SUMMER 2014

EPRI JOURNAL

ELECTRIC POWER RESEARCH INSTITUTE

SMART INVERTERS

ALSO IN THIS ISSUE:

Plant Health Maintenance Software

Advancing Sustainability at Utilities

Changing Mission Profiles for Power Plants

ELECTRIC POWER
RESEARCH INSTITUTE

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent approximately 90 percent of the electricity generated and delivered in the United States, and international participation extends to more than 30 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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WIRED IN

Perspectives on electricity

Zak Kuznar
Technology Development Manager
Duke Energy

Getting the Best Charge from Batteries

With almost 10 battery projects underway, Duke Energy has invested a lot in the future of energy storage and the 21st century electric grid. The quick verdict: We remain bullish on the prospects for storage, but know there's plenty of work to do.

Our efforts vary in size and chemistry. In Notrees, Texas, our 36-megawatt advanced lead acid battery is part of a pilot in the Electric Reliability Council of Texas (ERCOT) region, shaping the ancillary service market using a fast-responding resource. The installation is next to one of Duke Energy's wind farms.

On a smaller scale, we linked a solar array, lithium-titanate battery storage unit, and electric vehicle (EV) charging stations at the Clay Terrace Shopping Mall in Carmel, Indiana, to demonstrate a sustainable microgrid that can be used by the mall to attract additional business by offering free EV charging.

Energy storage hardware deployed on the grid has improved, costs are coming down, energy densities are improving, and the cycle life of systems is increasing. Technologies that were once limited to lead acid and lithium chemistries are now expanding, and pilot projects are coming on-line for technologies such as long-duration flow batteries and rechargeable metal-air systems.

But even the best battery is only as valuable as the benefits it brings to the grid. To date, much of the work in energy storage has focused on hardware. The other side of the equation—how to create value on the grid—is just beginning to be addressed.

At Duke Energy, we are focused not so much on finding the next great battery, but creating the best value for the grid and our customers. Better yet, how do we make energy storage tackle a number of tasks for the grid—instead of being limited to a single area?

At our McAlpine Energy Storage System in Charlotte, North Carolina, we deployed an islandable microgrid tied to a 24-kV distribution circuit. It is demonstrating how a utility-owned distribution asset can support the grid by integrating renewable generation while providing higher reliability to a city fire station—all using common utility assets.

What Does the Future Look Like?

While work continues on the multi-use of energy storage in transmission and distribution, the biggest breakthroughs might be seen in smaller, distributed batteries.

Residential or community energy storage units deployed today typically provide backup power or shift energy from peak to off-peak to reduce demand charges.

The cost of such systems can result in a tough business case to make for home and business owners who lose power infrequently. And it also doesn't come close to realizing the untapped potential of the technology located on the customer's premises.

But imagine thousands of such units controlled by the utility—shifting energy from off-peak to peak times during hot summer days, smoothing out solar generation's variable output, and reserving capacity to provide backup power to critical loads during a grid outage.

This creates value for both the grid and customers—and creates new, innovative business models of behind-the-meter ownership.

This "stacking of value streams" benefits customers and the electric grid. While we need to address the technological gaps that remain, such thinking can ultimately prepare and equip utilities to incorporate diverse energy storage configurations into our business models.

These are just a few of the possibilities for battery storage. When we combine what we are learning today with new developments in hardware and creative thinking elsewhere, we can see energy storage providing a welcome charge to the utility industry.

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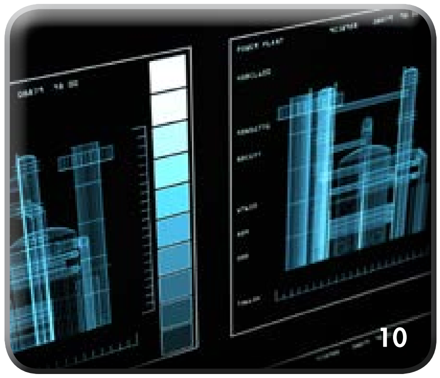
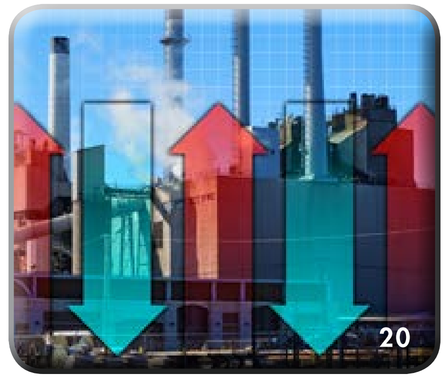




VIEWPOINT

FEATURES

DEPARTMENTS

VIEWPOINT

by Mike Howard, President and CEO, EPRI

Next Generation and "Next Gen"—Where We're Headed, Where We're Focused

Traditionally, when people speak of the next generation, they refer to their sons and daughters. In this technological age, we often refer to the new version of a given technology as "next generation." And today, as one technology gives way to another in just a few years, we increasingly use the hurry-up version of the term: "next gen."

In reading this issue of *EPRI Journal,* it's worth thinking about the electricity sector's next generations—both people and technology. It's a good way to frame the longer view and the rapid succession of changes.

Our cover story looks at smart inverters, which are poised to serve a new and pivotal role in the power system. They may become a signature technology of a power system able to integrate central and distributed resources in new and dynamic ways. I can foresee that this technology may progress from The Next Big Thing to a power system workhorse relatively soon. Forty years from now, power system engineers and operators may well have trouble recalling or imagining how the system operated without smart inverters.

Elsewhere in the *Journal,* we consider micro-electromechanical sensors that were brought to the fore by EPRI's Technology Innovation program for the early detection of turbine blade cracks. These sensors are small enough to be mounted on steam turbine and compressor blades, yet they are strong enough to withstand the turbine's extremely high temperatures, pressures, and centrifugal forces. Imagine going back in time 40 years and describing such a technology to a plant engineer.

Also looking back that far, we see the beginning of the world's longest running ecological monitoring program. We report on this 40-year-plus program, which has documented that water quality is improving in the Ohio River and that fish populations have not been negatively affected by power plant operations. Research of that duration and magnitude is literally a commitment by one generation to the next.

As scientists and engineers, we rely on data—whether we are looking back or looking ahead. Our generation has been equipped by computers to take large, diverse bodies of data and model different scenarios and outcomes. While such models do not provide definitive predictions, executives increasingly rely

on them in choosing technology options, investing capital, and charting a course for their businesses. The US-REGEN model covered in this issue looks at policy, markets, and technology to inform and guide these strategic decisions.

One of the best legacies from this generation to succeeding generations may be our bequest of accumulated experience and knowledge through digital technologies. You can read about EPRI's Fleet-Wide Prognostics and Health Management software, which "learns" as plant personnel enter their industry experience. The software uses this knowledge not only as a repository but also as an active diagnostic advisor. It's not much of a stretch to say that parts of us will live on for future generations through these intelligent technologies.

Finally, as we think about looking and moving from one generation to the next, consider the work we are doing with sustainability in the electricity sector. An EPRI-led interest group has developed strong participation and is helping bring focus and momentum to sustainability as a concept that includes environmental, social, and economic components. The term *sustainability* itself reinforces EPRI's bedrock conviction that electricity is essential to sustained human well-being over many generations. I hope that this conviction is clearly conveyed in this issue of *EPRI Journal* and in all that we do Together . . . Shaping the Future of Electricity.

Michael W. Howard
President and Chief Executive Officer

SHAPING THE FUTURE

Innovative approaches to upcoming challenges

Prototype Sensor Can Lower Costs and Increase Accuracy of Hydrogen Monitoring in Nuclear Plants

EPRI has completed a prototype of a sensor that could significantly reduce calibration time and the number of components in a nuclear plant's hydrogen monitoring system, lowering maintenance costs and boosting accuracy and reliability.

When a plant's reactor core is damaged in an accident, hydrogen may be generated as a by-product of reactions between steam and nuclear fuel assemblies. At certain concentrations, the hydrogen could cause an explosion in the containment structure that houses the reactor, threatening workers and exacerbating accident conditions. Monitoring hydrogen levels inside containment can help prevent this.

A station blackout, as experienced at Japan's Fukushima Daiichi Nuclear Power Plant, is one scenario that could lead to core damage and hydrogen generation if corrective actions are not taken. Continuous measurement of hydrogen concentrations during an accident helps plant operators determine actions needed to stabilize the plant and minimize the release of radiation.

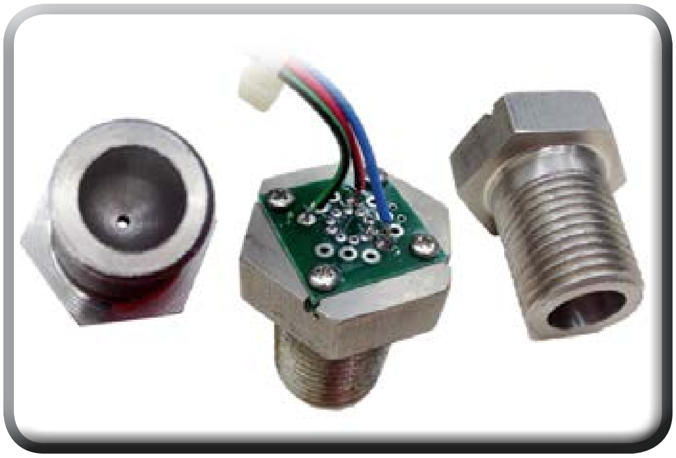
Conventional Sensors: Time-Intensive Calibration, Complex Infrastructure

In existing hydrogen monitoring systems, several sample lines in the containment structure take gas samples and transport them to an analysis cabinet outside containment. The cabinet houses thermal conductance sensors, which use a heated filament to measure hydrogen concentrations. These sensors require reagent gases for calibration and other supporting components to maintain the pressure and temperature of the sample gas. Periodic sensor calibration is labor-intensive and can take more than 40 work-hours to complete.

Dramatic Improvements

EPRI's prototype is a solid-state sensor with a nanostructure-based semiconductor material that can measure changes in hydrogen levels more accurately and quickly than the conventional thermal conductance sensor. The new sensor also has the potential to lower maintenance costs by significantly cutting calibration times, eliminating the need for reagent gases, and reducing the number of components in the cabinet by 20%.

In 2014, EPRI published a design study (3002002880) outlining considerations for power plants when replacing sensors with the new solid-state technology. The report shows that the process is simple, requiring minimal physical changes inside the analysis cabinet.



Research to improve hydrogen monitoring inside the nuclear reactor containment structure has resulted in a prototype that could cut operations and maintenance costs.

This year, EPRI will continue laboratory tests to improve the sensor's performance and stability of its materials under high levels of radiation exposure. A progress report is expected early in 2015. The next step is to line up a manufacturer to produce the sensor for field trials.

Long-Term Vision: Sensors Inside Containment

EPRI's work on the solid-state sensor is an early step in a long-term plan to develop a hydrogen monitoring system that sits completely inside the containment structure. As such, EPRI's prototype uses less power than existing sensors and can withstand harsh environmental conditions inside containment, such as high temperature, pressure, humidity, and concentrations of various gases. Moving the sensor closer to the hydrogen source can boost measurement accuracy and eliminate components in the monitoring system.

EPRI intends to design the sensor so that it can endure prolonged exposure to high radiation levels inside containment and harvest power from local sources so external power is not required. Research has identified two promising ways to recharge the sensor: one uses differences in temperatures to generate electrical current, and the other harvests electrons from a radioactive source.

A commercial version of an out-of-containment sensor using existing infrastructure could be deployed within a few years, followed by demonstration and deployment of an in-containment sensor.

For more information, contact Jeff Greene, jgreene@epri.com, 704.595.2666.

EPRI Model Aids Industry Future Scenario Analysis

New York Yankee baseball legend Yogi Berra's famous observation "The future ain't what it used to be" is open to interpretation. While it is often quoted, power company executives today may fairly claim this Yogi-ism for their own industry.

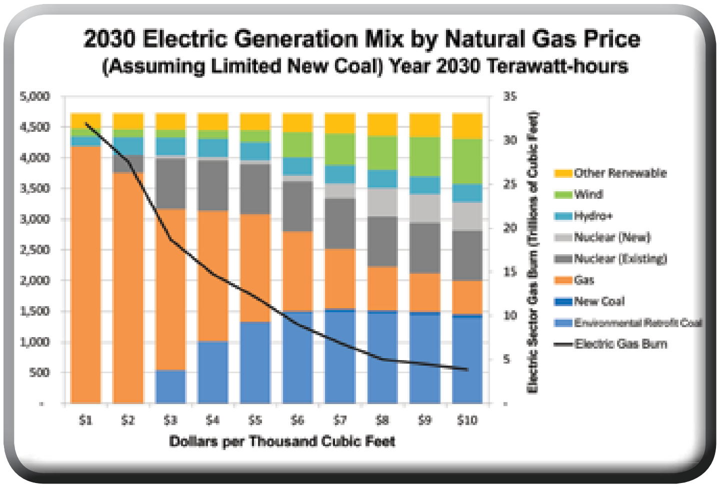
To help the industry evaluate possible futures, EPRI developed the U.S. Regional Economy, Greenhouse Gas, and Energy Model, or US-REGEN. By modeling a variety of scenarios, comparing the results, and asking "what if" questions, US-REGEN provides insights on how various policies and regulations, market dynamics, and technological innovations can affect and shape industry fundamentals such as the price of electricity, revenues, and greenhouse gas emissions. It is important to keep in mind that model analyses are not intended to be viewed as predictions or forecasts of particular outcomes.

"The electric power sector faces key uncertainties relating to economics, policy, and technology availability," said Francisco de la Chesnaye, program manager in EPRI's Energy and Environmental Analysis Group. "The combination of those things will impact the sector and therefore the resulting CO_2 emissions, generation mix, and a host of other measures in the coming decades."

A Multitude of Factors

Most of the factors that US-REGEN analyzes are beyond the control of power company executives and R&D program managers. For example, future natural gas prices will be determined by the market, and policy decisions about CO_2 emissions and renewable energy generation are made in Washington, D.C. and state capitals. Executives and managers can, however, directly influence technology and innovation, which are shaped by investment and research at power companies and EPRI.

US-REGEN combines different assumptions about these factors to help inform investment decisions. "What if the price of natural gas stays low for the next two decades, EPA rules on CO_2 are stringent, and the price of solar photovoltaics continues to decline?" said de la Chesnaye. "We put those things in the US-REGEN model, run the scenarios, and compare and contrast the outputs for a strategic assessment."



This US-REGEN analysis shows that electric sector gas burn at a $3 gas price is nearly three times the burn at a $7 price. At $3, power generation is dominated by natural gas, while at $7 the amount of coal generation triples, and nuclear and wind levels are significantly higher.

Different Versions of the Future

To illustrate how variations in just one factor can lead to dramatically different futures, consider US-REGEN's examination of natural gas prices (see chart above). Given prices ranging from $1 to $10 per thousand cubic feet, the model assessed the implications for the mix of coal, wind, nuclear, and other generation sources in 2030. Depending on the price, substantial differences emerge in each generation source's energy output and the electric sector's overall gas consumption.

