system be performed. To accomplish this, after the tank is opened, cleaned, inspected, and closed, a temporary pump/filter unit is installed in the system and oil is circulated at a velocity higher than that of the system when in normal operation. The oil may or may not be heated. Increasingly fine filter elements are used in the temporary unit until the target cleanliness is achieved. The filter elements usually are removed from the installed housings to focus all of the filtration activity on the temporary filters.

No. 2, Housekeeping

Poor housekeeping—especially on the tank top and in the surrounding areas of the package— can be a potent contamination source, both during normal operating periods and especially during top-offs. A bit of dirt can be brushed off or blow off a horizontal surface and slip into the tank before anyone sees it.

No. 1, Topping off

Most plants use one set of tools—funnels, containers, etc—versus a dedicated set for each type of oil for transferring the fluid from its storage location to the point of use. This can lead to oil degradation through mixing over time. Many plants use open containers (buckets) to move oil. It's uncommon for an oil storage location to be equipped with any kind of proper cleaning station that allows/encourages the technicians to keep the tools clean. With radial bearing clearances as low as 0.0017 in. cold, it does not take a large particle to cause damage when the bearing is at operating conditions.

Proper O-ring storage promotes leak-tight sealing

The actor Samuel L Jackson's intimidating line in a credit-card commercial ("So, what's in *your* wallet?") came to mind the other day while I was reading an excellent blog written by Kelly Forrest for Cleveland-based Brennan industries, entitled "What Do You Know About O-Ring Storage."

It pointed to the intricacies of O-ring storage, life limitations, and the various mitigating or aggravating factors that affect component life. It got me thinking about how many times I had pulled a new gasket or O-ring out of a plant warehouse and found it to be junk—either damaged by shelf wear, hard as a rock, or through some other mystical means, unusable.

4. O-rings should be stored in protective packaging to prevent damage and material degradation

The fallout: A frantic search for another (hopefully usable) part, the cost of the extended work stoppage, the cost of carrying a worthless part in inventory, etc. The very best intentions of (1) managers who authorized its purchase, (2) the supply-chain folks who bought it, (3) the warehouse people who stored it, (4) the maintenance planner who had it pulled from stock, and (5) the technician who was about to install it, all were swept away in an instant.

Can I get an *"A-men"*?

As Forrest pointed out in his blog, O-rings are not only subject to deterioration over time; temperature, humidity, ozone, UV radiation (sunlight), and ionizing radiation all can factor in. He points to SAE International Standard ARP5316D as a generic governing standard for O-ring storage, in addition to advice provided by manufacturers.

During an assignment some years back, I was surprised at how many things in the warehouse for a typical LM-powered generating plant have expiration dates—documented or undocumented. As I became more knowledgeable and vigilant on the

5. What does your warehouse look like? Air filtration and climate control may seem like a luxury (above) but not when you consider the financial impact of poor storage facilities (left)

topic, I learned that some of those items had been received *after* their expiration dates.

Many vendors didn't allow product returns solely for expiration; we had to write a statement into our purchase-order boilerplate giving us the specific right to return products arriving expired or unreasonably close to expiration.

As it turned out, almost every chemical compound we stocked, from lab reagents for testing boiler-water chemistry to greases to maintenance products, had some kind of life limit associated with it. We also became aware of specific storage requirements for a lot of items. Not just chemicals, but mechanical assemblies like servo valves and pumps.

In supplier manuals, we found storage requirements for both environmental conditions and periodic shelf maintenance (lubrication, exercising, etc) that we were not doing. Looking back, we wondered how many cases of spares "infant mortality" were actually attributable to inadequate care during storage. It was a little frightening.

Warehouse space always is at a premium, and managers usually are looking to reduce square footage, not increase it. No one wants to be questioned for building a "Taj Mahal" warehouse.

Typically, things like air filtration and climate control are seen as a luxury and not in the budget. Specialized shelving or Vidmar modular storage cabinets are out of the question. The warehouse has no manpower provision (assigned technicians or access to technicians) or budget for performing shelf maintenance on stored equipment.

Plus, warehouses often have no access to any kind of work-order system that allows for maintenance tracking on stored items. And yet, we entrust it with operational consumables and maintenance spares worth millions of dollars with an expectation that they will be ready for use when needed.

So, this brings me back to Jackson. But what's in your wallet isn't the question. The question is "What's in your *warehouse*?" How many useless items? How much wasted capital? How many hours of needless downtime? How much lost production? If that doesn't make most plant managers go "Hmmmmm. . ." I don't know what will. Understanding and assessing the impacts of inventory storage requirements should be a consideration when:

- Designing the warehouse space.
- Staffing the warehouse.
- Budgeting for the warehouse.
- Building processes for the warehouse.
- Operating the warehouse (and *training*).
- Deciding to add an item to the inventory.
- Making changes/improvements to the warehouse and/or warehouse processes.

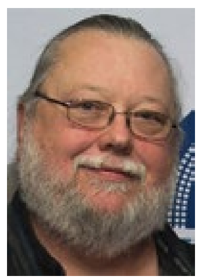
In other words, just about any time you're making warehousing decisions, thinking about what's in your warehouse—and how it needs to be cared for—is a good idea.

Much like Jackson in his commercial role, a lot of this can seem intimidating. Knowing and complying with all the storage requirements of each item you carry seems like a monumental task. But, there is help; you're not in this alone. You can:

- Get assistance from your vendors/distributors (make that an element in your purchase orders).
- Get assistance from professional groups (SAE, ASME, IEEE, etc).
- Find commercial resources—like Forrest's blog on O-rings.
- Find regulatory resources—such as Airworthiness Directives from the flight side regarding hoses.
- Use the technical publications supplied with your purchases.
- Provide awareness training to your supply-chain team (share the load).
- Bring your technical personnel into the warehouse to perform formalized storage audits.
- Develop "rule-of-thumb" observations to trigger storage questions on new items—such as:
  - Is it a chemical compound?
  - Is it a mechanical assembly?
  - Is it a "soft part"—that is, an O-ring, hose, pliable gasket, etc?

Being proactive when it comes to warehouse management isn't just a show of skills–it's a dedication to supporting the mission of the plant and the plant staff. Having what is needed when it's needed by the most economical means possible should always be the goal. CCJ

About the author



Brian Hulse has spent his 40+ post-college years dealing with gas turbines from many perspectives. These include the US Navy, EPC, O&M (owner and third party), asset management, component repair/reverse engineering/manufacture, mobile powerplant packaging, and depot MRO management.

Today, the former Western Turbine Users Inc board member is an independent consultant, sharing his expertise on safety, O&M, quality control, financial accountability, and team-building with leading owner/operators. Hulse's deep technical experience underpins his work in the development of depot-level work scopes, conduct of root-cause failure analyses, guidance on plant audits and best practices, and as an expert witness.

Acute levels of uncertainty pervade the industry

We're supposed to embrace change, but let's face it, change is unavoidable. It occurs with every passing moment, even if you can't sense it. So let's talk about rates of change. In the gas-fired power industry, rates of change may be approaching chaotic effects.

That's the conclusion from 18 one-on-one half-hour interviews conducted over a two-day period in spring 2018, more than half with users directly responsible for plants and equipment, the balance with representatives of vendors large and small—but not including the OEMs.

"Insurance companies and authorized inspectors show up who have no clue what an HRSG does."

When you consider the common themes in isolation, most simply confirm the trends you read and talk about every day. But the composite sketch of the industry as these themes converge is troubling at best. Perhaps the appropriate mental image is of a frog in a pot of water gradually heated to boiling.

Everything, these days, seems to be JIT—just in time—whether people, parts, money, or operating hours. As one user put it, "plants are run day to day."

Ground rules for the interviews were no attribution, no names, and no companies mentioned, so everyone could speak freely. Each conversation began with some version of, "what's happening out there that's troubling and making your life more difficult, what's happening that is exciting and making life easier, and what's innovative that might make a good on-the-record follow-up article?"

While much of this may seem melodramatic and dire, keep in mind that the electric power industry has weathered similar periods in the past while maintaining superior levels of reliability and more than reasonable prices to ratepayers for such a critical commodity. Yet, forewarned is forearmed.

"We're replacing skilled inspectors with robots to reduce costs at a time when starts/stops [on rotors] are going up exponentially."

Storm chasing. One overriding consequence from the themes which emerged is that a perfect storm may be brewing with the convergence of:

- Aging gas turbines and combined-cycle plant equipment.
- Acute shortages in skilled labor.
- OEMs in financial turmoil are buying jobs.
- Unpredictable operating tempos resulting from growing renewable energy in the markets.
- Shrinking O&M budgets.
- Frequent ownership changes of plant assets.
- Continuing staff reductions.
- Supply chain consolidation.

After all, when a person responsible for one of the largest gas-turbine fleets in the country says, with an eerie calm, that they are "very cash-strapped," and "we're going to take reliability risks, might even live with a crash, since we have plenty of capacity to back up the loss of output. . .," the eyes of the interviewer, an industry veteran, lit up. This asset manager also noted that when management insists on putting back in a "really bad HP steam rotor," it sets a poor precedent for the next questionable decision.

Another GT asset manager noted that wind and solar are "consuming" his organization, that there has been a total emphasis shift in the company. A multi-billion-dollar wind construction program is taking up all of the organizational oxygen. The utility is "close to shutting down a 1980s-vintage coal plant because of wind." So, it's no longer the older, smaller coal units under severe threat. Even a state like North Carolina is expected to add up to 6000 MW of solar PV over the next five years, according to one interviewee.

And based on recent news accounts, even recent-vintage combined-cycle plants in some areas of the country, California and Texas notably, are being shuttered. The "nuclear renaissance," a term coined 15 years ago, now appears to have become a slow march to the grave.

What's left? Must-run renewables (highly subsidized) and must-follow gas.

"Thirty percent of our non-hourly staff was let go; what's going to fall through the cracks?"

Old rotors, deep cycling. But here's the deeper issue with this scenario, another common theme among the interviewees: As a fleet, the F-class rotors are coming to end-of-life right when "GE is going lean," owner/operators and suppliers are starved for revenue, the first wave of more efficient and more flexible H- and J-class machines are coming into operation, growth in renewable projects continues unabated, and skilled workers are scarce.

Thus, F machines, which took the industry by storm in the 1997-2003 period and not necessarily designed for cycling, much less deep cycling, are headed for even harsher operating tempos.

One owner/operator likened it to "the Wild West" and noted that "there will have to be a change in thinking to manage this fleet." He referred to a recent presentation describing how an F-class rotor was "rebuilt from scratch" in a Houston repair facility.

"The only thing inhibiting business growth is finding the right people to hire."

A major third-party services vendor mentioned "brown plant solutions, something between a repair and an OEM replacement—there's a lot of 7FA.03 hardware out there!" Perhaps another example of this change in thinking is replacement hardware, such as for combustion systems, with more turndown capability.

One plant manager reported that a zero-hour replacement rotor "didn't run right, but we just lived with it." And because turbines are being operated in ways never intended in the original design, breakdowns are "non-standard."

Of course, it's not just the rotors which are affected. One repair-firm rep quipped, "starting and stopping 25- to 30-year-old units up to 300 times a year is hell on a generator."

What price outages? Outages and outage planning proved to be the most prevalent topic among both vendors and users. It makes sense as most of the perfect-storm elements noted above bear down during outage periods.

"People showing up to sell us stuff, and people designing powerplant products, have never even been in a powerplant."

On the front end, plants with few staff members, and owners with little in the way of corporate resources, have little time or inclination for proper outage planning. So-called "last-minute" outages are common, one vendor noting that while plant owners may have "scheduled" the outage, they don't necessarily "book" the outage.

Plants chasing ancillary-services market opportunities may hurry an outage together only after the last possible dollar is earned during the peak operating periods. One non-rotating-equipment services vendor noted, "money is only released at the last minute."

On the back end of these outages, users complain that "work quality is less than desirable" and, to work within constantly shrinking O&M budgets and outage scheduling constraints, "everybody is rushing, which isn't conducive to good outcomes; that's too bad, because performance going forward is directly tied to the outage going well."

"Work just keeps piling up with only 27 people at the plant."

One user also noted that "there are a lot of serial No. 1 major repair/replacement solutions out there." Another consequence of outages that proceed more like elementary-school fire drills is that overtime charges escalate for both plant staff and services firms.

The rule of thumb these days, according to one repair-firm rep, is an "opportunistic outage," one that isn't planned or forced, but taken when the plant is done making money that season. One plant manager from the Northeast with a nominal 500-MW plant said they take one one-week outage annually. A Midwest plant manager reported his spring outage was two days.

"As coal-plant capacity factors decline, resources are constantly shifting from station to station."

Where are my people? The shortage of skilled and experienced workers was another topic which cut across most of the interviews. Fewer and fewer people are coming into the trades these days, despite training programs utilities and others have initiated with colleges and schools in their regions around the country. Plants are enticing good people away from other nearby plants. Two service companies reported that every single employee was committed during the past spring outage season.

However, this past outage season may be an anomaly. One rep from a mechanical contracting firm noted that a major owner/operator forecasting an unusually hot summer was "getting work done now to run hard in the summer." Unless this owner was viewing results of a whiz-bang proprietary weather model, others owners were undoubtedly planning similarly.

You can get a sense of the depth and breadth of comments on the staffing topic from the quotes in large type scattered throughout this report.

Where are my parts? "Parts on the shelf are cash," said one plant engineer, and of course, no upstanding financial engineer is going to let cash sit at a plant. "Our people are constantly looking for parts," he continued. An assistant plant manager stated that her group is "creating depth" through user-group interactions.

Big dogs eat first. General Electric (GE) came up numerous times in these interviews. The power-industry behemoth has been making headlines with its financial woes. It's arch competitor, Siemens, released a statement, literally while these interviews were underway, that the company would be temporarily shutting down its Gas and Power Division.

"We're at the bleeding edge of staffing."

The concerns can be summarized by saying that the more the OEMs' new-unit business suffers (and new orders of gas turbines are down substantially), the more they buy repair and replacement jobs, squeezing out the third-party service firms.

One utility engineer said "smaller vendors are hurting from GE's aggressive pricing." A services-firm rep noted "OEMs are buying jobs." A plant manager lamented, "GE isn't doing us any favors; we can't get a schedule for a major outage that begins mid-September."

A plant engineer observed that "GE isn't giving their people the right tools and training so that they can use the 'GE systems and processes' and the people who know these systems and processes are gone." Finally, this from large repair-services firm: "We like GE when they're busy with their new-build, not so much when they are not."

Disruptions, in fact, are occurring all across the supply chain and the root cause appears to be—what else?—money. SCR suppliers reportedly are under-designing catalysts and employing formulations that "don't cut it." Prominent independent repair and service firms have been acquired by big-dog firms, cutting competition.

An owner/operator rep reported that his firm has negotiated broad agreements with suppliers like Siemens and MHI to perform scheduled outage work across its facilities.

Appetite for fuel. If you can't get fuel in, you can't get electricity out. Fuel supply issues came up only a few times. It's well known that the country is awash in natural gas available at historically low prices, but like other resources, it isn't optimally distributed. Manager of one plant "at the end of the pipeline," said gas transportation isn't keeping up with supply. "We're not in control of our fuel," he said, adding that other plants are facing the same thing. A GT asset manager anticipated that the arrival of the larger combined-cycle blocks based on H and J machines will compound gas infrastructure issues.

> *"Labor doing the work is typically not achieving the quality needed."*

Regulatory sinkholes. Several of the user representatives identified NERC and FERC regulations as more than a nuisance, more like a cost and resource sink all unto itself. At one large owner/operator, "two corporate departments work on this, and I've got one engineer working on NERC-CIPs exclusively." One plant superintendent noted that NERC issues are "costly and we have no NERC/FERC expertise on the plant staff." Another plant manager, after stating that nothing really keeps him up at night, said that "NERC is out of control, the regs seem to be ever-changing and never-ending!"

The big data (r)evolution. Given the noise level around "internet of things, industrial internet, big data, the cloud," and so on, you might expect data-driven solutions to have some prominence in these discussions. They didn't, or at least not comparable to the noise levels, but that doesn't mean it didn't come up.

> *"Knowledge retention is still a top issue in our organization."*

"We're relying on IT more than OT [operations technology]," said one plant manager, "but the consequence is that these IT systems are more complex." A representative of a filter company said his firm was developing predictive services and remote monitoring to help customers optimize filter replacements and cleaning cycles. An owner/operator said they were relying more and more on a simulator to keep operators fresh and trained. "They tend to forget," he said. And many are retiring.

"Everything on peaking units is getting automated," still another said.

Centralized M&D centers were mentioned in passing, although it seems those utilities who pioneered this concept are relying on them less and less, while several non-utility owner/operators are just now getting theirs built. One of the goals of such centers is to redistribute specialized expertise and leverage it across a fleet. Another utility rep mentioned a program to apply so-called smart M&D and advanced sensor technologies widely at the plants.

Frog legs, anyone? Though many of the conversations veered towards vent sessions on what's wrong with the industry, there were bright signs that the industry, as it always has, is coping and adapting.

For starters, many service firms reported they are busy, overloaded even, and anticipate more growth ahead. That beats the opposite scenario. In an environment where OEMs are reportedly cutting corners and users have little choice but to operate in reactive mode, firms which can develop and propose solutions, respond quickly, and keep plants running are highly prized.

> *"Contractors are not following procedures for weld repair of P91 components in HRSGs."*

One parts supplier noted his firm isn't "having problems with unpredictable outage scheduling and work," while a rep from a large repair firm said he had lost a few jobs to the OEM, but once the customers realize that the estimated first cost won't look anything like the final, it probably won't happen again.

A rep from a large third-party services firm says technologies are being brought to market that complement renewable energy and make older gas turbines more flexible. In addition, new manufacturing, fabrication, and casting equipment and methods will continue to drive costs out of aftermarket services.

A plant manager said, "We're doing what is required with as few people as possible." One asset management director waxed enthusiastically about a "risk app" they are developing with both a major OEM and insurance firm. Similarly, a plant manager spoke proudly of a risk-reduction program in partnership with their insurer, as well as a reliability centered maintenance (RCM) initiative to engage other users in developing failure modes and effects analysis (FMEA) for 7F machines and D11 steam turbines.

Finally, a repair services firm rep said, "unexpected customer outages don't bother us, we figure out a way to get it done." That attitude, frankly, underpinned all of the conversations in some way: "Whatever they throw at us, we'll figure it out." CCJ

Demin water replaces glycol solution, improves heat transfer at Termocandelaria

Miguel Perez Ghisays, general manager of the privately held Termocandelaria peaking facility near Cartagena, Colombia, and his talented staff, embrace a process of continual improvement in all facets of operation and maintenance.

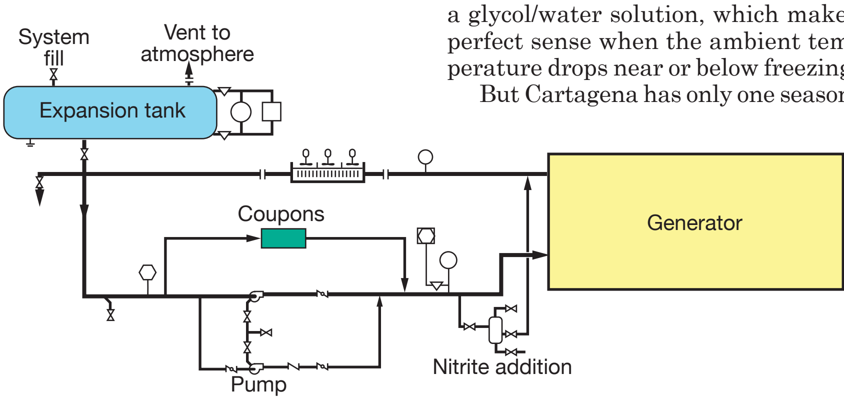
Readers may recall the plant's success in converting its two W501FC engines from gas-only to dual fuel in only 11 months after contract award (CCJ Second Quarter 2009, p 136) and the upgraded fuel system's outstanding performance during a difficult period when the country was subjected to an El Niño weather pattern (3Q/2016, p 85). If back copies of CCJ are not available to you, access www.ccj-online.com and type "Termocandelaria" in the search-function box.

Recently, Perez Ghisays contacted the editors about improvements made to the closed cooling systems serving the gas turbines' generators (Fig 1)—one a hydrogen-cooled (Unit 1), the other air-cooled (Unit 2). The heat-transfer medium in both systems was a glycol/water solution, which makes perfect sense when the ambient temperature drops near or below freezing.

But Cartagena has only one season, with average temperatures above 70F; it never freezes there. Staff found that the specific heat capacity of glycol/water solutions is lower than that of demineralized water, meaning the latter can absorb more thermal energy and increase heat-transfer efficiency. Plus, conversion to demin water-only would eliminate the significant expenses associated with glycol use. After the switch to demin water was made, more favorable temperatures at the system inlet and outlet confirmed the heat-transfer benefit.

With demin water as the cooling medium, Perez Ghisays said, it became necessary to consider corrosion control. Generally speaking, closed systems can suffer corrosion and fouling problems absent adequate chemical treatment and water management. Corrosion can attack system components or dissolve metals in one part of the system and deposit them elsewhere, the general manager continued. And if deposition occurs on heat-transfer surfaces it can cause restrictions in critical flow zones.

To assure proper water treatment at Termocandelaria, plant engineers designed equipment to inject chemicals directly into the closed cooling system (Fig 2). The chemical addition tank shown, designed for use at system pressure, enabled both acid washing after



1. Demineralized water replaced glycol/water as the heat-transfer medium in the generator closed cooling systems at Termocandelaria. Fig 3 shows actual installation

2. Chemical addition system for corrosion control protects the closed cooling system

3. Expansion tanks for the closed cooling systems are located high above the generators. Simplified system schematic is in Fig 1

Table 1: Corrosion coupon analysis 04/07/16, H_2-cooled generator, Run 1

Metal	Test start	Exposure, days	Corrosion rate, mils/yr
Copper	03/22/13	1112	0.001547
Admiralty brass	01/21/14	807	0.000575
Mild steel	01/21/14	807	0.000415

Table 2: Corrosion coupon analysis 04/07/16, air-cooled generator, Run 1

Metal	Test start	Exposure, days	Corrosion rate, mils/yr
Copper	03/22/13	1112	0.001238
Admiralty brass	01/21/14	807	0.000287
Mild steel	01/21/14	807	0.000312

Table 3: Typical ranges of corrosion rates in a closed system

Corrosion rate, mils/yr		Description of results
Mild steel	Copper alloys	
<0.1	<0.05	Excellent (negligible corrosion)
0.1-0.5	0.05-0.2	Very good (minimal corrosion)
0.5-1.0	0.2-0.35	Good (moderately high corrosion)
1.0-3.0	0.35-0.5	Poor (moderately high corrosion)
>3.0	>0.5	Unacceptable (severe corrosion)

Table 4: Corrosion coupon analysis 04/11/17, H_2-cooled generator, Run 2

Metal	Test start	Exposure, days	Corrosion rate, mils/yr
Copper	04/07/16	419	0.03608
Admiralty Brass	04/07/16	419	0.03363
Mild steel	04/07/16	419	0.03521

Table 5: Corrosion coupon analysis 04/11/17, air-cooled generator, Run 2

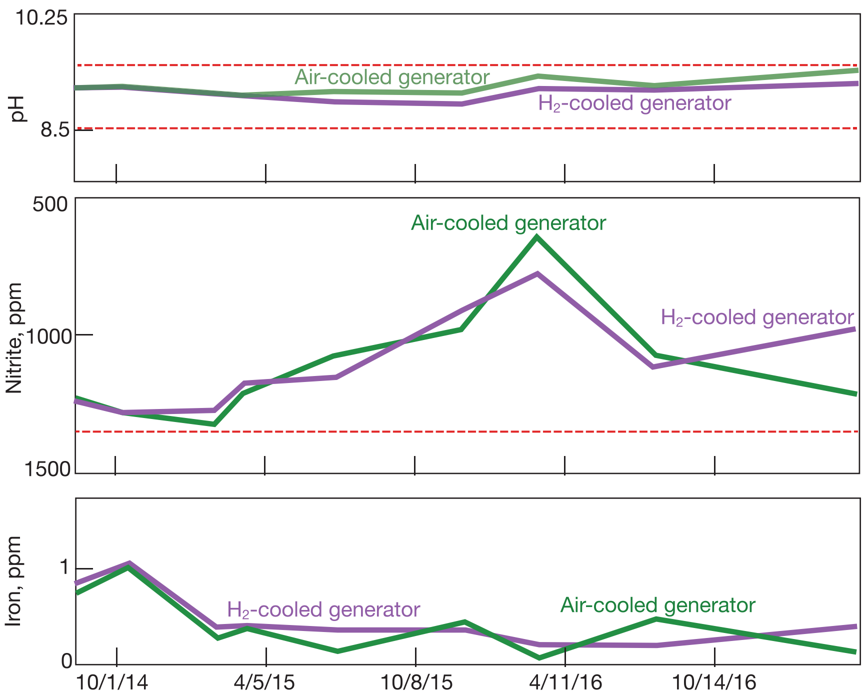
Metal	Test start	Exposure days	Corrosion rate, mils/yr
Copper	04/07/16	419	0.038490
Admiralty Brass	04/07/16	419	0.046087
Mild steel	04/07/16	419	0.074263

Table 6: Cooling-water analysis

Parameter	Units	Gen 1	Gen 2	Control range
pH	–	9.2	9.4	8.5-9.5
Conductivity	µS/cm	2073	2380	–
Alkalinity	ppm $CaCO_3$	160	200	–
Nitrite	ppm NO_2	1040	760	>600
Copper	ppb Cu	11	9	<20
Iron	ppm Fe	0.41	0.16	<3
Ammonium	ppm NH_3	1.4	1.1	<20

4. Corrosion coupons for copper (top), admiralty brass (center), mild steel (bottom) are arranged in parallel circuits and easily accessible to plant personnel (left)

5. Variables in water chemistry important to cooling-system health are monitored and trended (below)



the glycol/water solution was removed as well as ongoing chemical treatment of the system's demin water. The acid-wash step took about three days.

Analysis of the cooling-water systems revealed high levels of iron. An engineering review pointed to the vented carbon-steel expansion tanks in both generator cooling systems as the primary source of these corrosion products. Replacement with tanks made of Type 316 stainless steel resolved that issue (Fig 3).

Next, chemical treatments were selected to control both corrosion and bacterial colonies. Nitrite-based Nalco® 8338 was picked for control of corrosion and fouling; Nalco® PC56 for bacterial control.

Perez Ghisays and his staff decided that fouling and corrosion should be monitored to gather solid evidence of chemical effectiveness. Corrosion coupons are used for this purpose (Fig 4) and are evaluated periodically. Results from the first round of tests are presented in Tables 1 and 2. They compared favorably with corrosion data in Table 3 for mild-steel and copper alloys available in the literature and considered "excellent" (negligible corrosion).

Corrosion data from the second round of tests (Tables 4 and 5) were similar to the first-round results.

Table 6 shows data collected were within the "allowed" range based on industry resources. Note: The nitrite residual guarantees system-wide corrosion protection.

Fig 5 tracks important operating parameters—pH, nitrite, and iron—over a two-year period. CCJ

Cloud-based software service facilitates management of best practices, lessons learned

A quick call to a seasoned project director to inquire about how his company handles lessons learned elicited a response heard many times from powerplant managers: "I've never seen any plant staff or organization handle this well." Yet virtually everyone agrees that best practices and lessons learned (BP/LL) must be captured and followed so what worked last time is repeated, and what didn't is avoided.

Profitability and continuous-improvement assessments always key in on a managed, active, and robust feedback loop from past experience to future action, and continuity of knowledge transferred among appropriate staff.

For powerplants, the urgency on capturing BP/LL is acute—especially at facilities powered by gas turbines which may change ownership as frequently as every few years, and often are operated by third-party O&M firms. Multiple organizations, contractual responsibilities written in legalese, and what's become the transactional nature of power generation all make capture and dissemination of BP/LL that much more difficult.

On top of this, there's the critical issue of what platform to use. Tools may be available in Microsoft SharePoint, Excel spreadsheet, project management and scheduling software, maintenance management software, or even within the control and automation platform (slowly morphing into the facility knowledge-management platform). And that's if the organization has made the leap from Post-it® Notes, three-ring binders, and paper and ink.

EP3 LLC seeks to change all this. The company has designed a cloud-based software service now in commercial use by at least one portfolio owner/manager—Competitive Power Ventures Inc (CPV). As part of its Quad C® platform, the BP/LL module streamlines the entry, capture, and access to/propagation of activities ranging from commissioning, post-outage, projects, operations, and routine maintenance.

Perhaps best of all, the Quad C and BP/LL module has been designed by seasoned powerplant personnel for power generation facilities and is not part of a larger enterprise software system generally designed for other purposes.

It is intended to be a single repository for all company practices and lessons, with risk profiles and associated files and photos attached to each. Because it is built in Microsoft cloud-based software systems (with its cybersecurity practices), information can be easily shared with and accessed by all those with a need to know.

Managers can create, communicate, and track autonomous actions via email alerts to responsible parties. And of course, because it's a database, it can be queried and interrogated for performance and statistical assessments and reports.

CPV's BP/LL network

Successful implementation and use of the BP/LL module is particularly important to CPV, which considers itself the most active independent power producer of its size in the US. In the last two years, the company has brought online two state-of-the-art 2 × 1 combined cycles powered by GE 7FA.05 gas turbines: CPV Woodbridge Energy Center in New Jersey and CPV St. Charles Energy Center in Maryland. Two more advanced plants are scheduled to start up this year: CPV Towantic Energy Center in Connecticut, equipped with 7HA.01 gas turbines, and CPV Valley Energy Center in New York, which has Siemens Energy 501F4 engines.

Heat-tracing success critical

Heat tracing may look insignificant in the greater scheme of things during plant construction, but the failure of an important circuit during a cold snap can shut down your plant as fast as an exhaust-temperature excursion can trip your gas turbine.

Despite the close attention CPV Woodbridge Energy Center staff paid to heat tracing, it wasn't enough. Turns out the designer of the heat tracing system and the system installer didn't communicate well and plant personnel found many installation errors, especially in programming.

Given the vital importance of this system at Woodbridge, an outdoor plant located in the Northeast, CPV and the plant operator, Consolidated Asset Management Services (CAMS), engaged a third-party firm with heat-trace expertise to audit the system. Each circuit was inspected thoroughly. Electrical wiring was checked for proper configuration, current draws were measured, alarms set, etc.

The Woodbridge system is complex, as you might imagine. There are 17 heat-trace control panels plant-wide, with dozens of individual circuits tied into each one. Circuits include high/low current alarms and information that helps to anticipate failures. False alarms in mild weather were common and had to be addressed, since the alarms are directed to the control room and operators have to go to the local panel for access.

The extensive inspection effort and rework produced a treasure trove of best practices/lessons learned that helped avoid repeat problems at the other CPV plants in design and under construction. The following best practices and lessons learned pertaining to development/design and construction/startup illustrate the value of the EP3 software described in the main text; you may find a nugget for your plant among them.

Development/design:

- Add smart-panel amp indication

Reliability Engineer Preston Patterson mentioned that CPV is focused on ensuring that personnel company-wide gain from the experiences of their colleagues—both good and bad—"to maximize our potential to construct and commission new plants as smoothly as possible, as well as to maintain our current portfolio of plants operating with high availability and reliability." Management believes that collecting the knowledge gained from each plant issue will act as a force multiplier to incrementally improve fleet performance.

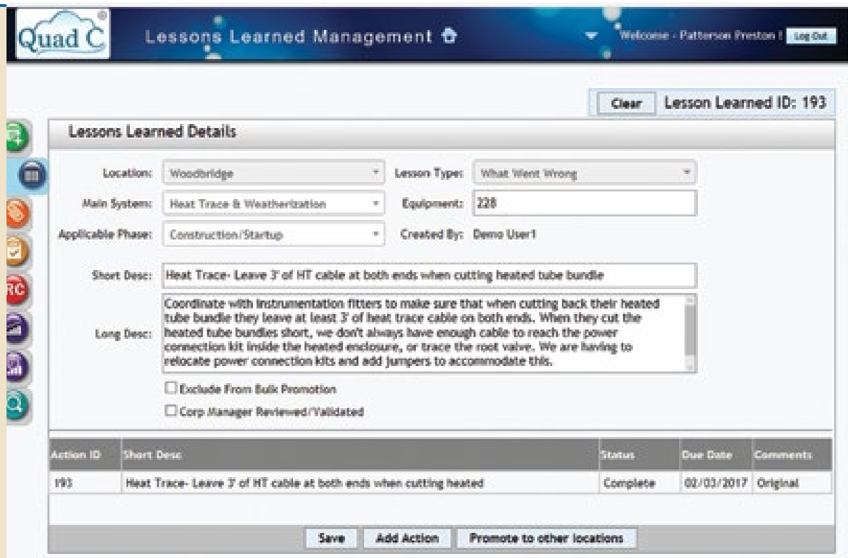
Patterson, whose responsibilities include building out the BP/LL database as experiences are gained in project development/design, construction/startup, operation, maintenance, safety, etc, said the challenges that impeded the company's goal of quickly and effectively compiling and sharing BP/LL across its fleet included these:

- Tracking of which best practices and lessons learned had been promoted where, when, and to whom using an Excel spreadsheet proved cumbersome. Plus, each time a new BP/LL was added, or new information was obtained, CPV couldn't easily update each affected plant with the new information.
- Using email to share BP/LL and solicit feedback from CPV's various third-party O&M providers and EPCs made it difficult to maintain adequate control of the most up-to-date version of the database.

to plant availability

on each circuit as well as a light to visually indicate that the circuit is energized (photos). This makes it easier for operators to walk down the system, verifying that the heat tracing is on and working when it should be.

- Have your engineer do a detailed evaluation of all vendor equipment (gas and steam turbines, HRSGs, etc) requiring heat tracing and make sure that the information is clearly presented to the heat-trace system supplier.
- The mechanical engineer responsible for the heat-trace design scope should be the same person who reviews the vendor's design isometrics. The field engineer may not necessarily understand the mechanical properties of the piping system and may miss things that should be included in the isometric drawings. In addition, the mechanical engineer is better positioned to be aware of potential piping changes needed.
- Since the heat-trace design usually is not complete until late in the project, the necessary conduit cannot be installed until very late in the schedule. You can benefit by moving a large portion of this work forward. For example, run small (12 in.) cable trays in areas known to require heat tracing (finger racks, main racks, bottom of HRSG, etc); once the heat-trace design is finalized and power connection devices are located, only short pieces of conduit from the tray to the devices are needed.



Screen shot illustrates information received via the best practices/lessons learned database

Add smart-panel amp indication on each circuit as well as a light to visually indicate when the circuit is energized to facilitate walk-down verification of proper operation

Construction/startup

- Ensure that compressor bleed-valve actuators and inlet-filter differential-pressure instruments are heat-traced and insulated properly for adequate freeze protection.
- Coordinate with the instrumentation fitters to make sure that when cutting back the heated tube bundles they leave at least 3 ft of heat-trace cable on both ends (screen shot). When they cut the heated tube bundles short, there is not always enough cable to reach the power connection kit inside the heated enclosure, or to trace the root valve. This results in having to relocate power-connection kits and add jumpers to accommodate.
- Ideally, start the heat-trace crew when the piping discipline is at least 65% complete. Prior to this, the pipe systems generally are not complete (missing valves, permanent supports not installed, etc) which creates rework for heat-trace crews. This will allow a large run-way ahead of the heat-trace crew, increasing productivity. Impact upon the project completion schedule and weather conditions may override this.
- When installing the rubber boots in the termination kits, the leads tend to bunch up at the bottom and touch. If there was a ground fault during commissioning, 80% of the time it was in the rubber-boot connection.
- Perform a thorough heat-trace audit during the summer to identify and address any issues before the next winter.

The functionality CPV expected from the solution it would implement included the following:

- A central, online location for maintaining version control and creating a master list of BP/LL that could be updated as new information became available.
- A tracking system to ensure PB/LL would be distributed to the relevant personnel in timely fashion.
- The ability to transfer knowledge more efficiently both internally and with third parties outside the CPV network.

How the BP/LL program works

The EP3 BP/LL solution selected by CPV allows the addition of new best practices and lessons learned from a simple web browser on any computer or mobile device, or by email to the CPV Asset Management team responsible for this effort. Each lesson can have multiple "actions" assigned to specific users or roles for follow-up. To illustrate: A plant manager can forward a lesson he/she has received as an action item for an operator to evaluate.

The software makes it easy to submit a new lesson, thereby lowering the barrier to entry and enabling the company to harvest as many good ideas as possible. CPV Asset Management, CPV Construction, and the O&M teams at each plant site can submit BP/LL directly into the system while experiencing it in real time or after the successful implementation of a solution. CPV also takes advantage of this system as a platform to incorporate best practices collected from its participation in user-group meetings and from industry publications.

CPV Asset Management receives and reviews all submitted BP/LL for applicability and approval before they are promoted to other projects. This serves as a quality check and allows the opportunity to clarify and gather additional information if needed—such as photos or files that support a particular lesson. Taking the extra step ensures the best practices and lessons learned are easy to understand and apply, thereby improving the chances of a positive impact. Alerts notify appropriate personnel regarding new material and changes to existing posts.

The BP/LL software folds into CPV's internal reliability program. It is through this platform that the company is able to develop trust in the quality and value of the material in the database, as well as provide training and support as necessary. In addition to interacting via the electronic network, personnel from each plant meet quarterly for discussions on key reliability topics.

CPV's fleet-wide success in developing and sharing best practices and lessons learned earned the company a 2018 Best Practices Award, presented by CCJ and the 7F Users Group at the latter's annual meeting in Atlanta, May 7-11.

Results

Since bringing Woodbridge Energy Center online in 2016 (CCJ 2Q/2015, p 92), CPV has benefited greatly from sharing fleet-wide the best practices and lessons learned during plant development, construction, commissioning, and operation. An outstanding example is freeze protection.

Several CPV plants are outdoor installations located in the Northeast. Failure to provide world-class freeze protection at these facilities could easily lead to a loss in availability. Thumbnails of several freeze-protection best practices among the dozens shared among CPV personnel are presented in the sidebar. Woodbridge was the CPV fleet leader on this topic having been the first plant to experience some of the challenges of initial design issues, and installation practices by contractors. The BP/LL shared by Woodbridge earned the plant a Best of the Best Award in 2017 (CCJ 2Q/2017, p 22).

Golden

Dave Lucier, founder and general manager of PAL Turbine Services LLC, headquartered near GE's Schenectady works, called CCJ in late May to ask the editors if we thought his 50-year pin might have gotten lost in the mail.

"Huh?"

Nineteen sixty-eight was an important year professionally for Lucier. He graduated from GE's field engineering program and was assigned by the company to assist in the installation of three four-unit MS5001L power blocks at Commonwealth Edison Co's Crawford Station, near Chicago. It was roaring start to a productive and enviable career now in the second half of its first century.

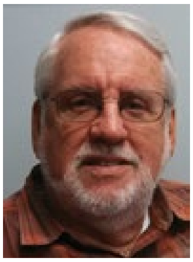
However well deserved, there's no pin, no watch to celebrate the moment, Dave. The endless piles of papers, reports, photographs, and ancient equipment worthy of a Smithsonian display (Fig 1) that reside in the PAL office and shop bear witness to your accomplishments. No field engineer worth his salt needs white-collar tchotchkes anyway.

Looking back, gas turbines and Lucier were destined for a lifetime partnership. Dave graduated from UMass Amherst with a mechanical engineering degree a few months after the Northeast Blackout in November 1965. That event triggered the first gas-turbine bubble as electric utilities across the country bought scores of GE Frame 5s and Pratt & Whitney FT4s, many as black-start units to enable quick recovery from forced outages.

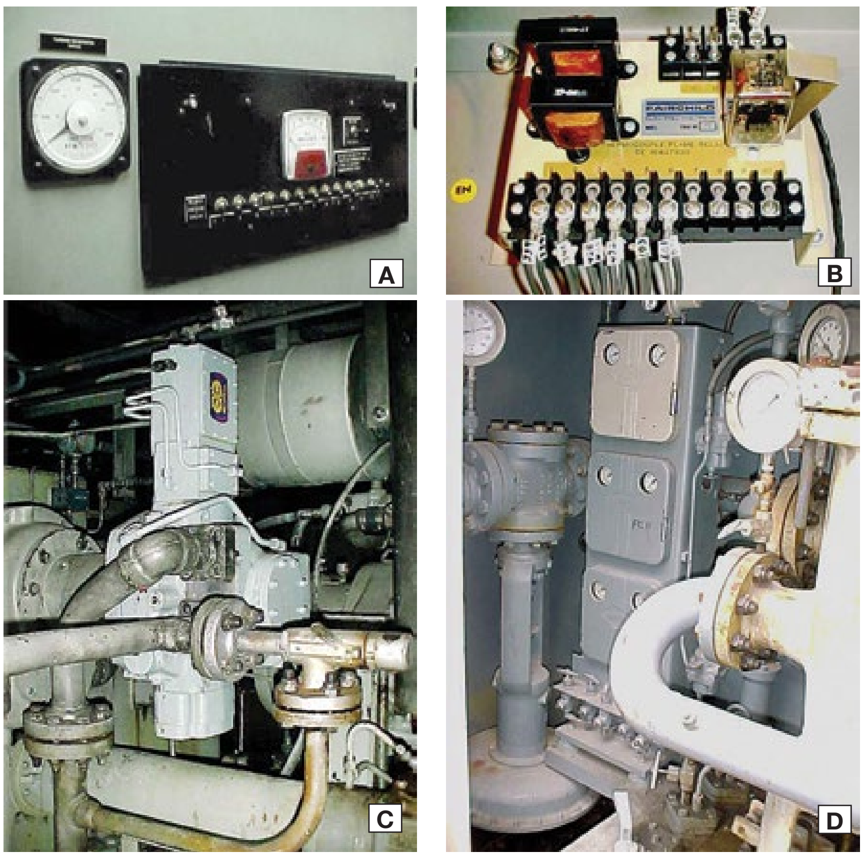
GE assigned hiree Lucier to its field engineering program (FEP), which opened in 1966. The crush of new business demanded capable, travel-flexible engineers for installs, startups, overhauls, and troubleshooting. It was a fossil steam world at that time and very few in the industry knew much about gas turbines. The Schenectady school, located then in Building 28, turned out some of the finest GT field engineers in the world.

Dave is passionate about gas turbines and has tracked their development back to the beginning of the land-based commercial era, becoming an industry historian in the process. In fact, he's the first person the editors call with questions on legacy (ancient) GE engines.

After several GT startups stateside for the OEM's Installation and Service Engineering group, Lucier got his first overseas gig to "rescue" two packaged powerplants in Esquintla, Guatemala, swamped by torrential storms (Fig 2). Assignments in over 20 countries soon followed—including locations in Europe, Asia, Middle East, and Latin America.



1. Dave Lucier has worked on some of the earliest commercial GE turbines. Here's some system components etched in his memory: Exhaust thermocouple averaging cabinet (A), Fairchild millivolt flame detector (B), fuel-oil gear pump (C), and gas fuel control valve (D)



Dave was appointed area engineer for Venezuela (including Colombia, Trinidad & Tobago, and the Netherlands Antilles) in 1971, returning to the US about 30 months later. The next highlight on his resume: Product test engineer at GE's Fitchburg facility where small steam turbines were made. Four years later Lucier transferred to the GE Field Engineering Development Center in Niskayuna, NY, as an instructor. He was appointed manager for entry-level training in gas and steam technology in 1980.

Dave's final assignment with GE came as site service manager at Tokyo Electric Power Co's Futsu site, where he managed 15 field engineers during the first phase of the installation of 14 Frame 9E STAG powerplants (Fig 3).

Lucier started his first company, I&SE Associates of Schenectady Inc, in 1986 to provide technical training and troubleshooting on early Frame 5, 6, and 7 gas turbines. In June 1999 he partnered with Charlie Pond to launch Pond and Lucier LLC, which became PAL Turbine Services LLC after Pond's passing in 2015.

It's business as usual at PAL after 19 years, which continues to provide technical advisory services to owner/operators of GE gas turbines. CCJ

2. "Rescue" was an appropriate description of Lucier's mission in Guatemala in 1969. Field engineers figure a way to get to and from the job to get the work done, no matter what's involved

3. Just to be sure . . . Shinto priest blesses turbine prior to commercial operation

Water cooling greatly increases intervals between valve overhauls

Reliable operation of dual-fuel gas turbines on oil demands that owner/operators protect against coking of distillate in fuel-system components. Active cooling is one solution available to users for assuring both reliable starts on liquid fuel and reliable fuel transfers from gas to oil.

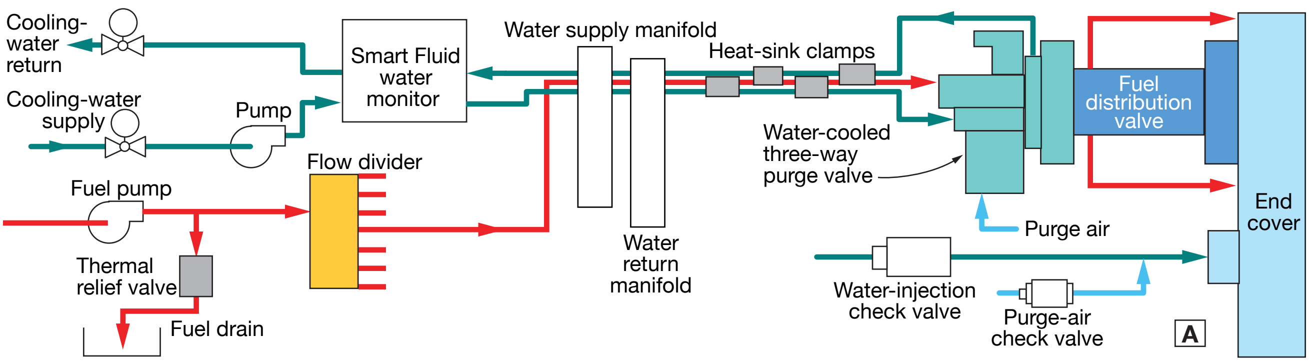
Recall that stagnant fuel in supply lines not protected against heat radiated from the gas-turbine casing (Fig 1) transitions to solid coke over time. In earlier stages of the coking process a tar-like substance is created that fouls check valves, coats fuel-nozzle passages, and builds up on the inside surface of oil piping. Case in point: Key components of liquid-fuel systems on many dual-fuel 7FA gas turbines are located in a 500F environment, double the nominal 250F temperature at which coking of distillate begins.

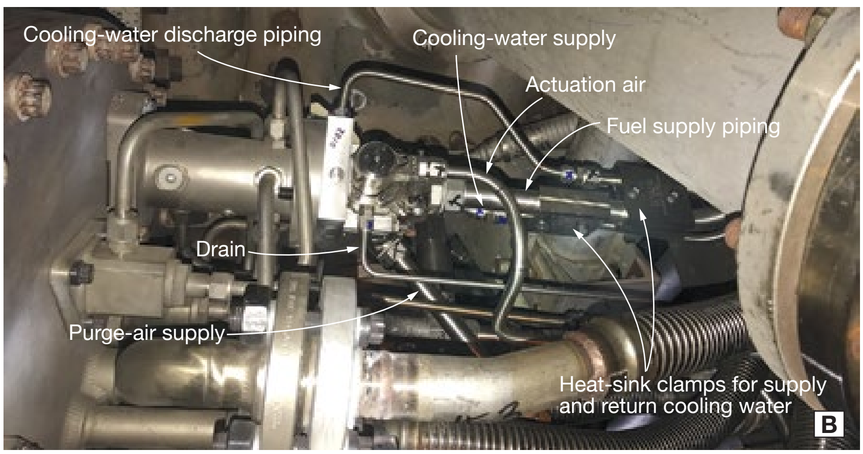
1. Reliable operation of dual-fuel engines on oil demands liquid-fuel piping be moved away from the casing to prevent coking of distillate remaining in those lines when gas is burned

JASC, Tempe, Ariz, has been at the forefront of industry efforts to improve the reliability of liquid fuel systems for well over a decade. The company's subject-matter expert, Schuyler McElrath, told the editors, "Active cooling of the fuel supply system has been a fundamental component of our technology and has demonstrated the ability to improve reliability."

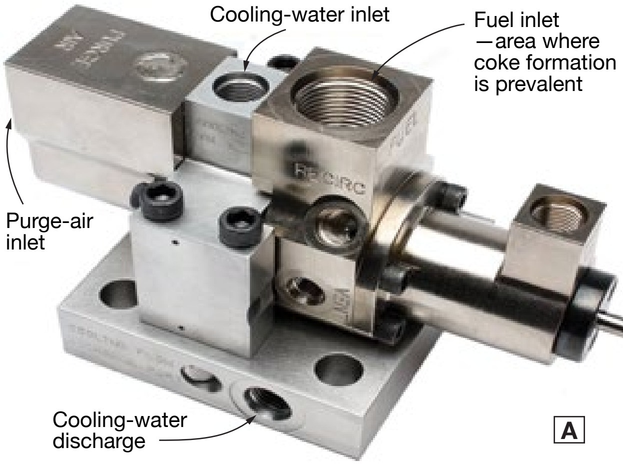
Until recently, owner/operators upgrading to active cooling were required to run on liquid fuel at least once a month to maintain system reliability. But the integration of JASC's heat-sink clamp into the fuel-supply system eliminates the need for monthly test runs at considerable saving in operating expenses. The drawing in Fig 2 illustrates where the water-cooled heat-sink clamp is installed and the photo shows how it supports fuel piping off the hot casing.

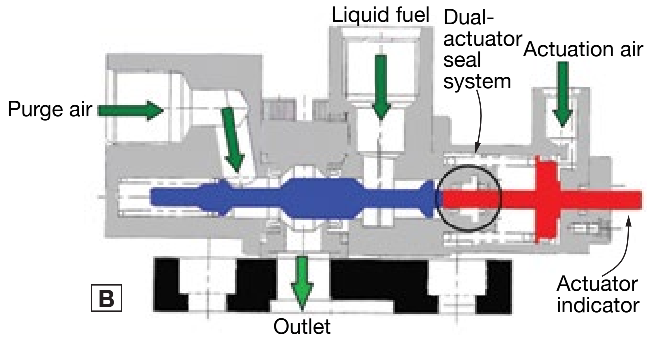
Note that the three-way purge valve in Fig 2 is water-cooled, which is critical for preventing coke formation. The valve is described in Fig 3 with the accompanying CFD analysis showing that components in contact with oil

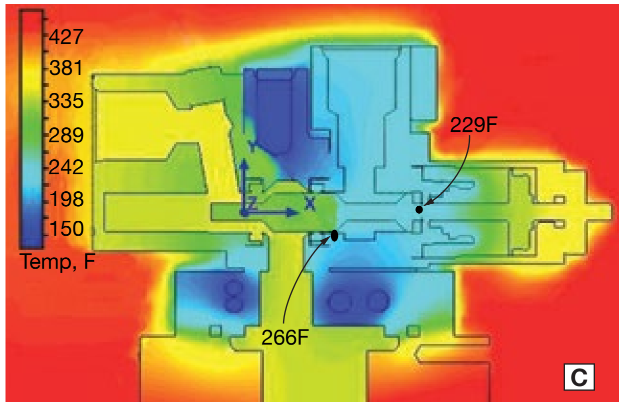




2. Liquid-fuel system illustrated is designed to keep distillate below the coking temperature, thereby enabling reliable transfers from gas to oil and vice versa. Photo shows how heat-sink clamps contribute to the cooling and help support fuel lines off the turbine casing







3. Water-cooled three-way purge valve is critical for preventing coking of oil in dual-fuel engines. Assembly photo (A) and cut-away drawing (B) illustrate the valve's operation. Thermal image (C) shows valve components in contact with oil are held below the coking temperature. Note that the CFD analysis uses temperatures 50% higher than expected for purge air and ambient conditions as a factor of safety

are maintained below the coking temperature. This is important for achieving valve refurbishment intervals of 24,000 to 32,000 hours consistent with industry norms for hot-gas-path inspections.

The current maintenance interval for uncooled or fuel-cooled three-way purge valves is *annual* and not related to operating hours. Water cooling can be added during refurbishment of uncooled valves with bolt-on hardware. Existing turbine purge air, liquid fuel, instrument-air piping, and valve flange connections remain the same, making the conversion economical for the benefits gained.

Fig 4 shows the coke buildup you can expect in the fuel inlet of an uncooled valve after several months of gas operation versus the "like-new" condition of a water-cooled valve recently overhauled. The latter illustrates the effectiveness of water cooling on the first 7FA equipped with both the three-way purge valve shown in Fig 2 and heat-sink clamps.

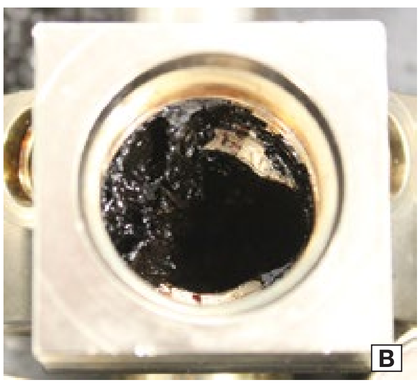
The unit operated on liquid fuel after every 25 runs on natural gas during the 2017 summer season and exclusively on liquid fuel during the winter. Based on the coke-free condition of the valves inspected, JASC has been advised the turbine owner to operate on liquid fuel after every 50 runs on natural gas during the 2018 summer season. CCJ

Backgrounder on the three-way purge valve

The three-way purge valve combines the features of a liquid-fuel check valve and purge-air check valve into a single component, improving reliability and reducing maintenance costs.

The valve normally is open to purge-air flow. The fuel seal from the factory provides a better-than ANSI Class VI seal in the reverse flow direction. This seal is critical to valve life expectancy because it prevents the reverse flow of gas into the fuel chamber. Either fuel pressure or actuation air will push the spool over to seal the purge-air chamber and open the fuel chamber.

Coking occurs in the fuel cavity when either no cooling is provided, or as in the case with fuel cooling, the fuel spool seal is compromised, thereby allowing both purge air and high-temperature combustion gas to reverse flow from the fuel nozzle into the valve's fuel inlet chamber.



4. Standard three-way purge valve reveals coking on disassembly (A). Inset shows coke deposit close up (B). Water-cooled valve offers no evidence of coking upon inspection (C)

ELECTRIC GENERATORS

2018 Annual Review

Sponsored by Mechanical Dynamics & Analysis (MD&A)

Meet the Editor

Generator consultant Clyde Maughan, now in the 67th year of his professional career, continues to amaze. You may recall that when still only 89 he recognized the need for a generator users group, put together a plan, invited some of the industry's top experts to present, and with help from NV Energy, Duke Energy, Power Users LLC, and a few generous sponsors, conducted the organization's first meeting in November 2015.

To celebrate his 90th birthday in July 2016, he came up with yet another idea: Publish an annual review of generator articles of value to owner/operators worldwide. The founding editor went to work and compiled *Electric GENERATORS, 2017 Annual Review,* a content-rich resource based primarily on presentations from the first two meetings of the Generator Users Group. The information in this 2018 Annual Review was compiled by Maughan from presentations made at the third GUG conference, August 28 – 31 in Phoenix.

Maughan's primary goal in publishing GENERATORS is to encourage your participation at GUG meetings and in the group's online forum.

If you have an idea for a presentation at the 2018 GUG meeting, email an abstract to Steering Committee Chairman Ryan Harrison (ryan.harrison@atcopower.com). Contact Maughan (cmaughan@nycap.rr.com) if you have editorial material to submit for the next edition of GENERATORS.

What's Inside

GENERATOR USERS GROUP

Your gateway to O&M best practices and lessons learned, methods for improving performance and safety, experience with new technologies, I&C, diagnostics, etc.

GUG's Generator Forum: Register today at no cost to stay current and connect with technology experts and industry colleagues (www.powerusers.org).

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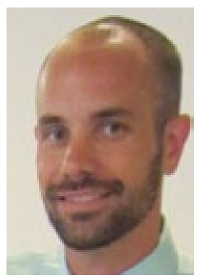

Fischli

Demcko

Riebau

Srirama

Smith

Attend the 2018 conference and vendor fair

August 27 - 30
Louisville Marriott Downtown
Louisville, Ky

Registration opens in April 2018 at www.genusers.org.

GENERATOR USERS GROUP

The benefits of participation

Welcome to the Generator Users Group (GUG). We are a consortium of electrical generator users. Our mission is to provide an opportunity for owner/operators of electrical generators worldwide (initially 1500/1800- and 3000/3600-rpm machines) to share experiences, best practices, and lessons learned on design, installation, operation, and maintenance of those machines. Expected outcomes are improved plant safety, maintainability, availability/reliability, and efficiency.

The GUG also serves to effectively transfer industry knowledge from experienced engineers to those with less experience. We are mostly made up of utility engineers and operators but utility maintenance and management personnel are encouraged to join and participate in the annual meeting. The benefits of becoming a member (there is no cost to join) is access to a resource of generator users to share knowledge and issues with and assist you in problem-solving for specific challenges at your station or in your fleet.

We have three main methods of information transfer: An annual users group meeting, this publication, and a 24/7 Web-based forum. As a member, you also will have access to contact information for other users and independent consultants knowledgeable in generator specifics. Access our website at www.genusers.org by scanning QR1 with your smartphone or tablet.

QR1

The GUG steering committee is made up of generator users. We are:

Chairman

Ryan Harrison, *lead generator engineer, ATCO Power (Canada)*

Vice Chairman

Dave Fischli, *generator program manager, Duke Energy*

Members

John Demcko, *lead excitation engineer, Arizona Public Service Co*

Joe Riebau, *senior manager of electrical engineering and NERC, Exelon Power*

Jagadeesh Srirama, *generator engineer, NV Energy*

Kent N Smith, *manager of generator engineering, Duke Energy.*

The Generator Users Group is a member of Power Users LLC, an umbrella organization serving five independent users groups—Steam Turbine (STUG), Combined Cycle (CCUG), GUG, 7F, and Controls—to minimize administrative costs. Our annual meeting normally is held at the same time and location as the STUG and CCUG meetings. The benefit: GUG attendees get complementary access to the CCUG and STUG presentations. In this manner, you can get information beyond just the generator proper.

User members will benefit greatly from the information provided by our all-volunteer organization. None of the committee members takes a salary or any other remuneration from the Generator Users Group. Many expenses associated with providing information to you (conference costs, publishing costs, website costs, etc) are covered by generous generator vendors and OEM sponsors. In this way the cost to users attending the annual meeting is minimized.

We are confident you will see the benefits of participating in the organization and hope you will join us in our efforts to share generator information. There is no cost to become a Generator Users Group forum member, so please sign up today at www.powerusers.com.

Finally, if you missed Clyde Maughan's summaries of the presentations from GUG 2015 and GUG 2016, you can access them easily by scanning QR2 with your smartphone or tablet.

QR2

Clyde V Maughan (right) the force behind the formation of the Generator Users Group, is recognized by GUG Chairman (2015-2017) Kent Smith for a "lifetime of sharing selflessly his extensive knowledge in the design, operation, and maintenance of electric generators."

ELECTRIC GENERATORS
2018 Annual Review

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PSI Media Inc, Las Vegas, Nev, publishes specialty print and electronic media serving energy producers in targeted national and regional markets. Media include the following:

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Of particular interest to generator owner/operators is Clyde Maughan's course on generator monitoring, inspection, and maintenance. The program is divided into seven one-hour segments culled from notes and slides extracted from Maughan's 2½-day training course—taken by more than 1000 users over the years. Listen to any segment at any time.

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GENERATOR USERS GROUP

Fourth Annual Meeting

Marriott Louisville Downtown, Louisville, Ky
August 27-30, 2018

Please mark your calendar and plan to attend
Registration opens in April at www.genusers.org

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

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

The GUG Steering Committee

Jagadeesh Srirama, *NV Energy;* Joe Riebau, *Constellation/Exelon;* Vice Chair Dave Fischli, *Duke Energy;* John Demcko, *Arizona Public Service Co;* Kent Smith, *Duke Energy;* Chair Ryan Harrison, *ATCO Power* (left to right)

Email Vice Chair Dave Fischli (dave.fischli@duke-energy.com) with your thoughts/ideas today.

Lessons learned, best practices shared at GUG 2017

That generators are "taken for granted" by the majority of plant personnel should not surprise. One of the reasons for this attitude is that staff often is not aware of the many things that can go wrong with electrical machines, how to identify problems, and what solutions are available to mitigate/correct issues.

GENERATORS' coverage of GUG 2017 affords the opportunity to see many of the problems engineers face regularly and why the opportunity to meet with other experts (users, OEMs, third-party solutions providers, and consultants) is so important. Attending the 2018 meeting of the Generator Users Group, in Louisville, August 27-30, is a good starting point. Visit www.genusers.org for more information.

Summaries of the 2017 presentations and discussions, prepared by IEEE Fellow Clyde V Maughan, president, Maughan Generator Consultants, is divided into these five sections:

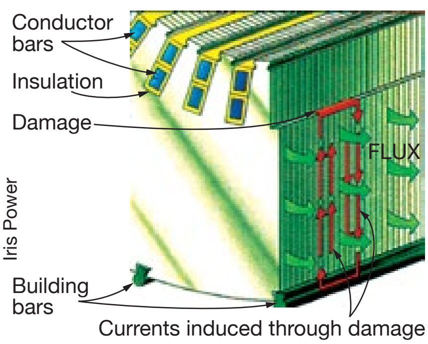
- Stator frames and magnetic cores.
- Stator windings and bus systems.
- Fields and excitation systems.
- Operation and monitoring.
- General topics.

Users wanting to dig deeper into any presentation can access the PowerPoint in the Power Users library at www.powerusers.org. Note that the Power Users Group is an administrative umbrella organization serving the generator, steam turbine, combined cycle, 7F, and controls users groups to reduce operating expenses.

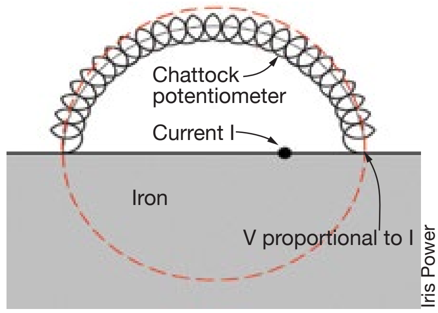
A. Stator frames and magnetic cores

ELCID trending, analysis

Electromagnetic Core Imperfection Detection (ELCID) is a low-excitation test with wide industry acceptance for assessing core health. Insulation breakdown causes fault currents to be set up as illustrated in Fig A1. A Chattock potentiometer (Fig A2) is used to measure the magnetic potential difference resulting from this current, with the somewhat complex equipment and circuit illustrated in Fig A3.



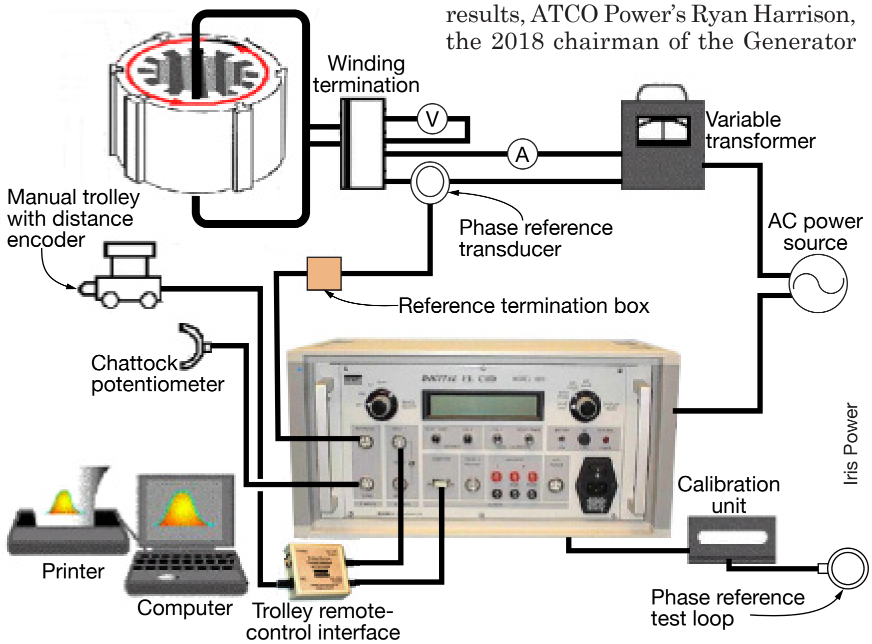
A1. Fault currents attributed to insulation breakdown create hot spots



A2. Chattock potentiometer measures the magnetic potential difference resulting from the fault currents caused by insulation breakdown illustrated in Fig A1

Bear in mind that fault currents create hot spots which can cause further deterioration to the core. If left unchecked, they can lead to damage of the stator core, windings, and the machine as a whole.

There are several setup challenges important for you to consider during analysis and trending of ELCID test results, ATCO Power's Ryan Harrison, the 2018 chairman of the Generator



A3. Circuitry and components required for the Chattock potentiometer are complex

Users Group, told attendees—including the following:

Core length. Depending on the operator and OEM versus non-OEM, different core lengths often are used. This leads to scaling issues in the traces and makes exact positioning a challenge.

Polarity. The orientation of the Chattock coil, and the orientation of reference transducer can lead to inversion of the quadrature signal.

Slot numbering. Decide whether to number the slots clockwise or counterclockwise, and which slot you select as Slot No. 1.

Trending areas of interest. Results are often standalone and on various scaling in the report. This makes assessment of areas of interest more difficult and, in some cases, more judgement-based. In addition, the digital files, which have valuable information such as phase current, often are not retained by the site/tester.

Software. The owner doesn't necessarily have the software to read the digital file. Furthermore the software is needed to export the values to a usable format. But only software "*.csv" is available; it is free to download.

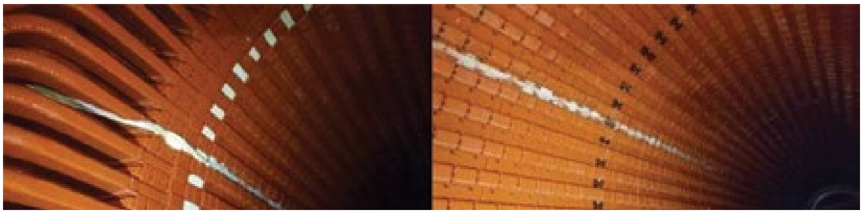
Filtering. The raw data files have noise, and filtering is applied to the final reported results. While not necessarily a problem it can be valuable to look at the raw data for which the original data file is needed.

Duration between tests. Depending on the machine, the duration can be quite long. Results can be lost over time which is important for establishing baseline values and fault tracking.

Several trending challenges also were discussed and illustrated by Harrison—for example, filtered versus unfiltered, noise, inversion of signal, alignment, vertical scaling, and vertical offset. Digital data can alleviate some of the challenges associated with trending; however, there is not a commercial solution available to help with this review. Harrison presented a scripted Matlab-based solution with alternative graphic representations.

Electromagnetic signal analysis

The signal capture equipment employed by Duke Energy until 2011, Kent Smith, Duke Energy's manager of generator engineering, told the group, was the EMC30-MKIV; today the Agilent E7402A. National Instruments' Labview 8.5 program was used to control (standardize) data capture. Frequency of data capture on 74 generators in the fleet was annually on large steam units and so-called Tier 1 gas turbines; "when available" on smaller GTs.



A4. Sensing fiber is easy to identify on top of stator wedges

The Labview program data-capture process was in four ranges of 2000 points each, as recommended by AEP /User's Group: Range 1, 30 - 300 kHz; Range 2, 300 kHz to 3 MHz; Range 3, 3 - 30 MHz; Range 4, 30 - 100 MHz. At the end of each range the program pauses to allow manual capture of peak signatures. The program consolidates all four ranges and displays signature. After signature is saved, the peaks of interest are demodulated, viewed on-screen, and saved to file. The data then are manually imported into Excel for reporting.

Smith, the GUG's immediate past chairman, then discussed two examples of data taken, aided by several slides showing signal analyses:

- Crystal River Unit 4. It was taken offline for testing in 2005. Results: Passed the Hydraulic Integrity Test (HIT); B phase megger was low (<500 Meg). Online testing in 2005 revealed a small amount of higher-frequency noise. In 2010, the electromagnetic signal analysis (EMSA) signature revealed a "hump" in mid-frequency range and had more of the higher-frequency noise. Work performed in 2010 included rewedging, the rotor mod recommended in TIL 1292, "Generator Rotor Dovetail Cracking," and repair of five major clip leaks. In addition, the isophase ground flex link at the generator bushings was found pitted and overheated; the link was replaced. A stator rewind was scheduled for 2011.
- Crystal River Unit 5. Online testing in 2010 found high EMSA signatures in the low and mid frequencies. Shaft voltage readings were extremely high (30 Vdc) and EMI sniffer was screaming at the exciter end. Later in the year, offline testing found hydrogen seal grounded, the HIT Skid test passed, and B phase resistance was 700 Meg with PI < 2.

The hydrogen seal was coked and pitted (electrolysis). A new hydrogen seal was installed but personnel could not get the new hydrogen seal insulation package to have a very good megger; resistance was acceptable, but suspect. Sniffer readings were still high. A stator rewind was scheduled in 2012.

Future plans include having baselines on all generators (even those for small GTs), developing database on failure mechanisms with signature data, expanding the program to include large motors, developing a continuous online monitor ported to PI for Tier 1 generators.

Fiberoptic temperature measurement for continuous monitoring

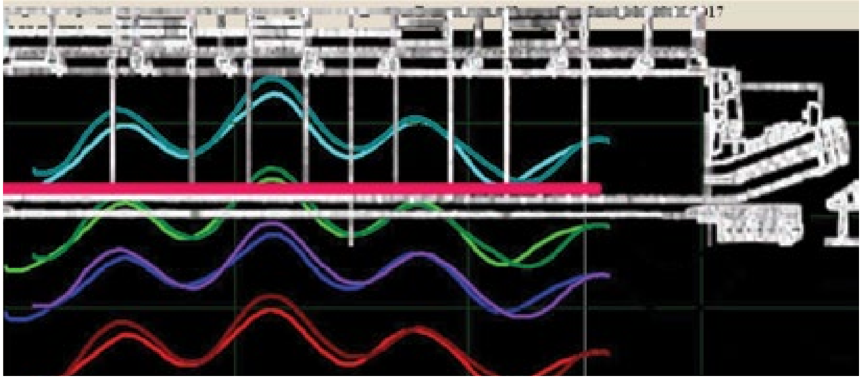
While generator core failures aren't common, their potential impact is up to the catastrophic level. Most generator cores are only indirectly monitored online through embedded RTDs situated between top and bottom stator bars at specific locations in particular core slots. These point sensors offer little protection to the large volume of the core.

Offline core testing, such as ELCID or ring/loop testing, can catch developing core issues, but both tests offer challenges in correlating measured values to actual online temperatures, and neither one offers protection from emergent issues online.

Fiberoptic temperature monitoring shows great promise in advancing core protection by permitting measurement of distributed temperatures along a length of fiber line, Calpine Corp's Director of Outage Services Craig Spencer told the group. Working with Fiber Optic Sensors LLC and Oz Optics Ltd, Calpine installed a proof-of-concept application into one of its Hermiston (Ore) combined-cycle generators. The sensing fiber was installed on top of the stator wedges (Fig A4), though an ideal installation would be under the wedges in the base shim stock.

Once online, temperature readings from the fiberoptic line compared well against the existing RTD readings. More importantly, excellent data curves emerged which clearly demonstrated the stator zone-cooling temperature affects along the length of the fiber (Fig A5). There were some small anomalies in the data, but personnel suspected these were installation-driven variances, to be proved out in the next test case.

Overall, the results were very encouraging for developing advanced online core thermal protection, as well as for additional applications of distributed temperature sensing.



A5. Color curves show temperature readings at various loads; solid red line is the length of the installed fiber

B. Stator windings and bus systems

Stator design

Ed Winegard, GE's principal engineer for armatures, opened his presentation by noting the high radial slot forces that must be contained in the stators of modern power generators—ranging from 10 to 110 pounds/inch of slot. Fortunately, he said, these forces are predominately downward, adding that about half the slots in a given stator retain bars for different phases, about half the same phase.

For slots with both bars in the same phase the force will be downward on both bars, he said. When the bars are for different phases, the force on the top bar will be slightly upward. Some type of compression system—top ripple springs, for example—is required to minimize bar movement and ensure it remains seated in the slot (Fig B1).

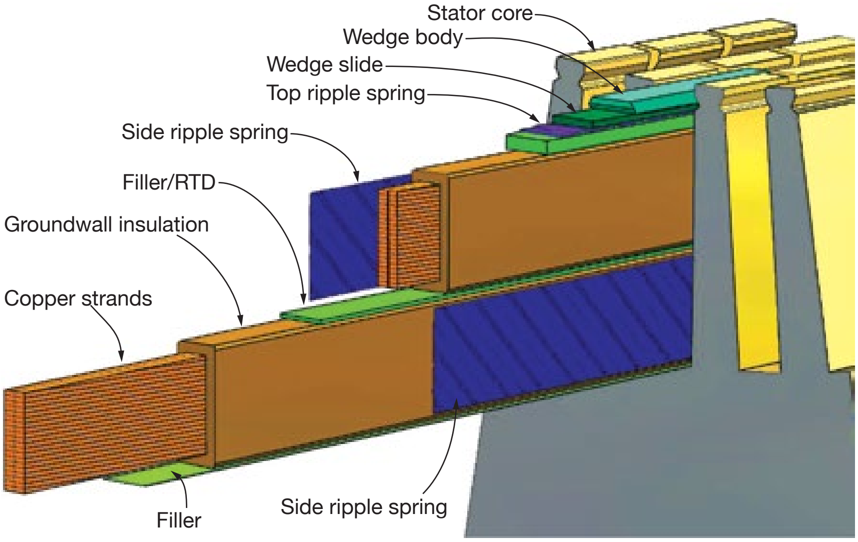
Bar lateral forces are minimal, Winegard continued. However, he pointed out the inherent tangential motion of the slot teeth caused by radial deflection of the core (Fig B2). This motion and its effect on the stator bar must be minimized. A similar method of ensuring the bar remains in contact with the slot wall is required and the side ripple spring (refer back to Fig B1) is ideally suited to meet this requirement.

There are also important stator wedging considerations which must be met, Winegard said: material properties (stiffness, creep, thermal aging, abrasion, etc), dimensions and tolerances (design clearances, tolerance stack up, component machining quality), assembly process (standard methods and sequence, compensation of assembly variation), and inspection (qualitative and quantitative validation).

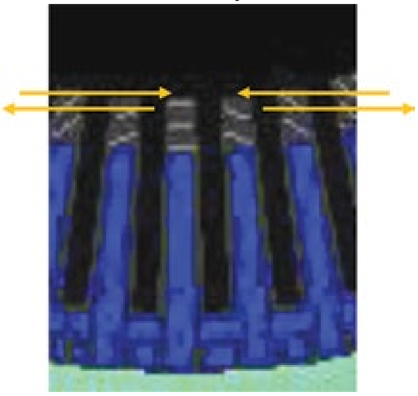
Aeropac rewind

The Siemens Aeropac generator discussed by Derek Hooper, president of BPHASE Inc, a small repair, inspection, and consulting company specializing in gas-turbine generators, was rewound by Alstom in 2014 because of moderate-to-severe spark erosion (Fig B3). Numerous concerns were experienced with this rewind, including the following: injection of clear resin into the dry tie material used made it difficult to determine if the cord was fully saturated (Fig B4), difficulty in obtaining proper series connection alignment (Fig B5), and use of semiconductive packing in the phase-break gaps to attenuate partial-discharge damage.

Two years later, BPHASE performed a minor inspection of the Alstom rewind. Focus was on visual inspection of the winding and evaluation of the core keybars. The keybars were intact and within torque specifications (Fig B6). While there was no evidence of keybar fracture in this unit, sister machines had suffered such fractures and plant personnel elected to reduce the keybar torque from 300 to 200 ft-lb.