In more than 50 modeling cases evaluated, the US-REGEN analyses illustrate that the future is likely to bring an appreciable change in power sector generation, with a long-term trend toward lower CO_2-emitting generation. This is due primarily to current and pending CO_2 regulations, expected low natural gas prices, and projected cost declines in renewable power technologies. US-REGEN will continue to be modified and refined so that a range of industry stakeholders can use the model to inform their planning efforts, including utility executives, R&D program managers, and policy makers.

For more information, contact Francisco de la Chesnaye, fdelachesnaye@epri.com, 202.293.6347.

SMART INVERTERS

Expanding the Handshake Between the Grid and Distributed Generation

THE STORY IN BRIEF

EPRI-led research has shown that smart inverters can allow for more grid-connected renewable energy and provide grid support. Studies and demonstration projects with 11 utilities are helping to prepare the grid for smart inverters and increase its capacity to host distributed renewable generation.

Like any good engineer, Justin Woodard approaches complex problems by asking probing questions. Lately, Woodard—who works for National Grid in Massachusetts—has applied his inquiring mind to the topic of how best to integrate a lot more renewable energy into his company's distribution system.

Woodard and National Grid have been grappling with this issue for quite a while. Thanks to Massachusetts' Green Communities Act of 2008, National Grid has already connected 300 megawatts of customer and third-party solar photovoltaic (PV) capacity. But Woodard points out that this new solar capacity has not been incorporated with adequate technical consideration of its impact or how it can provide system-wide benefits. "Right now, the PV goes in locations wherever the developer picks," he said. "We are trying to understand how to thoughtfully integrate—rather than just interconnect—this PV generation."

National Grid has a compelling reason to focus on smart integration of renewables—a topic at the heart of EPRI's recently unveiled Integrated Grid concept. After reaching its initial goal of 250 megawatts of solar ahead of schedule, Massachusetts upped its target to 1600 megawatts by 2020. To handle that influx of PV in a way that minimizes disruptions and provides full benefits to customers and the distribution grid, National Grid is focusing on inverters, the power electronics technology that changes the DC power produced by solar arrays to AC power compatible with the grid. National Grid wants to understand how inverters augmented with advanced grid-support functions, known as smart inverters, can increase PV *hosting capacity* of distribution grid *feeders* (for definitions, see "Key Terms" box, p. 8).

To aid that effort, National Grid recently made a filing with the state's Department of Public Utilities, asking for permission to equip 20 megawatts of new utility-owned solar with smart inverters. If approved, these projects will provide data and experience that Woodard and his colleagues need. "The point of the filing is to better understand the value of smart inverters and quantify that value so we know how renewables can enhance the grid versus just follow the grid," said Woodard. "As a general proposition, can smart inverters be a big help toward reaching that 1600-megawatt state target?"

Beyond Massachusetts, utilities around the United States and the world have witnessed significant increases in distributed solar and are seeking effective integration strategies. Along with its Integrated Grid initiative, EPRI has spearheaded a wide-ranging, three-year initiative to advance and understand smart inverters' capabilities and to help grid operators understand their benefits. With 11 utility participants and support from the U.S. Department of Energy (DOE), the project includes smart inverter demonstration projects in a range of grids across the United States, as well as modeling and simulation to expand the site-specific demonstration results to other grids. "We are looking at ways to better integrate distributed PV into the grid," said Lindsey Rogers, the EPRI project manager.

What Makes an Inverter Smart?

To understand the growing interest in smart inverters, it's helpful to examine what makes them different from their predecessors. EPRI Senior Technical Executive Tom Key emphasizes that traditional inverters already provide an important service. "Grid-connected inverters are relatively sophisticated power electronic devices designed to make the handshake between a variable PV array and the electric power grid," he said. "They shape the solar DC output to utility-quality AC power, synchronizing with the grid and managing energy flow. With smart inverters, we are trying to extend inverter functionality for a more integrated grid."

With more distributed PV, wind, and energy storage, inverters equipped with advanced functions can help distribution systems handle intermittent, distributed generation. Maintaining power quality and reliability can be challenging when passing clouds or changes in the wind vary the power output of renewables. "When you add a lot of PV, the first thing you worry about is the voltage fluctuations for end users, and we have already seen cases of over-voltages near the end of feeders with PV," said Key.

Sharp changes in PV power output raise concerns about maintaining electric service voltage to customers within required limits and wearing out the utility's regulation equipment, such as line voltage regulators. With particularly high levels of distributed generation come worries about *unintentional islanding*. Another problem can arise when system operators rely on the energy from uncontrolled PV or wind. "You start depending on solar, and then you have an event on the grid that trips it off-line," said Key. "You are left with more load than generation."

Enter smart inverters and their capacity to help compensate for variable generation's voltage fluctuations. Thanks to *reactive power compensation* and a *Volt-VAR function*, smart inverters can elevate or decrease voltage levels depending on what's happening on an individual feeder. Smart inverters also can be configured to perform a *fault ride-through function*. "Currently, IEEE standards say if there's a fault on the line, inverters must trip off and stay off for at least 5 minutes before coming back online," said Rogers. "Instead of shutting off, ride-through allows the PV to stay on-line during a short fault and then quickly recover normal operation after the fault is cleared from the system."

Ultimately, these and other advanced inverter functions allow for more renewable energy. One EPRI study estimates that smart inverters can double a feeder's PV hosting capacity while helping the grid operator to maintain power quality and reliability. Current and projected growth of distributed PV generation has prompted a sense of urgency with respect to smart inverters. DOE's SunShot Vision Study in 2012 reported that the United States could see as much as 302 gigawatts of PV installed by 2030.

Recent experience in Germany underscores the practical benefits of addressing grid integration early. More than 20% of the country's installed generation capacity is PV, creating frequency and voltage issues that have necessitated the spending of tens of millions of dollars to retrofit 300,000 PV inverters. "Getting the inverter right enables us to better utilize the existing grid and minimize the need to upgrade it or to limit additions of distributed renewable energy," said Key.

Prepping the Grid for Smart Inverters

Even with smart inverters, much work remains to prepare the grid to receive support from distributed generation. For example, planning and operations systems that utilities use to manage their distribution grids have not yet incorporated capabilities to integrate distributed generation support.

EPRI's Integration of Distributed Energy Resources program has taken a lead in preparing the grid. Beginning in 2009, EPRI's initial smart inverter grid-support research has included a range of partners, such as electric power companies, DOE, Solar Electric Power Association, National Institute of Standards and Technology, inverter manufacturers, and solar installation companies.

EPRI started an effort to define standard smart inverter functions. "There was a gap because every inverter manufacturer had its own proprietary protocol with its own set of functional definitions," said Rogers. "As PV has become more prevalent, there was a need for standardization." Over three years of regular EPRI-led meetings, an initial set of common functions was prioritized—including *Volt-VAR* curve, *Volt-Watt* curve, *power factor* settings, and *low- and high-voltage fault ride-through*—and subsequently incorporated into protocols and standards such as DNP3 and IEC 61850.

Key Terms

Fault or low-voltage ride-through: The ability of a generator, or end-use equipment, to remain grid-connected under fault conditions.

Feeder: Any power conductor and associated devices between consumers and a power supply.

Power factor: This attribute of a generator (or end-use equipment) is expressed as a ratio comparing the real power delivered (or used) to the total power (voltage multiplied by current).

Hosting capacity: Capacity of a power system conductor to accommodate deployment of distributed energy resources, usually expressed in megawatts.

Unintentional islanding: A situation in which portions of the grid remain energized during a utility outage, raising safety concerns.

Reactive power compensation/Volt-VAR: A smart inverter function that allows distributed energy resources to help maintain acceptable voltage along a feeder under various grid operating conditions.

Volt-Watt: A smart inverter function that allows distributed energy resources to manage power output based on the utility voltage.

In 2012, EPRI led an initiative to harmonize inverter-related communication standards and make them open. This ongoing effort has focused on how to coordinate smart inverter functions with traditional utility operations such as Volt-VAR optimization. "The idea is that if utilities are going to get to the point where they have to communicate regularly with these devices, you need all the devices to respond to the same messages in the same way," said Key.

Standard functions and communication protocols have laid the groundwork for utility field demonstrations now underway. Drawing from these demonstrations, EPRI has completed case studies, simulations, and modeling work that show the potential of smart inverters and identify questions still to be answered. Indeed, one EPRI study investigating four feeders in New York revealed that all smart inverter functions could increase hosting capacity to some degree, with power factor control yielding the greatest increase.

Challenges for smart inverters have also been identified. For instance, if not coordinated with existing feeder voltage controls or if inverter settings are incorrect, the Volt-VAR and Volt-Watt functions won't help increase hosting capacity. Even for settings coordinated with distribution operations, they may not be best for balancing electricity supply and demand at the transmission level. Additionally, there are questions about the most secure, cost-effective approach for communications between smart inverters and grid operators. "There is currently a lot of work going on in these areas," said Rogers. "We are beginning to get in the field to use support functions and measure their effects, good or bad."

What Comes Next?

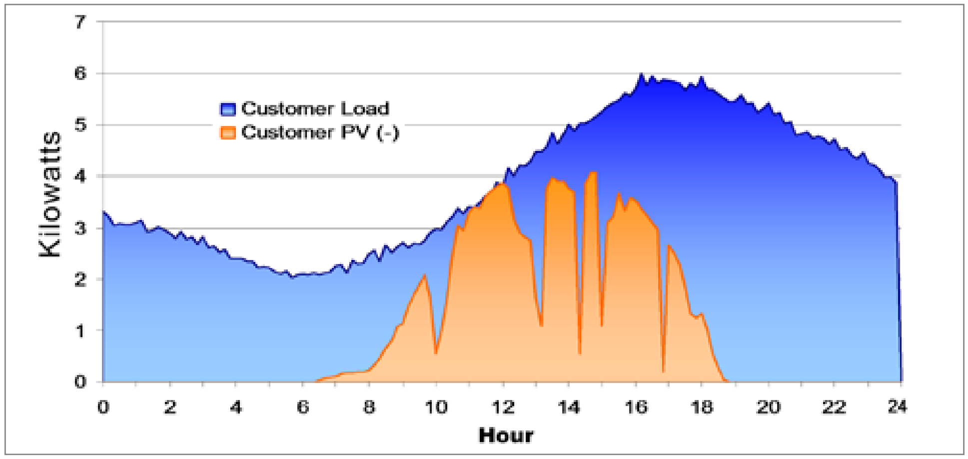
One priority research area is communications. Currently, some functions that make an inverter more grid-supportive, such as fixed power factor setting, are preprogrammed and cannot be controlled or adjusted remotely. EPRI-led research is exploring how this can be changed in a way that maintains grid security. "The next step is for utilities to be able to communicate with and control the inverters to change their response seasonally, daily, or as needed," said Rogers. "That is the missing link to turn a potential liability into an asset that can be valued."

Another important task involves grid codes and regulations. Several grid operator regulations and national standards, such as those in Germany, Spain, and Italy, require grid support functions in inverters. The IEEE 1547 interconnection standard was recently modified to allow distributed generators to play a larger role in grid support. California has followed Europe's lead by requiring smart inverter functions as part of its interconnection rules (Rule 21). One new area of EPRI research is to determine the optimal smart inverter settings that can inform interconnection standards across large jurisdictions with various needs and issues. Such settings are critical to fully utilize smart inverter technology and will first take shape in an EPRI project with California utilities to help inform Rule 21.

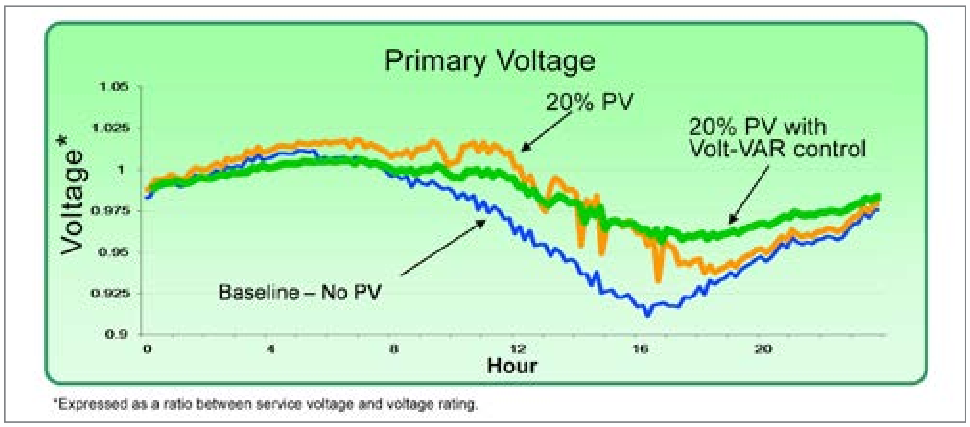
Educating policymakers is crucial. Insights from EPRI's demonstration projects can enable regulators and lawmakers to better understand how smart inverters can help integrate more renewable energy and maintain reliable grid operations. Education is happening through other channels as well. Michigan Public Service Commission staff and DTE Energy representatives have met to discuss smart inverters. "They realize it is something that is going to be needed in the industry," said Haukur Asgeirsson, DTE's Manager of Power Systems Technologies. "Every so many years, there's an opportunity to revisit interconnection rules. It's time to think about requirements for smart inverters."

Asgeirsson will soon be able to present regulators with local data on the benefits of smart inverters from a demonstration project in Ann Arbor, Michigan. Beyond the particular insights Asgeirsson hopes to gain through the project, he wants to understand more clearly how smart inverters can help DTE Energy do its job. "We got involved because we see advanced inverters playing a larger role going forward," he said. "We hope the outcome is to allow utilities to work with solar projects and other distributed generation to make the grid operate better."

How the Volt-VAR Inverter Function Benefits the Grid



The blue area shows the changing end-user electricity demand over the course of a day. The orange area represents PV generation at the same location, which rises and falls with passing clouds.



The blue line indicates the service voltage near the end of the distribution feeder without PV. The voltage fluctuations are small because utilities are required to maintain voltage within a narrow band. The orange line shows the larger voltage fluctuations at the same point with solar production at 20% of the feeder's peak demand. These fluctuations correspond with the cloud-induced troughs in solar production in the first chart. The green line shows how a Volt-VAR smart inverter function significantly flattens voltage fluctuations, allowing utilities to better regulate feeder voltage.

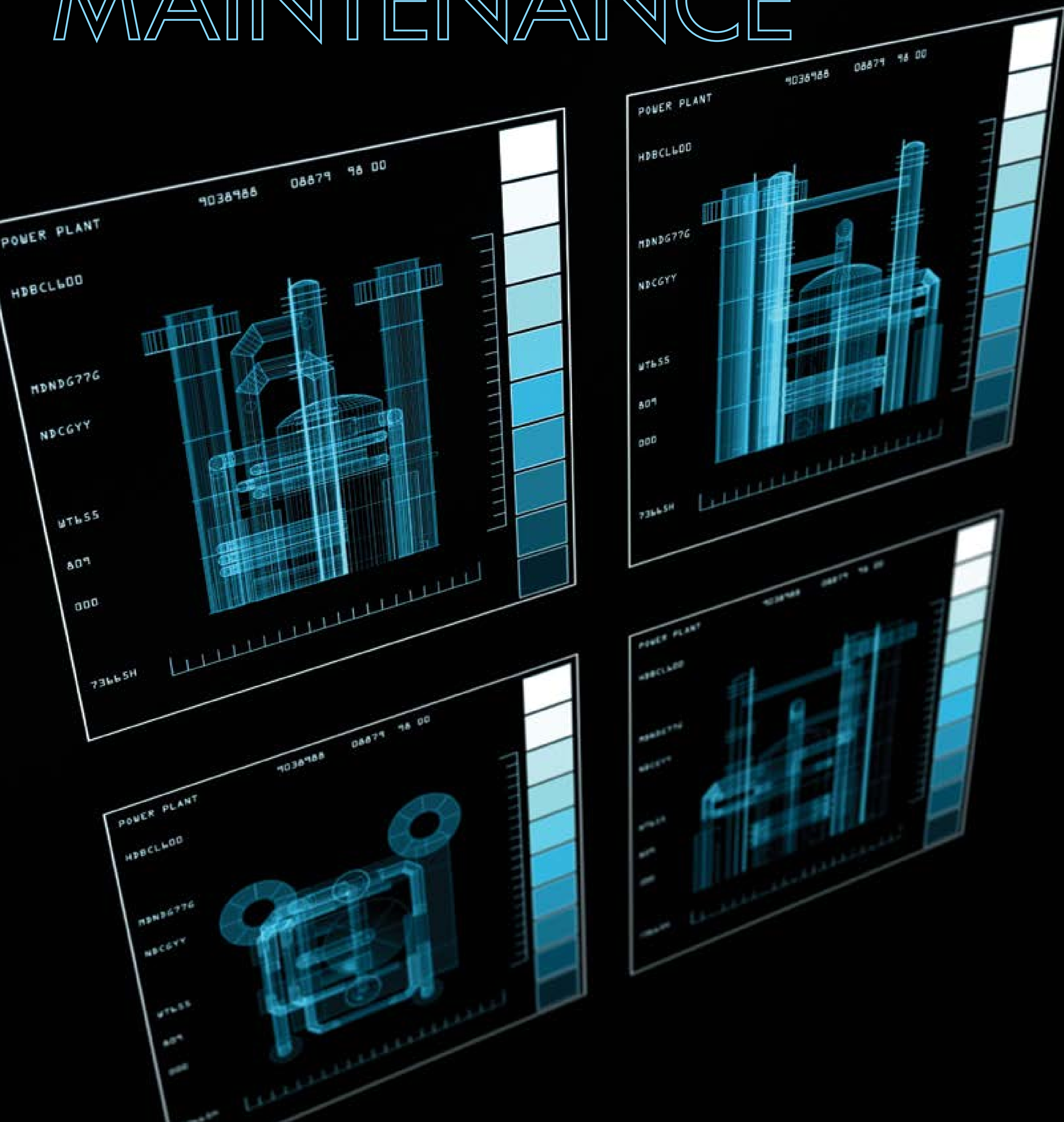
This article was written by Chris Warren. Background information was provided by Tom Key, tkey@epri.com, 865.218.8082, and Lindsey Rogers, lirogers@epri.com, 865.218.8092.

Tom Key, a senior technical executive at EPRI, manages the Integration of Distributed Energy Resources program. He has more than 40 years of experience with energy-related R&D with the U.S. Navy, Sandia National Laboratories, and EPRI.

Lindsey Rogers, a senior project engineer in EPRI's Integration of Distributed Renewables program, focuses on smart inverters, the business impacts of solar, interconnection screening, and hydro grid services.

In this brief video EPRI researchers Haresh Kamath and Thomas Cooke look at inverters and the need for them to handle the "in-rush current" necessary for powering up air-conditioners and other motor-driven loads. http://youtu.be/L7ICsafsups

A NEW ERA IN PLANT HEALTH MAINTENANCE



THE STORY IN BRIEF

Following years of collaborative development, EPRI has released *Fleet-Wide Prognostics and Health Management*, an automated power plant monitoring software system that dramatically reduces the time required to diagnose problems. The software learns over time as users enter new information, providing ongoing access to a wealth of industry experience.

One of the electric power industry's greatest assets is walking out the door. A sizable portion of its technical and engineering expertise is retiring. Utilities will lose some of the most senior troubleshooters who have spent 30–40 years in plants getting to know the equipment intimately, instinctively—the feel, sound, vibration, smell, crankiness, hot spots, failure modes, and required rhythm of maintenance. Imagine if their experience could be captured digitally, stored in a database, continuously updated, shared broadly, and transferred to a new generation of workers.

The development of experience-based diagnostics is one part of this knowledge capture, combining the efforts of EPRI, member utilities, and the national laboratories. It is now moving to implementation through the launch of a diagnostic system called *Fleet-Wide Prognostics and Health Management.* The objective is to dramatically reduce the time to diagnose plant problems. Instead of engineering staff spending the better part of a day with spreadsheets, work orders, parameter trends, and analysis reports to figure out what's wrong, the diagnosis can be done in seconds.

Origins

Monitoring technology in the power industry has been evolving for more than 20 years. Much of it emerged from the U.S. Department of Energy's research on advanced mathematical algorithms at the national laboratories, particularly Argonne National Laboratory. These algorithms were designed to be extraordinarily sensitive to plant anomalies, changes in equipment behavior, and process trends. In time, they were referred to as *advanced pattern recognition*, or *APR*. "Today, all software development companies essentially have the same core technology," said Rick Rusaw, senior technical leader in EPRI's Nuclear sector. "There are probably 10 to 20 companies out there that have some form of APR technology in their products."

APR has great strengths, including sensitivity and precision, but also limitations. The system looks at statistical correlations among different parameters, monitors the correlations, and sends a signal when a parameter trends outside the normal band. Some describe APR as "twitchy," meaning so sensitive that it can generate alerts for the smallest perturbation or deviation. "Imagine the light coming on in your car the moment your oil level drops a few teaspoons. That's what can happen with APR settings too high," said Rusaw. With thousands of parameters being tracked, it can be over-sensitive.

Summary for 906(Master)-BABBITT WEAR

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EPRI Real-time Component Operating Health Workshop, Charlotte, NC, April 2012. Entered by rbickford@expmicrosys.com

Fault Features

Exam Location	Technology	Exam	Fault Value	Effectiveness
RADIAL SLEEVE BEARING: OUTBOARD	VIBRATION	MAGNITUDE VALUE	MARGINAL	High
RADIAL SLEEVE BEARING: OUTBOARD	TEMPERATURE	VALUE	MARGINAL	High
LUBRICATING OIL	LUBRICATING OIL ANALYSIS	PARTICLE COUNT	MARGINAL	High
LUBRICATING OIL	LUBRICATING OIL ANALYSIS	ELEMENTAL SPECTROSCOPY	MARGINAL	Very High
LUBRICATING OIL	INSPECTION	COLOR CHANGE	ABNORMAL	Low
CASING	VIBRATION	MAGNITUDE VALUE	MARGINAL	Low

Fault Descriptions

Babbitt material on the face of a bearing surface or pad is worn away or removed by damage. Many of the mechanisms of radial sleeve bearing damage are ultimately manifest as Babbitt wear.

A key part of the software is a database that compiles fault signatures—combinations of measureable features that indicate specific problems. Users can search for fault signatures associated with power plant components and subcomponents. This image shows a fault signature called "Babbitt Wear" for the radial sleeve bearing in a nuclear plant condensate pump motor. The six measurable symptoms associated with this fault are listed under "Fault Features." The "Signature Source" describes the source of the information—in this case, several experts who participated in an EPRI workshop in 2012. In 2015, EPRI will continue to develop and refine fault signatures in the database through input from experts.

NUCLEAR STEAM TURBINE   PRESSURIZED WATER REACTOR   CONDENSATE   CONDENSATE PUMP

Technology	Exam	Description	Query Value
Temperature	Value	Assessment of a temperature value at radial bearing location.	MARGINAL
Vibration	Magnitude Value	Assessment of a vibration magnitude (time domain) value at a radial bearing location.	N/A
Maintenance Action	Disassemble & Assemble	Assessment of the disassembly and assembly of the asset at a radial bearing location.	N/A
Temperature	Change Pattern	A bearing temperature first trends lower than normal and then trends higher than normal.	N/A

This image shows a part of the software interface a user sees during a diagnosis query for a nuclear plant component called a condensate pump motor. The three columns on the left (called "Technology", "Exam", and "Description") describe various tests on the component. The user manually enters the results for each exam in the "Query Value" column. For example, the first row shows that a part of the condensate pump called the radial sleeve bearing had a "marginal" result in a temperature test. Exam results can also be automatically uploaded into the software from other sources, such as advanced pattern recognition tools.

Possible Diagnosis

Fault Location	Possible Diagnosis	Pattern Score (%)
CONDENSATE PUMP MOTOR : RADIAL SLEEVE BEARING INBOARD	MISALIGNMENT	25.81
CONDENSATE PUMP MOTOR : RADIAL SLEEVE BEARING INBOARD	BABBITT WEAR	25.81
CONDENSATE PUMP MOTOR : RADIAL SLEEVE BEARING INBOARD	OVERLOADING	22.58
CONDENSATE PUMP OIL SUPPLY : LUBRICATING OIL COOLER	IMPEDED WATER FLOW	12.9
CONDENSATE PUMP OIL SUPPLY : LUBRICATING OIL COOLER	INTERNAL WATER LEAK TO OIL	12.9

Based on all the inputted exam results from the query, the software looks through the fault signatures in the signature database and ranks several possible diagnoses in order of likelihood. The diagnoses refer to various forms of component degradation. In this case, misalignment of the radial sleeve bearing is the most likely diagnosis. Subsequently, the software recommends additional troubleshooting advice to narrow down the list of possible diagnoses.

Because the results of APR are highly plant-dependent, they are not readily transferable. "About 10 years ago, when APR was becoming more prevalent in the power industry, our members asked us if we could develop standardized, transferable APR templates," said Brian Hollingshaus, senior project manager in EPRI's Generation sector. "As we got into it, we realized that the short answer was 'not very easily.' One key reason is that APR models are based on statistical correlations unique to a particular plant site."

Simultaneity was another limitation. "With APR, you have to capture everything at the same time for the math to work," said Robert Austin, senior program manager in EPRI's Nuclear sector. "You can't combine a once-per-minute temperature reading with a once-every-20-seconds electrical reading with a once-per-quarter oil analysis." He added that although APR made anomaly detection much easier, it did nothing for interpretation of data. "What does the problem mean? Should I worry about it?" said Austin. "Software development over the last five years has focused on this very point: making the interpretation easier."

The research team moved toward a more inclusive, flexible model of interpretation, closely akin to medical diagnostics. In fact, the developers use the terms *symptoms* and *features* to differentiate this form of input from raw data. Five years ago, recalled Austin, "EPRI and its members had this breakthrough concept to start looking at diagnostically relevant information." The idea, he explained, was to look at general features rather than detailed algorithms. "Rather than say the temperature is exceeding the expected behavior by some precise number, simply describe it as *hot*," said Austin. The advantage of this approach is that features can be more easily combined with other input gathered from disparate sources at different times, and it can more easily incorporate human experience.

The key objective is decision making. "Data by itself is useless," said Rusaw. "The only way to make it useful is to transform it into actionable information."

Automated Diagnosis

The drive for actionable information to help plant personnel diagnose equipment issues faster led to the creation of *fault signatures*, telltale combinations of symptoms indicative of a specific problem. These signatures, which draw upon years of direct power plant experience, became the underpinning of a new tool that automates the diagnostic process, called the *Diagnostic Advisor*.

The companion tool, the *Asset Fault Signature Database*, contains a master file of all the signatures—similar to how a medical library may organize health symptoms as indicators of diseases. Plant personnel interrogate the database using the Diagnostic Advisor. They enter symptoms and then receive a prioritized list of possible diagnoses that can be further refined with additional information (see software screen shots on this page). "The Diagnostic Advisor is an analytic engine that allows users to input various conditions they are observing for a particular piece of equipment," said Hollingshaus. "You're not necessarily using a numeric value—this bearing is 110 degrees, and this vibration is so many inches per second. Instead you are entering symptoms—high vibration, very low temperature, or a moderate increase in a vibration ratio. The Diagnostic Advisor logic engine then queries the signature database for the best fit."

This database *learns*. Its value and sophistication grow as user participation increases and more content is entered. "Suppose there is an indication of a fault in the plant," said Austin. "The crew put the features into the software, and the Diagnostic Advisor comes back with three possible results in order of likelihood—the most likely being the thrust bearing, but there is also a chance it is the radial bearing, and possibly something wrong with the oil system. So they inspect, and the technician comes back and says it is the radial bearing, number two on the list. The monitoring technician then updates the database so that if this happens again, it will give the radial bearing as the number one option."

Development Process

Software development moved from concept to specifications in 2010–2011. "The specifications process was rigorous," said Hollanshaus. "We had to specify how the software would be set up, how users would interact with databases, and how to avoid duplication. It has taken the last three years or so, going through various pilot phases, testing and reworking the system." The beta version of Fleet-Wide Prognostics and Health Management was launched in 2013 and was tested by several EPRI-member utilities, including Duke and Exelon, as well as the Idaho National Laboratory. The first commercial versions of the software were released in June.

EPRI is building additional companion tools for prognosis, known as *Remaining Useful Life Advisor* and *Remaining Useful Life Database*. "Given the current state of the asset, how much longer do I have before I have to fix it or replace it?" said Rusaw. "We've developed the software to ask those questions, but we are still working on the math behind it."

Utility Experience

Exelon is one of the utilities working closely with EPRI to develop new ways to monitor power plants. "We are always looking for innovative ways to improve plant efficiency and ensure safety," said Mohammed Yousuf, manager of engineering programs at Byron Nuclear Power Plant. He explained that every parameter in a nuclear plant is carefully controlled and monitored by expert operators and engineers, but there are still processes performed manually. Exelon deployed the APR program at its fleet several years ago. "The program is serving us well and has identified several important catches," said Yousuf. "We are excited about moving to the next level of advanced monitoring and diagnostics. The Fleet-Wide Prognostics and Health Management application will help us in diagnosing equipment issues and provide advice on troubleshooting steps."

Exelon is currently testing the software by diagnosing diesel generator problems. "The diesel generator is a complex machine, and developing fault signatures was a significant undertaking," said Yousuf. "Exelon's experts are collaborating with EPRI and Idaho National Laboratory to develop fault signatures for various failure modes."

Working with EPRI in a similar process, Duke Energy is testing the software on a generator step-up transformer at Shearon Harris Nuclear Power Station. Although the software has been installed and is in use at Exelon and Duke, they have not yet had problems with these assets that would trigger monitoring alarms. Results will emerge through broader application of the software at more plants in 2014, 2015, and beyond.