B1. Top ripple springs minimize the relative motion of bars in their slots, mitigate insulation degradation



B2. Rotating magnetic field drives a rotating deflection of the stator core which causes alternating motion of the teeth on either side of the stator bar

B3. Siemens Aeropac generator was rewound by Alstom because of the moderate-to-severe spark erosion in evidence

B4. Resin was injected into the dry tie material used in the rewind

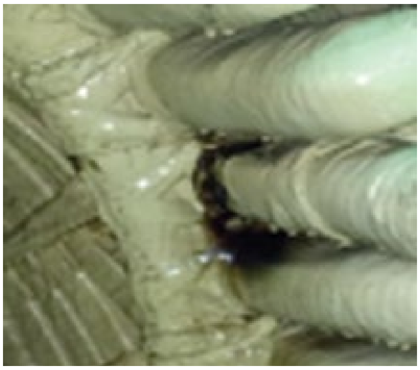
B5. Proper alignment of series connections were difficult to achieve because of bonding from the wet tie materials used

B6. Proper torqueing of keybars is critical in preventing their fracture

B7. Discharge oxidation at phase splits is easy to see

B8. Dusting is evidence of movement at the series connector interface with the outboard ring

B9. Visual inspection reveals indications of two previous repairs using a weeping epoxy



B10. Phase connection set-back had at least one prior repair attempt using the same epoxy

There was visible evidence of discharge oxidation at the phase splits (Fig B7). There was also significant evidence of movement at the series-connector interface with the outboard ring (Fig B8).

Because of vibration concerns, it was felt that blocking should be installed between the series connections for additional support. However, this would require bump testing. The outage was too short to allow necessary disassembly and the decision was made to install series blocking in short groups to limit any effect on the global modes of the baskets.

Monitoring of endwinding vibration

Iris Power's Mladen Sasic discussed monitoring of endwinding vibration. Although the problems associated with movement of endwindings are not new, because of changes in the design and operation of generators these issues have become a greater concern in recent years.

The endwinding region of large turbine/generator stator windings is one of the most complex parts of a generator relative to design, manufacturing, and maintenance. During normal operation, the endwindings are subject to high mechanical forces at twice power frequency because of currents in the stator bars, as well as mechanical forces transmitted via the core and bearings at rotational speed. Furthermore, during power system transients, the forces in the endwinding can reach 100 times higher than that of normal operation.

The design of the endwinding also must account for thermally induced axial expansion and contraction as the generator is loaded and unloaded. Metallic components to restrain the movement of stator bars caused by these forces normally are avoided because of the presence of high magnetic and electric fields.

Sasic shared his knowledge on the installation of vibration sensors, offline test results, and online monitoring data from a 288-MVA, 21-kV, air-cooled generator. Offline impact test data led to installation of fibreoptic endwinding vibration sensors. Continuous online monitoring of these sensors revealed an increase in vibration level, encouraging a visual inspection and bump test of the endwinding. The inspection/test confirmed loosening of endwinding support structure. Timely corrective maintenance was then possible to prevent a costly in-service failure.

Connection-ring inspection and repairs

Inspections of connection rings typically are focused on the physical support structure-to-ring interface. While there are other factors to consider—such as the connections to bars or coils and inner cooling circuitry—they aren't as common an issue and should become apparent through other testing, MD&A Generator Specialist Keith Campbell told GUG attendees.

Thorough visual inspection is vital to an accurate assessment of the overall condition of the rings. The 10 photos here illustrate typical problems associated with undesirable movement. To begin, the ties in Fig B9 offer indications of two previous repairs using a weeping epoxy. While oil intrusion was a contributing factor, the contamination (greasing) was removed well enough to allow for an adequate repair.

Fig B10 is of a phase-connection setback that had at least one prior repair attempt using the same epoxy. In this case, the contamination was under the ties and blocking, and could not be removed by cleaning alone. Fig B11 reflects an overall looseness in the endwinding structure as indicated by the large amount of greasing throughout. This was conducive to the possibility of a catastrophic failure. Fig B12 is of an original blocking and tie arrangement that does not meet quality standards.

Fig B13 shows a continuation of the previous repairs by additional application of epoxy. Fig B14 reveals ties removed for a better cleaning and application of new ties. Fig B15 is the result of excessive movement that dictated reinsulating and securing of components with a different material and by different methods than used by the OEM.

B11. Overall looseness in the endwinding structure is evident from the large amount of greasing

B12. Original blocking and tie arrangement does not meet quality standards

B13. Previous repairs continued with application of additional epoxy

B14. Ties were removed for a better cleaning and application of new ties

B15. Damage caused by excessive movement was corrected by reinsulating and securing with different material and methods than those used by the OEM

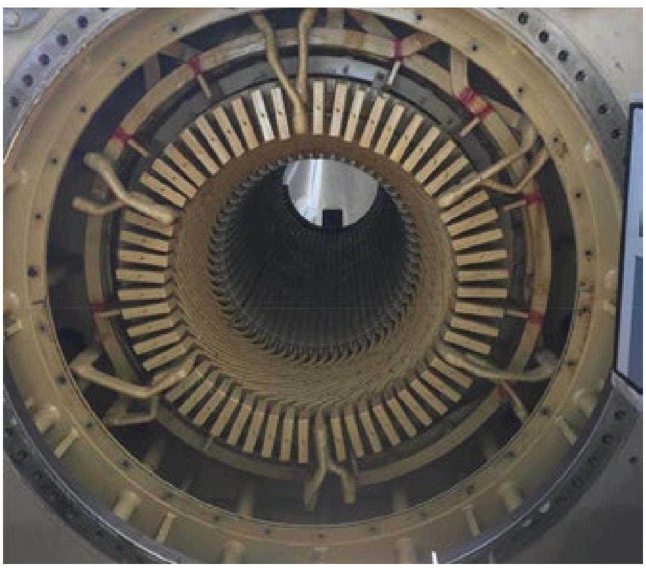
B16. New tie stands out after removal of the old tie and blocking, cleaning, and addition of new conforming material

Repairs complete, Fig B16 shows the new tie after the old tie and blocking had been removed, cleaned, and new conforming material had been added. Fig B17 illustrates the areas where epoxy was applied; the Fig B18 photo was taken after repairs to the endwinding structure were completed.

Hot-spot detection

NV Energy's Jagadeesh Srirama, a member of the GUG steering committee, profiled for attendees the recent inspection of a 391-MVA Alstom steam turbine/generator for an F-class combined cycle. This unit was put in service in 2004 and high vibrations had been recorded since installation. No issues were identified during a MAGIC (Miniature Air Gap Inspection Crawler) inspection done in 2013 and all the electrical test results were acceptable during this outage.

The unit was inspected again during a 2017 outage for simultaneous gas turbine, exhaust structure, and generator work. MAGIC identified four hot spots in the core iron and ELCID testing confirmed damage at those locations with exceptionally high readings of 1998, 1363, 674, and 976 mA. In addition to the hot spots, foreign material was found in the air gap. Management decided on immediate corrective action. To address the hot spots, it was neces-



B17. Areas where epoxy was applied are clearly visible

B18. Endwinding structure after completion of repairs

B19. Visual inspection of the stator identified several locations where overheating had occurred

B20. Core lamination material proved to be the foreign matter found during the inspection

B21. Loose side packing found near the endwindings was migrating upwards into the air gap

B22. Source of the foreign matter shown in Fig B20 was a very loose tooth package

B23. Damaged areas had a coat of red dye applied to weep into the laminations before coating with a buff paint

B24. Significant damage was done to the A-phase flex links

sary to remove the field—a challenge at this outdoor plant with major plant repairs already underway.

After rotor was removed, visual inspection identified several spots with obvious overheating similar to that in Fig B19; the debris was identified as core lamination material (Fig B20). Near the endwindings, some of the side packing had come loose and was migrating upwards into the air gap (Fig B21).

The lamination pieces came from a grossly loose tooth package, photographed in Fig B22. This tooth area was cleaned, inspected, and trimmed to make sure no more of the punchings would liberate. Mica then was placed in the shorted area and a tapered wedge inserted into the tooth to tighten the package. This wedge was epoxied in place. Note that the core step iron will have to be replaced when the stator is rewound in the future.

The side packing that came up from the top of the bar (refer back to Fig B21) was removed, air dry varnish applied, and new side packing installed. All damaged areas had a coat of red dye applied to weep into the laminations before coating with buff paint (Fig B23).

Importance of flex link maintenance

Duke Energy's Dave Fischli, manager of generator engineering, and vice chairman of the GUG steering committee, reviewed for attendees the case history of a Westinghouse 818-MVA, 20-kV generator (COD 1981) that tripped on an A-phase neutral ground only a couple of months before the meeting. The machine's field and stator had been rewound by Alstom in 2005.

Subsequent to the trip, a fire was reported at the lead box on the generator; site emergency responders used ABC dry chemical to extinguish the fire as the unit coasted down. External visual review showed significant damage to the A-phase lead area, with heat damage to the B-phase bushing area. Post-event data review showed some electrical anomalies starting eight minutes before trip.

Inspection revealed significant damage to the A-phase links; none of the 32 links remained intact (Fig B24). B- and C-phase links all were connected and appeared fine (Fig B25). There was a heavy layer of soot on the CTs for both the A and B phases, plus contamination at the bottom of lead box from fire-damaged components (Fig B26).

Investigators concluded that loose connections on one or more flex links caused a high-resistance contact which allowed current to flow through the bolt rather than the link contact surface area, and the bolt melted. Thus, loss of one flex link shifted its current to the remaining flex links, adding heat to them and amplifying the loose-connection problems and degraded condition of other flex links.

The A-phase links were too heavily

B25. B- and C-phase links were all connected and passed visual inspection

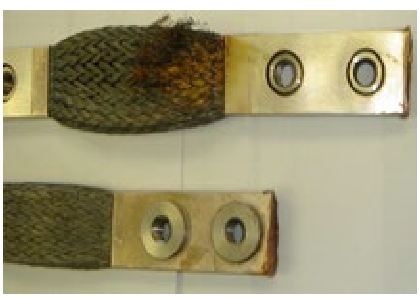
B26. Burning of gasket/sealing materials produced a heavy layer of soot

B27. The condition of Belleville washers used to secure phase links was called into question. Some had flattened out from repeated use, some had been installed upside down

B28. Some flex links were found in a frayed/degraded condition

B29. Arc damage is revealed on a bolted joint's bus face

B30. Flexible connector's cracked laminations were caused by vibration or air flow



B31. Rubbing and/or abuse damaged these flex braids

damaged to record torques, but torque checks performed when removing links from the B and C phases were satisfactory. Some Belleville washers removed from the B and C phases had been flattened out from repeated use, others had been installed upside down (Fig B27). Flex links from the B and C phases also revealed fraying and degradation (Fig B28). It was evident that previous visual inspections had not been sufficiently rigorous to identify degraded links for replacement.

Consequential damage. The ABC dry powder extinguishing agents include chemicals such as sodium bicarbonate, potassium bicarbonate, ammonium sulfate, and ammonium phosphate. These chemicals act as a desiccant, absorbing moisture, and under humid conditions become conductive. They are alkaline in nature and corrosive to electrical insulation and metal components within the generator.

There was extensive contamination of the lead box and exciter internals by soot and smoke particles. Basic cleaning was performed of all accessible areas without complete disassembly. Follow-up inspection and full cleaning is planned for a 2018 outage.

Lessons learned:

- Ensure work-order instructions are written correctly.
- Ensure craft technicians are trained on the importance of assembling high-current connections properly.
- Ensure flex links are completely removed for electrical isolation—not just unbolted on one end and bent back out of the way.
- Ensure fire extinguishers staged around generator and other electrical equipment are CO_2 or Halon (not ABC chemical).

Preventive maintenance of bus duct systems important

RMS Energy's Jesus Davila reviewed for attendees the several types of bus systems and components: cable bus, non-segregated and isolated-phase bus, terminations and disconnect links, insulating materials, expansion joints, seal-off bushings, etc. Each of these requires special maintenance. Critical items on the bus duct include flex/bolted connections (current carrying), expansion bellows/joints, insulators and mountings, seal-off bushings, groundings, and insulated joints. Examples of some of the issues discussed by Davila were the following:

- Electrical connections. Arc damage to bolted joint bus face (Fig B29).
- Flexible connectors. Cracked laminations caused by vibration or air flow (Fig B30); flex braids damaged by rubbing and/or abuse (Fig B31).
- Improper bolting or lack of maintenance at connection points. Damaged contact surfaces and gross heating issues (Fig B32).
- Expansion-bellows damage attributed to excessive movement often resulting in cracks (Fig B33).
- Bus failures. Overheating of non-segregated bus attributed to a lack of maintenance (Fig B34); line-to-

B32. Improper bolting and lack of maintenance are conducive to damaged contact surfaces at connection points

B33. Excessive movement of expansion bellows is conducive to cracking damage

B34. Overheating attributed to a lack of maintenance destroyed this non-seg bus

B35. Melting of the bus enclosure was caused by a line-to-ground fault

ground fault causing melting of the bus enclosure (Fig B35).

Most of the deterioration conditions listed above can be detected, particularly in advanced stages, by visual examination and/or temperature monitoring. All require immediate attention to prevent major equipment failure. If the condition is found before failure, refurbishment usually can be accomplished by obvious and/or well-established procedures.

C. Fields and excitation systems

Rotor arcing and repair

A common and destructive phenomenon in generators is negative sequence currents (I_2), MD&A Project Engineer Chris Keathley told GUG 2017 attendees. These can be caused by unbalanced three-phase currents, unbalanced loads, unbalanced system faults, open phases, and asynchronous operation.

The result of I_2 currents may be rotor body currents that can damage the rotor forging (Fig C1), retaining rings (Fig C2), slot wedges (Fig C3), and to a lesser degree, the field winding.

Three case studies were reviewed by the speaker, who brought to MD&A 16 years of experience with a major utility as a turbine/generator engineer, and another five years with the OEM.

Case Study No. 1. A 500-MVA, 22-kV, 3600-rpm generator had been involved in a motoring event of unknown size and duration five years before the inspection described was conducted. A visual assessment revealed relatively minor problems—such as slight burning between wedges, significant burning on wedge ends, and burning of the forging at wedge junctions. Eddy-current testing revealed 290 indications. Affected areas were cleaned and blended. A TIL 1292 ("Generator Rotor Dovetail Inspection") repair on the Coil No. 1 Slot was done and steel wedges were replaced with aluminum (except end wedges). A high-speed balance and heat run were conducted after rewind.

Case Study No. 2. A two-pole field suffered a double ground fault that caused severe arcing damage to the rotor, including melted material and cracking on a tooth (Figs C1 and C4). NDE of the area revealed a through-wall crack and an engineering evaluation determined the rotor unacceptable for operation. A temporary weld-repair solution was proposed to get the unit back in service until a replacement rotor could be obtained. The damaged portion of the tooth was removed (Fig C5) and the tooth reconfigured with weld build-up, rotor heat treatment, and re-machining of the tooth (Fig C6).

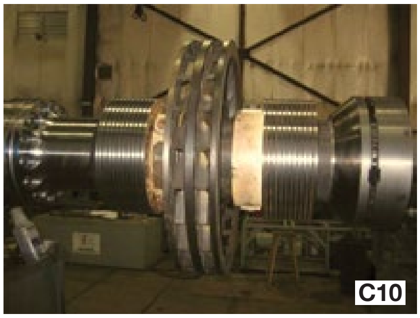
Finite-element models of the rotor and slot tooth were created to obtain the various stresses along the tooth height, the weld fusion line/HAZ, and the highly stressed wedge groove fillet radius. These stresses and mechanical properties were used in fracture-mechanics calculations; favorable results supported acceptance of the repair. A fatigue analysis of the repaired tooth suggested the reworked rotor was good for 150 start/stop cycles or 10 years of operation, whichever came first.

Case Study No. 3. A generator experienced a collector failure and ground to the main shaft that caused major arcing and heat damage to the

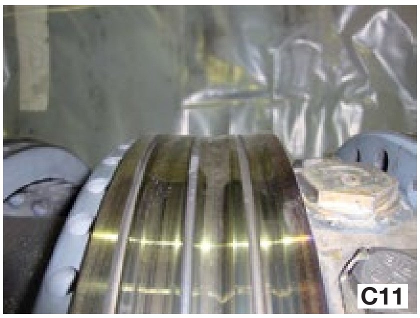
C1-C3. Negative sequence currents are a common and destructive phenomenon associated with generators. The result of these I_2 currents can be rotor body currents that can damage the rotor forging (left), retaining rings (center), and to a lesser degree, the field winding (right)

C4-C6. A double-ground fault caused severe arcing damage to the rotor, including melted material (refer back to Fig C1) and cracking on a tooth (left). The damaged portion of the tooth was removed (center) and replaced by weld build-up with appropriate heat treatment and re-machining of the tooth (right)

- On-site comprehensive testing and inspection
- Field rewinds and repairs
- Stator rewinds
- Wedge system upgrades
- Replacement retaining rings
- Collector rings
- Hydrogen seal rings and assemblies
- High voltage bushings and auxiliaries
- Insulated bearing rings
- Oil deflectors
- Exciter inspection
- Control and excitation field engineering and consulting
- High-Speed Balance with heat run capability/ High Speed Thermal Test (HSTT)



C7-C10. Collector failure and ground to the main shaft caused major arcing and heat damage to the end of the generator rotor forging, which could not continue in operation as found (Fig C7). The shaft was severed just outboard of the journal and bolt holes drilled and tapped for the new stub shaft (Fig C8). The assembled new shaft extension is in Fig C9 and the final assembly with fan and collector rings in Fig C10



end of the generator rotor forging (Fig C7). The amount of damage and heat-affected material made the shaft end forging unacceptable for continued operation. Stub-shaft replacement was proposed and accepted by the owner.

This was a major undertaking. The shaft was severed just outboard of the journal and bolt holes drilled and tapped for the new stub shaft (Fig C8). The assembled new shaft extension is shown in Fig C9, and the final assembly with the fan and collector rings in Fig C10.

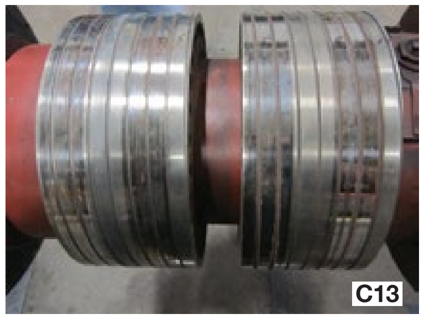
To conclude, negative sequence events and ground faults are preventable by good operation and monitoring equipment. When those defenses fail, considerable damage can occur. However, it does not always mean that the damage cannot be repaired and the unit returned to service. These case studies show that even when there is damage, advanced welding and machining processes can restore the unit to service relatively quickly.

Collector rings: Inspection and repair

MD&A's Keith Campbell, an industry veteran with four decades of experience, showed and discussed numerous photographs to illustrate the inspection, failure modes, and repair of collector rings.

Inspection. Typical conditions found during inspection are shown in photos C11-C15. Threading and grooving (Figs C11 and C12) naturally result from the wear and tear of long service. Photography (Fig C13) is not common nor well understood; it describes the phenomenon in which the pattern of the brush holders is replicated on the rings. There is inevitable contamination associated with the collector (Fig C14) from sources that include brush wear, induction of foreign material with the cooling-air flow, and uncorrected arcing. Massive contamination is caused by flashover failure (Fig C15).

Failure. Typical problems resulting from failure are seen in the photos C16-C19. In the first, the right ring was severely burned by a flashover to ground or severe arcing from poor maintenance. The adjacent image shows a similar condition but with the brush holder removed. Fig C18 is of damage to the main shaft from severe arcing to ground, C19 shows corresponding arc damage to the ring inside diameter.



C11-C15. Typical conditions found during inspection of collector rings are threading (Fig C11), grooving (Fig C12), photographing (Fig C13), contamination (Fig C14), and heavy contamination (C15)

Repairs. Figs C20-C22 illustrate steps in replacing an old collector with a new collector, Fig C23 is of a grinding operation for truing a worn, or new, ring.

An unusual generator field ground

The incident profiled here by John Demcko, PE, a senior consulting engineer at Arizona Public Service Co and member of the GUG steering committee, occurred at an APS plant equipped with three single-shaft combined cycles installed in the mid-1970s.

The generators serving these units are rated 146.7 MVA/13.8 kV; they were retrofitted with static excitation systems and redundant digital regulators several years ago. This update included a modern 64F field ground detection system, which experienced a continuous field ground alarm over a year ago. The incident was treated routinely—that is, management was informed.

Management was made aware of the risks associated in running with a known ground. The decision was made to remain online until an outage could be scheduled to evaluate the situation. When that happened, a Megger test of *all* components in the field winding circuits showed no ground.

The 64F relay is only operative when there is excitation on the machine since it is powered from the excitation power potential transformer. With the unit offline and not spinning the 64F was powered up with a "cheater" cord. No field ground was detected by the relay in this configuration. The 64F relay was switched out for an identical spare which also indicated no ground with the unit offline but did indicate one with it spinning and the field energized.

C16-C19. Problems resulting from collector-ring failure include burning caused by flashover to ground or severe arcing from poor maintenance (Figs C16 and C17 with brush holder removed), main-shaft damage caused by severe arcing to ground (Fig C18), and arcing damage to the ring ID (C19)

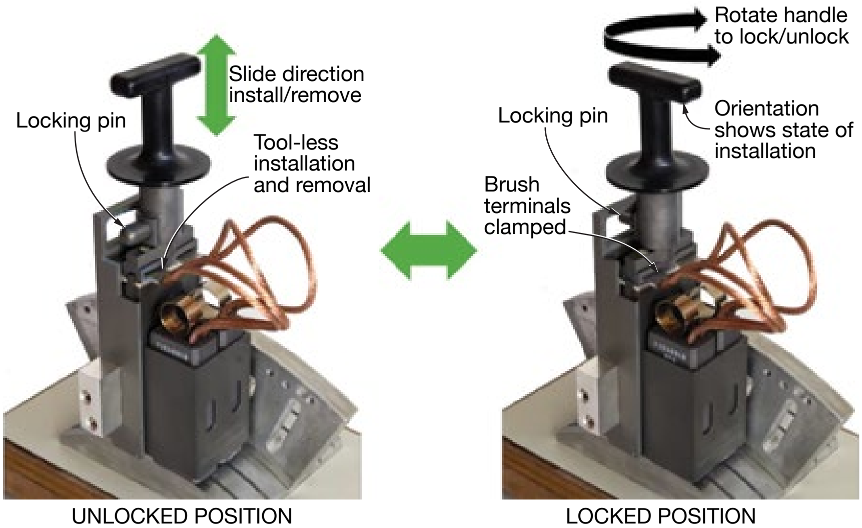
C20-C22. Major steps in replacing an old collector with a new one are shown left to right

This implied that the ground was on the rotor and was caused by the centrifugal loading of the field winding. The unit was put back in service and was run almost daily with the apparent field ground while a new 64F relay was ordered from another manufacturer. The new 64F was installed and behaved exactly as the previous two relays.

A last-ditch effort was made to spin the unit up to synchronous speed with excitation off. Meggering of the field via the carbon brushes and slip rings found the resistance to be in the megaohms range. There appeared to be an impasse when a ground was indicated in the field circuit but could not be localized.

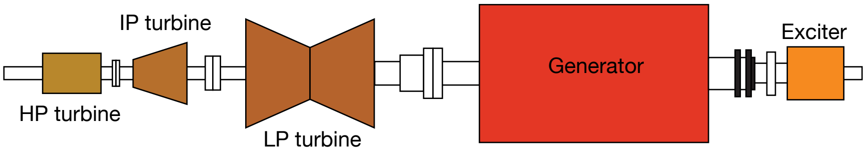
After re-verifying the accuracy of all data taken, an investigation was conducted to look for any other elements that can fault to ground when the exciter is running. Several manufacturers of field ground detection equipment were asked if their equipment could detect faults on the

C23. Grinding operation for truing a worn, or new, collector ring

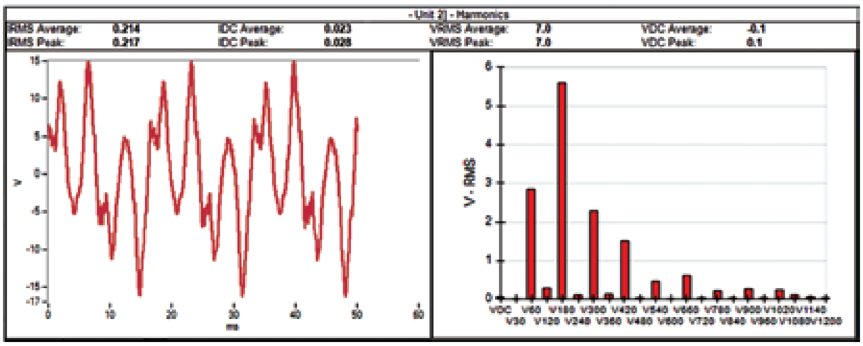


C24. Brush holder design from OEM is said to avoid collector incidents studied by engineers

C25. Excitation systems have evolved over the years from rheostats prior to the 1950s (photo) to electromechanical amplifier in the 1950s and 1960s, to magnetic/analog in the 1970s and 1980s, to today's digital excitation systems



C26. Typical configuration of a turbine/generator with exciter providing DC current for the rotor field and the turbine mechanical power to turn the generator



C27. AC and DC voltages can be induced in the shaft during rotation. Shaft earthing monitoring systems can record and identify the sources of voltage and current. Results from the voltage brush installed on the exciter end (typical) of one unit illustrated here provide time, waveform, spectral content, and DC and RMS values for analysis

AC side of the static excitation system. Responses were mixed, but one vendor said AC-side grounds can definitely be detected, although their occurrence is highly unusual.

Additional voltage-to-ground measurements were made on the AC side of the static excitation system breaker for all three units. A fundamental difference in readings was noted on Unit 2 as compared to Units 1 and 3 which did not have field grounds. This inferred an AC side excitation system ground was causing the 64F relay to indicate a field ground. A precise physical model of the static excitation system, including the same 64F, was constructed. It confirmed that an AC ground is easily detected by the 64F and the lab measurements very closely matched the data taken of the actual machine.

The unit will be operated until a scheduled outage allows for AC fault confirmation and repairs.

Brush-holder experience

John DiSanto's presentation focused on collector incidents and avoidance. The GE senior engineer, who is responsible for generator controls/excitation and protection fleet-wide with the goal of improving equipment reliability, reviewed nine recent root-cause-analysis investigations.

They involved collector flashovers, collector-ring overheating, improper collector-ring assembly, and a damaged insulating sleeve.

Two of the case studies illustrated unnecessary forced outages. One involved overheating of the inner collector-ring surfaces, molten brush holders, and arcing of collector housing. The second case revealed a heavily worn brush and brush-holder damage. The collector surface was found to have salt deposits and corrosion.

Daily, weekly, monthly, and outage inspection and maintenance were reviewed. DiSanto also offered a few comments on maintenance—for example, the importance of cleaning, collector-ring wear rates (1 mil per 1000 hours of operation is typical); permissible wear (the ring diameter can be reduced but must always be larger than the diameter of the bottom of the spiral groove); maintaining proper cooling on collector rings (design temperature is 40C); and recommended brush grade (National 634).

The presentation closed with a discussion of brush-rigging upgrades. GE was said to have a well-defined set of brush-holder design criteria, including the following:

- Allow for safe installation and removal of brush holders with the generator online.
- Improve ease of brush and spring replacement—no tools required.
- Eliminate brush "hang-ups" within the holder by having a fully supported brush and a smooth/slick brush pocket.
- Decrease the risk of flashover.
- Decrease susceptibility to brush current selectivity—that is, uneven current distribution among brushes.
- Allow easy integration for both servicing and replacement across all GE generator models.

The company's most recent brush-holder design for generators of moderate size (Fig C24) was said to meet these criteria.

Digital excitation replacing ageing technologies

If you were relatively new to the industry, listening to the presentation by Basler Electric Co's Richard Schaefer at GUG 2017 provided valuable perspective on excitation systems. A former chair of the IEEE PES Working Group, he's "seen it all" in more than four decades of service to power producers. His CliffsNotes on the evolution of excitation systems:

- Before the 1950s, rheostats (Fig C25).
- 1950s and '60s, amplidyne.
- 1970s and '80s, magnetic/analog.
- Late 1980s through today, digital.

Several factors affect how quickly systems become obsolete, he said—including, available materials, present technology, and available software. Examples of materials availability issues: carbon composition can no longer be manufactured, warlords have taken over the mines, material determined to be hazardous. Examples of hardware availability issues: primitive computers, present-day powerful computers.

Schaefer noted actions that have contributed to the slowing of obsolescence—for example, purchase of components from manufactures serving major long-survival industries (such as automotive), redesign of product with new components where practical, purchase large volumes of obsolete components.

Particularly in recent years, there has been upward evolution in software. For example multilingual capability, built-in powerful testing tools, enhancements to speed commissioning. Also there are options to facilitate retrofit—for example, replacement product fits into same location, provide replacement excitation cabinets but keep the power potential transformers, keep SCR bridges and provide new front-end electronics.

Shaft earthing monitoring

Andre Tetreault, director of tests and diagnostics at VibroSystM, and co-author Bernard Lemay, PEng, the company's Zoom analytical software expert, opened their presentation by reminding the GUG 2017 audience that, in the ideal, the generator shaft should be electrically and magnetically neutral during operation. The use of ferromagnetic materials in the construction of the shaft makes this component extremely conductive and subject to current flow and induced voltages. A typical turbine/generator configuration is shown in Fig C26; the exciter provides DC current for the field, the turbine provides mechanical power.

At least one generator bearing is insulated from ground. On other bearings, a thin oil film is the only barrier separating the shaft from the ground and this film may not act as insulation to current flow.

Both AC and DC voltages can be induced in the shaft, causing potential damage to the unit— especially the bearings. Shaft earthing monitoring systems can record and identify the various sources of voltage and current, allowing for analysis and damage prevention. One brush is installed to monitor voltage (diagnostics), usually on the generator exciter end, and one to monitor current (protection), usually on the turbine end.

Results from the voltage brush are shown in Fig C27. Time, waveform, spectral content, in addition to DC and RMS values, are available for analysis. Alarm levels are set after results are analyzed.

Protection schemes using trends of shaft currents are common, but do not provide diagnostics. In many cases, alarms triggered will confirm existing damage, instead of detecting ongoing issues and/or preventing future damage. Voltage frequency profiles should not evolve over time.

High-speed data acquisition, and comprehensive diagnostics software, allow for in-depth analysis of harmonics to identify various anomalies. Patterns such as high even harmonics may indicate rotor alignment or stator bar problems. If deviations are present, other symptoms may include stator vibration and/or bearing temperature variations.

High DC levels should trigger a ground connection investigation and if the shaft is magnetized, bearing temperatures should be verified.

D. Operation and monitoring

Mini turbine/generator model for training

John Demcko, PE, a senior consulting engineer at Arizona Public Service Co and member of the GUG steering committee, spoke to the industry's knowledge gap and work his company was doing to bridge that gap. Many new powerplant engineers and technicians, he said, have no formal training on how to bring generating units online and take them offline. Nor are they usually familiar with how generators interact with the grid.

The 40-plus-year industry veteran added that plant engineers and technicians are good at addressing mechanical issues but typically are not well versed in the electrical characteristics of synchronous machines. A PowerPoint-only class had been offered for many years at APS but personnel were not being prepared adequately for the challenges they faced daily.

Demcko's department of four engineers functions as a "consulting firm" internal to the utility. Over the years, electrical training responsibilities defaulted to his group because it was intimately involved with problems on the generator, exciter, automatic voltage regulator, and power-system stabilizer. Since operating staff tend to be "visual learners," he continued, a physical model-based training approach was proposed to management. It was accepted and a wish list of model functionality was developed. The search began for a commercially available training model.

The "wish list" of features desired for the model included the following:

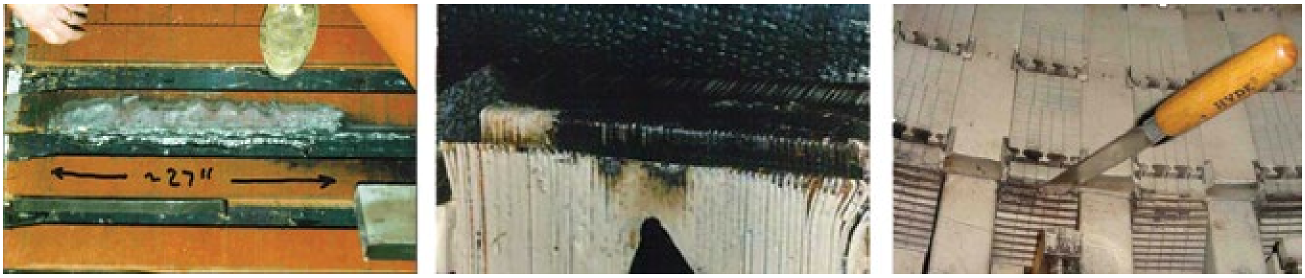
- Three-phase synchronous generator.
- Power level compatible with a nominal 5-amp CT output and 120-Vac PT output found in utility generation.
- Utility-style control switches and metering.
- Digital generation protection relay.
- Auto-synchronizer and emulation of generator breaker function.
- Drive motor with the ability to mimic turbine characteristics.
- Synch to grid at either 208 or 480 Vac.
- Have the look and feel of a typical physical generator control panel.
- Portability (movability).

Search results. North American universities were canvased and educational suppliers queried. Nothing commercially available met all of APS's requirements at any price. Conclusion: The utility would have to build a custom model.

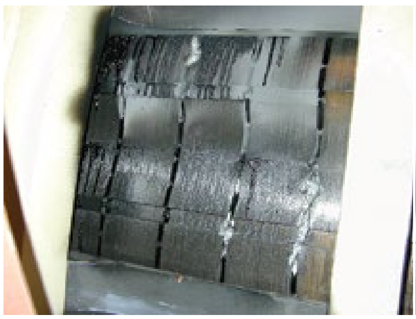
Custom build. Team Demcko received approval to build its own model with a modest hardware budget. Engineering and labor was to be done by staff on a time-available basis—such as between regular assignments. Cost of the model would be contained by purchasing/scrounging as many components as possible off-the-shelf. A target of one year was established for completion of the model.

Results/observations. The model, highly modular in construction, took two years to complete because of limited availability of labor (Figs D1 and D2). It was good for troubleshooting but had many terminal blocks for interconnection that could loosen. Classes started in April 2017; 102 APS employees were trained. The first

D1, D2. Mini turbine/generator model for training took two years to complete but was worth the wait



D3-D5. Causes of core failures include foreign object damage, lamination insulation failure (left), damage from repair work (center), and core looseness (right)



D6. Core over-fluxing in the extreme may cause total destruction of the core

D7. Collectors are the most significant contributor to operations-caused forced outages

four weeks of onsite plant training was completed near the end of August with 84 attendees. Remainder of the fossil fleet (several hundred "students") was scheduled for onsite training before yearend. Results: Almost all the design targets were achieved, but some refinements to the model were suggested.

One use of the model that Team Demcko did not fully anticipate was for training plant operators in manually closing the generator breaker to synch the unit. While an auto-synchronizer normally is relied on for this task, APS expects its control operators to have the ability to do it manually. Trainees appreciated being able to practice synchronizing the generator with the electric system using the model, without risking damage to critical equipment.

Generator abnormal operation

Ron Halpern of Generator Consulting Services opened his presentation by defining "abnormal operation" as any operation outside normal operating parameters that could damage the generator—such as operation outside of the generator capability curve.

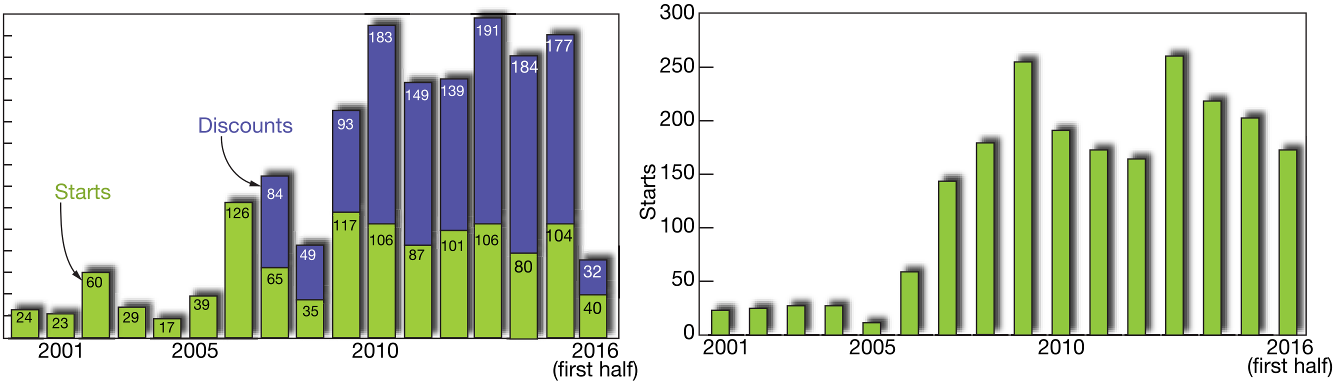
The speaker, who has been involved with generators for well over 40 years, 25 of those at GE, focused his presentation on the following:

- Stator—including core, oil, hydrogen leaks, grounds, stator cooling, water leaks and restrictions, bushings, and frame.
- Rotor—including grounds, shorted turns, thermal sensitivity, shaft voltage, and collectors.
- Auxiliaries—including loss of hydrogen seals, coolers out of service, and on moisture corrosion and contamination.
- Electrical and grid—including over fluxing, off-frequency operation, loss of synchronization, motoring.