Next Steps

Populating the database is the next major task, and efforts will continue well into 2015. EPRI recently brought together subject matter experts from its Nuclear, Generation, and Power Delivery and Utilization sectors to create an initial list of major components for fault signature development.

An important milestone for 2015 is the development of a users group to gain experience with the diagnostic engine and help populate the database. "Going forward, we want to work with all parts of the industry, with EPRI serving as a clearinghouse and maintaining the master database for these signatures and models," said Hollingshaus. "The broader the participation, the more useful the diagnostic engine becomes."

Austin believes it is feasible to get as many as 20 utilities involved in the users group. "There is significant interest out there," he said. "When I describe this product to nuclear members, they get interested in the speed of troubleshooting. This is a huge challenge—but if we get this done even remotely right, it will help the industry move forward in a significant way."

The industry's interest in advanced monitoring techniques is expected to grow as utilities such as Exelon and Duke deploy these technologies. "It's a new tool, and just like any new idea, it is taking its time to be accepted by the industry," said Yousuf. "The technology has now matured, and industry can make good use of it. The leadership at Exelon has the vision to see huge benefits in the use of this technology and commit the resources to make it successful. I am certain that soon the rest of the industry will follow Exelon's lead and adopt this technology."

This article was written by Brent Barker. Background information was provided by Robert Austin, raustin@epri.com, 704.595.2529; Rick Rusaw, rrusaw@epri.com, 704.595.2690; and Brian Hollingshaus, bhollingshaus@epri.com, 704.595.2579.

Robert Austin is a senior program manager in EPRI's Nuclear sector, with primary responsibility for the Instrumentation and Controls program. He has had extensive experience in a range of engineering, research, and technical management disciplines through previous positions with AREVA, Duke Engineering & Services, and Electric Boat.

Rick Rusaw is a senior technical leader in EPRI's Nuclear sector, focusing on Instrumentation and Control systems.

Brian Hollingshaus is a senior project manager in EPRI's Generation sector. He leads the Maintenance Management and Technology program, which focuses on process optimization of equipment maintenance and reliability programs at fossil power plants.

GETTING SERIOUS ABOUT SUSTAINABILITY

THE STORY IN BRIEF

Since 2008, EPRI's Energy Sustainability Interest Group has provided a collaborative forum to advance sustainability in the electric power sector. With more than 40 companies participating today, the group produces research and tools that are helping utilities rigorously define, measure, and achieve greater sustainability.

When Carol Brown was first tasked with helping Portland General Electric become a more sustainable utility in 2007, she pursued a host of environment-friendly measures. At the time, she developed a presentation for employees on the distribution side of the Oregon-based company, everyone from linemen to office workers. "We helped them identify some visual goals they could grab ahold of—things like double-sided printing and no idling of vehicles," recalled Brown, Portland General Electric's sustainability manager.

Although she spoke about those early sustainability efforts with fondness—it was a way to focus employee attention on the issue and do some positive things—Brown was quick to point out how limited they were. "They weren't all that strategic, and they only involved one part of the company," said Brown. Those initiatives seem especially modest in retrospect, given just how ambitious Brown's activities are today.

Indeed, with the help of EPRI's Energy Sustainability Interest Group, Portland General Electric has precisely defined what sustainability means at the company—a collection of 16 key issues, ranging from corporate governance and risk management to greenhouse gas emissions. Even more consequentially, Brown is working to incorporate sustainability into her company's business processes, including its extensive capital review procedure. "The approach we are taking is to embed sustainability into everything we do rather than take it on a project-by-project basis," she said. The utility will issue its first-ever sustainability report later this year.

Portland General Electric is hardly the only company engaged in an evolution of sustainability from something peripheral to a presence at the very core of its operations. Indeed, at utilities large and small—especially the 40-plus companies that have already joined EPRI's interest group—there is an accelerating commitment to approach sustainability with strategic rigor.

In the past, the general definition of *sustainability*—the management of resources to ensure the long-term well-being of people and the planet—has led to confusion and oversimplification in the electric power sector and other industries. "Early on, it always landed in the lap of the environmental manager. It came to be seen as all about being green when it's not," said Sandy Nessing, who leads American Electric Power's sustainability efforts. "Sustainability is really a business strategy. It's about pursuing sustainable business growth."

Today, companies must pinpoint a precise definition of sustainability—a concept that is now widely understood to include environmental, social, and economic components—and then make often difficult choices about how to pursue it. "Everyone is committed to sustainability in a broad context," said Jessica Fox, an EPRI technical executive who manages the interest group. "But what are your specific commitments? How do we make this real?" Brown pointed to the interest group as a major reason that sustainability has become real at Portland General Electric: "If it were not for the interest group, I don't think we would be nearly as far as we are."

A Need for Collaboration

The maturation of sustainability at Portland General Electric, American Electric Power, and other utilities mirrors the shift in the interest group's focus in recent years. When the group was first founded in 2008, it was primarily a forum for companies to share ideas and experiences about sustainability. Although information sharing and collaboration remain at the group's core, it has more aggressively pursued research and development of tools to help utilities become more sustainable. It also provides a stronger collective voice for member companies in their discussions with policymakers, regulators, non-governmental organizations, and the general public. "The group provides a platform to leverage our voices," said Brent Dorsey, director of corporate environmental programs at Entergy.

The need for the interest group's thought leadership has grown. According to American Electric Power's Nessing, a main factor driving her company's involvement with the group is the imperative to be more proactive in discussions with various stakeholders about sustainability. "As the scrutiny on our industry has increased, there has been more demand for transparency and information, and we're getting bombarded with third-party disclosure surveys," said Nessing, adding that at one time her company was reporting on 80 different sustainability measures. "We were at the back of the bus with everybody telling us what was important and where we should be going, and I felt it was time for us to be in the driver's seat."

Getting more sophisticated, fact-based, and strategic about sustainability

This diagram shows the 15 material sustainability issues for the electric power sector organized into the three pillars of sustainability. Utilities face the challenge of achieving sustainability goals while fulfilling the core mandate of safe, reliable, and affordable electricity.

allows for more effective communication about why certain utility decisions are made. "We want to be able to say to the rest of the world, 'This is how we measure the sustainability of our business because this is what matters' versus someone else saying, 'This is how you ought to be measured,'" Nessing said. American Electric Power has been pursuing sustainability initiatives since 2006. In 2010, the company moved to an integrated financial/sustainability report as a result of investor interest in some sustainability issues being measured.

There also are internal drivers. An interest group survey last year found that nearly 60% of utilities placed sustainability as either a top or very high priority. The respondents cited several reasons for placing a premium on sustainability, such as managing operational and regulatory risk, improving corporate reputation, and supporting core company values. These responses reflect how sustainability can put a utility in a better overall position. "Being sustainable reduces your exposure to risk and liability from stakeholder protests or shareholder resolutions," said EPRI's Jessica Fox. "Because you have lower social risk, your company may be financially stronger."

One Size Does Not Fit All

Because there is no blanket definition for sustainability, advancing corporate strategies is not simple. Indeed, what constitutes sustainability for a utility depends on many factors. For instance, any comprehensive approach will naturally include a measure of greenhouse gas emissions. Yet there are vast differences in emissions among power companies that distribute electricity only and vertically integrated utilities responsible for generation, transmission, and distribution. Location also matters. "You have different environmental conditions depending on where you are located. In the Midwest, you have tons of water, and California has a major drought this year," said Fox. "There's not a one-size-fits-all approach to sustainability."

Complicating matters even further, efforts to improve sustainability in one area—whether it's environmental, social, or economic—may impact sustainability in another area. For example, an initiative to reduce greenhouse gas emissions may cause electricity prices to rise, making it more difficult for a company to meet another equally important sustainability goal: affordability. "It's a constant balance that is unique to each company," said Fox.

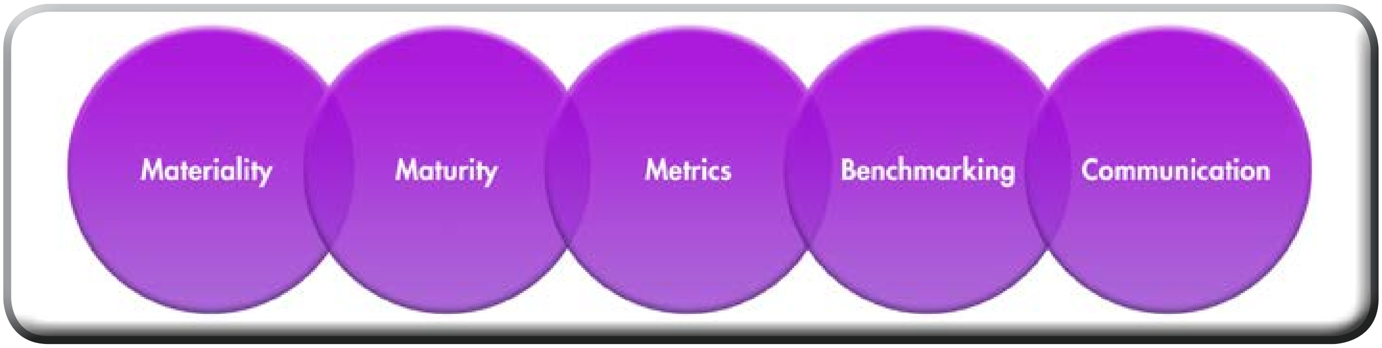
A Systematic Approach

EPRI's Energy Sustainability Interest Group provides a wide range of tools, research, and opportunities for collaboration that utilities need in order to chart their own course. "We help companies develop comprehensive sustainability strategies," said Fox.

To that end, the interest group supports five key steps in a sustainability strategy: materiality, maturity, metrics, benchmarking, and communication (see the figure on p. 17).

The first step, *materiality*, refers to the sustainability issues that are most relevant and important to a utility and its stakeholders. A recent EPRI report (3002000920) identified the 15 most material sustainability issues facing the electric power industry based on input from hundreds of utilities, government agencies, academic institutions, and environmental organizations. Grouped under the environmental, economic, and social pillars of sustainability, the issues include skilled workforce availability, greenhouse gas emissions, and water availability (see figure above). Companies like Entergy, Portland General Electric, and American Electric Power have already used the study to identify high-priority issues. In 2014, the interest group will issue a follow-up report outlining ways that utilities can address these issues.

The next step, *maturity*, involves self-assessment of progress in various



The five steps in a sustainability strategy

sustainability issues. "After you identify your issues, you figure out how you are doing on these issues and where you stand," said Fox. "That is your maturity." Last year, EPRI unveiled a pilot version of the Electric Power Sustainability Maturity Model, which allows utilities to gauge their maturity level in four material issues: greenhouse gas emissions, water availability, energy affordability, and energy reliability. A full version of the model incorporating all 15 material issues is anticipated for 2016.

To apply the model, EPRI runs expert-facilitated workshops to help companies accurately determine maturity, define goals, and identify concrete actions to support those goals. "At the workshop, we ask participants, 'Given where you are today, where do you want to be?" said Fox. "Based on the answer, we say, 'Here are the five things you need to do to achieve your goals.'"

An objective assessment of a utility's progress toward sustainability must include a rigorous way to measure and track performance—which is why *metrics* are a focus of the interest group's work in 2014 and 2015. "Am I using CO_2 equivalent per gigawatt-hour? Am I measuring water consumption or withdrawal? Do I care about the community that uses the water?" said Fox. "We are identifying the right metrics for the industry to measure their material issues."

Hand-in-hand with measurement is *benchmarking*, which allows utilities to compare their sustainability achievements with those of their peers. Under a collaborative agreement, EPRI will assume operation of the industry-wide benchmarking effort started by Tennessee Valley Authority in 2010. This initiative collects performance data for specific metrics and allows organizations to see where they stand relative to their peers through a process that blinds company-specific information. (For more information, see www.utilityenvironmentalfootprint.com.)

The interest group's fifth focus area is *communication*—how utilities broadcast their sustainability efforts to external audiences. This can happen through corporate social responsibility reports and voluntary disclosures to reporting organizations, such as the Global Reporting Initiative, the Carbon Disclosure Project, and the Sustainability Accounting Standards Board. The amount of effort required to track and interact with these and other reporting organizations is substantial. The interest group has formed a committee, led by representatives from Con Edison and NRG Energy, to inform these external reporting organizations and gain a better understanding of the costs, benefits, and current practices associated with participating in various disclosures. According to Fox, the research aims not only to inform what the reporting agencies request of companies, but also to provide a legitimate basis for why utilities use certain metrics and issue certain disclosures.

Giving Meaning to Sustainability

At the core of the interest group's work is crafting a more precise, measurable definition of sustainability for the electric power sector. The group ensures that all aspects of the work—whether it's identifying material issues and metrics or assessing costs and benefits—are based on facts and sound science.

At the same time, the group aims to provide a framework to translate the industry's collective lessons into customized sustainability strategies that fit the unique situation of each utility. Goals and targets, maturity levels, disclosures, and properly balanced decisions will always be individual propositions. Providing the tools to help utilities with these tasks will continue to be the interest group's focus for the foreseeable future.

In addition to advancing the industry, EPRI is advancing its own corporate sustainability efforts and recently hired Anda Ray as its first chief sustainability officer.

"Our sustainability effort has been integrated into our company DNA," said Entergy's Brent Dorsey. "EPRI is helping us further strengthen our sustainability strategies, leveraging the good into great."

This article was written by Chris Warren. Background information was provided by Jessica Fox, jfox@epri.com, 650.855.2138.

Jessica Fox is a technical executive at EPRI, where she leads efforts on water quality trading, ecosystem services, sustainability, and related work.

R&D Quick Hits

Electric Vehicles: A Good Deal for the Consumer Gets Better

Aided by substantial recent price declines, plug-in electric vehicles (PEVs) are more cost-effective for consumers than comparable conventional and hybrid vehicles, according to an EPRI report. Given a 150,000-mile vehicle life, the study found that the 2014 Chevrolet Volt, 2013 Nissan Leaf, 2013 Ford C-Max Energi, and 2014 Toyota Prius Plug-In have significantly lower costs than feature-matched conventional and hybrid vehicles. For example, the Leaf's total cost of ownership is $36,892, compared to $44,949 for a similarly equipped conventional model. Payback times for PEVs continue to shorten. Costs considered in the analysis include purchase price, maintenance, gasoline, electricity, and expenses to use another vehicle on days in which driving distances exceed PEV range.

The study reinforces the results of a 2013 EPRI report on the lifetime costs of the Volt and Leaf. In April 2014, cumulative PEV sales in the United States topped 200,000, doubling sales from April 2013. To download the report, go to www.epri.com and enter product ID 3002004054 in Search.

"Less Than One Millionth"—Sensitive Gauges Provide Early Warning System for Cracks in Nuclear Plants

For four years, EPRI has been developing a fiber-optic strain gauge system that can detect early stages of stress corrosion cracking, a type of degradation that can lead to failure of piping systems and other components in nuclear power plants. Recent tests have shown that the gauges, mounted on a pipe's outside surface, can detect the initial formation of cracks growing from the inside surface.