Typical abnormal-operation events discussed included the following:

- Core failures. They may be caused by foreign object damage, lamination insulation failure (Fig D3), damage from repair work (Fig D4), loose core (Fig D5), etc.
- Core over-flux, a complex phenomenon. Protection is via volts-per-hertz relay. Minor over-fluxing (105%-110%) increases core losses and elevates core temperature but should cause no damage. Over-fluxing above 110% saturates portions of the core to the point that flux flows out into adjacent structures and, if sufficient and sustained, may cause total core destruction (Fig D6).
- Rotor ground. The excitation system is ungrounded and a single ground will not cause damage (unless the cause is a broken conductor or coil short). However, a second ground can be disastrous. There are many possible causes—including groundwall insulation breakdown, contamination, electrical arcing, displaced insulation, and water intrusion into the exciter. Collectors are the most significant contributor to operations-caused forced outages on generators; the results can be dramatic and dangerous (Fig D7).
- Rotor turn/coil shorts. Shorts may not be a problem unless excessive and you run out of current, or if they result in high thermal-sensitivity vibration. But they can be destructive (Figs D8-D10).
- Thermal sensitivity can be prob-

D8-D10. Rotor turn/coil shorts may not be a problem unless excessive; then they can be troublesome and destructive



D11, D12. High stop/start counts caused by must-take renewables have adversely impacted generator availability and contributed to higher maintenance costs. Data for two different units reflect the dramatic increase in starts in the last 10 years

lematic. It causes rotor vibration to change as the field current is increased and can cause rotor bowing when (1) the temperature distribution is uneven circumferentially around the rotor and/or (2) axial forces are not distributed uniformly in the circumferential direction. The phenomenon, characterized by a once-per-revolution frequency response, may limit operation at high field currents or VAR loads because of excessive rotor vibration.

- Shorted-turn detection. The most reliable method for detecting shorts is by use of a flux probe. The technology is well understood and reliable.

Other items briefly discussed included oil in the generator, stator-bar slot support systems, high- voltage bushing, seal leaks, noise causes and investigations, and damage prevention in general.

Effects of negative-sequence and off-frequency currents

From early on, AC synchronous generators were designed to produce three-phase balanced voltages at their terminals, began Dr Izzy Kerszenbaum, PE, of IzzyTech. Over time, the design also incorporated features to reduce the harmonic content of the generated voltage. In the case of generators, the problem was (and still is) mainly related to unbalance in the load currents, while in the case of AC motors, the problem was (and still is) related to unbalanced supply voltage.

The negative-sequence current component circulating in the stator windings creates a magnetic flux in the airgap of the machine, continued Kerszenbaum, a well-respected teacher of things electrical and prolific author with more than 40 years of service to the industry. This flux rotates at synchronous speed, but in the direction opposite to the positive flux (the "normal" flux), he explained.

The rotor, also rotating in synchronous speed in tandem with the positive magnetic flux, is subject to a 2× synchronous frequency magnetic flux, by the negative flux. Then, by the law of electromagnetic induction (Faraday), 2× synchronous frequency voltages and eddy currents are induced in the rotor body. Given that these induced currents have a periodicity of 120 Hz in 60-Hz systems or 100 Hz in 50-Hz systems, they tend to flow mainly in the outer regions of the rotor, because of the "skin effect."

Net result: If large enough, the induced currents will spark and arc between wedges, wedges and forging, wedges and retaining rings, forging and retaining rings, and any component on the periphery of the rotor. Such sparking/arcing can cause hardening of the metal in critical areas, followed by the generation of cracks.

From the foregoing, it is obvious that negative-sequence current carries with it the potential to cause significant damage to the generator; thus, protection against these currents must be provided. In the event a large negative-sequence event occurs, (as with a major short-circuit between phases in the vicinity of the machine), it behooves the operators to carry out an assessment of the possible damage incurred by the machine, followed by a proper inspection, if warranted.

Impacts of cycling duty

Generators built during the gas-turbine order/installation "bubble" in the late 1990s and early 2000s, look very much like their predecessors built in the 1950s, 1960s, and 1970s. However, unlike their predecessors, the newer machines are not giving the 20 to 30, or more, years of reliable service expected.

OEMs have designed similarly sized machines for MVA ratings 40% to 50% higher than their predecessors, while pushing material capabilities to their maximum. Plus, demands on equipment have been exacerbated by the need to cycle these generators hundreds of times annually to accommodate must-take renewables.

Generators were designed to run at base load or, worst case, for minimal annual start/stop counts—perhaps 50 to 75. However, as the charts in Figs D11 and D12 for two case histories show, they are seeing 250+ starts per year. Units in renewables-heavy markets are exceeding 350-400 annual starts. This takes low-cycle stresses

D13. Severe core and wedge looseness was found during the first major on a 7FH2 generator

D14. Series connection braze failure caused a phase ground

from thermal expansion/contraction, and moves it into a high-cycle realm. The end result is that units are either suffering in-service failure or, at a minimum, are requiring very costly repairs or maintenance/upgrades at their first major outages, within 10 to 15 years.

In his presentation, AGT Services Inc's Jamie Clark pointed to common weaknesses exacerbated by these high cycling operations—including loose stator wedge systems (Fig D13), axially loose core iron, loose endwindings, global endwinding dusting or broken ties, loose belly bands, bar movement in the stator slots, high partial discharge and resulting corona damage, and increased opportunities for seal-oil problems resulting in oil entering the unit, which further accelerates the previous issues.

In the field, the impact is found in cracked or failed main leads, pole/pole and coil/coil crossover jumpers, migration of slot armor, deformation of field endwindings, loose/missing/broken distance blocking, migrating coils, insulation, or amortisseur springs resulting in blocked cooling, thermally sensitive fields, rapid turn short development, and myriad other issues (Fig D14).

Generator cyclic duty

In recent years there has been a changing of the generator lifecycle. These machines originally were intended for baseload operation and 30 years of service. There has been an industry shift to frequent starting/stopping, load cycling (described as more than two 20% changes in megawatt output in a 24-hr period with two primary load cycles (50% - 100%) in a typical day), VAR cycling, and seasonal influences.

Frequent starting/stopping imposes additional stress, with faster degradation of insulation and components, negative impact on generator life, higher risk of in-service operating incidents—all likely contributing to increased maintenance.

Cyclic duty involves start/stop operation, load cycles, and power-factor changes. Impact on stators includes vibration transients, thermal and mechanical stresses, and core-end heating. Some of the effects on stator windings and core are high- and low-cycle fatigue, insulation abrasion, strain, shorts or grounds, localized overheating, and core-iron melting. Typical failures are strand cracking and fracture (Fig D15), lead fracture and extensive arc damage (Fig D16), and insulation abrasion (Fig D17).

Cyclic-duty impact on rotors includes copper distortion, insulation breakdown, shorted turns, connector failures, grounds and forging damage. Typical resulting failures are shown in Figs D18-D21: slot liner abrasion, insulation fracture, copper distortion, and blocked vent (left to right).

Twenty-five-year GE veteran Ed Winegard, currently principal engineer for armatures, described for attendees several design features developed to accommodate cyclic operation. You can access a copy of Winegard's PowerPoint on the Power Users website at www.powerusers.org.

Maintenance and inspection suggestions for cyclic duty, also covered in the presentation, include the following:

- Maintain equipment in accordance with GEK 103566.
- Conduct additional testing during scheduled outages.
- Perform regular borescope and robotic inspections.
- Do modal testing of endwindings.
- Provide for additional monitoring during operation.

D15-D17. Failures in stator windings associated with cyclic duty include strand cracking and fracture (left), lead fracture and arc damage (center), and insulation abrasion (right)

D18-D21. Impacts on rotors of cyclic duty include the failures shown in the photos above: slot-liner abrasion, insulation fracture, copper distortion, and blocked vent (left to right)

E. General topics

Moisture ingress and storage mechanisms in large generators

Neil Kilpatrick, principal, GenMet LLC, integrated more than four decades of metallurgical knowledge into his presentation, covering several aspects of moisture ingress on generators: problems created, moisture opportunities, capillary basics, examples of planar capillaries in generator construction, damage mechanism affected by moisture storage, and why it is so difficult to dry out these machines.

As an example of a problem with moisture ingress and storage, a large generator located in the South (think humid) was found with water actually running out from under the ID of the rings. The cause was condensation on the rotor inner surfaces and planar capillaries and connected surfaces internal to the winding.

Large generators normally are dry under operating conditions. When open and cooled to ambient temperature, there's a tendency for moisture to accumulate on and in insulation materials. The usual remedy is to apply heat and ventilation in order to dry out the winding; this can be a lengthy process.

There are numerous moisture opportunities related to inadequate protection during shipment, storage, standby, and maintenance. Even during operation, there are opportunities for condensation from gas coolers, cooler leaks, and frame flooding. Outdoor units are a particular challenge given their exposure to weather. Hydrogen-cooled units have lower exposure than air-cooled units because of the controlled operating environment.

Capillaries behave the same whether horizontal or vertical. With dry air at the ends of capillaries, the capillaries contain only air. Increase the humidity to the point of condensation and water starts to condense inside the smallest capillaries. This occurs at about 92% relative humidity (metal temperature relative to dew-point temperature). With nearly saturated air at the ends of the capillaries, water starts to condense in small capillaries. Under saturation conditions, condensation occurs on free surfaces, and pooling begins. The capillaries will fill.

There are numerous capillaries on both the rotor and stator. On the rotor there are capillaries between turns and on both faces of the slot liner (Fig E1). On the stator, there are capillaries in the spaces between core laminations and the spaces between the bar surface on the fillers and core iron (Fig E2).

Damage mechanisms of moisture affect both metals and insulation. For generators which still have nonmagnetic retaining rings susceptible to stress corrosion, crack initiation and crack propagation occur under wet conditions. Note that retaining rings are under high stress at standstill and all other conditions. With long-term wet conditions, rust will form on steel surfaces which are bare and/or porous. Rust is hydroscopic, and will retain moisture—more opportunity for water storage.

On insulation, the major concern is for moisture on insulating surfaces. Typically, wet conditions in generators will result in low resistance to ground, and this must be corrected before return to service.

The issue of the difficulty in drying out a generator is interesting. A generator in operation tends to be inherently dry, because of the high temperature and high ventilation flow. On shutdown, there is no ventilation flow, so the entire machine becomes a large number of stagnant zones. Any stagnant zones that have some moisture content tend to become saturated. Capillary condensation will work to fill all the connected capillaries.

If the open machine is exposed to humid conditions, then the daily dew-point cycle may result in periods when the dew-point temperature is greater than the metal temperature. Condensation will occur, and the machine will take on water as long as condensation continues.

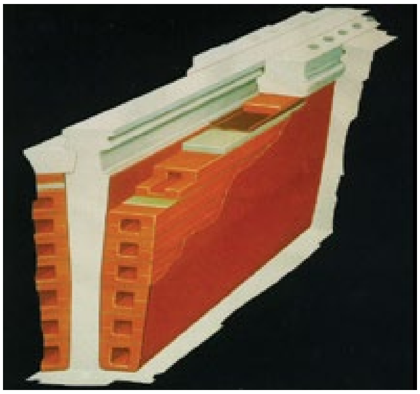
A filled capillary is relatively stable at moderate ambient temperatures and stagnant conditions. There is almost no driving force to evaporate water back out into a stagnant atmosphere at the same temperature. A significant increase in metal temperature will increase the evaporation rate by producing a decrease in local relative humidity. Significant ventilation flow should also break up the stagnant zones with the rapid inflow of dry air. For the rotor, a significant increase in shaft speed will provide a G loading which will tend to centrifuge water out of the rotor.

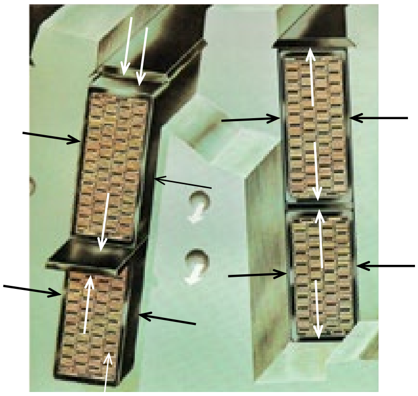
It is always better to keep a dry machine dry, than to dry out a wet machine. For maintenance and layup conditions, it is important to make sure that capillary condensation conditions cannot occur. Prevention can include maintaining some ventilation flow of dry air throughout the machine and maintaining temperature well above the ambient dew point; a healthy margin would be 80% relative humidity. For long-term layup, develop a system which combines fail-safe sealing, monitoring, and drying. A nitrogen blanket or dry gas feed might be considered.

Generator layup

Dhruv Bhatnagar, GE's technical leader for generator-fleet risk management, provided the OEM's guidelines for unit layup during non-operational conditions. Stator and rotor recommendations are the following:

- Stator layup for days. No recommendations for H_2-cooled units if the hydrogen is pressurized. For liquid-cooled stators, the cooling-water system (SCWS) should be operational, or shut down with water drained from the winding for any layup of more than 48 hours. For air-cooled units, or H_2-cooled units that are depressurized, turn on space heaters to prevent condensation.
- Stator layup for weeks or months. For air-cooled units, turn on space heaters to prevent condensation; same for H_2-cooled units, but depressurize before turning on space heaters. H_2-cooled units not purged should reduce gas pressure to 0.5 psig to minimize consumption. For liquid-cooled units,

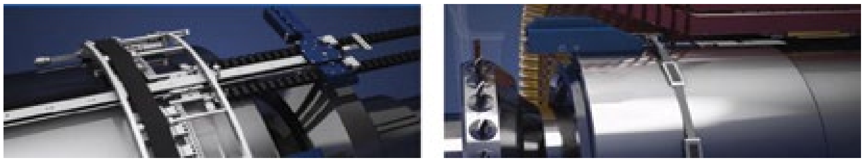




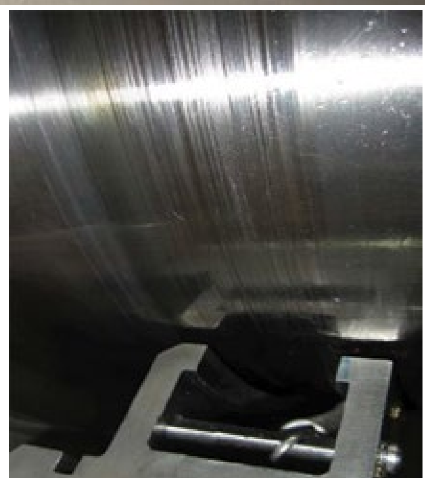
E1, E2. There are numerous capillaries in both the rotor and stator where unwanted condensation can occur. In the rotor, they are between turns and on both faces of the slot liner (left); in the stator, between core laminations and in the spaces between the bar surface on the fillers and core iron (right)

E3. Condensation on stator windings attributed to improper layup procedures caused unit to trip on restart after a planned outage

E4, E5. Ground alarm following a shutdown for lack of market demand alerted staff to rust accumulations on rotor and exciter components caused by condensation/improper layup



E6, E7. Retaining ring scanner at left and air-gap robot at right provide "eyes" to identify issues before they cause problems that can affect machine availability



E8, E9. Rub marks are in evidence on air-side seals and shaft surfaces; plus, seals are out of round

the winding and SCWS should be drained and vacuum-dried.

- Rotor layup for days. Rotor should be at rest with the pole axis in the vertical direction. Coat all exposed shaft surfaces with light lubricating oil.
- Rotor layup for weeks or months. Rotor should be at rest with the pole axis in the vertical direction. Megger field monthly and trend insulation resistance. A low megger indicates moisture in the generator. Inspect exposed shaft surfaces and the collector rings to ensure that the oil film is adequate.

Similar recommendations were provided for collector systems, seal-oil systems, and coolers.

In addition, the following case studies related to improper storage were discussed:

Case No. 1. Unit was in a planned outage (turbine upgrade). During restart after the outage, the unit tripped on stator differential protection. Upon inspection, damage was noted on the turbine-end series loop caps (Fig E3). The failure was attributed to condensation on stator windings.

Case No. 2. Unit was shut down because of grid issues. Upon restart, a field ground alarm was activated and the unit was shut down again. Inspectors noted rust had accumulated on the rotor and exciter components because of condensation and improper layup (Figs E4 and E5).

Implementing NERC Standard PRC-019

Douglas Selin, PE, consulting engineer, Arizona Public Service Co, provided an overview of the NERC standard and the process APS uses to implement the PRC-019 across its fleet of generators. A review of the standard outlined the functional entities required to comply with the mandate, the applicable facilities, and the individual requirements which involve coordinating voltage regulator controls with the protection system and the capabilities of the equipment (generators or synchronous condensers). The time requirements for implementing the standard on a fleet of generators also was presented.

The evaluation process used by APS includes the following five steps:

- Identify all of the voltage-regulator limiter and protection functions for a given generator.
- Identify all of the generator relay protection functions enabled.
- Determine what coordination must be evaluated based on a comparison of the items identified in Steps 1 and 2 above.
- Perform the needed evaluation and modify settings such that they coordinate.
- Document the results in a formal report.

Several methods of demonstrating how the coordination can be reviewed, visualized, and documented were presented for most of the voltage-regulator functions that would be encountered in such an evaluation. A summary list of learnings was offered to enhance the efficiency of the evaluation process.

The effort needed to perform the coordination analysis outlined is a requirement for all generator owners. It has the benefit of improving power-system reliability by avoiding unnecessary unit trips: Generator voltage regulators act to mitigate undesirable operating conditions before relays trip the unit.

Generator maintenance considerations and robotics

Revision L of GEK 103566, perhaps better known by number than its title, "Creating an Effective Maintenance Program," was reviewed by Dan Tragesser and Chris Markman to help owners operate their generators safely and reliably. Tragesser manages technical risk for GE's Global Generator Product Service Engineering, Markman is product manager for generator inspections.

Six key areas were discussed by the duo—including Rev L updates, rotor removal recommendations, inspection and maintenance intervals, how intervals are determined, examples of intervals, and rotor and retaining-ring life management. GEK 103566, which was said to contain information of importance to users, can be obtained from your GE rep.

Robotic inspections were the next topic with specific references made to the OEM's retaining-ring scanner (Fig E6) and air-gap robots (Fig E7). The speakers said robotic inspections were performed on 512 units between 2011 and 2016, with 8% having significant findings (defined as rotor removal required for repair) and half of those deferred to next outage. There were three forced outages associated with the 20 rotors pulled. Two had rotor grounds and one was forced out by a negative sequence current with arc strikes.

The speakers said electrical tests conducted on the rotors removed typically confirmed the findings of other tests or conditions—such as shorted turn and vibration. Data show robots typically find the same defects as visual inspections with the rotor out. Discussion regarding robot inspections that resulted in a rotor pull noted that more than 50% of these could have been planned for with better operations data review and outage management.

Relative to reliability, GE reported four cases of MAGIC (Miniature Air Gap Inspection Crawler) robots losing parts—including two burst bearings (encapsulated bearings are now used) and three fastener issues (redesigned). Relative to robots getting stuck, GE has emergency retrieval capability built into designs.

Also discussed was the stator cooling water system with focus on copper oxide buildup and removal.

Hydrogen seal-oil experience

GE's Dhruv Bhatnagar returned to the podium to address the challenges associated with seal-oil systems and how to mitigate them. Challenges include the following:

- The seal rings themselves. Damage, contamination, improper assembly, and cocked seals all can lead to operational issues—including oil ingress.
- Float traps require manual bypass during every startup/shutdown. Improper procedures are conducive to seal-oil ingress.
- Oil contamination of the hydrogen control panel.

Seal-oil-system mechanisms and effects was the next topic. Mechanisms include cocked seals, loss of seal oil, damaged anti-rotation pin, contaminants, damaged seals, generator pressurization, clogged drain lines, improper assembly, and misoperation.

Resulting effects include higher total and hydrogen-side seal-oil flow, improper liquid-level detector alarms, high float-trap oil level.

Checklists for disassembly and reassembly followed:

Disassembly. Measure rotor position from the outboard oil deflector fit to the shaft, measure the distance between the hydrogen seal casing and the rotor shaft, determine "as-found" seal clearances, inspect seals, and ensure seals are not out-of-round.

Reassembly. Inspect seals and ensure they are not out-of-round, check for any foreign material between the inner oil deflector and hydrogen seal casing, check vertical face of the end shield between the upper half and lower half for any steps across the horizontal joint, perform blue check and ensure 100% contact, check for any RTV that may have squeezed from between the upper half and lower half of the end shield, remove any RTV material that has come onto the horizontal joint of the lower-half casing, ensure seal-oil inlet feed and gas-side seal-oil drain in the end shield are clear.

The presentation closed with a case study of a unit that was offline, but pressurized and with seal-oil system in operation, when a blackout occurred. The DC system came online, but the site lost seal-oil differential pressure (DP). By the time DP was restored, the unit had dropped 10 psi in hydrogen pressure. The decrease in seal-oil DP allowed oil ingress.

The operator received multiple liquid-level detector alarms, and low and low-low lube-oil alarms. Site personnel tried to start up the unit next day but were unable to build lube-oil header pressure. Personnel purged and inspected the generator, which was flooded with lube oil. Air-side seals and shaft surfaces were found to have rub marks (Figs E8 and E9); seals were out of round.

Coordinated frequency response

Emerson's Thor Honda, an expert on the modernization of mechanical and electronic turbine controls, discussed the challenges associated with injecting into the grid large amounts of intermittent power produced by renewable resources. This new and evolving paradigm in electric generation has highlighted the need for synchronous turbine/generators to help stabilize system frequency.

The questions then arise: How do synchronous powerplants respond to system frequency disruptions and what changes may need to be made in order to comply with frequency response codes and standards? Synchronous generators add rotating inertia and have governors which detect frequency disruptions and raise/lower output to quickly balance generation to load (called "droop" control or primary frequency response).

These questions become more acute because tax credits and rapidly declining costs are driving ever more massive amounts of renewables power into existing transmission systems. A lower percentage of synchronous generators means less inertial response to frequency disruptions, and less inertial response means more turbine/generator response is needed. Synchronized turbine/generator droop control must give a sustained response to minimize the magnitude of frequency disruptions and maintain reliability.

NERC's 2012 Frequency Response Initiative Report found only 30% of the generators online provide primary frequency control, and that two-thirds of those that did respond exhibited "withdrawal" or "squelching" of the response. The reason is outside closed-loop control. Since only 10% of the units online were sustaining their expected primary-frequency-control "capability," a reliability issue arises: Balancing authorities (BAs) get a significant portion of frequency response from load and cannot predict the load response or control it (load's inertial contribution cannot be accurately predicted).

These issues have encouraged NERC and industry efforts to improve frequency reliability, thereby making the need for government regulations less likely. One step in that direction is GE Technical Information Letter 1961, "Steam Turbine Governor Studies to Meet NERC Frequency Response Advisory," which was supported by a webinar.

Honda closed his presentation with these recommendations for owner/operators:

- Verify unit-specific requirements with your BA.
- If operating in closed-loop automatic generation control (AGC), biasing may be required to pass BA compliance criteria.
- When implementing AGC bias, keep the following in mind:

1. AGC will not negate droop impact on site output, which may have economic considerations.
2. Ensure AGC bias is accurate and enabled accordingly. GEN

Tapping global know-how to expand local options

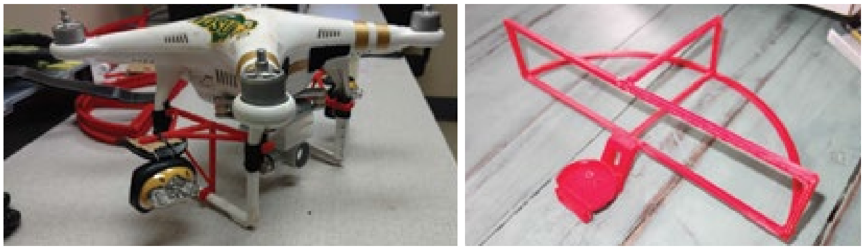
By **Steven C Stultz,** Consulting Editor

There is indeed only one *HRSG Forum with Bob Anderson.*

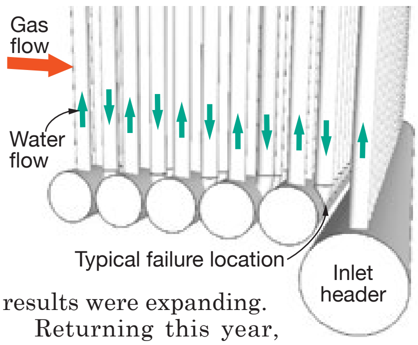
This year's event in Houston, like its predecessor in Charlotte, captured the topics of immediate interest to HRSG experts and combined-cycle system owners/operators. There were spirited discussions before, during, and after the formal technical agenda. Participants networked freely within this consolidation of equipment details, operating trials and errors, and forward-looking ideas.

The list of noted 2018 sponsors included the Electric Power Research Institute (EPRI), International Association for the Properties of Water and Steam (IAPWS), Structural Integrity Associates Inc (SI), Combined Cycle Journal (CCJ), Emerson, Precision Iceblast Corp, Dekomte, Nooter/Eriksen, Morgan Advanced Materials, Applied Technical Services, United Dynamics Corp, CECO Peerless, and Questek Solutions. More than 40 exhibitors were present for specific discussions.

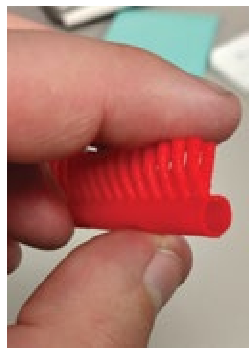
CCJ's report on the second annual *HRSG Forum with Bob Anderson* follows.



1. 3D-printed light attachment (left) and blade guard (right) are two improvements in drone technology developed by Xcel Energy's engineering team



2. Lower header area of preheater 1 is where failures were occurring repeatedly (left)



3. Preheater lower header, 3D-printed version, was valuable in project planning (right)

Drones return in 3D

Innovation spawns innovation.

One breakthrough presented at last year's inaugural *HRSG Forum with Bob Anderson* was HRSG inspection by unmanned aerial systems (UAS), aka drones. Xcel Energy's Scott Wambeke explained how these inspection tools were flying within the congested spaces of HRSGs, launching new dimensions in this cost-effective and time-saving technology.

Pilot skills had been established outdoors along vast transmission lines, then within the relatively open spaces of large coal-fired utility boilers, verifying the values of these recorded *flights.* Now, spaces were tight but beneficial results were expanding.

Returning this year, Wambeke explained the escalating benefits of 3D printing, an innovation developed while bringing UAS skills and benefits to Xcel's full power-generation fleet.

So what began as plastic drone parts has expanded into project planning and execution.

Better pieces and parts. Working with a local university, Wambeke's team has mastered specific drone-system improvements, driven in part by equipment damage during the all-too-familiar impact events. One fast-growing need has been replacement and more durable blade guards. Another has been customized attachment systems for prototype lighting (Fig 1).

The licensed outside flight crews at Xcel use some elaborate systems and equipment, and travel long distances in their investigations and inspections of power lines, rights of way, and similar tasks. The inside teams at Xcel began with less expensive, off-the-shelf commercial drones, often making their own repairs. "Every time we fly in these tight areas," explains Wambeke, "we know that there's a 30% chance of drone damage." Their drones are still considered consumable inspection tools.

Then the team purchased its first 3D printer. Repairs were made more quickly and innovation opportunities began.

"One critical advantage is being able to make improvements as you go," said Wambeke. "You can print a component, try it, improve it, and quickly try it again."

Last year's presentation concluded with a forward look at drone system advancements, and expanded applications. Both developments are moving quickly.

Navigating to projects. An operating HRSG was experiencing repeated failures in preheater 1, row 2 (stack side, Fig 2). Access clearance to the failures at the lower header was tight at 1.6 in.

The boiler/HRSG group was investigating a new printer and decided to

4. Preparation of the lower-header area for inspection and weld repair was facilitated by the model

try 3D printing. Engineers would look at 1:20-scale components.

When printing was done (Fig 3), project planners were able to see (and show to management) the processes for cutting header piping and drains free, then gaining access for repairs. The models also would serve as planning tools for NDE and provide tube-to-header joint geometry familiarization to the welding crews. In sum, the simple 3D printing process became proof of concept for what was deemed a five-day outage (Fig 4).

Said Wambeke, "This became an excellent tool for both planning and the actual repair. The project was finished ahead of schedule in four days."

More innovations. Wambeke concluded with a review of 3D printing hardware, use of dissolving media, and the joining of parts by friction welding. He also noted that 3D scanners can replicate geometries to help reverse-engineer old parts when drawings are not available.

Questions and discussions were varied. Small blimps also have been considered for inspection flights, but achieving lift is difficult without supplemental fans, and internal drafts can make stability difficult. Work on drones and options continues.

Costs were also discussed, including a note that printer plastic is priced well below printer ink.

New extended attemperators

Paul Lofton, Tampa Electric, and Ory Selzer, IMI-CCI, discussed HRSG attemperator replacements at two TECO Bayside power blocks installed during the "bubble" (2003 and 2004).

This presentation discussed systems for:

- HP (main steam) to cold reheat (CRH) bypass.
- HP (main steam) interstage.
- IP (reheat steam) interstage.

During a walkdown, a crack was

5. Crack in circumferential weld, visible at the time of discovery, became invisible to the naked eye when the pipe cooled

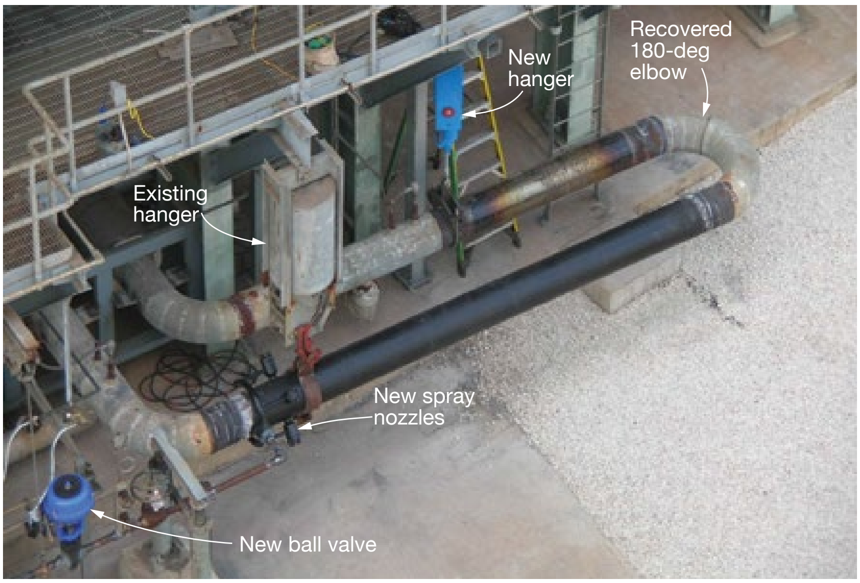
6. New, extended-length HP attemperators provide more residence time for the evaporation of spray-water droplets

discovered in the circumferential weld at the HP-to-CRH pressure control valve (Fig 5). "This indication was discovered completely by accident while escorting a vendor across the top of the plant," stated Lofton. The weld was cut out and replaced.

An HP interstage attemperator then showed girth-weld indications during linear phased-array UT inspection of the P22 pipe. One indication, 8 ft down from the spray nozzle, was 0.625 in. deep, originating from the inside wall and progressing toward the outside, approximately one third of the way around the pipe. All systems on both units were then inspected.

Plant layout fortunately allowed room for longer attemperator steam pipes. Seven new attemperators were purchased, twice the length of the old ones for improved dwell time to evaporate spray-water droplets (Fig 6). The resulting 16 to 18 ft total length gives more time to prevent quench damage. Four radial spray nozzles replaced the single nozzle of the original design; the existing 180-deg elbows were recovered (Fig 7).

All modifications were designed to provide added strength and life in cycling duty. The common theme: conventional equipment is rarely designed for cycling. System improvements



7. New HP attemperators feature four radial spray nozzles

included longer pipe legs, improved drain systems, radial nozzles, Stellite 6 hard-faced seats, and new actuators.

Many questions followed regarding thermocouple locations relative to welds. There were also extended questions and discussions about cycling impact on original designs, steam versus water atomization, modification costs and methods, OEM design variations, and overall design and repair options.

FAC remains Number One

Barry Dooley, Structural Integrity Associates Inc, provided an in-depth discussion and updates on "the Number One problem" for HRSGs: flow-accelerated corrosion (FAC).

He reiterated the chemistry influences on FAC, typical locations, appearances, and common mistakes in attempts to identify and control. "The problem is global, and it's not just the power industry," he stressed.

Background discussion included temperature ranges and the solubility of magnetite, timing of first appearance in both vertical and horizontal gas path units, and turbulent flows at bends and complex geometries. Air-cooled condensers also were addressed.

"It is very important to identify what type of FAC you have, because the two types (single- and two-phase) are controlled by different aspects of the cycle chemistry," he stressed. Many examples of appearance, location, and damage level were shown and characterized in detail.

Treatment options (and overall system chemistries) were discussed along with relevant IAPWS guidance documents. Component materials were also discussed, as were film-forming substances (FFS) that might help in protection. These would follow in a later presentation.

These changing steels, Part 2

One *shot across the bow* at last year's inaugural *HRSG Forum* was a report by Jeff Henry, Applus+ RTD. The topic: advanced alloys. The message: We now have residual elements in the steel to consider, and they're changing the material chemistry on a microscopic level (CCJ 1Q/2017, p 34).

Returning in 2018, Henry offered an update on the evolving issues with creep-strength-enhanced ferritic (CSEF) steels. His theme remained the continuously changing knowledge base, and the need for related ASME Code updates.

One initial Code focus is a reduction by ASME in the allowable stress for P91. According to Henry, who chairs the ASME Section II Committee, "reductions are now approved by ASME and will be in the 2019 edition of the *Boiler and Pressure Vessel Code.* Modified chemistry for Grade 91 Type II, currently a code case, could be released at the same time."

However, he explained, the Code does not adequately address heat-treatment specifics for these steels, even after 20 years of experience and data. "Heat treatment remains an important topic, and many questions are the same now as they were 20 years ago."

As he explained in 2017, CSEF steels are relatively complex materials and can vary according to their production process, "depending on heat-specific chemical composition and processing histories." This is where the interesting and disturbing topic of recycled materials appeared last year.

For clarity, Henry stated: "The degree of technical control required during all phases of implementation (design, production, manufacturing, and erection) is substantially greater than it is with traditional (that is, more tolerant) powerplant alloys, such as Grades 11 and 22."

Heat rules. "Improper heat treatment," Henry stated, "has been the single greatest cause of unnecessary failures, repairs, and replacements" involving these steels—particularly Grade 91.

Such improper practices have cost the industry hundreds of millions of dollars, and will continue to do so as "poorly heat-treated components that have not been properly inspected continue to fail prematurely."

This is not because of overly complex procedures or processes. "The requirements are not abnormally difficult to understand or implement," Henry explained. "Rather, there has been too little effort made to understand how the basic metallurgy (microstructure) of this class of steels dictates successful heat-treatment practice."

The industry is now left with many questions, including these:

- How many times can these materials be heat treated?
- Can poorly heat-treated materials be salvaged?

Henry followed this with a detailed review of typical heat-treatment processes, and various complicating issues. As one example, the Code specifies minimum hold times for postweld heat treatment, but not does not specify maximums. For temperature, he explained, the Code sets an upper limit, above which a material should be rejected. But the intention was never to hold material at this temperature. "Code needs to review this," he stated.

Many questions and discussions followed (as they did last year) including precise temperatures, cooling durations, weld inspections, impacts of wall thickness, adjacent materials, weld materials, and the benefits and risks of re-austenitizing.

"Austenitizing can reset the life clock," explained Henry, "but may not duplicate original material properties." EPRI's John Siefert took this further. "If creep damage is present, you cannot restore the material to virgin conditions."

Henry ended with a case history of salvaging improperly heat-treated Grade 91 large-diameter (28 in.) elbows.

Bottom line: keep good records. More questions followed on weld repairs, inspections and acceptances, and the global state of (or lack of) knowledge. The questions and discussions made clear the obvious concerns about these material properties, their complexities, and their quality issues.

And a key question: How do we track all of the actions that have taken place on all the pieces and parts that we have?

The awakening answer: Even looking back at the original materials, there is a lot that we just don't know. The best advice is to keep good records of everything you can.

Remaining life of millennials

"HRSGs are millennials," suggested Sargent & Lundy's Danial Azukas, meaning that most of those operating today were built in the 1990s and early 2000s. They were base-load designs for 30-year operation (300 cold, 1500 starts, and 6000 hot starts).

Then gas prices fluctuated, both up and down, and green power entered. As discussed throughout the *HRSG Forum*, cycling and unanticipated owner/operator challenges began.

Azukas discussed various cycling impacts through a case history, launching a theme of cycling and remaining life assessments that would appear throughout the organized meeting and the frequent open discussions.

One assessment element discussed was benchmarking with data and evaluations not tied directly to the subject plant. The North American Electric Reliability Corp maintains availability database systems that can add value to such reviews, highlighting outage events and other influencing data. Peer plant comparisons of outage factors, availability, and capacity can also help in the look forward.

Assessments would become a common topic throughout the conference.

Bypass-valve erosion

Bob Anderson discussed HP-bypass pressure control valves, stating that although these are considered severe duty, they can last 10 to 12 years before seat/plug repair, if properly controlled and operated.

The primary concern is erosion caused by water and/or steam passing through the valve (HP to CRH). This is not a problem with all units, nor is it a problem specific to any valve OEM.

He began with a single-shaft unit example in somewhat unique operating modes including open cycle, then followed with a 2 × 1 plant in typical operating modes.

In the first example, the HP-bypass pressure control valve began leaking through after one or two runs. Although correctly installed, the OEM modified the valve to improve erosion resistance, but rapid erosion continued. The issue was identified as part of open-cycle service when the gas turbine is at low load and the steam turbine is offline. This allows condensate to pool along the bottom of the main-steam pipe, shrinking it relative to the top of the pipe. The normal 1% slope downward becomes reverse slope.

In a second case study (2 × 1 in typical modes), leaking occurred after a period of years, and although modified by the OEM, recurred. Arrangement and start modes were reviewed. During a lag cold start, the bypass valve opens too early when main-steam temperature is still at saturation (Tsat). Delay in opening the PCV until 35-deg-F superheat is achieved should eliminate erosion damage. A bigger warming drain may be required (before the header isolation valve) to avoid excessive startup time.

Fitness, according to EPRI

Tom Sambor, EPRI's technical leader for Program 88 HRSG and BOP, discussed life assessment of boilers and pressure parts, particularly the fleet of HRSGs now reaching the *soft* design life.

Reviewing relevant background, he explained that in Western Europe fitness for service was "an integrated approach to operation and life management." Re-assessment for continued operation was common, he explained, due in part to long-term use of more complex materials.

This is not the history in the US and Canada. He explained that in the 1980s and 1990s, service fitness became an urgent need in North America because of header ligament cracking, dissimilar metal weld failures, and some catastrophic material events.

EPRI began pioneering with its RP2253 project.

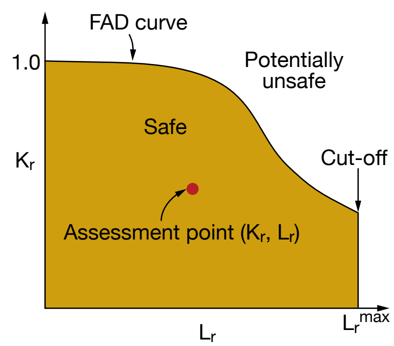
Sambor explained that EPRI now advocates a seven-point life management approach:

1. Understand how design, operation, fabrication, and metallurgy affect component performance.
2. Appreciate the historical issues (failures, statistical analysis).
3. Develop optimum specifications.
4. Set improved quality guidelines for design, manufacture, operation.
5. Determine when, where, and how to look for damage.
6. Develop component-specific methods for repair/replacement that exceed minimum Code rules.
7 Employ technology transfer of information to codes, standards, and the global community.

His presentation concentrated on the search for damage.

Another bit of history: The Central Electricity Generating Board (CEBG) in the UK performed foundational work in power-generation fitness for service in the 1960s. "Thousands of welds were identified to have fabrication flaws," explained Sambor. "Rather than simply repair or replace, the CEGB chose to evaluate." Assessments looked at "safe" versus "potentially unsafe" (Fig 8).

In the US, the wake-up catastrophic failure was in 1986, at DTE Monroe. The failure occurred in Unit 1. But Units 2 and 3 were not shut down. Both were needed to meet demand, and continued in reduced operation. This ongoing generation during assessment proved successful.



8. CEGB evaluation curve, safe versus potentially unsafe

Sambor's discussion centered on safe operation based on inspection results, and subsequent inspection planning. "In some cases," according to National Boiler Inspection Code (Part 2), "a visual inspection of the pressure-retaining item will suffice. However, more comprehensive condition-assessment methods may be needed—including an engineering evaluation performed by a competent technical source."

Detailed examples also are given in American Petroleum Institute's API 579, Section 1.1.2. As Sambor explained, "By its own definition API 579 does not independently determine if a component is fit for service; it *helps* determine." API 579 was released in 2000 and immediately received widespread acceptance both inside and outside of the refining industry.

Sambor explained further background and continuing activities, highlighting those by API and developments at ASME, specifically the *Boiler and Pressure Vessel Code* Main Committee. ASME and API now work together on the issues.

Then he presented specific examples of poorly performed fitness programs. Several cautions were discussed, including lack of communication and inherent limitations of some overly specialized consultants.

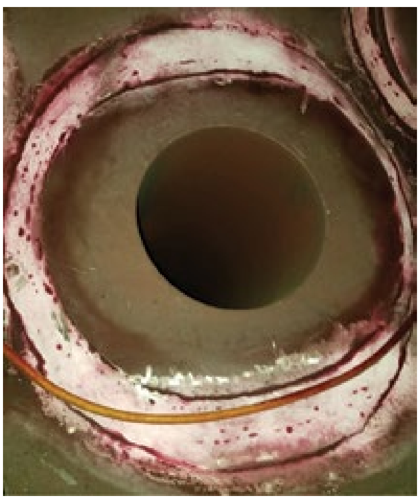
Sambor next focused on fitness-for-service challenges specific to HRSGs, including the following:

- For operations: Cycling, and significant duct firing.
- For materials: Extensive use of CSEF steels.
- For maintenance: Plants are forced to "do more with less."
- Other: Gas-turbine upgrades can have unintended consequences on HRSGs (and other downstream equipment).

Sambor then discussed these specific component challenges:

1. Large branch connections (Fig 9). This has become a significant industry problem, particularly with Grade 91.
2. Tube-to-header connections. This has led to numerous drain evaluations for condensate removal.
3. Drum nozzles (Fig 10). Circum-

9. P91 large branch connections are known for their susceptibility to flank-side cracking



10. Circumferential cracking of drum nozzles is increasingly common

ferential cracking at toe welds is increasingly common.

Many related issues were discussed throughout the 2018 Forum, including valve bodies and attemperator-induced quench cracking.

Sambor ended with EPRI's overall fitness philosophy, stating that proper methodologies must be:

- Based on engineering rigor.
- Relevant and no more complicated than necessary.
- Benchmarked against well-pedigreed test cases from the industry.
- Clear for key scenarios such as identified flaw, assumed flaw, creep (time-dependent), etc.
- Based on well-maintained and relevant databases, and active sharing of both present and past information.

"Most of all," he said, "safety must be paramount! Safety drives fitness for service."

Lengthy discussions followed including hands-on training of inspectors (AIs) and increased interaction with insurance carriers.

Evolving automation

Jim Nyenhuis, Emerson, followed with an update on automation and controls for combined cycles. He posed this question: "How can automation help, based on the changing world of plant operations?"

The presentation began with a look at classic closed-loop controls, and an interesting point: Controls look in real time. So the key is to also understand system dynamics, including the elements of time. In one example, Nyenhuis looked at unstable final steam temperatures caused by cycling, and PID-based load control. The question: What can refined control do for the long-term life of the components?

"If we can develop very refined models," he said, "this allows us to look forward and make predictions, then anticipate these in our controls strategy." The in-depth presentation appealed to those knowledgeable in the systems and tuning processes, but also reinforced the movement toward more forward-looking operations (the cycling world).

Discussions highlighted the complexities, including these:

- Predictive modeling should account for historical empirical data, weather, time of day, differing humidity.
- Other units on and running.
- Anticipating where the load will be in 20 to 30 minutes.
- Other operational challenges, including justifying the cost of a control-system change to management.

Drum instrumentation

Staying with the control theme, Jim Kolbus, Clark-Reliance Corp, discussed recent developments in drum level instrumentation, and a focus on ASME Code requirements.

"The only direct-reading device is a gage glass," he explained. "Indirect reading is a remote device." He then reviewed the options, pressure limits of each, and Code-permitted variations.

The discussion included minimum Section 1 water-gage requirement—including placement details, isolation and drain valves, permitted globe-type valves, and chain operation mechanisms for personnel and plant safety.

Common Code violations and concerns discussed included:

- Isolated inoperable water gages.
- Missing water gage glass.
- Missing illumination from water gages.
- Inadequate display of remote indicators in the control room.

Kolbus stressed "proper maintenance and routine inspection of these critical instruments," such as blowdown of small-diameter sensing lines to remove sediment.

Film-forming substances

Stephen Shulder, EPRI, addressed the increasingly dynamic topic of FFS for corrosion resistance and layup protection. This topic now has its own international conference, most recently in Prague, organized by IAPWS.

He offered background. Amine/filming chemistry is being used or considered for many reasons, including:

- Better layup protection during outages of varying duration. Film-forming substances can place a hydrophobic barrier between metal surfaces and liquid. Limits on capital expenditures or personnel could restrict the full use of dehumidified air systems, a viable alternative.
- Non-optimized corrosion-product transport with recommended feedwater treatment programs. Cycling operation means more startups, and excessive use of ammonia can lead to vapors within the plant and short polisher runs.
- Two-phase FAC damage. Neutralizing amines may provide better dissociation and distribution than ammonia, and higher localized at-temperature pH.

Shulder discussed filming amines and filming products, amine chemical structure, and application benefits and risks. He then turned to case studies, including potential impact on and benefits to air-cooled condensers.

Considerable time was spent on the details of FFS research, followed by storage, feed considerations, and application schedules.

His key two-part message:

1. Any use of film-forming substances should be in combination with, not in lieu of, best cycle chemistry by international standards.
2. You can't control what you can't identify and measure.

Shulder ended with a list of questions to ask any FFS supplier.

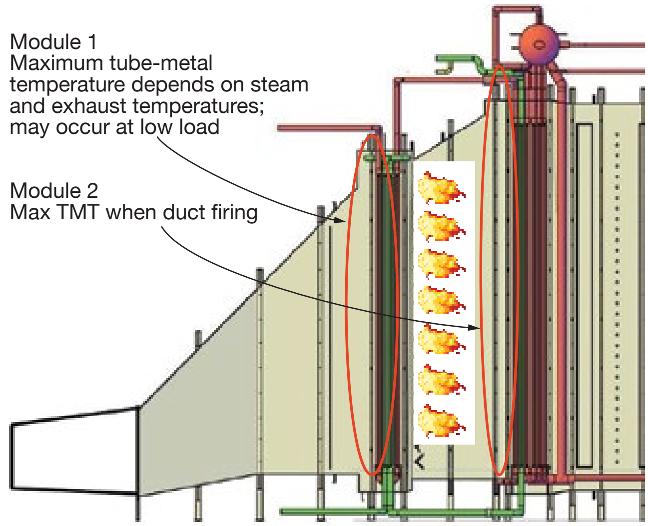
Barry Dooley stressed that "There is a whole series of failures that can occur with these substances," and reiterated that a definitive consensus document is now available at no charge through www.iapws.org, namely Technical Guidance Document "Application of Film-Forming Amines in Fossil, Combined Cycle, and Biomass Power Plants" (TGD 8-16).

Tube-to-header weld evaluations

Matt Dowling of Applied Technical Services followed with a case study on HP/RH-tube-stub-to-header welds at the Ontelaunee Energy Facility. The F-class 2 × 1 combined cycle has accumulated more than 80,000 operating hours since COD in 2002.

History includes 73 failures, all in the upper-header bent tube rows.

11. One of 73 failures in the upper header bent-tube rows experienced at an F-class plant



12. Tube-metal-temperature areas of concern in Modules 1 and 2

Analysis showed that damage initiated at the outer edge of the heat-affected zone, approximately 0.125 in. from the toe of the weld on the tube side (Fig 11).

Dowling covered the details of OD, ID, and mid-wall inspections, some difficult because of geometry. To date, 27 repairs have been completed, and further testing continues. Root cause is not yet identified.

Forum participants offered ideas and suggestions, and interesting insights going forward. This is a bubble unit; subsequent designs were modified.

SH/RH metal temperatures

HRST Inc's Bryan Craig explained the primary factors affecting HRSG superheater and reheater tube metal temperatures, and typical areas of concern.

"For some HRSGs," he explained, "the highest tube-metal temperatures could be in Module 1, during low-load unfired operation". "In HRSGs with duct burners," he continued, "maximums will be in Module 2 with burners firing."

And why is this important? "A temperature increase of 15 to 20 deg F can reduce equipment life by half," he stated.

Long flames and gas-temperature variations downstream of burners were discussed, and rule-of-thumb observations were given including duct-burner cameras.

Failing or missing gas baffles are also a major contributor, allowing high-temperature exhaust gas to come in contact with downstream tubes designed for lower temperatures. Craig presented photos of numerous gas-baffle failures.

Gas-turbine upgrades can also push HRSG tube-metal temperatures above their design limit. Gas temperatures increase, but steam temperatures can remain constant, controlled by the attemperators.

Internal oxide growth also was discussed. During comments, Barry Dooley mentioned that a workshop on materials and overheating was held at the *Australasian HRSG Users Group,* and was on the agenda for the *European HRSG Forum,* held recently in Spain. "We are discussing overheating in HRSGs as a serious problem, and looking at doing some proactive work, particularly with a large global database on oxides in various materials." This will become a topic for the *HRSG Forum.*

Full disclosure

EPRI's John Siefert discussed technology-transfer achievements (and open information exchange) as an approach to equipment life management, specifically regarding CSEF steels. Looking back to 2006, he stated that "after 10 years of research and more than $15 million invested by collaborative industry projects, there is now sufficient insight to provide an integrated strategy for life management of CSEF steels. This includes more than 125 individual reports and the world's most comprehensive understanding of these materials in powerplant components."

He then repeated that "variability is a reality in 9Cr martensitic CSEF steels." The inconsistency is in deformation and damage resistance. "This reality," he stated, "increases the complexity of an integrated life-management strategy."

Siefert outlined the resistance specifics and discussed the need for more stringent control of both up-front (heat-to-heat) composition and various material heat-treatment practices.

"One current emphasis," he said, "is to merge two items of EPRI's seven-point life management approach:

- Understand how design, operation, fabrication, and metallurgy affect performance, and
- Transfer this information to industry codes and standards, and the global electricity-supply community."

The presentation offered details on programs by EPRI, ASME, and NBIC, and included a list of publicly available EPRI reports.

Questions included applicable codes for repair of older materials.

Exhaust casings

Jake Waterhouse, Dekomte, presented exhaust-casing insulation inspection and repair examples for liner upgrades, insulation repacking, hot-spot elimination, apertures, and openings.

He began with cold-casing duct insulation issues (insulation loss leading to hot spots). Operational impacts highlighted the multiple negative effects of two-shifting and cycling including temperature transient fatigue and stress, movement, and dew-point condensation (acid and water).

Both standard and high-turbulence liner arrangements were described including the potential benefits of scallops. Duct insulation options included traditional, staggered, and stacked.

Pumpable repairs were described, including techniques and thermographic modeling during application. High-turbulence exhaust-diffuser repairs followed, including an example repair during operation. Fabric expansion-joint technology was described in detail for penetration seals.

Effective monitoring during plant

operation was emphasized throughout the presentation and discussions.

Steam-cooled desuperheaters

Attemperators that cool with saturated steam were described, primarily interstage and final desuperheaters designed to reduce thermal shock damage. The design discussed by Karel van Wijk, Advanced Valve Solutions, has been in operation for 10 years.

Thermal-shock calculations reviewed estimate that by reducing temperature differential by about 125 deg F, the number of expected startups without damage increases enormously. Sample calculations and predictions were reviewed.

Desuperheater positions, designs, and materials were examined in detail.

Capacitance sensing

Qussai Metashdeh, Tech4Imaging LLC, concluded the sessions with a discussion of non-invasive imaging and monitoring technologies. He concentrated on electric-capacitance volume tomography (ECVT), specifically for two-phase flow applications in HRSGs.

Also discussed was adaptability to various locations, concentrating on evaporator steam quality for ramping purposes.

ECVT is also applicable for three-phase flow (water, air, oil) and work is being supported by the DOE's National Energy Technical Laboratory.

Questions included solids monitoring (fluidized beds) and testing with hydrocarbons.

HRSG Forum and common global elements

As Barry Dooley tells us about flow-accelerated corrosion in combined-cycle systems, some things are simply global—the same everywhere.

Many of the topics covered in the second annual *HRSG Forum with Bob Anderson* are being discussed throughout the world at the *Australasian HRSG Users Group (AHUG),* the *European HRSG Forum,* the *Canadian HRSG Forum,* and others.

Recently in Australia, a full-day workshop was dedicated to materials issues in HRSGs, the same issues discussed in Houston. Topics included P91 damage mechanisms and case studies (CSEF steels), failure mechanisms, life-prediction and remaining-life assessment methods, weld repairs, and oxide growth and exfoliation of HRSG materials. Open discussions at the 2018 *HRSG Forum* focused on these issues as well.

AHUG presentations also covered the common elements of tube cleaning and efficiency, the impact of cycling, severe-service valves, attemperation, condensate detection and removal, and a list of active case studies throughout that part of the world. Plus, cycle chemistry and updates on film-forming substances.

Overheating of HRSGs was characterized in Sydney by HRST Inc's Lester Stanley, showing the global nature of such overheat issues as:

Non-pressure parts:

- Liner plates. Type-409 stainless steel in inlet ducts; Type 304 in firing ducts.
- Tube ties. Chrome-plated in inlet ducts; Type 304 in firing ducts.
- Gas baffles (firing ducts).
- Duct burners. Type-304 components.

Pressure parts:

- Tubes.
- Headers.
- Link pipes between tubes and headers.
- Steam outlet piping.

But there is great value also in the local case studies, the sharing of successes and failures, and the awareness that many of these issues are indeed global.

Area-specific presentations could be of significant interest regardless of location:

- New-build cycle-chemistry challenge in the Middle East.
- Long-term dry-layup concerns and tactics at Stanwell's Swanbank Plant in Queensland.
- Inspection and assessment updates for several units in Australia and New Zealand.
- Even failure of P91 steam superheater tubes in an ethylene cracker furnace.

Many presentations made reference to operational data, and the need for sharing these data with other owner/operators. Such was also the recommendation of EPRI during the HRSG Forum in Houston.

2019

In both 2017 and 2018, Bob Anderson encouraged and stimulated the discussion of experience and ideas, the interplay of frustrations and successes, the exposure of things heard in the field and around the world, supporting it all with his in-depth knowledge and the expertise of his colleagues. Plans are in progress for the third annual *HRSG Forum with Bob Anderson.* Details will be posted at www.HRSGforum.com as they become available. CCJ

WTUI, CCJ collaborate on best practices

The Western Turbine Users and CCJ are working together to expand the sharing of best practices and lessons learned among owner/operators of GE aero engines. WTUI VP Ed Jackson, plant manager of Missouri River Energy Services' Exira Generating Station in Brayton, Iowa, said the organization's mission is to help members better operate and maintain their plants, and a proactive best practices program supports this objective.

Jackson announced the joint program at the user organization's 26th Annual Meeting (2016) in Palm Springs where he encouraged attendees to support the initiative and explained how they would benefit from the experience. The latest fruits of that effort are the best practices profiled on the next several pages, submitted by the 11 plants listed at the right. Last year, eight plants participated.

Recall that CCJ launched its industry-wide Best Practices Awards program in late 2004. Its primary objective, says General Manager Scott Schwieger, is recognition of the valuable contributions made by owner/operator personnel to improve the safety and performance of generating facilities powered by gas turbines. Schwieger and Jackson are working together to grow participation by aero users.

Best Practices Award
for Aerodeivative Plants

Equus Power I LP
J-Power Long Island Fleet
Lawrence Generating Station
Orange Cogeneration Facility
Orange Grove Energy Center
Pinelawn Power LLC
Reo Town Cogeneration Plant
Shoreham Energy LLC
Terry Bundy Generating Station
West Valley Power
Worthington Generation LLC

Presented by the **COMBINED CYCLE** Journal and **Western Turbine Users Inc**

2018

LM6000 remote start/stop alert notification system

Equus Power I, LP

Owned by J-Power USA

Operated by NAES Corp

50-MW, dual-fuel, remote-start simple-cycle LM6000 located in Freeport, NY

Plant manager: Kenneth Ford

Challenge. Equus Power I entered the New York merchant power market in late 2017. An important revenue stream for the facility is the NY ISO 10-min-start market. Plant is operated remotely from another NAES gas-turbine facility, Pinelawn Power LLC, about 20 miles away.

It was necessary to assure that real-time start and stop signals were received and acted upon immediately by the Pineland operators. Prior to implementing the alert notification system one of Pinelawn's two O&M techs had to remain in the control room to fulfill this function, limiting the OMTs' ability to perform their regular inspection and maintenance activities. The challenge: Install a system that allowed OMTs to leave the control room to perform their Pinelawn duties yet still receive immediate notice of remote start/stop requests for the Equus turbine.

Solution. The Equus site already was equipped with hand-held radios that linked the Equus and Pinelawn sites via an electronic network. Their primary purpose was to enable a "Man-Down" alert system to provide a safety net when staff were tasked with working alone at Equus.

Site management pursued expanded capabilities for the radio system—including interfacing it with the Equus control system so start/stop signals could be transmitted to all radios on the Equus-Pinelawn network.

Today, upon receipt of an Equus start/stop signal, all radios on the network will both display a text message and annunciate an alarm tone. Plus, hardware installed to support the new radio system was modified to activate a contact closure that sounds mechanical alarm bells strategically placed in high noise areas of the Pinelawn plant, thereby providing further assurance that an Equus start/stop signal will be heard and acted upon immediately.

Results. The remote alert notification system provided immediate results. Specifically, a Pinelawn OMT is no longer required to remain in the control room to monitor for an Equus start/stop signal. This allows Pinelawn OMTs more time to complete equipment inspections and perform required maintenance. Also, the robust start/stop notification system helps ensure Equus can continue to successfully compete in the New York ISO 10-min-start market.

Project participants: Kenneth Ford, Mark Whitney, Dan Frederick, and Brett Miller

Terry Bundy

Steam-turbine rotor/case upgrades and heating system

Challenge. The Terry Bundy Generating Station is dispatched primarily to address peaks in the SPP market, resulting in daily on/off cycling. In 2016, the combined cycle's steam-turbine vendor significantly increased the equivalent operating-hour (EOH) factor for cold starts. The new cold-start EOH factor would have required major inspection/maintenance cycles for the turbine every seven years, at a cost of over $7.6 million over the next 25 years.

Solution. Staff evaluated the benefits of reducing the number of "cold" starts and associated maintenance cycles by upgrading turbine components and installing a turbine case/rotor heating system.

Results. Project scope covered the evaluation of mechanical modifications to the turbine rotor and installing a turbine rotor/case heating system to allow the unit to remain in hot standby mode for multiple days after coming offline. The heating system and turbine modifications significantly reduced the operating-hour penalties associated with cold starts and reduced future scheduled maintenance costs.

> **Terry Bundy Generating Station**
>
> *Lincoln Electric System*
>
> 170-MW, natural-gas-fired, 2 × 1 combined cycle and a simple-cycle LM6000, plus three landfill-gas-fired internal combustion engines, located in Lincoln, Neb
>
> **Plant manager:** Jim Dutton

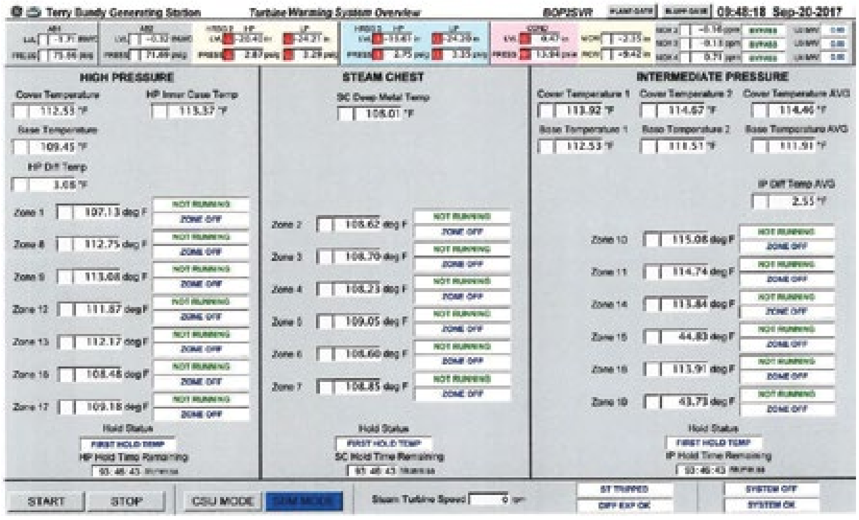
The overall goal was to improve unit operating economics and reduce the equivalent operating hours associated with cold starts, thereby cutting maintenance costs by extending the interval between major inspections. Rotor mods reduced the original cold-start EOH penalty from 530 to 235 EOH.

The turbine modifications included machining the rotor ends to increase case clearance, modifying the blade root configuration, changing the geometry of the thermal relief groove, and installing upgraded blades. The heating system maintains the steam-chest temperature at 650F, further reducing the EOH penalty for a start to 36 EOH.

A key requirement of the project was designing a monitoring system to estimate rotor temperature. The main challenge with designing the temperature monitoring system was that the dual-case design of the turbine made it challenging to accurately measure turbine temperature. Working with the turbine OEM, seven additional thermocouples were installed in the turbine-case HP and IP sections, including one which extended into an HP inner-case structure.

This allowed the system to assign the correct EOH factor for hot (644F and above), warm (266F to 644F) and cold starts (less than 266F) based on actual rotor condition; as opposed to the original EOH factor system that used the amount of time since shutdown to determine which EOH factor to apply to the next start.

The heating system, designed to bring the turbine from a cold condition to 260F using approximately 2067 kWh of energy, consists of 19 heating-blanket zones that are



Operator screen for overview of turbine warming system

sequenced on and off depending on measured case/rotor temperature and time since the unit was taken offline (screen photo).

The heating system is sequenced to maintain the turbine at 675F from the time the steam turbine is taken offline until 96 hours have passed. It then lowers the maintenance temperature to 575F for the next 72 hours. Finally, the system holds the turbine at 375F for 48 hours before allowing the temperature to decay to ambient.

In addition to extending the interval between maintenance periods, the heating system reduced the steam-turbine dispatch time by 45 minutes. The shorter dispatch time improved unit economics and will potentially lead to better market utilization of the generating resource.

Economic analysis of the benefits of this system indicate over $5.5 million in total savings from extending the maintenance intervals. The economic benefits of the shorter dispatch time have not yet been quantified. Lincoln Electric System is still evaluating the amount of energy, and associated cost, for heating-system operation.

Project cost breakdown

- Heating system design, installation, and commissioning: $1,263,764
- Estimated net present value of maintenance-cost reduction: $5,538,000
- Peak heating electrical demand: 150 kW

First hold temperature, trip to 96 hours.

- HP end section, 650F.
- Steam chest, 675F.
- IP end section, 375F.

Second hold temperature, 97 to 168 hours.

- HP end section, 550F.
- Steam chest, 575F.
- IP end section, 275F.

Third hold temperature, 169 to 216 hours.

- HP end section, 375F.
- Steam chest, 375F.
- IP end section, 200F.

Project participants:

Jim Dutton, plant manager
Chris Hodges, Nickolas Wischhof, and Byron Bakenhus, project engineers

EVM I

Energía del Valle de Mexico I

Owned by EVM Energia SAPI de CV

Operated by NAES Corp

100-MW (net), gas-fired, three simple-cycle LM6000PF gas turbines located near Mexico City

Plant manager: Javier Badillo

Chiller condensate recovery cuts costs, benefits community

Challenge: How to increase output/maximize revenue when electricity demand and prices peak during the warm months.

EVM I was designed with a chiller-type power-augmentation system. When inlet air approaches saturation, moisture begins to condense. The condensate formed—as much as 16,500 gal/day—dropped to a collector in the filter house and was piped to plant drains. Disposing of this much water was expensive given the fee structure specified in the plant's wastewater permit.

Staff wanted to recover the condensate for use as makeup for the small boiler onsite, for filling of the service-water tank, and for providing demineralized water for chiller makeup and for gas-turbine compressor water washing.

Solution. After considering several possible solutions, personnel came up with a design for a system that could direct the condensate formed either to the plant's sumps or to a collector tank. Once filled, these tanks would be pumped to the service water tank and/or the demineralized-water tank, as required.

During a planned outage, staff modified the condensate drain pipe for each gas turbine, installing two valves: one to direct the condensate to the drain, the other to a 290-gal collector tank added alongside the auxiliary skid serving each engine. Next, a pump was installed in each circuit to pump water to the service-water and/or demin tank.

A simple level-control device keeps the system working in automatic, or in manual mode, as required. It relies on an electrical float to start and stop the pump. When the collector tank is full, the water is pumped to the service tank; the float stops the pump when the tank is empty. The 220-V system is powered by the gas-turbine lighting boards.

Results. The system described allows recovery of up to 16,500 gal/day of water. Given the variation in relative humidity and ambient temperature, condensate production also is variable. Staff calculated a monthly baseline using actual daily production from July 2016 through June 2017 (table below).

Month	Avg RH, %	Avg temp, F	Condensate produced per unit, gal/day
July 2016	63	63	6747
August	71	61	7119
September	72	60	6998
October	69	58	4715
November	71	55	3925
December	63	55	2936
January 2017	51	54	. . .
February	46	56	. . .
March	52	58	. . .
April	55	64	4889
May	55	64	5671
June	60	63	6364

Because the state of Mexico has imposed a ban on obtaining fresh water from new wells, the plant would have to buy water for services and for making demineralized water. It made a considerable difference to its operating budget that the plant was able to recover approximately 159,000 gallons from the commissioning period (October 10-16) through the end of the month.

At about $0.06/gal, plant saved about $9500 in October alone. This means that the condensate recovery system, which cost roughly $10,500 in materials and labor, more than paid for itself in its first month of operation. Management does not expect to buy fresh water for the remainder of the plant's service life.

In fact, because EVM I recovers substantially more water than it uses, the plant supplies the local community with badly needed water for crop irrigation and other uses, allowing it to reduce its wastewater disposal cost to practically zero, while improving relations with neighboring communities.

A laboratory analysis showed the condensate to be of high quality. Conductivity measures less than 5 µS and pH averages 6.5-7. With reclaimed-water specs close to those for demin water, plant can use it directly for offline and online compressor water washing. Given the plant typically was paying $5600 annually for demin water, this reduces operating costs further.

Project participants: Alonso Saldivar, plant engineer

J-Power Long Island

One way to avoid air-permit violations

Challenge. Four LM6000s at multiple Long Island sites have strict NO_x limits (2.5 ppm one-hour average on

gas, 9 ppm on oil). Thus, a hiccup in NO_x water or ammonia injection might cause a significant spike in stack NO_x, likely resulting in a reportable air-permit exceedance.

The challenge was to establish a method to automatically detect an abnormality in the emissions control system and immediately start a GT shutdown. The goal was to eliminate the time needed for an operator to detect, analyze, and act on system abnormalities thus reducing the chances of the CEMS Data Acquisition and Handling System recording a steady state, one-hour-average, air-permit exceedance.

Solution. Plant managers identified the following conditions at which an automatic GT shutdown should be initiated:

- GT load greater than 25 MW and NO_x water flow rate drops below 5 gpm.
- GT load greater than 25 MW and 25 minutes have elapsed since startup (assures SCR is warmed up and ammonia is being injected) and ammonia flow drops to less than 10 lb/hr for more than 10 seconds.

Once the above thresholds were identified, an outside vendor specializing in GT and BOP control-system architecture was contracted to develop and implement logic to support the desired actions.

Results. Following implementation of automatic shutdown logic, none of the four engines has experienced a reportable air-permit exceedance as a result of water- or ammonia-injection anomalies. Best estimate: Eight reportable events were prevented in the last two years.

Project participants: Kenneth Ford, Mark Whitney, and John Lawton

J-Power Long Island Fleet

Owned by J-Power USA

Operated by NAES Corp

Edgewood: 90-MW, two-unit, peaking facility located in Brentwood, NY

Equus: 50-MW remote-start peaker located in Freeport, NY

Pinelawn: 80-MW, dual-fuel, 1 × 1 combined cycle located in West Babylon, NY

Shoreham: 90-MW, two-unit, peaking facility located in Shoreham, NY

Plant manager: Kenneth Ford

Custom platforms, modified access doors to filter compartment improve safety

Challenge. Plant personnel noticed a major design flaw and safety hazard in the generator filter compartment: Access doors on both sides of the compartment were located 20 ft above ground level, with no established means of access. In addition, a support beam blocked both doors' travel, allowing them to open only about 10 in. This severely limited access to the air filters and critical operating transmitters.

Solution. Safety committee brainstormed the problem and came up with a plan to add custom-built platforms supported by existing structural members to access the filter compartment. In addition, the top corner of each access door would be cut off, then reattached with hinges so it would swing out of the way, allowing the access door to open fully without obstruction (left photo). When bolted, the access door would still maintain its integrity (right photo).

The solution developed as follows:

- Met with two fabrication contractors to get ideas for a possible design.
- Safety committee gathered input and came up with a feasible, cost-effective design.
- Had a structural engineer come on site to evaluate and approve the design.
- Added permanent, separately supported platforms with handrails and vertical ladders to allow personnel to safely access elevated compartment doors.
- Cut off top corner of each access door using a triangular "Nabisco cut," reattached with stainless-steel hinges.

Hinged "Nabisco cut" allows door to open fully despite beam obstruction (left). When the Nabisco cut is secured with a bolt, full integrity of the access door is restored (right)

Lawrence Generating Station

Owned by Hoosier Energy (four units) and Wabash Valley Power Assn (two units)

Operated by NAES Corp

258 MW, six simple-cycle LM6000 natural-gas-fired peaking units, located in Lawrence County, Ind, and connected to Hoosier's 161-kV transmission line

Plant manager: Robert VanDenburgh

Results. Staff can now access the generator filter compartment without the need for extension ladders, scaffolding, or fall arrest protection onsite. Routine filter changes, calibrations, and damper maintenance can be done safely, quickly, and conveniently.

During peak operation last summer, staff discovered an additional, unanticipated benefit of the access solution. When a damper actuator failed, it caused the filter-compartment temperature to rise rapidly. The unit was ready to trip offline because of the excessive heat, but operator on duty accessed the inlet door quickly and opened the Nabisco cut, which provided enough air flow to arrest the temperature increase and give personnel time to get the damper open and restore normal operations.

Project participants: Matthew O'Hara, lead O&M tech
Jared Thomas, O&M and IC&E tech

EPT
cleanoil.com

Lubricant Management Services

$100 Million + Savings Reported

Expert Analysis, Filtration, and Flushing

West Valley

Upgrading lube-oil hoses reduces forced outages

Challenge. West Valley's generator lube-oil discharge hoses had ruptured at least once per unit per year. Each incident resulted in an unscheduled outage of at least four hours and the loss of 50 to 100 gallons of lube oil. The OEM equipment consisted of two stainless-steel flanges connected by a rubber hose—a design apparently not up to the task.

West Valley Power

Owned by Utah Municipal Power Agency

Operated by NAES Corp

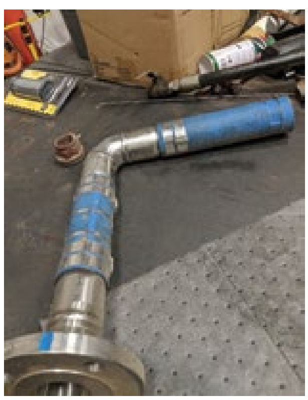
200-MW, gas-fired, five simple-cycle LM6000s located in West Valley City, Utah

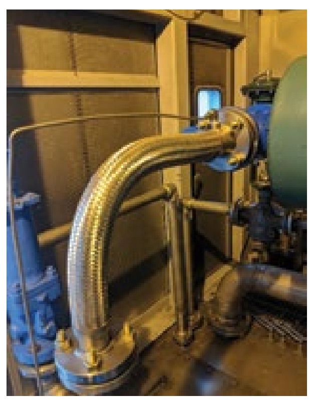
Plant manager: Jerame Blevins

Solution. Even after staff had replaced the ruptured hoses numerous times with OEM approved parts—and upgraded the hose material—the issue persisted (photo left). Plant personnel considered several solutions, settling on having a braided stainless-steel-reinforced hose manufactured for each unit (photo, right). Careful measurements were taken on each unit before having the five new hoses fabricated by a local shop.

Results. Since West Valley installed the new hoses four years ago, it has not had a single rupture, saving about 500 gal/yr valued at $8100. It has also reduced the call-in hours for two extra operators to clean up five spills and replace five hoses, which totaled more than $2200 annually. Overall, it has reduced the number of forced outages by five per year (at four hours per outage).

Project participants:
Stephen Rogers, shift supervisor
Chris Cook, OMT
Brett Argyle, OMT





Original hose after failure is at the left, braided stainless-steel-reinforced replacement hose at right

Pinelawn

Chain fall/come-along storage cart

Pinelawn Power LLC

Owned by J-Power USA

Operated by NAES Corp

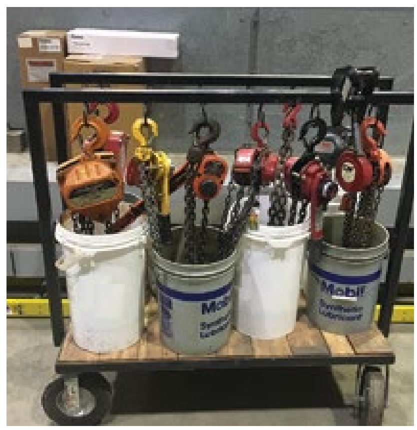
80-MW, dual-fuel, 1 × 1 combined cycle located in West Babylon, NY

Plant manager: Kenneth Ford

Challenge. Chain falls and come-alongs are available in various sizes (based on load rating) with varying lengths of operating (pull) chain and load-bearing chain. Carrying these devices introduces a safety hazard since they can be heavy and their long lengths of chain make them cumbersome to handle when walking. Plus, they require periodic lubrication to maintain good working order, but drips of lubricants can present both an environmental and a slip/trip hazard.

The challenge was to create a way to both store and transport the site's chain falls and come-alongs in a safe and environmentally responsible manner.

Solution. Site OMTs met the challenge by building a wheeled transport cart constructed primarily of angle iron, tubular steel, wood decking, and eyelets. The chain falls and come-alongs are hung from the eyelets and their chains are stowed in 5-gal buckets to allow for neat storage as well as capture of any oil drippings (photo).



Results. The transport cart provided immediate elimination of the safety hazards associated with carrying chain falls and come-alongs. One OMT can now easily move multiple devices to work locations onsite. Storage of chains in buckets eliminates the environmental hazard of accumulated oil drippings and the safety hazard of a slippery walking surface.

Project participants:
Pinelawn OMTs

Shoreham

Turbine lube-oil-reservoir filling process

Challenge. The turbine lube-oil reservoir, as constructed, offered no accommodation to add oil other than to stand on top of an adjacent motor and manually add oil to the top of the reservoir, through the fill port, with a 5-gal bucket. Identifying this as a potential safety concern, the site set about to make the process safer.

Over time, multiple investments were made to provide a stable, secure, and safe means to perform the task of adding oil to the reservoir. The first method was to install a "hatch" in the wall of the site's mechanical building—provides access to the top of the reservoir—along with a fixed platform outside the building. While this did solve one problem (safe access to the top of the reservoir), employees still were required to manually add the oil using 5-gal buckets.

The second "fix" was the purchase of a wheeled cart, with a self-contained oil storage reservoir and pump (photo left). Through a hose, employees were now able to add oil simply by running the hose to the top reservoir, into the fill port, and starting the pump. When complete, all that was required was to stop the pump. While successful, employees found this method somewhat cumbersome in that great care needed to be taken to ensure oil would not spill from the hose once removed from the fill port.

Shoreham Energy LLC
Owned by J-Power USA
Operated by NAES Corp
90-MW, two-unit, peaking facility located in Shoreham, NY
Plant manager: Kenneth Ford

Solution: The addition of a tee, with a quick-connect fitting, at the top of the reservoir on the return line from a recently installed oil purifier. A compatible fitting on the discharge hose of the oil cart's installed pump created a "leak-free" connection, making oil transfer safer, easier, and cleaner (photo right).