The remarkably sensitive gauges can detect changes in a pipe's length, caused by cracking, that are less than one millionth of the original length. By flagging tiny changes in cracks for more detailed inspection, the gauges can help boost awareness of component conditions and plant safety. No other technology is available that can be attached directly to surfaces and discern new cracks without damaging the component. To download the report on the most recent test results, go to www.epri.com and enter product ID 3002003219 in Search.

R&D Oracles: Delphi Panels Inform Long-Range Research Priorities

EPRI has convened Delphi panels—opinion leaders from academia, government, and industry—to assess those business drivers that can affect R&D priorities substantially for EPRI, power companies, and government agencies over the next 20 years, with the goal of developing robust research portfolios. The three main drivers are energy policy changes, demand for electricity, and natural gas prices.

As the greatest uncertainty, the panels identified action in the United States to address climate change, with near-term regulation potentially leading to broader policy addressing power sector emissions. The panels generally agreed that gas prices will remain between $4 and $7 per MMBtu out to 2025, and that demand for grid power in the United States will stabilize or decline as a result of energy efficiency gains, rooftop solar systems, and other distributed resources.

EPRI will continue engaging the Delphi panels to dig deeper into the three drivers. In addition, EPRI has started research on methods to forecast electricity demand, the effects of new climate policies on the generation mix, and emissions from increased central and distributed gas-fired generation.

Facts, Figures, and Findings from EPRI Research, Reports, and Other Sources

Meet Phoebe: She Can Do 8 Trillion of These per Second

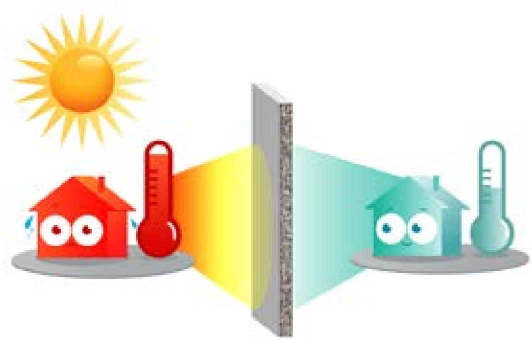
As the world's supercomputers gain speed and power, they offer game-changing potential for addressing the power industry's multilayered challenges through modeling and simulation. Aware of this potential, EPRI in 2013 plugged in Phoebe, a refrigerator-sized computer that can make 8 trillion calculations per second.

Even with 31 nodes (network connection points), each with two Intel® Xeon® central processing units, Phoebe is not nearly as powerful as Oak Ridge National Laboratory's basketball court–sized Titan, the fastest supercomputer in the United States and capable of 27 quadrillion calculations per second. But Phoebe is still lightning-fast—1000 times faster than a typical home or work computer.

Phoebe can advance work across EPRI's research areas by revealing trends in vast amounts of data and by enabling the evaluation of complex scenarios and virtual experiments. For example, nuclear researchers at EPRI, in partnership with the Consortium for Advanced Simulation of Light Water Reactors, are using Phoebe to test fuel performance software that can improve nuclear plant operations. EPRI generation researchers are using Phoebe to run simulations to better understand processes inside coal-fired boilers.

From Candles to Cooling: Can Meltable Wall Materials Make Homes More Energy-Efficient?

Embedding engineered paraffin beads in drywall can reduce heat transfer into homes and summer energy consumption of air conditioning units, according to a preliminary EPRI study. Paraffin designed to melt near room temperature can absorb heat during melting that would otherwise be transferred indoors. The heat is released later, as the paraffin solidifies.



In EPRI's Knoxville, Tennessee, laboratory, researchers built a typical house wall with gypsum-based drywall embedded with tiny paraffin beads that melt at about 23°C. They exposed the wall's interior and exterior surfaces to indoor and outdoor temperatures typical of summer days and nights, and recorded temperatures in different parts of the wall over time. A wall without paraffin served as the control.

The data show that the paraffin increased heat storage in the wall and reduced heat flow to the internal space—indicating that further investigation is warranted. To download the report, go to www.epri.com and enter product ID 3002002459 in Search.

Turning Up the "Smarts" in Thermostats and Home Energy Management

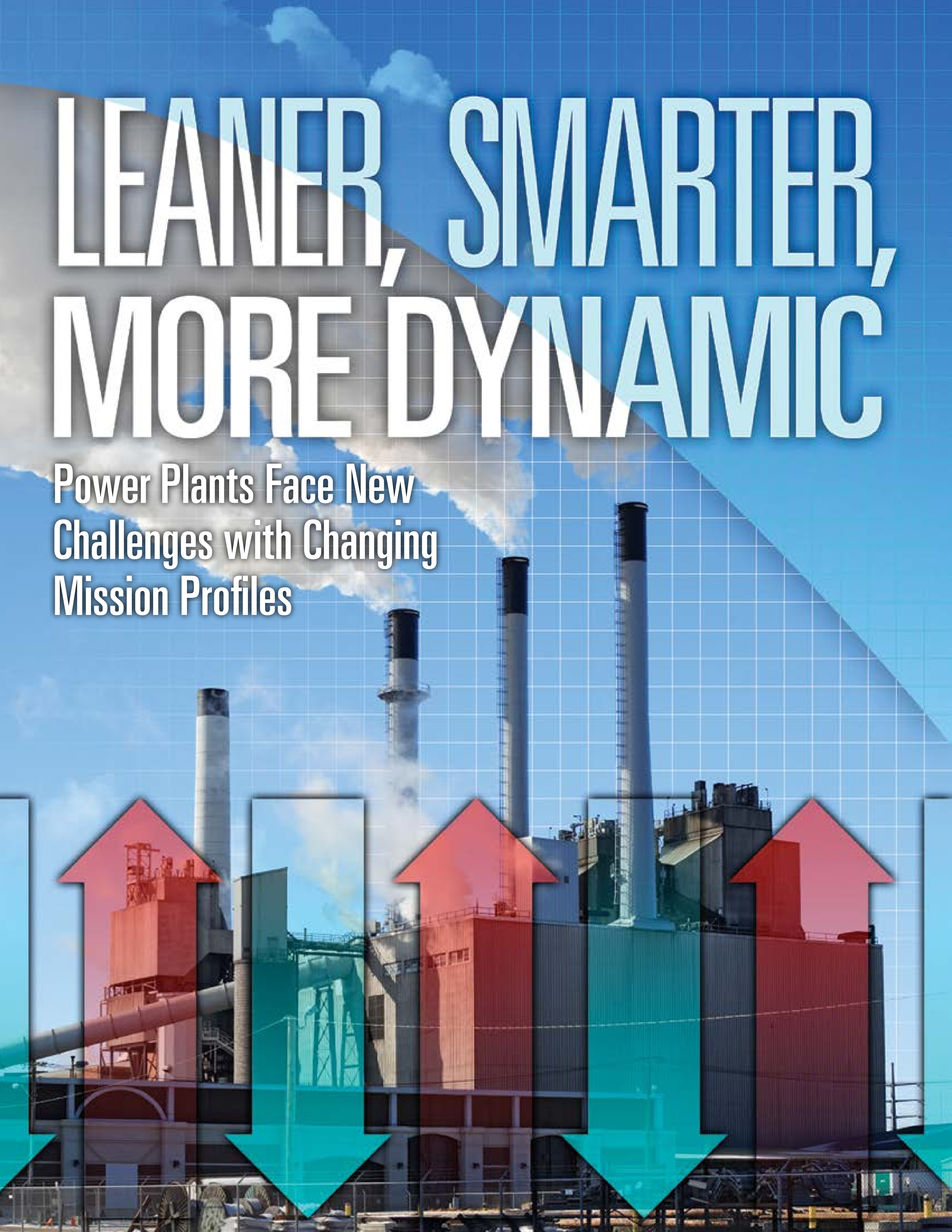
EPRI has created an industry forum to guide the development of national standards and technology for home energy management systems, which include smart thermostats and other devices that measure, control, and analyze energy use in homes. To promote collaboration among stakeholders in this rapidly growing market, EPRI convened a summit in June with 10 device vendors, 22 utilities, the U.S. Environmental Protection Agency (EPA), and the U.S. Department of Energy. The summit explored important topics, including factors that drive consumers to purchase these devices, connectivity approaches that enable utility goals, data ownership and privacy, and utility access and use of data.

A key discussion focused on how to evaluate the energy savings and demand response potential from these devices. This is timely in light of EPA's recent announcement that it is considering a new ENERGY STAR program to measure and rate the effectiveness of smart climate control systems through periodic submission of data from the devices. Using insights on evaluation methods from the summit as a starting point, EPA will continue to work with EPRI on new standards.

EPRI plans to make this an ongoing forum. For more information, contact Ram Narayanamurthy, rnarayanamurthy@epri.com, 650.855.2419.

LEANER, SMARTER, MORE DYNAMIC

Power Plants Face New Challenges with Changing Mission Profiles



In the wake of 1990s electricity sector reforms, virtually the entire fleet of coal- and natural gas-fired power plants in the United Kingdom faced the daunting transition from traditional, steady-state baseload operation to various modes of flexible operation.

In an effort to survive in the country's fast-paced, privatized power sector, Britain's fossil fleet operators abandoned the established practice of continuous year-round full-power generation, for which most plants principally were designed. Instead, they began daily cycles of starting and stopping, sometimes twice a day, ramping down to minimum levels overnight or sporadically shutting off for days, weeks, and months.

"A lot of plants in the UK did serious damage when they started doing flexible operations, most of it due to poor planning," recalled Mike Woodhouse, a veteran UK-based power plant engineer and station manager with nearly three decades of experience at Scottish Power, PowerGen, and the Central Electricity Generating Board.

Little did UK plant operators know back then that they were the first to face the challenges associated with fossil and nuclear generation's changing mission profiles, which today affect electric power companies around the world.

THE STORY IN BRIEF

Driven by the growth of intermittent renewable generation, more dynamic demand, tightening emissions standards, shrinking budgets, and the loss of experienced operators, fossil fuel and nuclear power plants face changing mission profiles. They must operate within narrower parameters, address component degradation, and maintain environmental control system performance—all of which place greater demands on staff. EPRI is working with the electric power industry on many fronts to address these challenges.

Many Drivers and Challenges

Historically, power plant design, operational and maintenance strategies, staff training, and research have focused on supporting the mission of a stable operating condition at relatively high capacity factors. Today, increasingly stringent environmental regulations, tighter operational budgets, higher levels of renewable energy generation, and more demand response have created a wider range of mission profiles for generation assets:

- More variation in operating demands (for example, cycling between output levels)
- Increased potential for extended unit layup periods
- Prolonged operations at low output levels, known as *low turndown*
- Many activities for maintaining environmental control systems performance

To enable different mission profiles while meeting reliability, economic, compliance, and safety expectations, power companies face the challenge of defining cost-effective optimal operations under different combinations of constraints. Changing mission profiles increase the complexity of long-range planning for the entire fleet.

An automobile analogy illustrates the concept. Consider a car, driven for years by the same person, mostly on the freeway, with occasional short trips on city streets. In that role, it served reliably and economically. Now it is used as a taxi, with frequent stops and starts, great variety in passengers and cargo, and long idles at curbside waiting for the next fare. The taxi also has new systems under the hood to reduce its tailpipe emissions. Keeping this car running smoothly in this more demanding role requires new driver skills and strategies for fuel management, maintenance, and repairs.

Fossil-fueled and nuclear power plants today face a similar—yet more complex—change. Growing deployment of intermittent renewable generation is forcing fossil plants to ramp up and down, or *cycle*, to balance electricity supply and demand. Combined-cycle plants fueled by low-cost natural gas are dispatched ahead of coal units in some regions, requiring some units to shut down, sometimes for extended layups. Under such non-baseload conditions, it is typically more difficult to maintain environmental control systems performance to meet increasingly stringent pollution regulations. Demand is becoming more variable as demand response and distributed generation play larger roles in the electric system.

Resulting mission profiles run the gamut from baseload generation to operating only a few weeks, days, or even hours a year while meeting reliability, regulatory, and safety requirements. These changes coincide with tightening operations and maintenance (O&M) budgets, even as O&M staff address plant component degradation resulting from flexible operations, while tailoring these activities to specific operating modes.

EPRI is collaborating with power companies to address key challenges associated with new mission profiles:

1. Tighter design margins. For temperature, pressure, and other process conditions in which systems and components must operate, the range is shrinking, making plant management more complex.

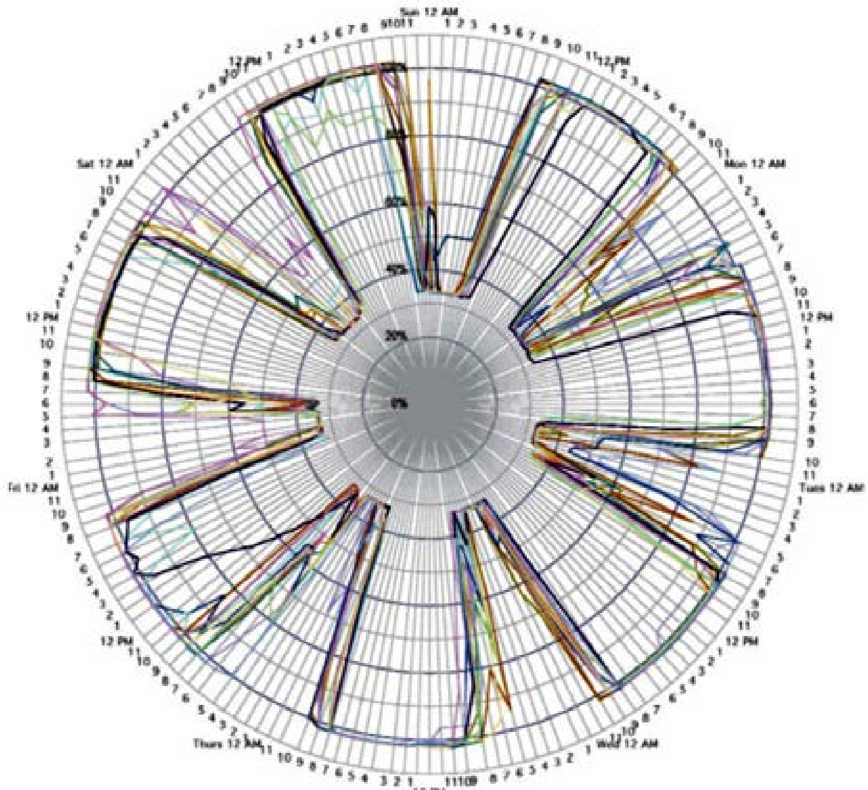


Illustration of a two-shifting operational mode—startup and shutdown once a day to meet demand. The circular shape represents a week of operation.

Plants are operating closer to their components' design limits. As a result, there may be more dependence on measurement, optimization and process controls, and burdens on plant operators. To address this challenge, EPRI R&D includes the development of new instrumentation and controls to manage frequent ramping more effectively.

2. Unintended impacts. Multiple environmental control systems, new O&M strategies, and operating systems within smaller windows can combine to create unintended adverse effects for equipment condition and system performance. Such impacts typically are not well defined or documented, and EPRI is developing research to systematically identify and manage them.