Results. Employees now are able to add lube oil to the turbine reservoir without the potential of an injury from a misstep or fall, or environmental concern caused by residual leakage from the oil delivery hose.

Project participants:
Anthony Angieri, chief engineer
John Lawton, O&M manager

REO Town

REO Town Cogeneration Plant

Lansing Board of Water & Light

100-MW, gas-fired, 2 × 1 combined-cycle cogeneration facility located in Lansing, Mich

Plant manager: Tom Dickinson

Natural-gas leak detection program

Challenge. Shortly after commissioning of the REO Cogeneration Plant, several forced outages were caused by natural-gas leaks in the gas compressor building and other areas. A root cause analysis revealed gasket damage at several flanged joints in the fuel handling system because of improper tightening and torqueing procedures.

Solution. Immediately after the RCA was completed, all gaskets in the fuel handling system were replaced to mitigate safety and financial risks. Proper flange applications and torqueing procedures were carefully implemented.

Next, plant management, in collaboration with the maintenance mechanic group, developed the framework for implementation of an in-house natural-gas leak detection program. It uses a risk-assessment and risk-management approach by establishing gas leak levels of from 1 to 3, based on the concentration of methane and the lower explosion limit.

Grade 1 is the most severe level and requires immediate investigation, a forced outage, and repairs to protect life and property and eliminate the hazardous condition. Grades 2 and 3 are progressively lower in risk and would allow more time for maintenance planning for and/or repair.

The leak detection program requires regular testing, data tracking, and classification to determine the proper response to any evolving leak (photo). A preventive-maintenance work order was created for mechanics to conduct a wall-to-wall plant leak test survey every other week. Test results are recorded on a worksheet, then discussed with the operations supervisor, and later scanned and saved.

All plant employees have been trained in natural-gas leak detection. Training included the following:

- Review of the plant operations manual, including maintenance procedures.
- Natural-gas fundamentals, including physical and chemical properties.
- Natural-gas detection and equipment.
- Inspections, safety equipment, reporting, and communications.

Results. The REO Cogen natural-gas leak detection program, in effect since May 2015, has provided the following benefits:

- Collaboration of management and bargaining-unit employees to develop an in-house program to address the operational and safety problems associated with natural-gas leaks. This has been conducive to a collaborative work environment to solve other issues as well.

- A risk-management program for gas leak detection, based on concentration thresholds and test frequency, which increases the chance of detecting an incipient gas leak and allows for better response planning.
- A safer work environment exhibiting a proven reduction of fire risks through the prevention of gas leaks.
- A workforce trained in the physical and chemical properties of natural gas, including hands-on training on gas detection techniques and equipment.
- The use of natural-gas leak detection as a quality control program for the effectiveness of flange selection, installation, and torqueing procedures.
- A culture of collaboration and commitment to safety, quality, and efficiency.
- A dramatic reduction in the number of forced outages—from 19 in the first two years of plant operations to virtually zero today. Only four minor gas leaks have been detected since program implementation.
- Elimination of gas leaks in the gas-compressor building, as demonstrated by the regularly collected data and confirmed by the annual leak-test survey performed by a third party.
- A significant increase in plant availability after the first year of

Maintenance mechanic checks for gas leaks

program implementation: from 87.52% in 2014 to 95.47% in 2015.

Finally, the realized benefits of the adoption of a leak detection program as an in-house best practice can be summarized thusly:

1. Development of new skills for maintenance personnel, such as:
   - Awareness of natural-gas risks in the plant environment.
   - Specialized training for gas detection.
   - Ability to provide a specific response to gas leaks according to the methane concentration thresholds (leak grade levels).
2. Improvement in plant performance, including:
   - A significant increase in plant availability.
   - Implementation of an in-house program for identifying/correcting gas leaks abnormalities with trigger points for action.
3. Development of a new plant safety procedure, based on methane concentration thresholds and frequency of leak testing, that go beyond the requirements of NFPA 56 for cleaning and purging of flammable gas piping systems to permit maintenance and repair.
4. Use of the leak detection program as a quality control method to evaluate the accuracy and effectiveness of the installation, maintenance, and/or repair of valve flanges and other systems related to fuel handling and treatment.

Project participants:

Roberto Hodge, director of electric production
Tom Dickinson, plant manager
Craig Smith, operations supervisor
Pat Sibley, maintenance supervisor
Joshua Zussman, technical safety trainer
Mickey Fountain, maintenance leader
Charlie Jenkins, George Berry, Jim Erickson, Roger Sosebee, Ken Martin, and Brian Knapp, maintenance mechanics

Orange Grove

Water management plan cuts costs and pollution, plus . . .

Orange Grove Energy

Owned by J-Power USA

Operated by NAES Corp.

96-MW, gas-fired, two-unit, peaking facility located in Pala, Calif

Plant manager: John Hutson

Challenge. Orange Grove Energy (OGE) is required by the California Energy Commission to maintain landscaping and irrigation around the plant's eight-acre parcel. Recycled water is supplied for this purpose by the Fallbrook Public Utility District, which trucks it to OGE.

However, Fallbrook residents had expressed concern regarding the number of large trucks traveling through their community. The route used had seen multiple accidents, some involving fatalities, since OGE began operating in June 2010. In sum, trucking water was an expensive, dangerous and environmentally dirty process.

Solution. Minimizing water use was important. To do that effectively, the plant installed a totalizing flow meter in the irrigation system to monitor consumption. This enabled staff to respond quickly to increases in irrigation flow and fix broken pipes and nozzles—substantially reducing water use.

A spreadsheet tracker was established to monitor and log flow rates and usage as they trended up or down—either in small increments or step changes. Overall, the totalizer—along with active monitoring, tracking, and trending—allowed staff to better communicate and keep the irrigation system in excellent condition.

Results. The new tracking system sharply reduced trucking requirements; savings in labor, maintenance, and fuel amounted to over $30,000 annually. Fallbrook residents have expressed appreciation to OGE for reducing traffic and diesel emissions. Plus, fewer trips to haul water means road accidents are less likely.

Project participants:
John Hutson, plant manager
Ramiro Garcia, compliance manager
Anthony Moretto, lead O&M tech
Paul Braemer, Al DeLuna, and Amy Bowersox, O&M techs
Meredith Albertelli, plant administrator

Improved oil-pump breather reduces maintenance

Challenge. OGE's gas turbines are supplied NO_x water by a Roto-Jet® pump. The pump bearings are oil-lubricated by a self-enclosed sump, which is equipped with a simple air breather that becomes saturated with oil and leaks externally soon after it's cleaned or replaced. In time, personnel were adding oil every other week and operators were wiping up oil in the pump house daily.

Solution. The existing filter (photo left) was upgraded with a breather that allows air to pass through the filter but drains the oil back to the sump. Personnel also added a 6-in.

Simple breather (left) became saturated with oil and leaked. New Hy-Pro breather/filter and piping arrangement (right) allow oil to pass through the filter and then return to the pump rather than saturating the filter extension and two 90-deg elbows to give a change of direction and further decrease the likelihood of oil reaching the filter (photo right).

Results. This simple solution solved the plant's problem immediately and economically. The cost of removing the old filters and installing the new breather/filters totaled $125, saving an estimated $2600 annually in replacement parts and labor.

Project participants:
John Hutson, plant manager
Ramiro Garcia, compliance manager
Anthony Moretto, lead O&M tech
Paul Braemer, Al DeLuna, and Amy Bowersox, O&M techs
Meredith Albertelli, plant administrator

Eliminating pigeon problem mitigates health, safety risks

Challenge. Pigeons are the most common bird pests in urban areas worldwide. They often are unwelcome

residents at powerplants and pose a threat to the health and safety of plant employees. Example: Pigeon droppings create slip-and-fall hazards on concrete walkways and steel deck grating. They also startle unsuspecting employees working in areas where the birds have taken refuge, sometimes causing a trip or fall.

Solution. After consulting with state regulatory agencies and a local pest control contractor, staff decided to use pretreated Avitrol corn to control and drive away pigeons from the site. Compared to other methods considered, Avitrol used in low concentrations offers a humane, environmentally friendly and cost-effective solution to the problem.

The active ingredient in Avitrol acts on the pigeons' central and motor nervous systems, causing them to emit distress signals, alarm cries, and visual displays similar to those used when a predator is attacking the flock. These signals frighten away the rest of the flock from the site.

Program began by placing feeding stations—trays filled with untreated corn—in strategic locations around the plant to familiarize the pigeons with them. Stations were inspected weekly and refilled as needed until personnel observed significant feeding activity—which took about two months.

During the third month, staff began filling the stations with the Avitrol-treated corn, inspecting and refilling them as needed. After about two months, there was less activity at the stations. Inspections were reduced to biweekly, then monthly. After about nine months, the pigeons had disappeared and have not returned. Today the feeding stations are inspected quarterly to monitor for signs of pigeon activity.

Results. As of January 2018, the site had been pigeon-free for about 18 months.

Project participants:
Entire OGE staff
Jason Blakeley, contractor

Worthington

Worthington Generating Station

Owned by Hoosier Energy Rural Electric Co-op Inc

Operated by NAES Corp

174 MW, four simple-cycle LM6000 natural-gas-fired peaking units, located in Greene County, Ind, and connected to Hoosier's 138-kV transmission line

Plant manager: Robert VanDenburgh

Chiller isolation and bypass valve installation

Challenge. During summer peaks, Worthington uses four 1800-ton chillers to produce the 40F chilled water required to maximize GT performance with 43F compressor inlet air. For winter operation, staff adds 40% glycol to the chilled-water loop and a small boiler operates to heat and maintain loop temperature at 54F. The glycol/water mixture circulates through the air inlet house to maintain compressor inlet air at the desired temperature.

Chiller issues developed when the ambient temperature was extremely low. The glycol/water mixture loop temperature dropped below 30F, causing an unusually cold mixture to flow through the system, including the chiller evaporators.

The chillers are laid up during the winter off-cycle, so the evaporator and condenser normally stay at the same pressure and temperature. However, the extremely low evaporator temperatures allowed low refrigerant temperatures to transfer from the evaporator to the condenser, causing trapped residual water from annual tube cleaning to freeze in the condenser tubes. Eventually cracks developed that damaged the chiller.

To sum up the challenge:

- Prevent flow through the chiller evaporators when the loop temperature drops below 40F.
- Maintain proper operating pressure and flow rates without using the chiller evaporator as a pass-through.
- Change procedures to prevent water from settling in the condenser tubes while the chiller is laid up for the winter.

Solution. Staff's root cause analysis concluded that the chiller evaporators must not be used as a pass-through during winter operations. An alternative plan was to allow the glycol/water mixture to bypass the chiller evaporators while maintaining the integrity of the loop. Isolation valves were installed in the chiller inlet and outlet piping that completely disconnected the chiller from the loop to prevent any refrigerant transfer to the condenser.

Plant also added a bypass valve upstream of the isolation valves to maintain the flow path. To address the standing water in the condenser tubes, low-point drains were installed. The winter lay-up procedure was revised to ensure that the condenser tubes could dry thoroughly following annual cleaning.

Results. By completely isolating the chiller from the glycol/water mixture loop, the plant increased chiller reliability and has experienced no further chiller downtime caused by cold evaporator temperatures. Removing the condenser end bells for the winter allows the condenser tubes to thoroughly air-dry, while adding the low-point drains prevents residual water from settling in the condenser tubes after the annual cleaning.

It's too early to assess long-term results, but staff expects these last two measures to eliminate the freezing/cracking problem in the condenser tubes.

Project participants:
Matthew O'Hara, lead O&M tech
Jason Robertson, O&M and IC&E tech

Lighter, hinged manhole covers safer

Challenge. Worthington has three vaults with manholes that provide access to valves. The existing manhole covers (photo, left) required the efforts of two operators to remove them, and they still posed a hazard because of their weight and design.

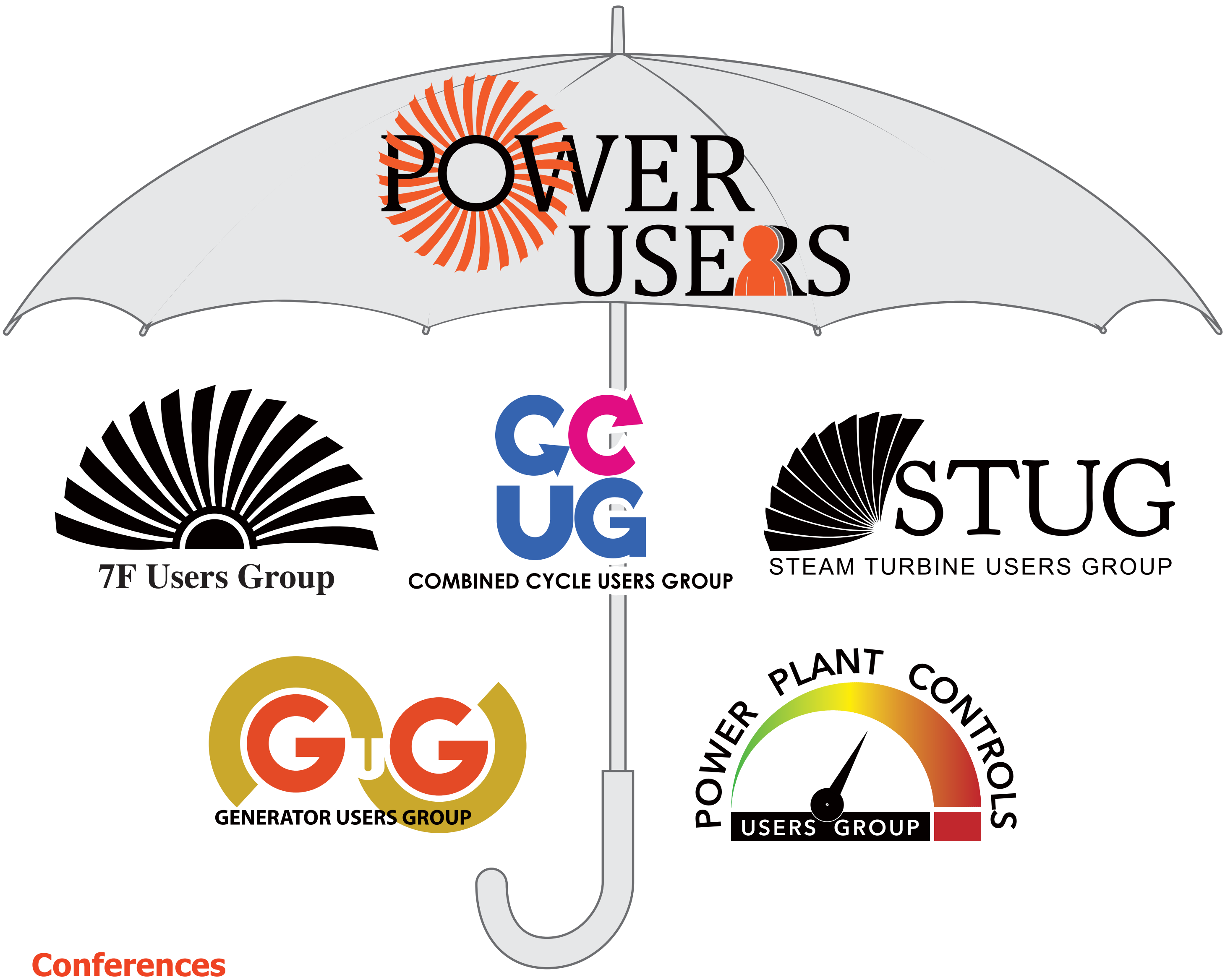
Solution. Plant's safety committee worked with a local welding company to design a lighter-weight cover (photo, right) that eliminates the need for two-person removal and replacement. Plus, the hinged design eliminates the hazards associated with moving and storing the cover during vault access.

Results. In addition to eliminating the need for two-person operation, the hinged cover requires no tools for removal. It causes zero back strain and presents few if any pinch points.

Project participants:
Matthew O'Hara, lead O&M tech
Jason Robertson, O&M and IC&E tech

Original manhole arrangement is at left, new hinged manhole cover at right

Power Users is the umbrella organization for managing and coordinating the technical programs for the industry's leading User groups



Conferences

- Each year in May:
  - 7F Users Group annual conference: www.7FUsers.org
- Each year in August:
  Three separate conferences… three different agendas
  Same dates, same location, shared meals and shared vendor fair
  - Combined Cycle Users Group – www.ccusers.org
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  - Steam Turbine Users Group – www.stusers.org
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  - Power Plant Controls Symposium

Forums

- 7F Combustion Turbines
- Combined-Cycle Steam Turbines
- Combined-Cycle Users
- Generators
- Heat-Recovery Steam Generators
  (moderated by Bob Anderson)
- Power Plant Controls

Power Users Group is a non-profit company managed by Users for Users. It is designed to help Users share information and get solutions to power-production problems.

www.PowerUsers.org

Orange Cogen

Backup diesel air compressor for black-plant situations

Challenge. Orange Cogeneration is connected to the grid via the local utility's 69-kV system. Historically, inclement weather events cause this section of the system to disconnect, blacking out Orange Cogen.

The plant was designed with a station battery system, but the air compressors were not connected to it. Not having instrument air for more than two hours during a black-plant event presents the following challenges, among others:

- Control of air-operated valves is lost with possible financial impact. Example: Losing control of boiler feedwater flow causes excessive wear and tear and thermal stress on expensive HRSG components and support equipment.
- Fire system dry-pipe deluge systems require instrument air for proper operation. Deluge valves were arranged to open after air-receiver capacity was exceeded and pressure dropped below 45 psig, requiring technicians to disassemble and reset the valves.

Solution. Orange Cogen staff investigated solutions for maintaining instrument air pressure when the plant lost power—including adding a receiver or replacing the existing one with a larger receiver. However, the storage capacity required to supply air for two hours was considerable.

A backup generator also was considered, but the cost of a unit to run a 100-hp air compressor, plus associated switchgear, was prohibitive. Adding the compressors to the station battery system had its drawbacks, too: Additional cells would have been required and the battery room was too small to accommodate them.

A diesel-powered air compressor was the optimal choice. A trailer-mounted unit was selected so personnel could use it for maintenance purposes when the plant was not in operation. A successful result hinged on integrating the portable air compressor into the existing air system and allowing for the exhaust gasses to safely vent to atmosphere. This was doable.

The local supplier added a controls package, enabling the new compressor to start at 95-psig system pressure and unload at 105 psig; plus shut down after running unloaded for five minutes. The permanently installed electric compressors are arranged in a lead/lag scheme with the lead unloading at 120 psig and loading at 110, the standby loading at 105 psig and unloading at 115.

The diesel compressor was located outside the water treatment building under a protective roof (photo). Piping and conduit for the new machine was run in-house after trenching to avoid a trip hazard. The conduit was to provide a 120-V ac circuit for a charger/battery tender to keep the compressor starting battery in top condition.

The diesel compressor has one drawback: It is not an instant-on machine like a motor-driven compressor. The diesel requires 30 seconds to heat up intake air before it will fire and there is a short warmup period before it will load. Starting time may vary depending on ambient temperature.

After two actual events, staff learned that system pressure dropped to 65 psig before the diesel compressor picked up load and raised system pressure. However, this was adequate serve control valves plant-wide, plus maintain pressure to the fire-system deluge valves.

Results. The diesel compressor was tested by turning off the electric compressors when the plant was offline and it performed as expected. Operators were able to bring the plant to a safe condition with the deluge valves remaining shut.

Another event confirmed the value of the new equipment: With an electric compressor down for quarterly maintenance, a close lightning strike took out the running air compressor along with several other motors while the plant was operating. The diesel compressor started and allowed operators to maintain normal operation, preventing a forced outage.

Project participants:
Allen Czerkiewicz, plant manager
Joe Shaffer, maintenance manager
David Courson, maintenance mechanic
Steve Shore, I&E technician
Charles Chancey, I&E techncian
Henry Leon, senior operator

Orange Cogeneration

Owned by Northern Star Generation

Operated by Consolidated Asset Management Services LLC

104-MW, gas-fired 2 × 1 combined-cycle cogeneration plant powered by DLN-equipped LM6000 engines, located in Bartow, Fla. Condensing, extraction steam turbine is rated 25 MW. Steam is sold to producers of orange juice and ethanol

Plant manager: Allen Czerkiewicz

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

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AECOM

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AGTSI offers a full range of aeroderivative gas-turbine, off-engine, and package parts from the most basic to the most critical. An expansive inventory of spares and replacement parts is maintained at our warehouse for all models of GE LM2500, LM5000, LM6000, and LMS100, as well as P&W GG4/FT4.

AGTServices

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American Chemical Technologies

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ARNOLD Group

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Specializes in the design, installation, commissioning, and 24/7/365 service and aftermarket support of all types of fire protection and life safety systems for the power generation and petrochemical industry. ISO 9001:2015 certified company.

BBM-CPG Technology

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Provider of repairs and custom technology upgrades for turbomachinery. Designs and manufactures an integrated solution to meet specific requirements for every operating environ-

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ment, applying the latest fluid film bearing and high-performing seal technology to legacy equipment to optimize performance.

Bremco

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

C C Jensen Oil Maintenance

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

Caldwell Energy

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

Camfil Farr Power Systems

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Cemtek KVB-Enertec

Leading supplier of custom-engineered extractive, dilution, and mercury CEMS from single units to multiple complex units in cabinets and shelters; and provider of support for compliance and non-compliance applications.

Chanute Manufacturing

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

CMI Energy

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

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%.

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

Creative Power Solutions

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

Crown Electric Engineering & Manufacturing

Engineers, designs, fabricates, and installs isolated phase bus, large bus duct systems, and outdoor switchgear. Specializes in rapid response needs such as IPB for GSU change-outs, quick-ship fabrication, and emergency on-site service needs.

CSE Engineering

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

Cust-O-Fab Specialty Services

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

Cutsforth

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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

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ECT-Engine Cleaning Technologies

Offers R-MC and Power-Back 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.

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Emerson Automation Solutions

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 Inc (EAI)

Experts in CO_2 blast cleaning, surface preparation, and onsite dry-ice pellet production for HRSGs, SCR and CO catalyst, ammonia injection grids, gas and steam turbines, ACCs, and electric motors. Services also include scaffolding erection, sky-climber installation, deep bundle cleaning, and tube spreading.

EthosEnergy

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

Evapco-BLCT Dry Cooling Inc

Specializes in the design and supply of air-cooled condensers (ACCs) and air-cooled heat exchangers (ACHEs) for the power industry with over 5000 MW of operating references in the USA and considered a premier ACC supplier for the global power market.

EvapTech Inc

Full service provider of new towers and aftermarket services for field erected cooling towers. World leader in evaporative and hybrid cooling technologies specializing in design, component manufacturing, construction services, parts, upgrades, and consultation.

Falcon Crest Aviation

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

Federal Steel Supply Inc

Distributor of seamless HRSG high-energy pipe and power piping. Scheduled and heavier than scheduled walls in stock for headers, steam lines, etc. SA106 B/C and SA335 P11/P22/P91. Fittings to complement all pipe. Offering cut-to-length, custom fittings, specialty end preparation, supplemental testing, and emergency same-day shipments.

Frenzelit North America

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

Gas Turbine Controls

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

Gas Turbine Efficiency

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

Gas Turbine Specialty Parts

Provides patent-pending products that are new, cutting-edge, add value, and promote a safer work environment. GTSP presently has two unique products designed for the utility industry: 1) flange leak detection and 2) open air exhaust thermowell.

GP Strategies

Provides training, engineering, and performance improvement services specifically designed for the power industry: The EtaPRO™ Performance and Condition Monitoring System and GPiLEARN+™.

Groome Industrial Service Group

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

GTC Services

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

Haldor Topsoe

Our air pollution technology includes a series of unique catalysts for Selective Catalytic Reduction (SCR) systems for the control of nitrogen oxides (NO_X), and the reduction of carbon monoxide (CO) and volatile organic compounds (VOCs), from stationary and mobile sources.

Hilliard

The HILCO® Division cost-effectively brings fluid-contamination problems under control and engineers a full-range of filters, cartridges, vessels, vent mist eliminators, transfer valves, reclaimers, coolant recyclers and systems, and membrane filtration systems.

HRST

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

Hydro

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

Hy-Pro Filtration

Provides innovative products, support, and solutions to solve hydraulic, lubrication, and diesel contamination problems. Company's global distribution and technical-support networks enable customers to get the most out of their diesel, hydraulic, and lube-oil assets. ISO 9001 certified.

JASC

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

KnechtionRepair Tools

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

Kobelco Compressors America

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

Liburdi Turbine Services

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

M & M Engineering

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

Mechanical Dynamics & Analysis

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

Membrana, a 3M company

Market-leading producer of microporous membranes and membrane devices used in healthcare and industrial degassing applications. The Industrial & Specialty Filtration Group manufactures Liqui-Flux® ultrafiltration and microfiltration modules as well as Liqui-Cel® membrane contactors.

Mitten Manufacturing

Leading fluid system packager for numerous OEMs, EPC firms, utilities, and plant operators all over the world offering a number of value-added designs, spare parts management, and field services.

Multifab Inc (MFI)

Over 40 years of experience in design and manufacturing of products used for high-temp equipment along with air and flue gas applications. Offers a wide variety of services for all types of expansion joints, dampers, and high-temp products including installation, removal, repair, and splicing.

NAES

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

National Breaker Services

Industry leader in switchgear life optimization, life extension, and system upgrades. Manufactures new, highly customized low- and medium-voltage switchgear and provides on-site troubleshooting, maintenance, and testing of existing systems.

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.

Parker Balston

Develops and manufactures nitrogen generators for all your power generation needs including boiler layup, gas seals, purging gas lines prior to service, blanketing demin water tanks, and LNG terminals.

Parker Hannifin

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

Parker Hannifin Gas Turbine Filtration

With over 50 years of experience delivering innovative solutions for GT inlet filtration and monitoring fleet-wide performance data, our industry and applications experts will select the appropriate filter for your site designed to meet specific operating goals.

Power Service Consultants

Boutique consulting group focusing on LTSA contract negotiation support for owner/operators of gas turbines, steam turbines, and generators. With over 30 years of experience in power systems service, our focus is to drive down avoidable maintenance costs.

Praxair Surface Technologies

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

Precision Iceblast

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

PSM

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

PW Power Systems

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

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

Performs all aspects of isolated phase bus duct maintenance, inspections, removal, installations, retrofitting and testing. Services also include cutting, aluminum and substation welding, transformer termination compartment removal, and provision of replacement parts.

Sargent & Lundy

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

Siemens Energy

A leading global supplier for the generation, transmission, and distribution of power and for the extraction, conversion, and transport of oil and gas. Leadership in the increasingly complex energy business makes it a first-choice supplier for global customers. Known for innovation, excellence and responsibility, company has the answers to the sustainability, flexibility, reliability, and cost challenges facing customers today.

SNC Lavalin

Global engineering, construction, and project management company, and a major player in the ownership of infrastructure. Our passion for solving complex problems has allowed us to excel across many industrial sectors. We are a market leader in thermal power, having designed and constructed more than 50 GW of power capacity in over 200 locations.

SSS Clutch Company

Clutches enable operators to disconnect generators from simple-cycle turbines for synchronous-condenser service. Clutches also find application in CHP plants and in single-shaft combined-cycle facilities where operating flexibility is beneficial.

Strategic Power Systems

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

Sulzer

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

TEC-The Energy Corp

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

TEi Services

Offers a full range of heat-transfer products and services and fully trained, certified maintenance personnel. Provides world-class emergency repair services, underpinned by a 75-yr history in the design and manufacture of condensers, feedwater heaters, and heat exchangers.

TesTex Inc

World leader in electromagnetic non-destructive testing (NDT). We continually define the state-of-the-art for the testing of ferrous and non-ferrous materials and structures through applied research and development.

Turbine Technology Services (TTS)

Wide range of expert engineering and consulting services, conversion, modification and upgrade services, GT installation and reapplication services, and design and implementation of complete turbine management systems.

ValvTechnologies

Global leader in the design and manufacturing of zero-leakage metal-seated ball valve solutions for severe service applications. Committed, dependable partner providing the best isolation solutions to ensure customer satisfaction, safety and reliability, and improved process and performance.

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.

World of Controls

Worldwide, low-cost provider of DCS circuit boards offering an array of ancillary services which include testing/repair of circuit boards, parts, DCS troubleshooting, Dos support, HMI upgrades/backup and field-based mechanical and controls training.

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.

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Clean air is our business. The GTC-802 (NOx/CO-VOC) "Dual Function" catalyst will help your plant meet stricter emission standards while improving performance and profitability. **GTC-802 combines two catalysts in one, delivering both superior NOx reduction and outstanding CO and VOC oxidation.** Lowest pressure drop, near zero SO_2 oxidation and reduced ammonia slip add up to improved heat rate, increased power output and fewer cold-end maintenance issues. GTC-802 is positioned downstream of the ammonia injection grid in the same location as the current SCR catalyst. As an added benefit, the catalyst allows direct injection of liquid ammonia or urea in place of the traditional vaporized ammonia.
http://secc.umicore.com

ELECTRIC GENERATORS

2018 Annual Review

Sponsored by Mechanical Dynamics & Analysis (MD&A)

Meet the Editor

Generator consultant Clyde Maughan, now in the 67th year of his professional career, continues to amaze. You may recall that when still only 89 he recognized the need for a generator users group, put together a plan, invited some of the industry's top experts to present, and with help from NV Energy, Duke Energy, Power Users LLC, and a few generous sponsors, conducted the organization's first meeting in November 2015.

To celebrate his 90th birthday in July 2016, he came up with yet another idea: Publish an annual review of generator articles of value to owner/operators worldwide. The founding editor went to work and compiled *Electric GENERATORS, 2017 Annual Review,* a content-rich resource based primarily on presentations from the first two meetings of the Generator Users Group. The information in this 2018 Annual Review was compiled by Maughan from presentations made at the third GUG conference, August 28 – 31 in Phoenix.

Maughan's primary goal in publishing GENERATORS is to encourage your participation at GUG meetings and in the group's online forum.

If you have an idea for a presentation at the 2018 GUG meeting, email an abstract to Steering Committee Chairman Ryan Harrison (ryan.harrison@atcopower.com). Contact Maughan (cmaughan@nycap.rr.com) if you have editorial material to submit for the next edition of GENERATORS.

What's Inside

GENERATOR USERS GROUP

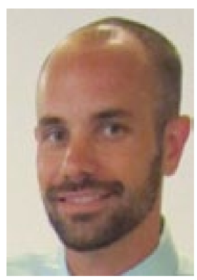
Your gateway to O&M best practices and lessons learned, methods for improving performance and safety, experience with new technologies, I&C, diagnostics, etc.

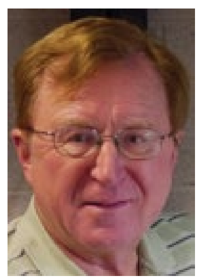
GUG's Generator Forum: Register today at no cost to stay current and connect with technology experts and industry colleagues (www.powerusers.org).

Steering Committee

Chair: Ryan Harrison, PEng, *ATCO Power (Canada)*
Vice Chair: Dave Fischli, PE, *Duke Energy*
John Demcko, PE, *Arizona Public Service Co*
Joe Riebau, *Constellation, an Exelon company*
Jagadeesh (JD) Srirama, PE, *NV Energy*
Kent N Smith, *Duke Energy*


Harrison


Fischli


Demcko


Riebau


Srirama


Smith

Attend the 2018 conference and vendor fair

August 27 - 30
Louisville Marriott Downtown
Louisville, Ky

Registration opens in April 2018 at www.genusers.org.

The benefits of participation

Welcome to the Generator Users Group (GUG). We are a consortium of electrical generator users. Our mission is to provide an opportunity for owner/operators of electrical generators worldwide (initially 1500/1800- and 3000/3600-rpm machines) to share experiences, best practices, and lessons learned on design, installation, operation, and maintenance of those machines. Expected outcomes are improved plant safety, maintainability, availability/reliability, and efficiency.

The GUG also serves to effectively transfer industry knowledge from experienced engineers to those with less experience. We are mostly made up of utility engineers and operators but utility maintenance and management personnel are encouraged to join and participate in the annual meeting. The benefits of becoming a member (there is no cost to join) is access to a resource of generator users to share knowledge and issues with and assist you in problem-solving for specific challenges at your station or in your fleet.

We have three main methods of information transfer: An annual users group meeting, this publication, and a 24/7 Web-based forum. As a member, you also will have access to contact information for other users and independent consultants knowledgeable in generator specifics. Access our website at www.genusers.org by scanning QR1 with your smartphone or tablet.

QR1

The GUG steering committee is made up of generator users. We are:

Chairman
Ryan Harrison, *lead generator engineer, ATCO Power (Canada)*

Vice Chairman
Dave Fischli, *generator program manager, Duke Energy*

Members
John Demcko, *lead excitation engineer, Arizona Public Service Co*
Joe Riebau, *senior manager of electrical engineering and NERC, Exelon Power*
Jagadeesh Srirama, *generator engineer, NV Energy*
Kent N Smith, *manager of generator engineering, Duke Energy.*

The Generator Users Group is a member of Power Users LLC, an umbrella organization serving five independent users groups—Steam Turbine (STUG), Combined Cycle (CCUG), GUG, 7F, and Controls—to minimize administrative costs. Our annual meeting normally is held at the same time and location as the STUG and CCUG meetings. The benefit: GUG attendees get complementary access to the CCUG and STUG presentations. In this manner, you can get information beyond just the generator proper.

User members will benefit greatly from the information provided by our all-volunteer organization. None of the committee members takes a salary or any other remuneration from the Generator Users Group. Many expenses associated with providing information to you (conference costs, publishing costs, website costs, etc) are covered by generous generator vendors and OEM sponsors. In this way the cost to users attending the annual meeting is minimized.

We are confident you will see the benefits of participating in the organization and hope you will join us in our efforts to share generator information. There is no cost to become a Generator Users Group forum member, so please sign up today at www.powerusers.com.

Finally, if you missed Clyde Maughan's summaries of the presentations from GUG 2015 and GUG 2016, you can access them easily by scanning QR2 with your smartphone or tablet.

QR2

Clyde V Maughan (right) the force behind the formation of the Generator Users Group, is recognized by GUG Chairman (2015-2017) Kent Smith for a "lifetime of sharing selflessly his extensive knowledge in the design, operation, and maintenance of electric generators."

ELECTRIC GENERATORS
2018 Annual Review

Published by
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PSI Media Inc, Las Vegas, Nev, publishes specialty print and electronic media serving energy producers in targeted national and regional markets. Media include the following:

CCJ, a quarterly print publication with ongoing coverage of electric generators in each issue.

CCJ ONline, www.ccj-online.com. Your one-stop-shop for generator information. Here you can find the latest CCJ, archives, industry best practices and lessons learned, user-group information, and vendor services. Our search engine will direct you to the material you need.

CCJ ONsite, www.ccj-online.com/onsite. Our up-to-the minute information portal. Live reports from the field and the industry's most important user group meetings. Email updates keep users informed of the latest technical developments and solutions.

CCJ ONscreen, www.ccj-online.com/onscreen. Our interactive Web-based learning resource with a classroom feel. Meet screen-to-screen with industry experts, listen to and view presentations, and connect with fellow users from the comfort of your office or home, or any other location with an Internet connection.

Of particular interest to generator owner/operators is Clyde Maughan's course on generator monitoring, inspection, and maintenance. The program is divided into seven one-hour segments culled from notes and slides extracted from Maughan's 2½-day training course—taken by more than 1000 users over the years. Listen to any segment at any time.

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GENERATOR USERS GROUP

Fourth Annual Meeting

Marriott Louisville Downtown, Louisville, Ky
August 27-30, 2018

Please mark your calendar and plan to attend
Registration opens in April at www.genusers.org

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

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

The GUG Steering Committee

Jagadeesh Srirama, *NV Energy;* Joe Riebau, *Constellation/Exelon;* Vice Chair Dave Fischli, *Duke Energy;* John Demcko, *Arizona Public Service Co;* Kent Smith, *Duke Energy;* Chair Ryan Harrison, *ATCO Power* (left to right)

Email Vice Chair Dave Fischli (dave.fischli@duke-energy.com) with your thoughts/ideas today.

Lessons learned, best practices shared at GUG 2017

That generators are "taken for granted" by the majority of plant personnel should not surprise. One of the reasons for this attitude is that staff often is not aware of the many things that can go wrong with electrical machines, how to identify problems, and what solutions are available to mitigate/correct issues.

GENERATORS' coverage of GUG 2017 affords the opportunity to see many of the problems engineers face regularly and why the opportunity to meet with other experts (users, OEMs, third-party solutions providers, and consultants) is so important. Attending the 2018 meeting of the Generator Users Group, in Louisville, August 27-30, is a good starting point. Visit www.genusers.org for more information.

Summaries of the 2017 presentations and discussions, prepared by IEEE Fellow Clyde V Maughan, president, Maughan Generator Consultants, is divided into these five sections:

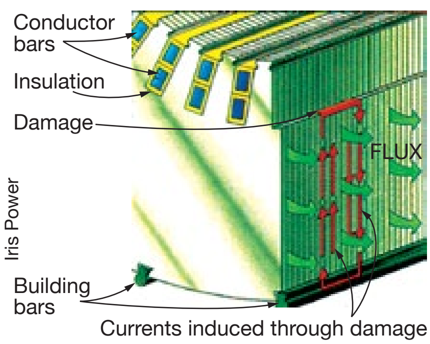
- Stator frames and magnetic cores.
- Stator windings and bus systems.
- Fields and excitation systems.
- Operation and monitoring.
- General topics.

Users wanting to dig deeper into any presentation can access the PowerPoint in the Power Users library at www.powerusers.org. Note that the Power Users Group is an administrative umbrella organization serving the generator, steam turbine, combined cycle, 7F, and controls users groups to reduce operating expenses.