3. Greater demands on staff. Changes to plant design and operational missions tend to place a larger burden on plant staff. While market trends will drive some plant owners to invest capital in plant modifications, others will focus on changing O&M strategies and processes. Such changes can place more responsibility, knowledge requirements, and restrictions on plant staff. For example, instead of installing a new baghouse to meet particulate standards, some companies will rely on improving the performance of electrostatic precipitators (another emissions control system) and better monitoring and controlling of scrubbers and their chemistry—approaches that may require additional staff training.

4. Real-time experimentation. Because of the unprecedented speed in which plant mission profiles are changing, power companies have been, in effect, managing these challenges in real time while operating their plants—and the results are informing significant investment decisions. EPRI is helping to communicate insights from these activities across the industry.

5. Need for new skills. Driven by more quality data, a changing workforce, and the need for leaner O&M, data analytics and centralized monitoring and diagnostics will become increasingly important in managing plant performance. Advanced technologies and data integration require new skills in data analysis, interpretation, and aggregation. Power companies are likely to focus staff training in these areas.

Preparing for Operational Flexibility

A critical component of changing mission profiles is enhancing plants' operational flexibility, and EPRI is focusing substantial R&D resources here. Although fossil and nuclear plants may have the technical ability to operate flexibly, they were primarily designed and optimized for continuous, full-power baseload generation. EPRI is investigating the design and operational impacts of flexible operations to equip owners of current and future plants to make sound asset decisions.

Flexible operations "has been an issue on and off over the past few decades, depending on whether there is an oversupply of generation," said EPRI's Steve Hesler. "Now, for the first time, the dynamics include the combination of increasing must-take, non-dispatchable renewables and historically low gas prices, and the accelerated retirement of smaller, more flexible assets."

Drawing from lessons that Mike Woodhouse and other experts learned through converting fossil plants from baseload to flexible operations, EPRI recently published *Flexible Operations Readiness Guide* (3002002070) a basic reference for plant operators seeking to develop site-specific approaches to efficient flexible operations.

Published in a practical Excel spreadsheet format, the guide focuses on critical issues, main areas of concern, and possible solutions associated with operating and maintaining gas- and coal-fired units in six specific duty modes of flexible operation. These include two-shifting and double two-shifting—startup and shutdown once and twice a day—as well as weekend shutdown and sporadic operation. The guide also addresses operating at varying load as

Flexible Operation of Nuclear Power Plants

EPRI conducts a significant R&D program aimed at understanding the impacts of flexible operations on nuclear power plants.

"Not all nuclear plants will have to consider flexible operations," said EPRI Program Manager Sherry Bernhoft. However, if a nuclear power plant operator has decided to explore the possibility of operating flexibly, "we want to do the research that will be needed to ensure that such operating modes will not have a negative impact on fuel integrity, safety, and reliability. Those requirements are non-negotiable," she said.

While some countries have experience with flexible operations of nuclear power plants, the knowledge base is rather limited, she added.

In addition to evaluating fuel integrity questions, EPRI's nuclear flexibility program is concerned with issues such as maintaining proper system chemistry to protect components from corrosion and wear, developing a prioritization matrix of highest cost and highest risk components—such as turbines, moisture separator reheaters, and separator pumps—and installing instrumentation to give operators real-time updates. These and other issues are detailed in a 2014 EPRI report, *Approach to Transition Nuclear Power Plants to Flexible Power Operations* (3002002612).

Developed in coordination with the Institute of Nuclear Power Operations, the report includes a detailed investigation of the necessary modifications in power control methods, primary system and components, and balance of plant for each reactor type.

For more information on flexible operations at nuclear power plants, contact Sherry Bernhoft at sbernhoft@epri.com.

demand changes (load following) and daytime baseload operation with nighttime minimum operation (on-load cycling).

Covered in detail are cycling-related impacts such as thermal fatigue, thermal expansion, and corrosion on key power plant components, including heat recovery steam generators, boilers, turbines, feedwater and condensing systems, and balance-of-plant components.

The *Readiness Guide* project is one of more than 50 diverse EPRI R&D efforts in operational flexibility completed in recent years, underway, or planned. The common thread is the focus on improving the flexible operation of existing fleets and designing more flexibility into future fleets.

For example, research on flexible operation of coal plants is featured in a 2013 EPRI report, *Flexible Operation of Current and Next-Generation Coal Plants, With and Without Carbon Capture* (3002001561), which presents design improvements for current and future coal generation.

Other research is addressing the ability to run units for periods of time at the lowest possible load. "Having a unit 'parked' at low load provides the grid with significant spinning reserve that can be dispatched very quickly to respond to fluctuations in supply of renewables," said Hesler. But, he added, "both combined-cycle and most coal plants are limited in how low they can operate due to the need to prevent damage to the nitrogen-oxide removal systems."

EPRI is addressing issues associated with low-load operation in its 2014 research project "Systematic Approach to Reducing Minimum Load," which focuses on coal-fired power plants.

Based on previous EPRI technical reports on such low-load operation, the Tennessee Valley Authority developed a strategy to improve the turndown of approximately 1500 MW of generation at minimum load periods. The new strategy resulted in a significant savings in startup costs without affecting the reliability of the cycled units.

But even with such successes, new challenges with flexible operation are bound to emerge in coming years because of "the retirement issue," said Hesler. "A lot of old coal plants that are not very efficient are going to be forced to retire soon, but because they are small and do not have emissions control systems, they are very flexible. So we are going to start shutting down the smaller, more flexible units, and flexibility will have to be taken up by larger units." But larger units have emissions control equipment that limits their ability to turn down, he added.

Changing mission profiles for electric generation units are driving power companies to address a complex set of issues holistically, simultaneously, and in real time. Addressing these challenges is fundamental to EPRI's R&D strategy.

This article was written by Garrett Hering. Background information was provided by Revis James, rejames@epri.com, 202.293.6348; Norris Hirota, nhirota@epri.com, 650.855.2084; and Steve Hesler, shesler@epri.com, 704.595.2680.

Revis James, a director in EPRI's Generation sector, is responsible for several research programs including advanced coal generation, steam turbine-generators, boiler life and availability, and large-scale industry demonstration projects.

Norris Hirota, a director in EPRI's Generation sector, manages technology development programs for power plant operations, maintenance, materials, chemistry, and environmental controls.

Steve Hesler, a program manager in EPRI's Generation sector, is responsible for flexible operations research to assess impacts of power plant cycling and develop damage mitigation strategies.

New Utility Business Strategies:

An Evolution Rather Than a Revolution

Julia Hamm is president and CEO of the Solar Electric Power Association (SEPA), an educational non-profit organization that helps utilities integrate solar energy into their portfolios. In this interview with *EPRI Journal*, she discusses key aspects of shifting utility business models, including the role of regulators, the pace of the transition, and opportunities for collaboration.

EJ: Recent discussion has sometimes characterized deployment of distributed energy resources as a threat to traditional utility business models. Is "threat" the right word? What are the fundamental challenges?

Hamm: We can see how it can reasonably be stated that this is a threat that utilities should be concerned about, but I also think there has been a little bit of overdramatizing of the situation. There are very few places in the United States where distributed generation penetration is at or close to reaching levels that truly threaten the utility business model.

I see it more as an evolution than a revolution. In the long term, the business model is going to have to change; the regulatory model is going to have to change. What that looks like, I honestly don't know yet. The main challenge for investor-owned utilities is changing the regulatory paradigm, the regulatory compact. Ultimately, it's up to regulators how the business model can shift, how the utility makes its money, what the utility is allowed to do. The biggest challenge is for the utility industry and the regulatory bodies to collectively figure out a road map by which the status quo can be changed and to make sure the grid itself can be maintained by an entity that is competent in grid service.

EJ: How can federal and state regulators facilitate the shift in utility business models that ultimately support customers and greater reliability?

Hamm: One thing that's been very effective is when regulators have said to utilities and the active stakeholders in the state, "Go negotiate outside of the regulatory hearing room, and then bring it back to us." That in almost all cases has been quite effective, as opposed to situations where that did not happen and things just got very ugly during the regulatory process and ultimately, in the end, no one is very happy.

The slowness of the regulatory process is really an impediment. Things are starting to change quickly when it comes to consumers and the technology that's available to them, and it's very hard for utilities to react fast enough to what's going on in the market. Once those parties can come back to the commission with something they've negotiated, then the regulators can act pretty quickly.

EJ: What examples come to mind?

Hamm: In Colorado, there was a negotiated deal between Xcel and the Solar Energy Industries Association around the solar incentive program. Massachusetts utilities and stakeholders are getting close to an agreement for a minimum bill for customers, in exchange for uncapped net metering. There are other components, but that's the big piece of the deal.

In South Carolina, there isn't much of any solar market yet, but Duke Energy has been focusing for over a year with local renewable energy interests, local environmental groups, and other stakeholders to have some common objectives about helping to increase solar penetration in the state.

EJ: What is your perspective on the efforts in New York?

Hamm: One of the key elements is the conversation around re-designing things so that the utilities don't have to stop at the meter, but can become more of a full-service energy service provider. It will be interesting to see whether this makes vertically integrated utilities more open to restructuring and separating out the generation component, if in exchange, they can go behind the meter from a services perspective.

EJ: From your experience engaging with utilities, how would you characterize their responses to distributed resources deployment?

Hamm: The conversation has changed quite dramatically. I think we're out of the denial phase. Across the board, utility executives at this point acknowledge that even if they're not seeing a lot of distributed resources today, they know it's coming soon. We're spending a lot of time with utility teams, starting with their executives and their officers, talking about distributed resources from a corporate strategy standpoint. Historically, conversations about solar, renewables, and other distributed resources have been siloed in utilities, but now it's part of the big-picture corporate strategy. In most cases, we see them looking at this—or wanting to

"The biggest challenge is for the utility industry and the regulatory bodies to collectively figure out a road map by which the status quo can be changed and to make sure the grid itself can be maintained by an entity that is competent in grid service."

look at this—as an opportunity they can capitalize on rather than as a threat.

EJ: In your conversations with executives, do you present a choice between business as usual and offering new services, or is it more complicated?

Hamm: We always talk in terms of a transition plan. We believe it would be extremely difficult to come up with some new strategy, flip the switch overnight, and just go forward with the new way. Certainly a significant portion of what utilities do will be business as usual, at least for the foreseeable future. But rolling out new services to customers is more complicated. It's going to be different for different utilities—to know what the ideal end state looks like and then consistently and progressively move in that direction.

EJ: How much time is involved?

Hamm: I think it's going to be different for every utility based on how rapid the deployment of distributed energy resources is in their service territory. Certainly some of the California utilities and a handful of others across the country can't move slowly, and business as usual is not going to work.

I use San Diego Gas & Electric as an example. A year ago, they were getting on average about 600 customer PV interconnection applications a month. Now they're getting 1200. At that pace, a significant portion of their customer base will have on-site, distributed resources, and they have to figure out pretty quickly what they're going to do differently to operate and maintain the grid and stay in business.

EJ: If there is to be a productive discussion about the grid's 'evolution' as you put it, what is the best way to talk to the public in general? What key points need to be made so that people can collaborate as you described earlier?

Hamm: I'll point right back to EPRI and say the value of The Integrated Grid work you are doing is an important part of that conversation. I think there are some misperceptions by customers—not understanding that if you have solar, you still need the grid in most cases. Many customers don't understand that even with a PV system, they still rely on the grid to a significant degree. As things exist today, if the power goes out, your PV system isn't going to be working.

Obviously, utilities want to make customers aware of this, but reputable solar companies want to make sure customers understand those things as well. It is not in a reputable solar company's interest for any customer to have false expectations of the product that they're purchasing. There are opportunities for the two industries to work together to say you're not eliminating your need for the grid. You still need it, and in fact through the grid and grid-tied services, your solar can grow in value.

EJ: What kind of research and work is SEPA doing in these areas?

Hamm: We've been monitoring different business models that utilities are doing, and we have a database that catalogs about 400 utilities and all of the different solar elements within those utilities. We have a 'solar strategic framework' that we walk utilities through to help them cover the bases and ask the right questions in the right order.

We're also doing deeper dives into various strategies. For example, community solar is one of the hottest topics of conversation among the utilities that we work with—utilities creating a community solar offering for their customers. The utility can place a larger solar PV system on the grid in a location that makes the most sense from a technical standpoint, and they can offer solar to a much broader swath of the customer base. Close to three-quarters of residential customers in the United States

"Across the board, utility executives at this point acknowledge that even if they're not seeing a lot of distributed resources today, they know it's coming soon."

cannot have rooftop PV at any price, because they live in a condo or apartment, or their roof is shaded or lacks the right orientation. We have a community solar design guide, and there's a lot of other work happening in that space.

We're looking at how the holding companies are acquiring commercial/industrial solar rooftop installation companies, such as Edison International's purchase of SoCore Energy. A number of years ago, Edison pursued the commercial rooftop space through the regulated utility. When that didn't really work as they thought it would, the holding company said, 'Well, we still like that space; we still think it's the right space to be in, but we're going to acquire a solar developer that already exists and have that as part of our unregulated business.' Similarly, NextEra purchased a solar developer focused on the commercial/industrial space.

My perception is that it's much easier to pursue this on the unregulated side because they don't have to go through the regulatory process. Utilities are able to get their foot in the door, benefit financially from the market, and learn about the industry and technology, everything they need to know—which will ultimately impact the regulated side of the business.

EJ: What do you see with respect to utility collaboration with third-party solar developers and others?

Hamm: We have a paper about all the different opportunities or approaches utilities could take to work with third-party owners of solar installations. We've seen a couple of things already happen, much around one company in particular, and that's Clean Power Finance.

Clean Power Finance offers financing and a software platform for companies that do residential solar installations. And some utilities have made investments in Clean Power Finance.

Integrys is working with Clean Power Finance to have a solar lease or PPA [power purchase agreement] product available as a utility-branded solar offering.

EJ: Do you see business models that have real promise in taking advantage of the full integration of distributed resources?

Hamm: We published a paper recently laying out the business case for utilities to own smart inverters—not the PV system on someone's house—but the smart inverter since it looks like a traditional utility distribution asset. This doesn't require a huge business model change because they would earn money in the same way they have in the past, but just investing in different assets.

If you can combine control of the smart inverter, storage, and demand-side management, you can see a very strong opportunity to manage a highly distributed electric system. This idea has been kicked around for three or four years, but it just hasn't gotten a lot of air time. We're really trying to raise the visibility of that.

EJ: So what new thinking needs to go with new opportunities?

Hamm: Historically, anything related to solar was isolated within the utility. People who had renewable energy in their job titles were in a room coming up with something and then rolling it out. Solar touches almost every function within the utility. It cannot be this isolated conversation anymore. Utilities have to figure out where to place accountabilities related to solar projects or programs and how information needs to flow across functions.

Community solar is a great example. It has to immediately involve the billing department, the customer service team, the marketing department, the legal team, and so on.