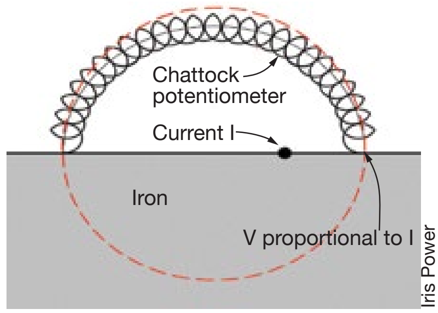
A. Stator frames and magnetic cores

ELCID trending, analysis

Electromagnetic Core Imperfection Detection (ELCID) is a low-excitation test with wide industry acceptance for assessing core health. Insulation breakdown causes fault currents to be set up as illustrated in Fig A1. A Chattock potentiometer (Fig A2) is used to measure the magnetic potential difference resulting from this current, with the somewhat complex equipment and circuit illustrated in Fig A3.



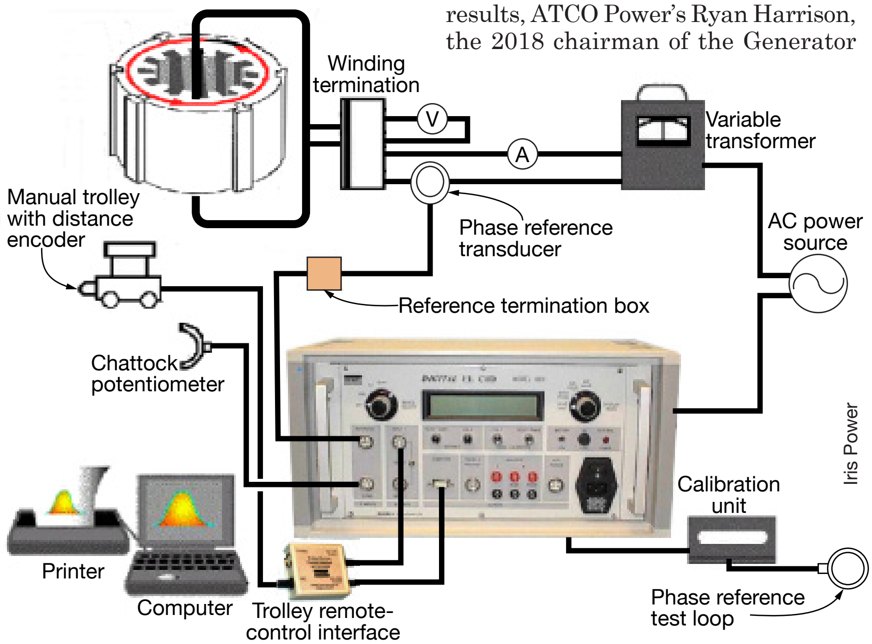
A1. Fault currents attributed to insulation breakdown create hot spots



A2. Chattock potentiometer measures the magnetic potential difference resulting from the fault currents caused by insulation breakdown illustrated in Fig A1

Bear in mind that fault currents create hot spots which can cause further deterioration to the core. If left unchecked, they can lead to damage of the stator core, windings, and the machine as a whole.

There are several setup challenges important for you to consider during analysis and trending of ELCID test results, ATCO Power's Ryan Harrison, the 2018 chairman of the Generator



A3. Circuitry and components required for the Chattock potentiometer are complex

Users Group, told attendees—including the following:

Core length. Depending on the operator and OEM versus non-OEM, different core lengths often are used. This leads to scaling issues in the traces and makes exact positioning a challenge.

Polarity. The orientation of the Chattock coil, and the orientation of reference transducer can lead to inversion of the quadrature signal.

Slot numbering. Decide whether to number the slots clockwise or counterclockwise, and which slot you select as Slot No. 1.

Trending areas of interest. Results are often standalone and on various scaling in the report. This makes assessment of areas of interest more difficult and, in some cases, more judgement-based. In addition, the digital files, which have valuable information such as phase current, often are not retained by the site/tester.

Software. The owner doesn't necessarily have the software to read the digital file. Furthermore the software is needed to export the values to a usable format. But only software "*.csv" is available; it is free to download.

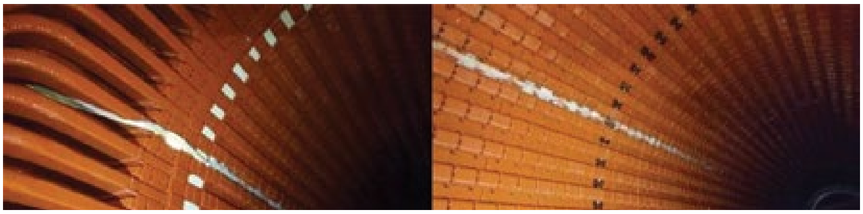
Filtering. The raw data files have noise, and filtering is applied to the final reported results. While not necessarily a problem it can be valuable to look at the raw data for which the original data file is needed.

Duration between tests. Depending on the machine, the duration can be quite long. Results can be lost over time which is important for establishing baseline values and fault tracking.

Several trending challenges also were discussed and illustrated by Harrison—for example, filtered versus unfiltered, noise, inversion of signal, alignment, vertical scaling, and vertical offset. Digital data can alleviate some of the challenges associated with trending; however, there is not a commercial solution available to help with this review. Harrison presented a scripted Matlab-based solution with alternative graphic representations.

Electromagnetic signal analysis

The signal capture equipment employed by Duke Energy until 2011, Kent Smith, Duke Energy's manager of generator engineering, told the group, was the EMC30-MKIV; today the Agilent E7402A. National Instruments' Labview 8.5 program was used to control (standardize) data capture. Frequency of data capture on 74 generators in the fleet was annually on large steam units and so-called Tier 1 gas turbines; "when available" on smaller GTs.



A4. Sensing fiber is easy to identify on top of stator wedges

The Labview program data-capture process was in four ranges of 2000 points each, as recommended by AEP /User's Group: Range 1, 30 - 300 kHz; Range 2, 300 kHz to 3 MHz; Range 3, 3 - 30 MHz; Range 4, 30 - 100 MHz. At the end of each range the program pauses to allow manual capture of peak signatures. The program consolidates all four ranges and displays signature. After signature is saved, the peaks of interest are demodulated, viewed on-screen, and saved to file. The data then are manually imported into Excel for reporting.

Smith, the GUG's immediate past chairman, then discussed two examples of data taken, aided by several slides showing signal analyses:

- Crystal River Unit 4. It was taken offline for testing in 2005. Results: Passed the Hydraulic Integrity Test (HIT); B phase megger was low (<500 Meg). Online testing in 2005 revealed a small amount of higher-frequency noise. In 2010, the electromagnetic signal analysis (EMSA) signature revealed a "hump" in mid-frequency range and had more of the higher-frequency noise. Work performed in 2010 included rewedging, the rotor mod recommended in TIL 1292, "Generator Rotor Dovetail Cracking," and repair of five major clip leaks. In addition, the isophase ground flex link at the generator bushings was found pitted and overheated; the link was replaced. A stator rewind was scheduled for 2011.
- Crystal River Unit 5. Online testing in 2010 found high EMSA signatures in the low and mid frequencies. Shaft voltage readings were extremely high (30 Vdc) and EMI sniffer was screaming at the exciter end. Later in the year, offline testing found hydrogen seal grounded, the HIT Skid test passed, and B phase resistance was 700 Meg with PI < 2.

The hydrogen seal was coked and pitted (electrolysis). A new hydrogen seal was installed but personnel could not get the new hydrogen seal insulation package to have a very good megger; resistance was acceptable, but suspect. Sniffer readings were still high. A stator rewind was scheduled in 2012.

Future plans include having baselines on all generators (even those for small GTs), developing database on failure mechanisms with signature data, expanding the program to include large motors, developing a continuous online monitor ported to PI for Tier 1 generators.

Fiberoptic temperature measurement for continuous monitoring

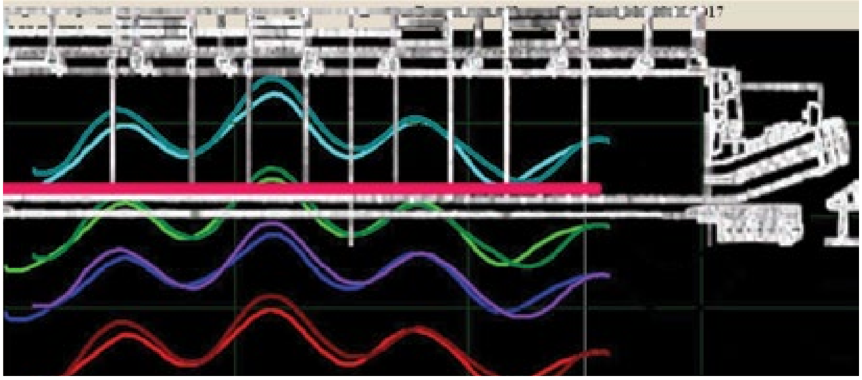
While generator core failures aren't common, their potential impact is up to the catastrophic level. Most generator cores are only indirectly monitored online through embedded RTDs situated between top and bottom stator bars at specific locations in particular core slots. These point sensors offer little protection to the large volume of the core.

Offline core testing, such as ELCID or ring/loop testing, can catch developing core issues, but both tests offer challenges in correlating measured values to actual online temperatures, and neither one offers protection from emergent issues online.

Fiberoptic temperature monitoring shows great promise in advancing core protection by permitting measurement of distributed temperatures along a length of fiber line, Calpine Corp's Director of Outage Services Craig Spencer told the group. Working with Fiber Optic Sensors LLC and Oz Optics Ltd, Calpine installed a proof-of-concept application into one of its Hermiston (Ore) combined-cycle generators. The sensing fiber was installed on top of the stator wedges (Fig A4), though an ideal installation would be under the wedges in the base shim stock.

Once online, temperature readings from the fiberoptic line compared well against the existing RTD readings. More importantly, excellent data curves emerged which clearly demonstrated the stator zone-cooling temperature affects along the length of the fiber (Fig A5). There were some small anomalies in the data, but personnel suspected these were installation-driven variances, to be proved out in the next test case.

Overall, the results were very encouraging for developing advanced online core thermal protection, as well as for additional applications of distributed temperature sensing.



A5. Color curves show temperature readings at various loads; solid red line is the length of the installed fiber

B. Stator windings and bus systems

Stator design

Ed Winegard, GE's principal engineer for armatures, opened his presentation by noting the high radial slot forces that must be contained in the stators of modern power generators—ranging from 10 to 110 pounds/inch of slot. Fortunately, he said, these forces are predominately downward, adding that about half the slots in a given stator retain bars for different phases, about half the same phase.

For slots with both bars in the same phase the force will be downward on both bars, he said. When the bars are for different phases, the force on the top bar will be slightly upward. Some type of compression system—top ripple springs, for example—is required to minimize bar movement and ensure it remains seated in the slot (Fig B1).

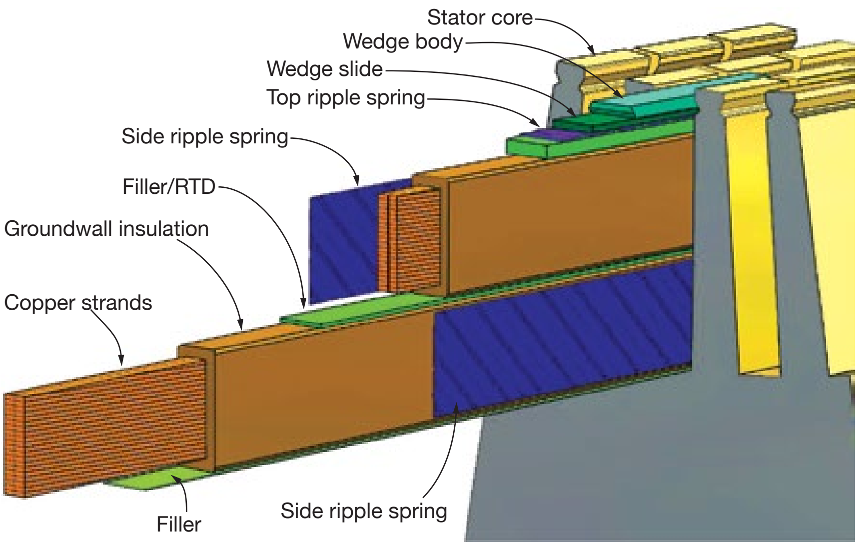
Bar lateral forces are minimal, Winegard continued. However, he pointed out the inherent tangential motion of the slot teeth caused by radial deflection of the core (Fig B2). This motion and its effect on the stator bar must be minimized. A similar method of ensuring the bar remains in contact with the slot wall is required and the side ripple spring (refer back to Fig B1) is ideally suited to meet this requirement.

There are also important stator wedging considerations which must be met, Winegard said: material properties (stiffness, creep, thermal aging, abrasion, etc), dimensions and tolerances (design clearances, tolerance stack up, component machining quality), assembly process (standard methods and sequence, compensation of assembly variation), and inspection (qualitative and quantitative validation).

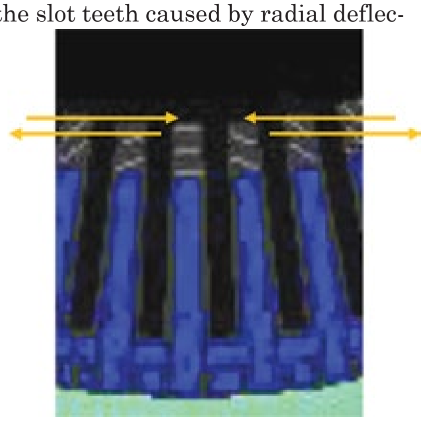
Aeropac rewind

The Siemens Aeropac generator discussed by Derek Hooper, president of BPHASE Inc, a small repair, inspection, and consulting company specializing in gas-turbine generators, was rewound by Alstom in 2014 because of moderate-to-severe spark erosion (Fig B3). Numerous concerns were experienced with this rewind, including the following: injection of clear resin into the dry tie material used made it difficult to determine if the cord was fully saturated (Fig B4), difficulty in obtaining proper series connection alignment (Fig B5), and use of semiconductive packing in the phase-break gaps to attenuate partial-discharge damage.

Two years later, BPHASE performed a minor inspection of the Alstom rewind. Focus was on visual inspection of the winding and evaluation of the core keybars. The keybars were intact and within torque specifications (Fig B6). While there was no evidence of keybar fracture in this unit, sister machines had suffered such fractures and plant personnel elected to reduce the keybar torque from 300 to 200 ft-lb.



B1. Top ripple springs minimize the relative motion of bars in their slots, mitigate insulation degradation



B2. Rotating magnetic field drives a rotating deflection of the stator core which causes alternating motion of the teeth on either side of the stator bar

B3. Siemens Aeropac generator was rewound by Alstom because of the moderate-to-severe spark erosion in evidence

B4. Resin was injected into the dry tie material used in the rewind

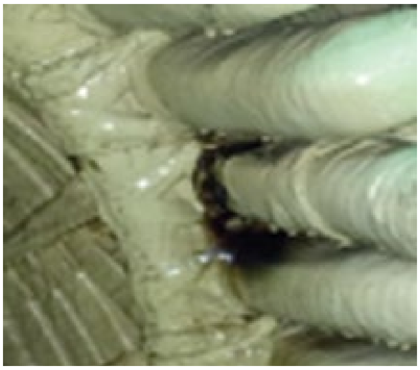
B5. Proper alignment of series connections were difficult to achieve because of bonding from the wet tie materials used

B6. Proper torqueing of keybars is critical in preventing their fracture

B7. Discharge oxidation at phase splits is easy to see

B8. Dusting is evidence of movement at the series connector interface with the outboard ring

B9. Visual inspection reveals indications of two previous repairs using a weeping epoxy



B10. Phase connection set-back had at least one prior repair attempt using the same epoxy

There was visible evidence of discharge oxidation at the phase splits (Fig B7). There was also significant evidence of movement at the series-connector interface with the outboard ring (Fig B8).

Because of vibration concerns, it was felt that blocking should be installed between the series connections for additional support. However, this would require bump testing. The outage was too short to allow necessary disassembly and the decision was made to install series blocking in short groups to limit any effect on the global modes of the baskets.

Monitoring of endwinding vibration

Iris Power's Mladen Sasic discussed monitoring of endwinding vibration. Although the problems associated with movement of endwindings are not new, because of changes in the design and operation of generators these issues have become a greater concern in recent years.

The endwinding region of large turbine/generator stator windings is one of the most complex parts of a generator relative to design, manufacturing, and maintenance. During normal operation, the endwindings are subject to high mechanical forces at twice power frequency because of currents in the stator bars, as well as mechanical forces transmitted via the core and bearings at rotational speed. Furthermore, during power system transients, the forces in the endwinding can reach 100 times higher than that of normal operation.

The design of the endwinding also must account for thermally induced axial expansion and contraction as the generator is loaded and unloaded. Metallic components to restrain the movement of stator bars caused by these forces normally are avoided because of the presence of high magnetic and electric fields.

Sasic shared his knowledge on the installation of vibration sensors, offline test results, and online monitoring data from a 288-MVA, 21-kV, air-cooled generator. Offline impact test data led to installation of fibreoptic endwinding vibration sensors. Continuous online monitoring of these sensors revealed an increase in vibration level, encouraging a visual inspection and bump test of the endwinding. The inspection/test confirmed loosening of endwinding support structure. Timely corrective maintenance was then possible to prevent a costly in-service failure.

Connection-ring inspection and repairs

Inspections of connection rings typically are focused on the physical support structure-to-ring interface. While there are other factors to consider—such as the connections to bars or coils and inner cooling circuitry—they aren't as common an issue and should become apparent through other testing, MD&A Generator Specialist Keith Campbell told GUG attendees.

Thorough visual inspection is vital to an accurate assessment of the overall condition of the rings. The 10 photos here illustrate typical problems associated with undesirable movement. To begin, the ties in Fig B9 offer indications of two previous repairs using a weeping epoxy. While oil intrusion was a contributing factor, the contamination (greasing) was removed well enough to allow for an adequate repair.

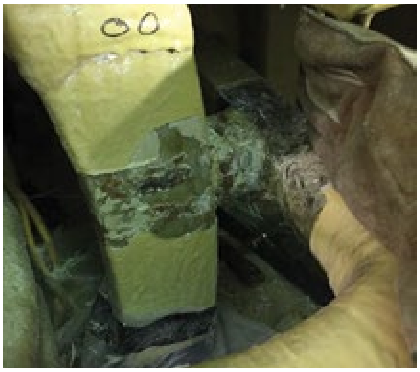
Fig B10 is of a phase-connection setback that had at least one prior repair attempt using the same epoxy. In this case, the contamination was under the ties and blocking, and could not be removed by cleaning alone. Fig B11 reflects an overall looseness in the endwinding structure as indicated by the large amount of greasing throughout. This was conducive to the possibility of a catastrophic failure. Fig B12 is of an original blocking and tie arrangement that does not meet quality standards.

Fig B13 shows a continuation of the previous repairs by additional application of epoxy. Fig B14 reveals ties removed for a better cleaning and application of new ties. Fig B15 is the result of excessive movement that dictated reinsulating and securing of components with a different material and by different methods than used by the OEM.

B11. Overall looseness in the end-winding structure is evident from the large amount of greasing

B12. Original blocking and tie arrangement does not meet quality standards

B13. Previous repairs continued with application of additional epoxy



B14. Ties were removed for a better cleaning and application of new ties

B15. Damage caused by excessive movement was corrected by reinsulating and securing with different material and methods than those used by the OEM

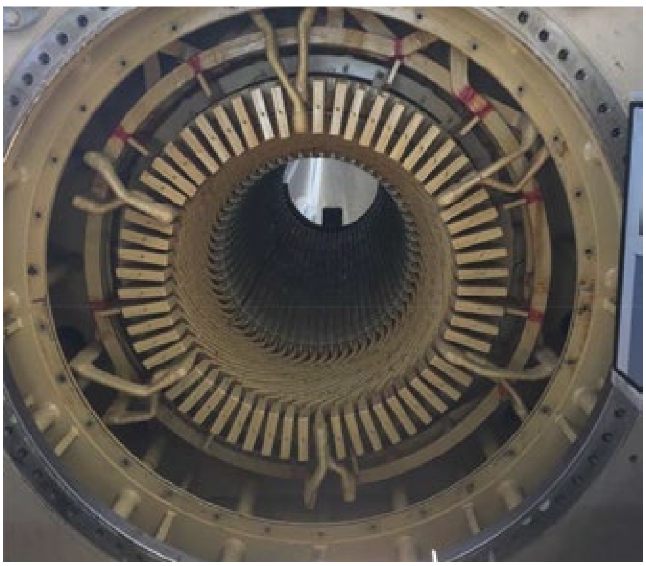
B16. New tie stands out after removal of the old tie and blocking, cleaning, and addition of new conforming material

Repairs complete, Fig B16 shows the new tie after the old tie and blocking had been removed, cleaned, and new conforming material had been added. Fig B17 illustrates the areas where epoxy was applied; the Fig B18 photo was taken after repairs to the endwinding structure were completed.

Hot-spot detection

NV Energy's Jagadeesh Srirama, a member of the GUG steering committee, profiled for attendees the recent inspection of a 391-MVA Alstom steam turbine/generator for an F-class combined cycle. This unit was put in service in 2004 and high vibrations had been recorded since installation. No issues were identified during a MAGIC (Miniature Air Gap Inspection Crawler) inspection done in 2013 and all the electrical test results were acceptable during this outage.

The unit was inspected again during a 2017 outage for simultaneous gas turbine, exhaust structure, and generator work. MAGIC identified four hot spots in the core iron and ELCID testing confirmed damage at those locations with exceptionally high readings of 1998, 1363, 674, and 976 mA. In addition to the hot spots, foreign material was found in the air gap. Management decided on immediate corrective action. To address the hot spots, it was neces-



B17. Areas where epoxy was applied are clearly visible

B18. Endwinding structure after completion of repairs

B19. Visual inspection of the stator identified several locations where overheating had occurred

B20. Core lamination material proved to be the foreign matter found during the inspection

B21. Loose side packing found near the endwindings was migrating upwards into the air gap

B22. Source of the foreign matter shown in Fig B20 was a very loose tooth package

B23. Damaged areas had a coat of red dye applied to weep into the laminations before coating with a buff paint

B24. Significant damage was done to the A-phase flex links

B25. B- and C-phase links were all connected and passed visual inspection

B26. Burning of gasket/sealing materials produced a heavy layer of soot

sary to remove the field—a challenge at this outdoor plant with major plant repairs already underway.

After rotor was removed, visual inspection identified several spots with obvious overheating similar to that in Fig B19; the debris was identified as core lamination material (Fig B20). Near the endwindings, some of the side packing had come loose and was migrating upwards into the air gap (Fig B21).

The lamination pieces came from a grossly loose tooth package, photographed in Fig B22. This tooth area was cleaned, inspected, and trimmed to make sure no more of the punchings would liberate. Mica then was placed in the shorted area and a tapered wedge inserted into the tooth to tighten the package. This wedge was epoxied in place. Note that the core step iron will have to be replaced when the stator is rewound in the future.

The side packing that came up from the top of the bar (refer back to Fig B21) was removed, air dry varnish applied, and new side packing installed. All damaged areas had a coat of red dye applied to weep into the laminations before coating with buff paint (Fig B23).

Importance of flex link maintenance

Duke Energy's Dave Fischli, manager of generator engineering, and vice chairman of the GUG steering committee, reviewed for attendees the case history of a Westinghouse 818-MVA, 20-kV generator (COD 1981) that tripped on an A-phase neutral ground only a couple of months before the meeting. The machine's field and stator had been rewound by Alstom in 2005.

Subsequent to the trip, a fire was reported at the lead box on the generator; site emergency responders used ABC dry chemical to extinguish the fire as the unit coasted down. External visual review showed significant damage to the A-phase lead area, with heat damage to the B-phase bushing area. Post-event data review showed some electrical anomalies starting eight minutes before trip.

Inspection revealed significant damage to the A-phase links; none of the 32 links remained intact (Fig B24). B- and C-phase links all were connected and appeared fine (Fig B25). There was a heavy layer of soot on the CTs for both the A and B phases, plus contamination at the bottom of lead box from fire-damaged components (Fig B26).

Investigators concluded that loose connections on one or more flex links caused a high-resistance contact which allowed current to flow through the bolt rather than the link contact surface area, and the bolt melted. Thus, loss of one flex link shifted its current to the remaining flex links, adding heat to them and amplifying the loose-connection problems and degraded condition of other flex links.

The A-phase links were too heavily

B27. The condition of Belleville washers used to secure phase links was called into question. Some had flattened out from repeated use, some had been installed upside down

B28. Some flex links were found in a frayed/degraded condition

B29. Arc damage is revealed on a bolted joint's bus face

B30. Flexible connector's cracked laminations were caused by vibration or air flow

B31. Rubbing and/or abuse damaged these flex braids

damaged to record torques, but torque checks performed when removing links from the B and C phases were satisfactory. Some Belleville washers removed from the B and C phases had been flattened out from repeated use, others had been installed upside down (Fig B27). Flex links from the B and C phases also revealed fraying and degradation (Fig B28). It was evident that previous visual inspections had not been sufficiently rigorous to identify degraded links for replacement.

Consequential damage. The ABC dry powder extinguishing agents include chemicals such as sodium bicarbonate, potassium bicarbonate, ammonium sulfate, and ammonium phosphate. These chemicals act as a desiccant, absorbing moisture, and under humid conditions become conductive. They are alkaline in nature and corrosive to electrical insulation and metal components within the generator.

There was extensive contamination of the lead box and exciter internals by soot and smoke particles. Basic cleaning was performed of all accessible areas without complete disassembly. Follow-up inspection and full cleaning is planned for a 2018 outage.

Lessons learned:

- Ensure work-order instructions are written correctly.
- Ensure craft technicians are trained on the importance of assembling high-current connections properly.
- Ensure flex links are completely removed for electrical isolation—not just unbolted on one end and bent back out of the way.
- Ensure fire extinguishers staged around generator and other electrical equipment are CO_2 or Halon (not ABC chemical).

Preventive maintenance of bus duct systems important

RMS Energy's Jesus Davila reviewed for attendees the several types of bus systems and components: cable bus, non-segregated and isolated-phase bus, terminations and disconnect links, insulating materials, expansion joints, seal-off bushings, etc. Each of these requires special maintenance. Critical items on the bus duct include flex/bolted connections (current carrying), expansion bellows/joints, insulators and mountings, seal-off bushings, groundings, and insulated joints. Examples of some of the issues discussed by Davila were the following:

- Electrical connections. Arc damage to bolted joint bus face (Fig B29).
- Flexible connectors. Cracked laminations caused by vibration or air flow (Fig B30); flex braids damaged by rubbing and/or abuse (Fig B31).
- Improper bolting or lack of maintenance at connection points. Damaged contact surfaces and gross heating issues (Fig B32).
- Expansion-bellows damage attributed to excessive movement often resulting in cracks (Fig B33).
- Bus failures. Overheating of non-segregated bus attributed to a lack of maintenance (Fig B34); line-to-

B32. Improper bolting and lack of maintenance are conducive to damaged contact surfaces at connection points

B33. Excessive movement of expansion bellows is conducive to cracking damage

B34. Overheating attributed to a lack of maintenance destroyed this non-seg bus

B35. Melting of the bus enclosure was caused by a line-to-ground fault

ground fault causing melting of the bus enclosure (Fig B35).

Most of the deterioration conditions listed above can be detected, particularly in advanced stages, by visual examination and/or temperature monitoring. All require immediate attention to prevent major equipment failure. If the condition is found before failure, refurbishment usually can be accomplished by obvious and/or well-established procedures.

C. Fields and excitation systems

Rotor arcing and repair

A common and destructive phenomenon in generators is negative sequence currents (I_2), MD&A Project Engineer Chris Keathley told GUG 2017 attendees. These can be caused by unbalanced three-phase currents, unbalanced loads, unbalanced system faults, open phases, and asynchronous operation.

The result of I_2 currents may be rotor body currents that can damage the rotor forging (Fig C1), retaining rings (Fig C2), slot wedges (Fig C3), and to a lesser degree, the field winding.

Three case studies were reviewed by the speaker, who brought to MD&A 16 years of experience with a major utility as a turbine/generator engineer, and another five years with the OEM.

Case Study No. 1. A 500-MVA, 22-kV, 3600-rpm generator had been involved in a motoring event of unknown size and duration five years before the inspection described was conducted. A visual assessment revealed relatively minor problems—such as slight burning between wedges, significant burning on wedge ends, and burning of the forging at wedge junctions. Eddy-current testing revealed 290 indications. Affected areas were cleaned and blended. A TIL 1292 ("Generator Rotor Dovetail Inspection") repair on the Coil No. 1 Slot was done and steel wedges were replaced with aluminum (except end wedges). A high-speed balance and heat run were conducted after rewind.

Case Study No. 2. A two-pole field suffered a double ground fault that caused severe arcing damage to the rotor, including melted material and cracking on a tooth (Figs C1 and C4). NDE of the area revealed a through-wall crack and an engineering evaluation determined the rotor unacceptable for operation. A temporary weld-repair solution was proposed to get the unit back in service until a replacement rotor could be obtained. The damaged portion of the tooth was removed (Fig C5) and the tooth reconfigured with weld build-up, rotor heat treatment, and re-machining of the tooth (Fig C6).

Finite-element models of the rotor and slot tooth were created to obtain the various stresses along the tooth height, the weld fusion line/HAZ, and the highly stressed wedge groove fillet radius. These stresses and mechanical properties were used in fracture-mechanics calculations; favorable results supported acceptance of the repair. A fatigue analysis of the repaired tooth suggested the reworked rotor was good for 150 start/stop cycles or 10 years of operation, whichever came first.

Case Study No. 3. A generator experienced a collector failure and ground to the main shaft that caused major arcing and heat damage to the

C1-C3. Negative sequence currents are a common and destructive phenomenon associated with generators. The result of these I_2 currents can be rotor body currents that can damage the rotor forging (left), retaining rings (center), and to a lesser degree, the field winding (right)

C4-C6. A double-ground fault caused severe arcing damage to the rotor, including melted material (refer back to Fig C1) and cracking on a tooth (left). The damaged portion of the tooth was removed (center) and replaced by weld build-up with appropriate heat treatment and re-machining of the tooth (right)

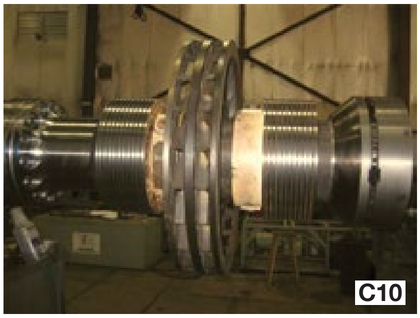
- On-site comprehensive testing and inspection
- Field rewinds and repairs
- Stator rewinds
- Wedge system upgrades
- Replacement retaining rings
- Collector rings
- Hydrogen seal rings and assemblies
- High voltage bushings and auxiliaries
- Insulated bearing rings
- Oil deflectors
- Exciter inspection
- Control and excitation field engineering and consulting
- High-Speed Balance with heat run capability/ High Speed Thermal Test (HSTT)

PARTS | SERVICES | REPAIRS

C7

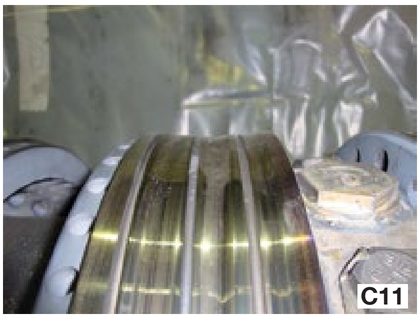
C8

C9



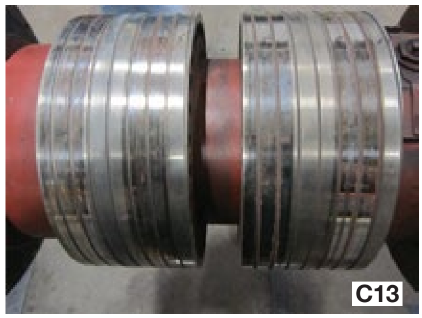
C10

C7-C10. Collector failure and ground to the main shaft caused major arcing and heat damage to the end of the generator rotor forging, which could not continue in operation as found (Fig C7). The shaft was severed just outboard of the journal and bolt holes drilled and tapped for the new stub shaft (Fig C8). The assembled new shaft extension is in Fig C9 and the final assembly with fan and collector rings in Fig C10



C11

C12



C13

C14

C15

C11-C15. Typical conditions found during inspection of collector rings are threading (Fig C11), grooving (Fig C12), photographing (Fig C13), contamination (Fig C14), and heavy contamination (C15)

end of the generator rotor forging (Fig C7). The amount of damage and heat-affected material made the shaft end forging unacceptable for continued operation. Stub-shaft replacement was proposed and accepted by the owner.

This was a major undertaking. The shaft was severed just outboard of the journal and bolt holes drilled and tapped for the new stub shaft (Fig C8). The assembled new shaft extension is shown in Fig C9, and the final assembly with the fan and collector rings in Fig C10.

To conclude, negative sequence events and ground faults are preventable by good operation and monitoring equipment. When those defenses fail, considerable damage can occur. However, it does not always mean that the damage cannot be repaired and the unit returned to service. These case studies show that even when there is damage, advanced welding and machining processes can restore the unit to service relatively quickly.

Collector rings: Inspection and repair

MD&A's Keith Campbell, an industry veteran with four decades of experience, showed and discussed numerous photographs to illustrate the inspection, failure modes, and repair of collector rings.

Inspection. Typical conditions found during inspection are shown in photos C11-C15. Threading and grooving (Figs C11 and C12) naturally result from the wear and tear of long service. Photography (Fig C13) is not common nor well understood; it describes the phenomenon in which the pattern of the brush holders is replicated on the rings. There is inevitable contamination associated with the collector (Fig C14) from sources that include brush wear, induction of foreign material with the cooling-air flow, and uncorrected arcing. Massive contamination is caused by flashover failure (Fig C15).

Failure. Typical problems resulting from failure are seen in the photos C16-C19. In the first, the right ring was severely burned by a flashover to ground or severe arcing from poor maintenance. The adjacent image shows a similar condition but with the brush holder removed. Fig C18 is of damage to the main shaft from severe arcing to ground, C19 shows corresponding arc damage to the ring inside diameter.

Repairs. Figs C20-C22 illustrate steps in replacing an old collector with a new collector, Fig C23 is of a grinding operation for truing a worn, or new, ring.

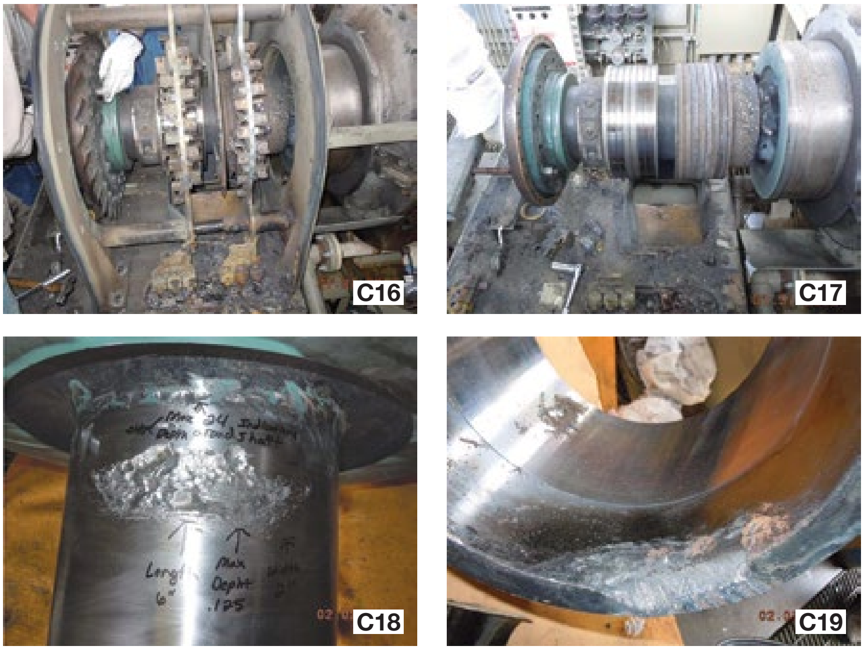
An unusual generator field ground

The incident profiled here by John Demcko, PE, a senior consulting engineer at Arizona Public Service Co and member of the GUG steering committee, occurred at an APS plant equipped with three single-shaft combined cycles installed in the mid-1970s.

The generators serving these units are rated 146.7 MVA/13.8 kV; they were retrofitted with static excitation systems and redundant digital regulators several years ago. This update included a modern 64F field ground detection system, which experienced a continuous field ground alarm over a year ago. The incident was treated routinely—that is, management was informed.

Management was made aware of the risks associated in running with a known ground. The decision was made to remain online until an outage could be scheduled to evaluate the situation. When that happened, a Megger test of *all* components in the field winding circuits showed no ground.

The 64F relay is only operative when there is excitation on the machine since it is powered from the excitation power potential transformer. With the unit offline and not spinning the 64F was powered up with a "cheater" cord. No field ground was detected by the relay in this configuration. The 64F relay was switched out for an identical spare which also indicated no ground with the unit offline but did indicate one with it spinning and the field energized.



C16-C19. Problems resulting from collector-ring failure include burning caused by flashover to ground or severe arcing from poor maintenance (Figs C16 and C17 with brush holder removed), main-shaft damage caused by severe arcing to ground (Fig C18), and arcing damage to the ring ID (C19)

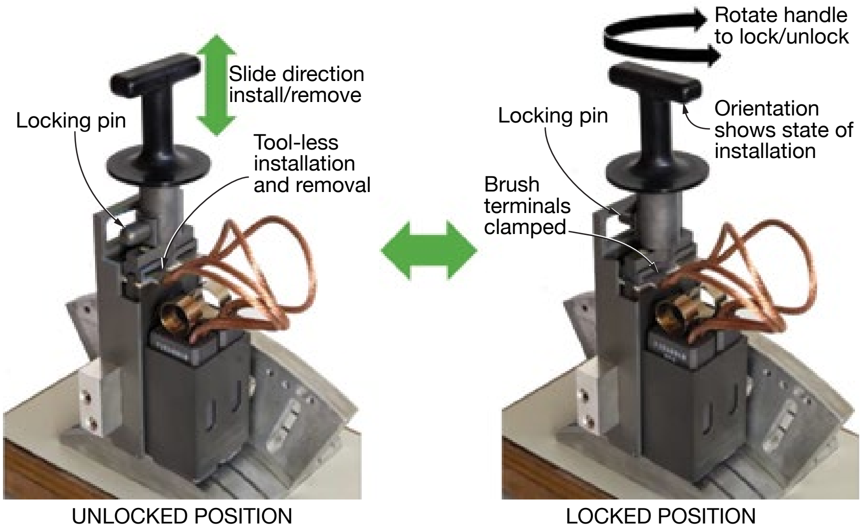
C20-C22. Major steps in replacing an old collector with a new one are shown left to right

This implied that the ground was on the rotor and was caused by the centrifugal loading of the field winding. The unit was put back in service and was run almost daily with the apparent field ground while a new 64F relay was ordered from another manufacturer. The new 64F was installed and behaved exactly as the previous two relays.