EJ: Any technologies that have your particular interest right now?

Hamm: Solar forecasting software is important from a grid management standpoint. We've surveyed the landscape to help utilities understand which companies are doing solar forecasting and what they have to offer. If we can start combining smart inverters, storage, and improved forecasting, utilities can get much more comfortable with managing a distributed grid.

EJ: Where is it good to focus R&D?

Hamm: How all the pieces fit together, not just specific technologies or items in isolation, but all of these things in combination. It's about making all the pieces work together from a technological or grid management standpoint and being able to stay relevant as a business.

"...community solar is one of the hottest topics of conversation among the utilities that we work with..."

"Solar touches almost every function within the utility. It cannot be this isolated conversation anymore."

Addressing Security Threats: New Guidelines Help Utilities Detect, Assess, and Respond Through an Integrated Center

A new EPRI report (3002000374) outlines strategies for utilities to begin planning and implementing an integrated security operations center (ISOC). The research is based on a review of existing studies, examination of ISOC implementation efforts outside the electricity sector, and input from utilities. The report guides utilities through important initial steps, including making the internal business case, identifying potential organizational roadblocks, and laying out a realistic implementation process.

Response to an Evolving Threat

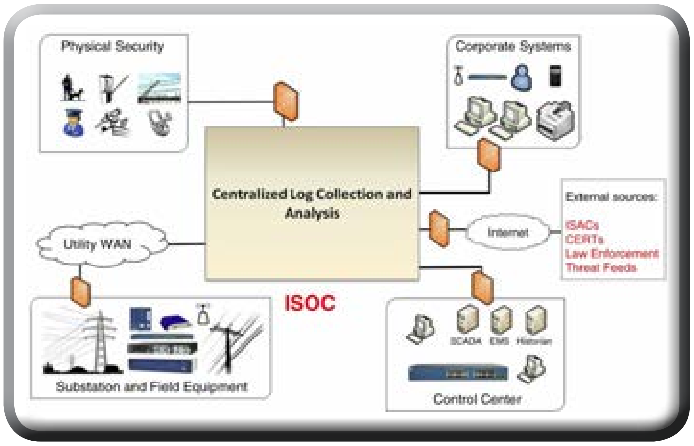
Cyber and physical threats to utilities are expanding in number and complexity, but approaches to detecting and responding to them have not evolved sufficiently. Today, multiple entities within utilities collect and analyze security information on everything from data centers to energy management systems to field equipment. Corralling and making sense of large amounts of data from numerous sources is such a large undertaking that suspicious activity is often discovered after a security event has taken place.

An ISOC is a central hub to synthesize and respond to information and alarms issued by traditionally siloed security organizations, potentially offering real-time intelligence, improved threat analysis, better use of security resources, and central security incident management. EPRI's research revealed substantial challenges that utilities must address before implementing an ISOC, including delicate organizational dynamics, technology, and training. Doing it properly requires staff time and resources.

A Multiyear Process

A key insight from EPRI's research is that ISOC planning and implementation cannot be accomplished overnight. A methodical approach addressing both technology and personnel is best. EPRI's recommendations include:

- **Foster executive support.** Because ISOC implementation requires capital investment and potential reorganizations, senior management support is essential. A good starting point: summarize utility security risks and explain how an ISOC can address them.
- **Engage business units.** Interdepartmental collaboration is vital to the success of an ISOC. To lay the groundwork for an ISOC initiative, demonstrate how it will benefit each business unit's operations and build trust among divisions.



An example of an ISOC architecture

- **Prioritize ISOC business unit implementation.** This is especially challenging because so many systems, devices, and vendors are involved in power delivery and generation facility security. It's critical for utilities to determine how and when to phase-in and coordinate devices and monitoring systems from each unit.
- **Develop event log requirements.** Be clear on what to do with the massive amount of data generated. One important question is how long to retain data in a readily available format.
- **Select ISOC architecture and technology.** Much of this will be determined by a utility's current capabilities and ISOC goals. Decide whether the ISOC will be managed in-house, by a third party, or through a hybrid approach.
- **Take it slow.** Staff need to be trained or hired. New technologies and work processes must be implemented and refined. This takes time and a willingness to revisit past decisions.

Moving Beyond Planning

The next phase of EPRI's ISOC research will focus on retrieving event logs from field devices, normalizing logs and alarms from various equipment providers, and identifying gaps in device security alarms. The aim is to educate utilities on how to effectively begin deploying an ISOC.

For more information, contact Galen Rasche, grasche@epri.com, 650.855.8779.

EPRI, EPA Collaborate on Research to Make Air Quality Health Assessment Tool More Robust

Ongoing EPRI research is working to improve a widely used tool for evaluating the benefits of air quality regulations. Developed by the U.S. Environmental Protection Agency (EPA), the Benefits Mapping and Analysis Program, or BenMAP, is a Windows®-based computer program used to estimate the health and economic impacts of changes in air quality.

A prominent recent example is EPA's proposed Mercury and Air Toxics Standards (MATS) rule to regulate power plant emissions of hazardous air pollutants. Using BenMAP, EPA estimates that the rule's implementation would save an estimated 4,200–11,000 lives each year—a decrease in mortality due entirely to the reduction of fine particulate matter. Applied routinely as part of EPA's regulatory impact analyses, BenMAP can also estimate monetary benefit from improved air quality—for instance, a dollar amount calculated by multiplying the number of estimated deaths avoided by a set statistical value of a life.

Room for Improvement

Although a helpful tool for regulators, policymakers, and other stakeholders, BenMAP's current version has limitations, and EPRI is collaborating with EPA to improve it. In the first phase, EPRI's analysis focused on BenMAP's concentration-response functions for particulate matter. In simple terms, a *concentration-response function* expresses the association between long-term exposure to a pollutant and a health outcome—in BenMAP's case, mortality.

While there is a large body of academic research examining the relationship between particulate matter concentrations and mortality, BenMAP's calculations rely on just three concentration-response functions from three studies. "We identified 59 functions in the scientific literature," said Annette Rohr, principal technical leader, Air Quality and Health at EPRI. "It was clear that BenMAP didn't reflect the breadth of the literature available. We want to be sure that the benefits calculated accurately reflect all the research."

Also, BenMAP's three concentration-response functions do not reflect other credible studies that found no mortality due to particulate matter. "When the full range of concentration-response functions is included in a benefits calculation, the numerical range of the results is wider than what the EPA estimates, and importantly, includes zero," said Rohr. This is a significant shortcoming, particularly because regulatory impact analyses don't have the same level of peer review as other documents do in setting particulate matter standards.

EPRI research is helping to improve an EPA tool used to assess the benefits of air quality regulations.

A More Comprehensive Tool and Next Steps

EPRI's analysis revealed the tool's inability to consider specific components of particulate matter. In light of increasing evidence that some components may have a stronger impact on health than others, this gap demonstrates room for improvement. Indeed, EPRI research has shown that carbon-containing components from traffic and woodsmoke may be more harmful to health than other components, such as sulfates emitted by power plants.

Another concern is that BenMAP cannot perform integrated uncertainty analyses, which simultaneously look at all sources of uncertainty in a risk assessment. Developing new ways to incorporate uncertainty into BenMAP's calculations is the focus of the research phase now underway.

EPA plans to use EPRI's research findings to improve BenMAP by facilitating the incorporation of an additional 56 concentration-response functions into a database linked to BenMAP. Although these new functions won't be default options, they will make the tool more versatile.

A Collaborative Relationship

EPA has been a helpful collaborator throughout EPRI's assessment of BenMAP. "We want to be open and transparent and work with the Agency," said Rohr. She added that one of her EPA contacts reviewed an article about EPRI's BenMAP research, to be published in the journal *Risk Analysis*. "The continuing collaboration with EPA is of great value to the project," she said.

For more information, contact Annette Rohr, arohr@epri.com, 425.298.4374.

Micro-Technology Evaluated in a Vibration Sensor That Rides on Turbine Blades

EPRI is investigating how to manufacture a sensor that can continuously measure vibrations of low-pressure steam turbine blades in fossil fuel and nuclear power plants as well as inlet blades of combustion-turbine compressors. The novel sensor, based on a micro-electromechanical accelerometer, will enable early detection of blade cracks—reducing the risk of costly repairs following blade failures. In 2015, EPRI will incorporate this accelerometer into a prototype device that can be affixed to turbine blades. Demonstrations in turbine spin test facilities are expected by 2016.

Limitations of Existing Technology

During plant operation, the long blades of turbines are susceptible to vibration, which can cause cracks, blade failures, and turbine downtime. Blade failures present a safety risk and can result in as much as $50 million in repair costs and expenses to purchase replacement power.

Existing approaches to monitor turbine vibrations come with limitations. All plants have systems that measure turbine shaft vibrations, but they are not designed to detect blade vibrations caused by steam flow. Telemetry systems to measure blade vibrations of low-pressure turbines are costly, and the time-intensive installation must be performed when a power plant is off-line for at least 10 days. Limited battery life makes these systems impractical for long-term monitoring.

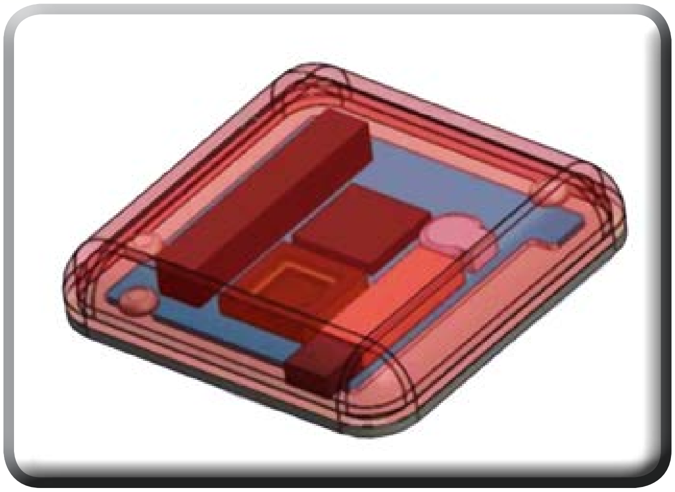
Sensors can be attached to the turbine casing above the blade tips to collect data on the timing of tip motion. But such systems, usually deployed after blade cracks are discovered, require more complex analyses to estimate blade vibrations.

Power plant operators also can check for cracks through visual or ultrasonic blade inspections, but these are infrequent—and it is difficult to thoroughly inspect those blade parts most susceptible to cracking without removing the blades.

Micro-electromechanical Accelerometer Sensor: Self-Powered, Wireless, Rugged

Since 2009, EPRI has been developing the concept for a new sensor designed to provide vibration data through continuous blade monitoring and wireless data transmission, allowing operators to detect early signs of growing cracks and schedule timely repairs. The Smart System Technology & Commercialization Center at the SUNY College of Nanoscale Science and Engineering has been a collaborator on the project.

The micro-electromechanical accelerometer sensor can measure blade tip vibrations while withstanding the large centrifugal forces associated with turbine rotation. Researchers are investigating ways to manufacture the accelerometer.



EPRI is developing a self-powered device that can measure turbine blade vibrations for early crack detection.

In 2015, the accelerometer will be incorporated into a prototype of a device, known as a *mote*. The current design concept of the mote is a 30 millimeter-by-30 millimeter circuit board—containing an analog-to-digital converter, transmitter, and power management circuit—which will require rugged encapsulation to protect it from high-speed wet steam. The mote will be self-powered, with a coil in the sensor picking up energy every time it moves past a small magnet attached to the turbine casing.

The mote's other components will undergo testing to ensure that they can survive the tough environment of turbine operation. For example, they will be put in a centrifuge to assess their ability to survive sustained strong centrifugal forces. The completed prototype sensor will be deployed in a turbine rotor spin test facility in 2016.

For more information, contact Steve Hesler, shesler@epri.com, 704.595.2680.

Study Identifies Ways to Optimize Retrofits of Flue Gas Desulfurization Systems

An EPRI study has documented upgrades used by the electricity sector for flue gas desulfurization (FGD) systems—components in coal-fired power plant boilers to control sulfur dioxide (SO_2) emissions. Drawing from technical papers published by design and engineering firms during the past 10 years, the report (3002001448) describes retrofit projects that enable under-performing equipment to achieve required emission reductions without the high cost of installing new FGD systems.

Perforated trays can be used in absorbers to increase contact between flue gas and slurry. Source: Sargent & Lundy

Evolution of FGD Control

In typical wet FGD systems, flue gas from the plant's boiler enters a structure called an *absorber*, where a liquid slurry is sprayed into the gas to absorb SO_2. The slurry contains a reagent, usually lime or limestone, that enhances absorption and neutralization of SO_2, yielding a solid compound that is later removed by other equipment.

During the past 40–50 years, technologies to control SO_2 emissions have evolved in several ways, including larger equipment, higher removal efficiencies, and lower cost and more reliable performance. To remain competitive, fossil plants with older FGD systems must upgrade control technologies to meet tighter regulatory standards while minimizing compliance costs. When systems degrade to the point that they can no longer provide adequate control, the age or value of the plant may not justify new, advanced control systems. Under federal regulations, which allow generators to reduce emissions at the lowest cost, a viable alternative is to retrofit FGD systems to boost performance.

Retrofit Options

The EPRI study identified a range of available equipment and techniques for retrofitting FGD systems. The options can be used to address different regulatory requirements, plant configurations, and process chemistries. The study outlined options in three general areas:

- **Process chemistry.** Several chemical reactions take place in the FGD system's absorber, and the chemistry of these processes can be optimized to boost SO_2 removal efficiency. For example, a substance called *dibasic acid* can be added to the absorber's liquid slurry to increase the limestone's SO_2-neutralizing action.
- **Mechanical design changes.** These include modifications to the absorber to increase distribution of the flue gas or contact between the flue gas and the slurry. For instance, the nozzles that spray the slurry can be relocated so that no flue gas passes through the absorber without coming into contact with the spray. Other examples are liquid distribution rings, which spray slurry along the absorber walls, and perforated trays, which increase liquid surface area in contact with the gas.
- **Optimizing the reagent.** Changes to the slurry reagent in the absorber can boost SO_2 removal efficiency and reduce costs. One option is to convert from lime to lower cost limestone. Grinding the limestone reagent into finer particles increases the pH and utilization of the slurry, enhancing SO_2 removal.

In addition to SO_2 reduction rules, power plants must also meet environmental requirements for wastewater reduction and control of hazardous air pollutants such as mercury, lead, and arsenic. Selecting the best FGD retrofit option will increasingly involve tooling these control systems to work together optimally and cost-effectively. In the future, EPRI will monitor emerging technical challenges with FGD retrofits, including more frequent startups and shutdowns under cycling operations.

For more information, contact Nanda Srinivasan, nsrinivasan@epri.com, 650.855.2438; Jaspal Saini, jsaini@epri.com, 650.855.8913; or Chuck Dene, cdene@epri.com, 650.855.2425.