A last-ditch effort was made to spin the unit up to synchronous speed with excitation off. Meggering of the field via the carbon brushes and slip rings found the resistance to be in the megaohms range. There appeared to be an impasse when a ground was indicated in the field circuit but could not be localized.

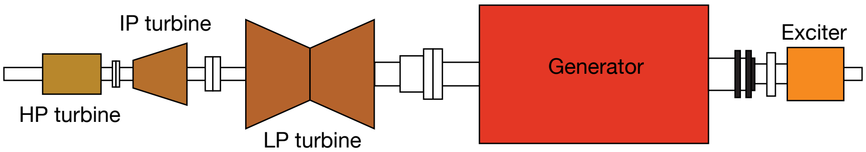
After re-verifying the accuracy of all data taken, an investigation was conducted to look for any other elements that can fault to ground when the exciter is running. Several manufacturers of field ground detection equipment were asked if their equipment could detect faults on the

C23. Grinding operation for truing a worn, or new, collector ring

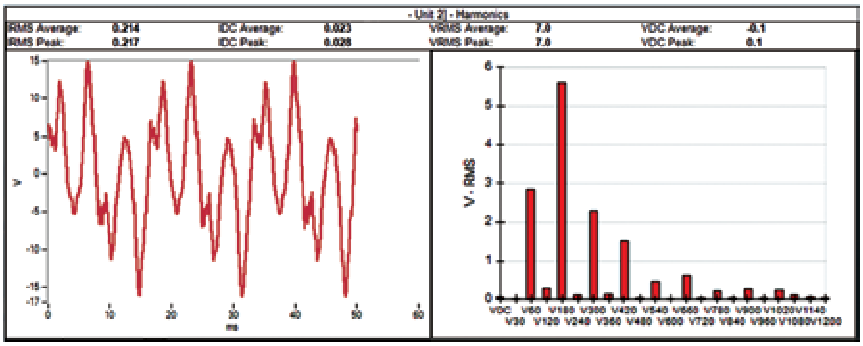


C24. Brush holder design from OEM is said to avoid collector incidents studied by engineers

C25. Excitation systems have evolved over the years from rheostats prior to the 1950s (photo) to electromechanical amplifier in the 1950s and 1960s, to magnetic/analog in the 1970s and 1980s, to today's digital excitation systems



C26. Typical configuration of a turbine/generator with exciter providing DC current for the rotor field and the turbine mechanical power to turn the generator



C27. AC and DC voltages can be induced in the shaft during rotation. Shaft earthing monitoring systems can record and identify the sources of voltage and current. Results from the voltage brush installed on the exciter end (typical) of one unit illustrated here provide time, waveform, spectral content, and DC and RMS values for analysis

AC side of the static excitation system. Responses were mixed, but one vendor said AC-side grounds can definitely be detected, although their occurrence is highly unusual.

Additional voltage-to-ground measurements were made on the AC side of the static excitation system breaker for all three units. A fundamental difference in readings was noted on Unit 2 as compared to Units 1 and 3 which did not have field grounds. This inferred an AC side excitation system ground was causing the 64F relay to indicate a field ground. A precise physical model of the static excitation system, including the same 64F, was constructed. It confirmed that an AC ground is easily detected by the 64F and the lab measurements very closely matched the data taken of the actual machine.

The unit will be operated until a scheduled outage allows for AC fault confirmation and repairs.

Brush-holder experience

John DiSanto's presentation focused on collector incidents and avoidance. The GE senior engineer, who is responsible for generator controls/excitation and protection fleet-wide with the goal of improving equipment reliability, reviewed nine recent root-cause-analysis investigations.

They involved collector flashovers, collector-ring overheating, improper collector-ring assembly, and a damaged insulating sleeve.

Two of the case studies illustrated unnecessary forced outages. One involved overheating of the inner collector-ring surfaces, molten brush holders, and arcing of collector housing. The second case revealed a heavily worn brush and brush-holder damage. The collector surface was found to have salt deposits and corrosion.

Daily, weekly, monthly, and outage inspection and maintenance were reviewed. DiSanto also offered a few comments on maintenance—for example, the importance of cleaning, collector-ring wear rates (1 mil per 1000 hours of operation is typical); permissible wear (the ring diameter can be reduced but must always be larger than the diameter of the bottom of the spiral groove); maintaining proper cooling on collector rings (design temperature is 40C); and recommended brush grade (National 634).

The presentation closed with a discussion of brush-rigging upgrades. GE was said to have a well-defined set of brush-holder design criteria, including the following:

- Allow for safe installation and removal of brush holders with the generator online.
- Improve ease of brush and spring replacement—no tools required.
- Eliminate brush "hang-ups" within the holder by having a fully supported brush and a smooth/slick brush pocket.
- Decrease the risk of flashover.
- Decrease susceptibility to brush current selectivity—that is, uneven current distribution among brushes.
- Allow easy integration for both servicing and replacement across all GE generator models.

The company's most recent brush-holder design for generators of moderate size (Fig C24) was said to meet these criteria.

Digital excitation replacing ageing technologies

If you were relatively new to the industry, listening to the presentation by Basler Electric Co's Richard Schaefer at GUG 2017 provided valuable perspective on excitation systems. A former chair of the IEEE PES Working Group, he's "seen it all" in more than four decades of service to power producers. His CliffsNotes on the evolution of excitation systems:

- Before the 1950s, rheostats (Fig C25).
- 1950s and '60s, amplidyne.
- 1970s and '80s, magnetic/analog.
- Late 1980s through today, digital.

Several factors affect how quickly systems become obsolete, he said—including, available materials, present technology, and available software. Examples of materials availability issues: carbon composition can no longer be manufactured, warlords have taken over the mines, material determined to be hazardous. Examples of hardware availability issues: primitive computers, present-day powerful computers.

Schaefer noted actions that have contributed to the slowing of obsolescence—for example, purchase of components from manufactures serving major long-survival industries (such as automotive), redesign of product with new components where practical, purchase large volumes of obsolete components.

Particularly in recent years, there has been upward evolution in software. For example multilingual capability, built-in powerful testing tools, enhancements to speed commissioning. Also there are options to facilitate retrofit—for example, replacement product fits into same location, provide replacement excitation cabinets but keep the power potential transformers, keep SCR bridges and provide new front-end electronics.

Shaft earthing monitoring

Andre Tetreault, director of tests and diagnostics at VibroSystM, and co-author Bernard Lemay, PEng, the company's Zoom analytical software expert, opened their presentation by reminding the GUG 2017 audience that, in the ideal, the generator shaft should be electrically and magnetically neutral during operation. The use of ferromagnetic materials in the construction of the shaft makes this component extremely conductive and subject to current flow and induced voltages. A typical turbine/generator configuration is shown in Fig C26; the exciter provides DC current for the field, the turbine provides mechanical power.

At least one generator bearing is insulated from ground. On other bearings, a thin oil film is the only barrier separating the shaft from the ground and this film may not act as insulation to current flow.

Both AC and DC voltages can be induced in the shaft, causing potential damage to the unit— especially the bearings. Shaft earthing monitoring systems can record and identify the various sources of voltage and current, allowing for analysis and damage prevention. One brush is installed to monitor voltage (diagnostics), usually on the generator exciter end, and one to monitor current (protection), usually on the turbine end.

Results from the voltage brush are shown in Fig C27. Time, waveform, spectral content, in addition to DC and RMS values, are available for analysis. Alarm levels are set after results are analyzed.

Protection schemes using trends of shaft currents are common, but do not provide diagnostics. In many cases, alarms triggered will confirm existing damage, instead of detecting ongoing issues and/or preventing future damage. Voltage frequency profiles should not evolve over time.

High-speed data acquisition, and comprehensive diagnostics software, allow for in-depth analysis of harmonics to identify various anomalies. Patterns such as high even harmonics may indicate rotor alignment or stator bar problems. If deviations are present, other symptoms may include stator vibration and/or bearing temperature variations.

High DC levels should trigger a ground connection investigation and if the shaft is magnetized, bearing temperatures should be verified.

D. Operation and monitoring

Mini turbine/generator model for training

John Demcko, PE, a senior consulting engineer at Arizona Public Service Co and member of the GUG steering committee, spoke to the industry's knowledge gap and work his company was doing to bridge that gap. Many new powerplant engineers and technicians, he said, have no formal training on how to bring generating units online and take them offline. Nor are they usually familiar with how generators interact with the grid.

The 40-plus-year industry veteran added that plant engineers and technicians are good at addressing mechanical issues but typically are not well versed in the electrical characteristics of synchronous machines. A PowerPoint-only class had been offered for many years at APS but personnel were not being prepared adequately for the challenges they faced daily.

Demcko's department of four engineers functions as a "consulting firm" internal to the utility. Over the years, electrical training responsibilities defaulted to his group because it was intimately involved with problems on the generator, exciter, automatic voltage regulator, and power-system stabilizer. Since operating staff tend to be "visual learners," he continued, a physical model-based training approach was proposed to management. It was accepted and a wish list of model functionality was developed. The search began for a commercially available training model.

The "wish list" of features desired for the model included the following:

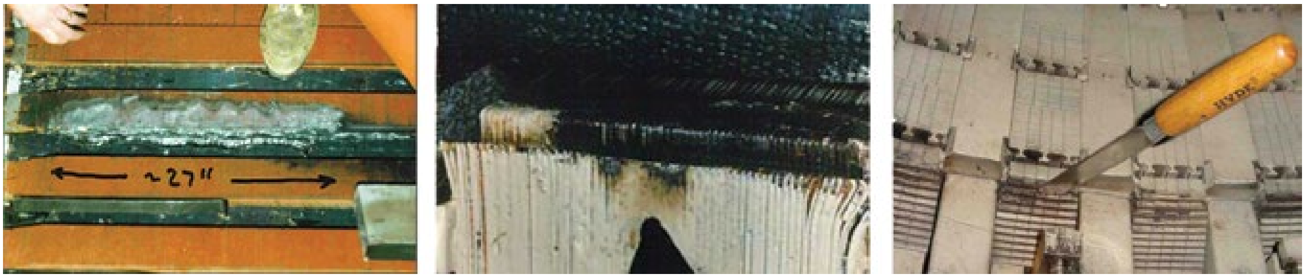
- Three-phase synchronous generator.
- Power level compatible with a nominal 5-amp CT output and 120-Vac PT output found in utility generation.
- Utility-style control switches and metering.
- Digital generation protection relay.
- Auto-synchronizer and emulation of generator breaker function.
- Drive motor with the ability to mimic turbine characteristics.
- Synch to grid at either 208 or 480 Vac.
- Have the look and feel of a typical physical generator control panel.
- Portability (movability).

Search results. North American universities were canvased and educational suppliers queried. Nothing commercially available met all of APS's requirements at any price. Conclusion: The utility would have to build a custom model.

Custom build. Team Demcko received approval to build its own model with a modest hardware budget. Engineering and labor was to be done by staff on a time-available basis—such as between regular assignments. Cost of the model would be contained by purchasing/scrounging as many components as possible off-the-shelf. A target of one year was established for completion of the model.

Results/observations. The model, highly modular in construction, took two years to complete because of limited availability of labor (Figs D1 and D2). It was good for troubleshooting but had many terminal blocks for interconnection that could loosen. Classes started in April 2017; 102 APS employees were trained. The first

D1, D2. Mini turbine/generator model for training took two years to complete but was worth the wait



D3-D5. Causes of core failures include foreign object damage, lamination insulation failure (left), damage from repair work (center), and core looseness (right)

four weeks of onsite plant training was completed near the end of August with 84 attendees. Remainder of the fossil fleet (several hundred "students") was scheduled for onsite training before yearend. Results: Almost all the design targets were achieved, but some refinements to the model were suggested.

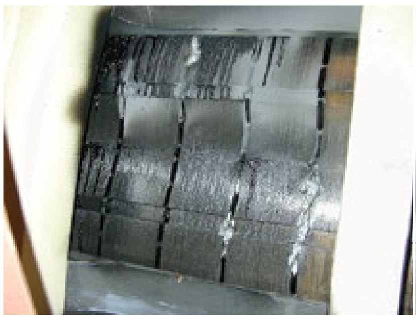
One use of the model that Team Demcko did not fully anticipate was for training plant operators in manually closing the generator breaker to synch the unit. While an auto-synchronizer normally is relied on for this task, APS expects its control operators to have the ability to do it manually. Trainees appreciated being able to practice synchronizing the generator with the electric system using the model, without risking damage to critical equipment.

Generator abnormal operation

Ron Halpern of Generator Consulting Services opened his presentation by defining "abnormal operation" as any operation outside normal operating parameters that could damage the generator—such as operation outside of the generator capability curve.

The speaker, who has been involved with generators for well over 40 years, 25 of those at GE, focused his presentation on the following:

- Stator—including core, oil, hydrogen leaks, grounds, stator cooling, water leaks and restrictions, bushings, and frame.
- Rotor—including grounds, shorted turns, thermal sensitivity, shaft voltage, and collectors.
- Auxiliaries—including loss of hydrogen seals, coolers out of service, and on moisture corrosion and contamination.
- Electrical and grid—including over fluxing, off-frequency operation, loss of synchronization, motoring.



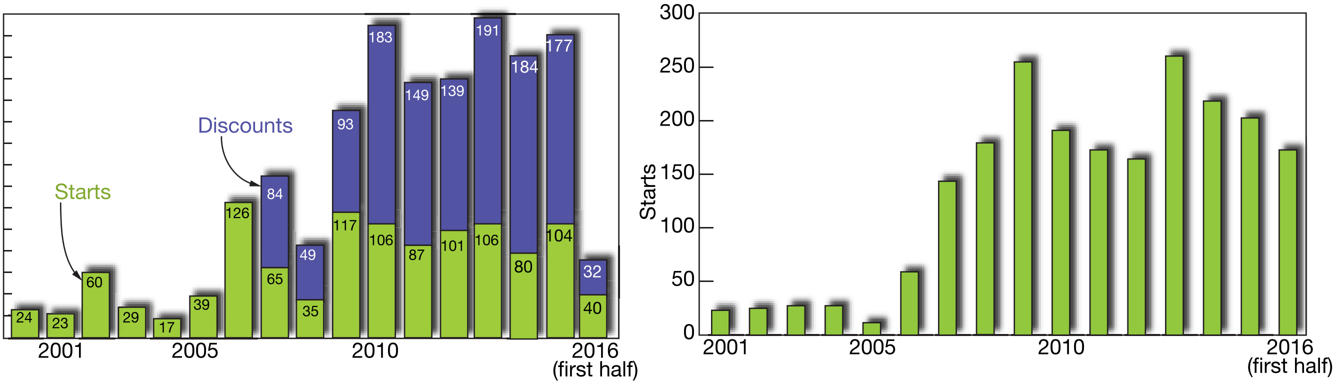
D6. Core over-fluxing in the extreme may cause total destruction of the core

D7. Collectors are the most significant contributor to operations-caused forced outages

Typical abnormal-operation events discussed included the following:

- Core failures. They may be caused by foreign object damage, lamination insulation failure (Fig D3), damage from repair work (Fig D4), loose core (Fig D5), etc.
- Core over-flux, a complex phenomenon. Protection is via volts-per-hertz relay. Minor over-fluxing (105%-110%) increases core losses and elevates core temperature but should cause no damage. Over-fluxing above 110% saturates portions of the core to the point that flux flows out into adjacent structures and, if sufficient and sustained, may cause total core destruction (Fig D6).
- Rotor ground. The excitation system is ungrounded and a single ground will not cause damage (unless the cause is a broken conductor or coil short). However, a second ground can be disastrous. There are many possible causes—including groundwall insulation breakdown, contamination, electrical arcing, displaced insulation, and water intrusion into the exciter. Collectors are the most significant contributor to operations-caused forced outages on generators; the results can be dramatic and dangerous (Fig D7).
- Rotor turn/coil shorts. Shorts may not be a problem unless excessive and you run out of current, or if they result in high thermal-sensitivity vibration. But they can be destructive (Figs D8-D10).
- Thermal sensitivity can be prob-

D8-D10. Rotor turn/coil shorts may not be a problem unless excessive; then they can be troublesome and destructive



D11, D12. High stop/start counts caused by must-take renewables have adversely impacted generator availability and contributed to higher maintenance costs. Data for two different units reflect the dramatic increase in starts in the last 10 years

lematic. It causes rotor vibration to change as the field current is increased and can cause rotor bowing when (1) the temperature distribution is uneven circumferentially around the rotor and/or (2) axial forces are not distributed uniformly in the circumferential direction. The phenomenon, characterized by a once-per-revolution frequency response, may limit operation at high field currents or VAR loads because of excessive rotor vibration.

- Shorted-turn detection. The most reliable method for detecting shorts is by use of a flux probe. The technology is well understood and reliable.

Other items briefly discussed included oil in the generator, stator-bar slot support systems, high- voltage bushing, seal leaks, noise causes and investigations, and damage prevention in general.

Effects of negative-sequence and off-frequency currents

From early on, AC synchronous generators were designed to produce three-phase balanced voltages at their terminals, began Dr Izzy Kerszenbaum, PE, of IzzyTech. Over time, the design also incorporated features to reduce the harmonic content of the generated voltage. In the case of generators, the problem was (and still is) mainly related to unbalance in the load currents, while in the case of AC motors, the problem was (and still is) related to unbalanced supply voltage.

The negative-sequence current component circulating in the stator windings creates a magnetic flux in the airgap of the machine, continued Kerszenbaum, a well-respected teacher of things electrical and prolific author with more than 40 years of service to the industry. This flux rotates at synchronous speed, but in the direction opposite to the positive flux (the "normal" flux), he explained.

The rotor, also rotating in synchronous speed in tandem with the positive magnetic flux, is subject to a 2× synchronous frequency magnetic flux, by the negative flux. Then, by the law of electromagnetic induction (Faraday), 2× synchronous frequency voltages and eddy currents are induced in the rotor body. Given that these induced currents have a periodicity of 120 Hz in 60-Hz systems or 100 Hz in 50-Hz systems, they tend to flow mainly in the outer regions of the rotor, because of the "skin effect."

Net result: If large enough, the induced currents will spark and arc between wedges, wedges and forging, wedges and retaining rings, forging and retaining rings, and any component on the periphery of the rotor. Such sparking/arcing can cause hardening of the metal in critical areas, followed by the generation of cracks.

From the foregoing, it is obvious that negative-sequence current carries with it the potential to cause significant damage to the generator; thus, protection against these currents must be provided. In the event a large negative-sequence event occurs, (as with a major short-circuit between phases in the vicinity of the machine), it behooves the operators to carry out an assessment of the possible damage incurred by the machine, followed by a proper inspection, if warranted.

Impacts of cycling duty

Generators built during the gas-turbine order/installation "bubble" in the late 1990s and early 2000s, look very much like their predecessors built in the 1950s, 1960s, and 1970s. However, unlike their predecessors, the newer machines are not giving the 20 to 30, or more, years of reliable service expected.

OEMs have designed similarly sized machines for MVA ratings 40% to 50% higher than their predecessors, while pushing material capabilities to their maximum. Plus, demands on equipment have been exacerbated by the need to cycle these generators hundreds of times annually to accommodate must-take renewables.

Generators were designed to run at base load or, worst case, for minimal annual start/stop counts—perhaps 50 to 75. However, as the charts in Figs D11 and D12 for two case histories show, they are seeing 250+ starts per year. Units in renewables-heavy markets are exceeding 350-400 annual starts. This takes low-cycle stresses

D13. Severe core and wedge looseness was found during the first major on a 7FH2 generator

D14. Series connection braze failure caused a phase ground

from thermal expansion/contraction, and moves it into a high-cycle realm. The end result is that units are either suffering in-service failure or, at a minimum, are requiring very costly repairs or maintenance/upgrades at their first major outages, within 10 to 15 years.

In his presentation, AGT Services Inc's Jamie Clark pointed to common weaknesses exacerbated by these high cycling operations—including loose stator wedge systems (Fig D13), axially loose core iron, loose endwindings, global endwinding dusting or broken ties, loose belly bands, bar movement in the stator slots, high partial discharge and resulting corona damage, and increased opportunities for seal-oil problems resulting in oil entering the unit, which further accelerates the previous issues.

In the field, the impact is found in cracked or failed main leads, pole/pole and coil/coil crossover jumpers, migration of slot armor, deformation of field endwindings, loose/missing/broken distance blocking, migrating coils, insulation, or amortisseur springs resulting in blocked cooling, thermally sensitive fields, rapid turn short development, and myriad other issues (Fig D14).

Generator cyclic duty

In recent years there has been a changing of the generator lifecycle. These machines originally were intended for baseload operation and 30 years of service. There has been an industry shift to frequent starting/stopping, load cycling (described as more than two 20% changes in megawatt output in a 24-hr period with two primary load cycles (50% - 100%) in a typical day), VAR cycling, and seasonal influences.

Frequent starting/stopping imposes additional stress, with faster degradation of insulation and components, negative impact on generator life, higher risk of in-service operating incidents—all likely contributing to increased maintenance.

Cyclic duty involves start/stop operation, load cycles, and power-factor changes. Impact on stators includes vibration transients, thermal and mechanical stresses, and core-end heating. Some of the effects on stator windings and core are high- and low-cycle fatigue, insulation abrasion, strain, shorts or grounds, localized overheating, and core-iron melting. Typical failures are strand cracking and fracture (Fig D15), lead fracture and extensive arc damage (Fig D16), and insulation abrasion (Fig D17).

Cyclic-duty impact on rotors includes copper distortion, insulation breakdown, shorted turns, connector failures, grounds and forging damage. Typical resulting failures are shown in Figs D18-D21: slot liner abrasion, insulation fracture, copper distortion, and blocked vent (left to right).

Twenty-five-year GE veteran Ed Winegard, currently principal engineer for armatures, described for attendees several design features developed to accommodate cyclic operation. You can access a copy of Winegard's PowerPoint on the Power Users website at www.powerusers.org.

Maintenance and inspection suggestions for cyclic duty, also covered in the presentation, include the following:

- Maintain equipment in accordance with GEK 103566.
- Conduct additional testing during scheduled outages.
- Perform regular borescope and robotic inspections.
- Do modal testing of endwindings.
- Provide for additional monitoring during operation.

D15-D17. Failures in stator windings associated with cyclic duty include strand cracking and fracture (left), lead fracture and arc damage (center), and insulation abrasion (right)

D18-D21. Impacts on rotors of cyclic duty include the failures shown in the photos above: slot-liner abrasion, insulation fracture, copper distortion, and blocked vent (left to right)

E. General topics

Moisture ingress and storage mechanisms in large generators

Neil Kilpatrick, principal, GenMet LLC, integrated more than four decades of metallurgical knowledge into his presentation, covering several aspects of moisture ingress on generators: problems created, moisture opportunities, capillary basics, examples of planar capillaries in generator construction, damage mechanism affected by moisture storage, and why it is so difficult to dry out these machines.

As an example of a problem with moisture ingress and storage, a large generator located in the South (think humid) was found with water actually running out from under the ID of the rings. The cause was condensation on the rotor inner surfaces and planar capillaries and connected surfaces internal to the winding.

Large generators normally are dry under operating conditions. When open and cooled to ambient temperature, there's a tendency for moisture to accumulate on and in insulation materials. The usual remedy is to apply heat and ventilation in order to dry out the winding; this can be a lengthy process.

There are numerous moisture opportunities related to inadequate protection during shipment, storage, standby, and maintenance. Even during operation, there are opportunities for condensation from gas coolers, cooler leaks, and frame flooding. Outdoor units are a particular challenge given their exposure to weather. Hydrogen-cooled units have lower exposure than air-cooled units because of the controlled operating environment.

Capillaries behave the same whether horizontal or vertical. With dry air at the ends of capillaries, the capillaries contain only air. Increase the humidity to the point of condensation and water starts to condense inside the smallest capillaries. This occurs at about 92% relative humidity (metal temperature relative to dew-point temperature). With nearly saturated air at the ends of the capillaries, water starts to condense in small capillaries. Under saturation conditions, condensation occurs on free surfaces, and pooling begins. The capillaries will fill.

There are numerous capillaries on both the rotor and stator. On the rotor there are capillaries between turns and on both faces of the slot liner (Fig E1). On the stator, there are capillaries in the spaces between core laminations and the spaces between the bar surface on the fillers and core iron (Fig E2).

Damage mechanisms of moisture affect both metals and insulation. For generators which still have nonmagnetic retaining rings susceptible to stress corrosion, crack initiation and crack propagation occur under wet conditions. Note that retaining rings are under high stress at standstill and all other conditions. With long-term wet conditions, rust will form on steel surfaces which are bare and/or porous. Rust is hydroscopic, and will retain moisture—more opportunity for water storage.

On insulation, the major concern is for moisture on insulating surfaces. Typically, wet conditions in generators will result in low resistance to ground, and this must be corrected before return to service.

The issue of the difficulty in drying out a generator is interesting. A generator in operation tends to be inherently dry, because of the high temperature and high ventilation flow. On shutdown, there is no ventilation flow, so the entire machine becomes a large number of stagnant zones. Any stagnant zones that have some moisture content tend to become saturated. Capillary condensation will work to fill all the connected capillaries.

If the open machine is exposed to humid conditions, then the daily dew-point cycle may result in periods when the dew-point temperature is greater than the metal temperature. Condensation will occur, and the machine will take on water as long as condensation continues.

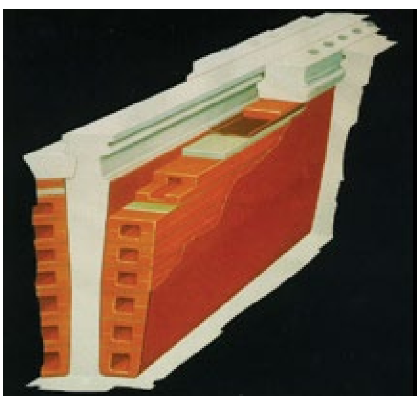
A filled capillary is relatively stable at moderate ambient temperatures and stagnant conditions. There is almost no driving force to evaporate water back out into a stagnant atmosphere at the same temperature. A significant increase in metal temperature will increase the evaporation rate by producing a decrease in local relative humidity. Significant ventilation flow should also break up the stagnant zones with the rapid inflow of dry air. For the rotor, a significant increase in shaft speed will provide a G loading which will tend to centrifuge water out of the rotor.

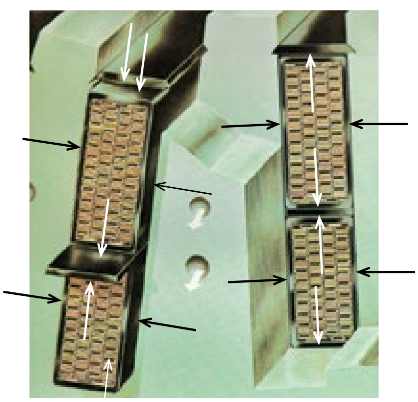
It is always better to keep a dry machine dry, than to dry out a wet machine. For maintenance and layup conditions, it is important to make sure that capillary condensation conditions cannot occur. Prevention can include maintaining some ventilation flow of dry air throughout the machine and maintaining temperature well above the ambient dew point; a healthy margin would be 80% relative humidity. For long-term layup, develop a system which combines fail-safe sealing, monitoring, and drying. A nitrogen blanket or dry gas feed might be considered.

Generator layup

Dhruv Bhatnagar, GE's technical leader for generator-fleet risk management, provided the OEM's guidelines for unit layup during non-operational conditions. Stator and rotor recommendations are the following:

- Stator layup for days. No recommendations for H_2-cooled units if the hydrogen is pressurized. For liquid-cooled stators, the cooling-water system (SCWS) should be operational, or shut down with water drained from the winding for any layup of more than 48 hours. For air-cooled units, or H_2-cooled units that are depressurized, turn on space heaters to prevent condensation.
- Stator layup for weeks or months. For air-cooled units, turn on space heaters to prevent condensation; same for H_2-cooled units, but depressurize before turning on space heaters. H_2-cooled units not purged should reduce gas pressure to 0.5 psig to minimize consumption. For liquid-cooled units,



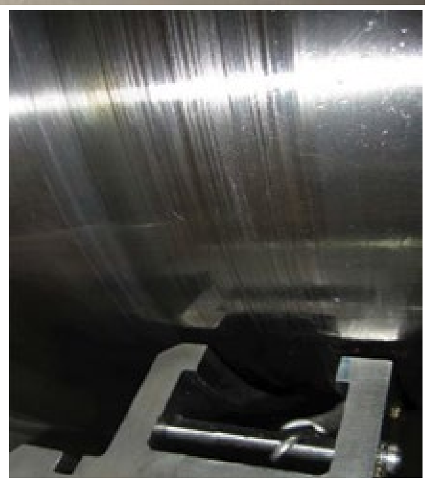


E1, E2. There are numerous capillaries in both the rotor and stator where unwanted condensation can occur. In the rotor, they are between turns and on both faces of the slot liner (left); in the stator, between core laminations and in the spaces between the bar surface on the fillers and core iron (right)

E3. Condensation on stator windings attributed to improper layup procedures caused unit to trip on restart after a planned outage

E4, E5. Ground alarm following a shutdown for lack of market demand alerted staff to rust accumulations on rotor and exciter components caused by condensation/improper layup

E6, E7. Retaining ring scanner at left and air-gap robot at right provide "eyes" to identify issues before they cause problems that can affect machine availability



E8, E9. Rub marks are in evidence on air-side seals and shaft surfaces; plus, seals are out of round

the winding and SCWS should be drained and vacuum-dried.

- Rotor layup for days. Rotor should be at rest with the pole axis in the vertical direction. Coat all exposed shaft surfaces with light lubricating oil.
- Rotor layup for weeks or months. Rotor should be at rest with the pole axis in the vertical direction. Megger field monthly and trend insulation resistance. A low megger indicates moisture in the generator. Inspect exposed shaft surfaces and the collector rings to ensure that the oil film is adequate.

Similar recommendations were provided for collector systems, seal-oil systems, and coolers.

In addition, the following case studies related to improper storage were discussed:

Case No. 1. Unit was in a planned outage (turbine upgrade). During restart after the outage, the unit tripped on stator differential protection. Upon inspection, damage was noted on the turbine-end series loop caps (Fig E3). The failure was attributed to condensation on stator windings.

Case No. 2. Unit was shut down because of grid issues. Upon restart, a field ground alarm was activated and the unit was shut down again. Inspectors noted rust had accumulated on the rotor and exciter components because of condensation and improper layup (Figs E4 and E5).

Implementing NERC Standard PRC-019

Douglas Selin, PE, consulting engineer, Arizona Public Service Co, provided an overview of the NERC standard and the process APS uses to implement the PRC-019 across its fleet of generators. A review of the standard outlined the functional entities required to comply with the mandate, the applicable facilities, and the individual requirements which involve coordinating voltage regulator controls with the protection system and the capabilities of the equipment (generators or synchronous condensers). The time requirements for implementing the standard on a fleet of generators also was presented.

The evaluation process used by APS includes the following five steps:

- Identify all of the voltage-regulator limiter and protection functions for a given generator.
- Identify all of the generator relay protection functions enabled.
- Determine what coordination must be evaluated based on a comparison of the items identified in Steps 1 and 2 above.
- Perform the needed evaluation and modify settings such that they coordinate.
- Document the results in a formal report.

Several methods of demonstrating how the coordination can be reviewed, visualized, and documented were presented for most of the voltage-regulator functions that would be encountered in such an evaluation. A summary list of learnings was offered to enhance the efficiency of the evaluation process.

The effort needed to perform the coordination analysis outlined is a requirement for all generator owners. It has the benefit of improving power-system reliability by avoiding unnecessary unit trips: Generator voltage regulators act to mitigate undesirable operating conditions before relays trip the unit.

Generator maintenance considerations and robotics

Revision L of GEK 103566, perhaps better known by number than its title, "Creating an Effective Maintenance Program," was reviewed by Dan Tragesser and Chris Markman to help owners operate their generators safely and reliably. Tragesser manages technical risk for GE's Global Generator Product Service Engineering, Markman is product manager for generator inspections.

Six key areas were discussed by the duo—including Rev L updates, rotor removal recommendations, inspection and maintenance intervals, how intervals are determined, examples of intervals, and rotor and retaining-ring life management. GEK 103566, which was said to contain information of importance to users, can be obtained from your GE rep.

Robotic inspections were the next topic with specific references made to the OEM's retaining-ring scanner (Fig E6) and air-gap robots (Fig E7). The speakers said robotic inspections were performed on 512 units between 2011 and 2016, with 8% having significant findings (defined as rotor removal required for repair) and half of those deferred to next outage. There were three forced outages associated with the 20 rotors pulled. Two had rotor grounds and one was forced out by a negative sequence current with arc strikes.

The speakers said electrical tests conducted on the rotors removed typically confirmed the findings of other tests or conditions—such as shorted turn and vibration. Data show robots typically find the same defects as visual inspections with the rotor out. Discussion regarding robot inspections that resulted in a rotor pull noted that more than 50% of these could have been planned for with better operations data review and outage management.

Relative to reliability, GE reported four cases of MAGIC (Miniature Air Gap Inspection Crawler) robots losing parts—including two burst bearings (encapsulated bearings are now used) and three fastener issues (redesigned). Relative to robots getting stuck, GE has emergency retrieval capability built into designs.

Also discussed was the stator cooling water system with focus on copper oxide buildup and removal.

Hydrogen seal-oil experience

GE's Dhruv Bhatnagar returned to the podium to address the challenges associated with seal-oil systems and how to mitigate them. Challenges include the following:

- The seal rings themselves. Damage, contamination, improper assembly, and cocked seals all can lead to operational issues—including oil ingress.
- Float traps require manual bypass during every startup/shutdown. Improper procedures are conducive to seal-oil ingress.
- Oil contamination of the hydrogen control panel.

Seal-oil-system mechanisms and effects was the next topic. Mechanisms include cocked seals, loss of seal oil, damaged anti-rotation pin, contaminants, damaged seals, generator pressurization, clogged drain lines, improper assembly, and misoperation.

Resulting effects include higher total and hydrogen-side seal-oil flow, improper liquid-level detector alarms, high float-trap oil level.

Checklists for disassembly and reassembly followed:

Disassembly. Measure rotor position from the outboard oil deflector fit to the shaft, measure the distance between the hydrogen seal casing and the rotor shaft, determine "as-found" seal clearances, inspect seals, and ensure seals are not out-of-round.

Reassembly. Inspect seals and ensure they are not out-of-round, check for any foreign material between the inner oil deflector and hydrogen seal casing, check vertical face of the end shield between the upper half and lower half for any steps across the horizontal joint, perform blue check and ensure 100% contact, check for any RTV that may have squeezed from between the upper half and lower half of the end shield, remove any RTV material that has come onto the horizontal joint of the lower-half casing, ensure seal-oil inlet feed and gas-side seal-oil drain in the end shield are clear.

The presentation closed with a case study of a unit that was offline, but pressurized and with seal-oil system in operation, when a blackout occurred. The DC system came online, but the site lost seal-oil differential pressure (DP). By the time DP was restored, the unit had dropped 10 psi in hydrogen pressure. The decrease in seal-oil DP allowed oil ingress.

The operator received multiple liquid-level detector alarms, and low and low-low lube-oil alarms. Site personnel tried to start up the unit next day but were unable to build lube-oil header pressure. Personnel purged and inspected the generator, which was flooded with lube oil. Air-side seals and shaft surfaces were found to have rub marks (Figs E8 and E9); seals were out of round.

Coordinated frequency response

Emerson's Thor Honda, an expert on the modernization of mechanical and electronic turbine controls, discussed the challenges associated with injecting into the grid large amounts of intermittent power produced by renewable resources. This new and evolving paradigm in electric generation has highlighted the need for synchronous turbine/generators to help stabilize system frequency.

The questions then arise: How do synchronous powerplants respond to system frequency disruptions and what changes may need to be made in order to comply with frequency response codes and standards? Synchronous generators add rotating inertia and have governors which detect frequency disruptions and raise/lower output to quickly balance generation to load (called "droop" control or primary frequency response).

These questions become more acute because tax credits and rapidly declining costs are driving ever more massive amounts of renewables power into existing transmission systems. A lower percentage of synchronous generators means less inertial response to frequency disruptions, and less inertial response means more turbine/generator response is needed. Synchronized turbine/generator droop control must give a sustained response to minimize the magnitude of frequency disruptions and maintain reliability.

NERC's 2012 Frequency Response Initiative Report found only 30% of the generators online provide primary frequency control, and that two-thirds of those that did respond exhibited "withdrawal" or "squelching" of the response. The reason is outside closed-loop control. Since only 10% of the units online were sustaining their expected primary-frequency-control "capability," a reliability issue arises: Balancing authorities (BAs) get a significant portion of frequency response from load and cannot predict the load response or control it (load's inertial contribution cannot be accurately predicted).

These issues have encouraged NERC and industry efforts to improve frequency reliability, thereby making the need for government regulations less likely. One step in that direction is GE Technical Information Letter 1961, "Steam Turbine Governor Studies to Meet NERC Frequency Response Advisory," which was supported by a webinar.

Honda closed his presentation with these recommendations for owner/operators:

- Verify unit-specific requirements with your BA.
- If operating in closed-loop automatic generation control (AGC), biasing may be required to pass BA compliance criteria.
- When implementing AGC bias, keep the following in mind:

1. AGC will not negate droop impact on site output, which may have economic considerations.
2. Ensure AGC bias is accurate and enabled accordingly. GEN