Decades of Testing Provide Detailed Findings on Plant Operations, Water Quality, and Fisheries

The largest and longest running power plant ecological monitoring program in the world has consistently demonstrated that Ohio River fish populations have not been negatively impacted by plant operations. That's one of the recent findings by the Ohio River Ecological Research Program (ORERP), which has been conducting fish, habitat, and water quality studies upstream and downstream from power plants since 1970.

In fact, the past 40-plus years of data from ORERP, managed by EPRI since 2002, have shown that fish communities—including predominant species such as the emerald shiner, gizzard shad, and channel shiner—have been on the upswing thanks to steadily improving water quality in the Ohio River. Data collected by ORERP in 2011, the results of which were reported last year (3002001755), analyzed ecological conditions at 11 power plants stretching across 600 miles of river.

A Long-Term, Collective Effort

In 1970, 10 electric utilities formed ORERP to conduct collaborative research supporting environmental stewardship of the Ohio River, including an assessment of power plant impacts on local fish populations.

Through insights from this research, ORERP has helped plants comply with federal and state environmental regulations—in particular, the Clean Water Act, which requires that electric utility companies maintain balanced ecological communities even when thermal discharges from river-cooled plants exceed temperature standards. This law also mandates that company operations don't harm fish populations, despite some levels of impingement and entrainment—which occur when fish, shellfish eggs, and larvae get caught on cooling water intake screens (impingement) or pass through the cooling water intake structure into a power plant's cooling system (entrainment). ORERP submits data annually to state regulators and the Ohio River Sanitation Commission (ORSANCO), which sets permit criteria and conditions for the river.

Benefits Beyond Compliance

ORERP provides consistent, long-term scientifically sound data on fish community health that can be used by power companies to respond to current or proposed regulations. "ORERP gets all of us on the Ohio River organized as one voice," said Michael Winkler, manager of environmental programs at Louisville Gas & Electric and Kentucky Utilities Company (LG&E KU). "You have the same monitoring vendors using the same equipment year in and year out, so the data are much more reliable than a scattering of data done by different people using different methods."

Long-running program: ORERP fish sampling work in 1978

Tim Lohner, a consulting environmental specialist with American Electric Power (AEP), pointed out that participation in ORERP is cost-effective. "By pooling our resources, we benefit from economies of scale," he said. "We have been able to avoid or reduce the scope of our compliance studies by providing ORERP information to the Ohio Environmental Protection Agency and other state regulatory agencies." AEP estimated that one typical Clean Water Act study involving fish collection, plume modeling, and demonstrations costs at least $300,000—more than four times its annual $64,000 cost to fund ORERP.

Accolades and an Ongoing Effort

Last year, Tim Lohner of AEP and Michael Winkler of LG&E KU used their experience with ORERP as the basis for an article in the journal *Environmental Monitoring and Assessment*. The story details the benefits of ORERP's long-term environmental monitoring on the Ohio River. Representatives from AEP, LG&E KU, and six other power companies received a 2013 EPRI Technology Transfer award to recognize their leadership working with ORERP.

ORERP's work is ongoing, with fish sampling typically taking place three times each year. With more than four decades of research and field work, it represents a unique contribution to science and plant operations. "No other voluntary industry program is equivalent to ORERP," said Doug Dixon, an EPRI technical executive who manages the program. "This research collaboration provides a very valuable source of information on Ohio River fisheries and fish population for our members."

For more information, contact Doug Dixon, ddixon@epri.com, 804.642.1025.

Augmented Reality Application Equips Field Workers to Seamlessly Connect with Back-Office Systems

Through a successful field demonstration in Long Island, EPRI has shown that augmented reality applications can streamline utility efforts to assess and respond to storm damage.

Augmented reality provides a live view of the environment augmented by computer-generated graphics, video, and other data. A familiar example is the first-down marker shown on a televised football game.

In 2012, EPRI launched research to show how the application of augmented reality can reduce the time and cost of storm damage assessment. The typical utility approach to evaluating storm damage is labor-intensive and susceptible to mistakes: Workers canvass and visually inspect various field sites, manually enter the results on forms, then submit the paperwork to other workers who enter the data into a computer.

Streamlining this field assessment and data input can enable utilities to devise storm response plans and implement field operations more quickly and cost-effectively.

Proving the Concept in the Field

In 2013, EPRI completed a field demonstration of an augmented reality application with Long Island Power Authority. Researchers created Google-based maps and satellite views of the utility's service area, overlaid with icons representing various grid components. For example, dots marked poles, and lines marked wires. These icons were linked to historical maintenance data on the components. EPRI loaded the maps and linked data on iPads for utility workers to conduct visual field inspections.

By viewing a section of the distribution grid through the iPad's application, workers can see whether a particular component is missing or damaged. Tapping the corresponding icon produces a menu of options through which workers can fill out a damage report, view the component's history and maintenance manuals, or inform the utility back office that a component is in a location different from what is indicated in the augmented reality application (see photo).

The demonstration project successfully showed that grid components can be represented in map, satellite, and augmented reality views and that these views can interface with a range of utility back-office systems.

This iPad shows the augmented reality application used in the Long Island demonstration project. The purple lines on the streets represent power wires.

The Future of Augmented Reality

EPRI is planning more demonstration projects in 2014 with Entergy in Louisiana and Gas Natural Fenosa in Spain. Entergy is interested in testing augmented reality applications for storm damage assessment, work management, and other activities. Gas Natural Fenosa plans to use the technology for inspecting gas and electric distribution assets.

EPRI's long-term plan is to expand the augmented reality technology developed in the Long Island project for other applications. EPRI will focus on providing standard frameworks for these applications. These will promote the development of non-proprietary interfaces between field devices and other utility systems (such as geographic information systems) and enable innovation.

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TECHNOLOGY AT WORK

Member applications of EPRI science and technology

SCANA Completes Successful Concrete Pour at South Carolina Nuclear Plant

The foundation for SCANA's Virgil C. Summer Unit 2 required a continuous pour of 7000 cubic yards of concrete over more than 51 hours. In achieving this project milestone, SCANA relied on an EPRI field guide on concrete placement that draws on extensive research of design and effective quality control measures for construction and maintenance of concrete pads. With nearly 70 nuclear power plants under construction worldwide, the guide proved timely for SCANA's South Carolina project, which is one of the first nuclear reactors to be built in the United States in 30 years.

Guidelines to Build Strong Concrete Foundations

Nuclear power plants require a high-strength concrete support structure for long-term reliable operations. Such a foundation relies on a closely supervised concrete pouring process with effective quality control procedures. Poorly executed concrete placement can lead to the formation of honeycombs or air pockets, which can reduce the structure's durability and result in more repairs during its lifetime. Other problems include debris not removed before pouring as well as corrosion of rebar that can lead to cracks.

EPRI's field guide on concrete helped SCANA effectively monitor quality control procedures during concrete pad construction at the V. C. Summer plant. Photo courtesy of SCANA Corp.

The report, *General Outline for Conducting Quality Inspections and Tests of Concrete Placement at Nuclear Facilities* (3002000520), outlines critical considerations for concrete pouring projects, including developing concrete mixes, inspecting batching facilities, reviewing construction procedures, and creating inspection and testing plans. It provides checklists for inspecting the construction site before, during, and after the concrete pour and recommends testing to ensure quality work.

An Historic Moment

SCANA began building V. C. Summer Unit 2 in 2013. Members of SCANA's inspection team reviewed an early draft of the EPRI guidelines report, helping them craft construction plans and monitor quality control for the concrete pour at Unit 2, which was completed in March of that year. The team provided EPRI with feedback on the guide after the project. SCANA successfully completed a second concrete placement of the Unit 3 basemat in November 2013.

"The EPRI guidelines provided valuable insights to our staff and contributed to a successful concrete pour," said Brad Stokes, general manager of engineering services for SCANA's new nuclear project.

Future Concrete R&D

EPRI researchers continue to investigate a range of issues related to building and maintaining concrete foundations at nuclear power plants, including the use of high-strength rebar to eliminate air pocket formation in concrete during construction. They are developing a protocol for regular concrete pad inspections and exploring the use of mobile devices for monitoring and documenting quality control.

EPRI members can view the concrete guide and learn about other concrete-related research at this website: https://membercenter.epri.com/sectors/CrossSector/Pages/Concrete.aspx.

For more information, contact Ken Barry, kbarry@epri.com, 704.595.2540 or Maria Guimaraes, mguimaraes@epri.com, 704.595.2708.

Tracing Trace Metals to Their Source: Innovative Methodology Provides Insights on Emissions

In the first study ever to combine atmospheric and watershed modeling on a regional scale, EPRI is assessing impacts of power plant emissions in the 25,000-square-mile San Juan River watershed in Arizona, Utah, New Mexico, and Colorado. The novel approach created a detailed picture of the fate of atmospheric emissions of trace metals across the watershed, revealing that most mercury in the water and fish comes from sources outside the United States.

Emissions modeling on Arizona Public Service's (APS's) coal-fired Four Corners Power Plant in New Mexico is complete, and a similar analysis for Salt River Project's (SRP's) Navajo Generating Station in Arizona is underway, with completion expected in 2015.

Data Gathering and Modeling

The research seeks to determine the contribution of different sources of atmospheric emissions to the deposition in the basin of three trace substances: mercury, arsenic, and selenium. For all three elements, the study looks at the concentration in the water. For mercury, the study is the first to quantify the relationship between atmospheric sources and concentrations in tissues of local fish species, focusing on two endangered predators—Colorado pikeminnow and razorback sucker.

To evaluate mercury in the watershed, EPRI used emissions data from the two power plants, North American locations outside the watershed, and global sources including China. Analysis of arsenic and selenium concentrations was based on emissions data from the regional power plants and sampling data from San Juan waterways. Contributions of arsenic and selenium from global and other regional sources were calculated from the watershed data.

Using these data, which span 1986–2012, the researchers used air and watershed models to analyze the metals' fate. The air model evaluated atmospheric drift of each metal from its origin to where a portion of it settles into the San Juan River watershed. The model's output was then fit to the spatial grid of EPRI's watershed model, which assessed the metals' fate in different parts of the watershed. By linking the two models, researchers were able to attribute changes in watershed metal concentrations to individual emissions sources. Because past research on this topic has not combined air and water modeling, such attributions have not previously been possible.

The San Juan River basin

Researchers calculated changes in the three elements' concentrations in different parts of the watershed out to the year 2074. The long-term horizon is crucial because flow of the metals in the environment is slowed by the watershed's soils. The mercury projections take into account different power plant operational scenarios and projected changes in emissions from China, which is the largest source of man-made mercury emissions.

Overseas Sources Make Largest Contribution

The modeling revealed that most mercury in the water and fish comes from sources outside the United States, including fossil fuel combustion in other countries, geological emissions such as those from volcanoes, and forest fires. Emissions from the APS plant make up a small portion of the total mercury in the water and fish.

The results suggest that contributions of atmospheric mercury deposition from non-U.S. sources will become more dominant in future years as U.S. emissions drop, and confirm in greater detail findings of previous atmospheric studies. The research also demonstrates that EPRI's linked-model methodology can be applied to other U.S. regions to address similar questions. EPRI provided the results to APS and the federal Office of Surface Mining, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, and U.S. Geological Survey.

Because the APS and SRP plants sit on Navajo Nation land, the companies are required to assess environmental impacts of operations before renewing their licenses. The results of this research will be used in these relicensing efforts.

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REPORTS AND SOFTWARE

Key deliverables now available

The following is a small selection of items recently published by EPRI. To view complete lists of your company-funded research reports, updates, software, training announcements, and other program deliverables, log in at www.epri.com and go to Program Cockpits.

System Flexibility Screening and Assessment Tool (InFLEXion) v2.0 (3002000333)

This software tool can assist planners in assessing operational flexibility of electric power systems based on inputted data on demand, variable generation, and generation schedules. It analyzes system requirements to balance future supply and demand of energy, supporting long-term generation and transmission planning.

Coordinated Updates to Chemistry and Fuel Reliability Guidelines for Nuclear Plants

Recognizing the unique interrelationships between fuel and water chemistry, EPRI's Nuclear sector has completed a two-year effort to revise and simultaneously publish five guidelines. These guidelines are used at nuclear plants around the world to inform safe, reliable operation. The five documents are: *PWR Primary Water Chemistry Guidelines, Revision 7* (3002000505); *PWR Fuel Cladding Corrosion and Crud Guidelines, Revision 1* (3002002795); *Fuel Surveillance and Inspection Guidelines, Revision 2* (3002002877); *BWR Fuel Cladding Corrosion and Crud Guidelines, Revision 1* (3002002720); and *BWR Water Chemistry Guidelines, Revision 1* (3002002623).

Magnetic Field Calculation Program Based on UTWorkstation v6.3M (3002002278)

This software calculates magnetic fields in the vicinity of pipe-type, extruded, and self-contained fluid-filled underground cables.

Cyber Security Procurement Methodology Training Module Rev. 14.00 (3002002499)

Power plant operators planning to install digital instrumentation and control systems must account for increasing cyber security regulatory requirements. A companion to the EPRI report *Cyber Security Procurement Methodology, Rev. 1* (3002001824), this computer-based training module provides guidance to plant and vendor engineers on procuring these systems with the necessary cyber security controls.

Equipment Reliability (ER) Matrix v1.5 (3002002757)

This web-based software application allows EPRI members to organize and view EPRI products available to them in a color-coded matrix table, locate information about the products, and access links to download documents. Users can easily switch between English, Czech, French, Japanese, Spanish, and Korean versions.

Solar PV Market Update, Volume 9: Q1 2014 (3002003174)

The latest installment of this series discusses global solar photovoltaic market activities, price trends for equipment and power purchase agreements, and cell and module efficiency improvements. By synthesizing data from many sources, the report highlights economic, policy, and technology developments likely to impact utility solar investment and planning.

Evaluation of Electromagnetic Nondestructive Evaluation for Detection of Wall Thinning in HRSG Finned Tubes (3002003410)

Inspecting the inside surfaces of the finned, tightly spaced tubes of heat recovery steam generators requires complex robotics or cutting components open. EPRI researchers investigated the performance of two nondestructive electromagnetic methods to detect pitting and wall thinning in the tubes from their outside surface. They found that the low-frequency electromagnetic technique can detect local and general wall loss and that the saturation low-frequency eddy current technique is unable to detect pitting and general wall loss in tubes with long fins.

Range and Applicability of Heat Rate Improvements (3002003457)

Reducing a coal-fired power plant's heat rate can lower emissions, fuel consumption, and costs. Reductions can often be achieved through better operating practices, avoiding expenses on new technology. This report summarizes methods to assess and implement measures for improving heat rate and characterizes the range of achievable reductions.

Clean Water Act §316(b) Existing Facility Rule Summary (3002004150)

In May 2014, the U.S. Environmental Protection Agency released a prepublication copy of its final Clean Water Act §316(b) Rule to Establish Requirements for Cooling Water Intake Structures at Existing Facilities and Amend Requirements at Phase I Facilities. The rule applies to more than a thousand facilities in many industrial sectors (including electric power plants) that withdraw at least 2 million gallons of cooling water per day. This report summarizes the rule's compliance standards, information and monitoring requirements, and schedule.

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