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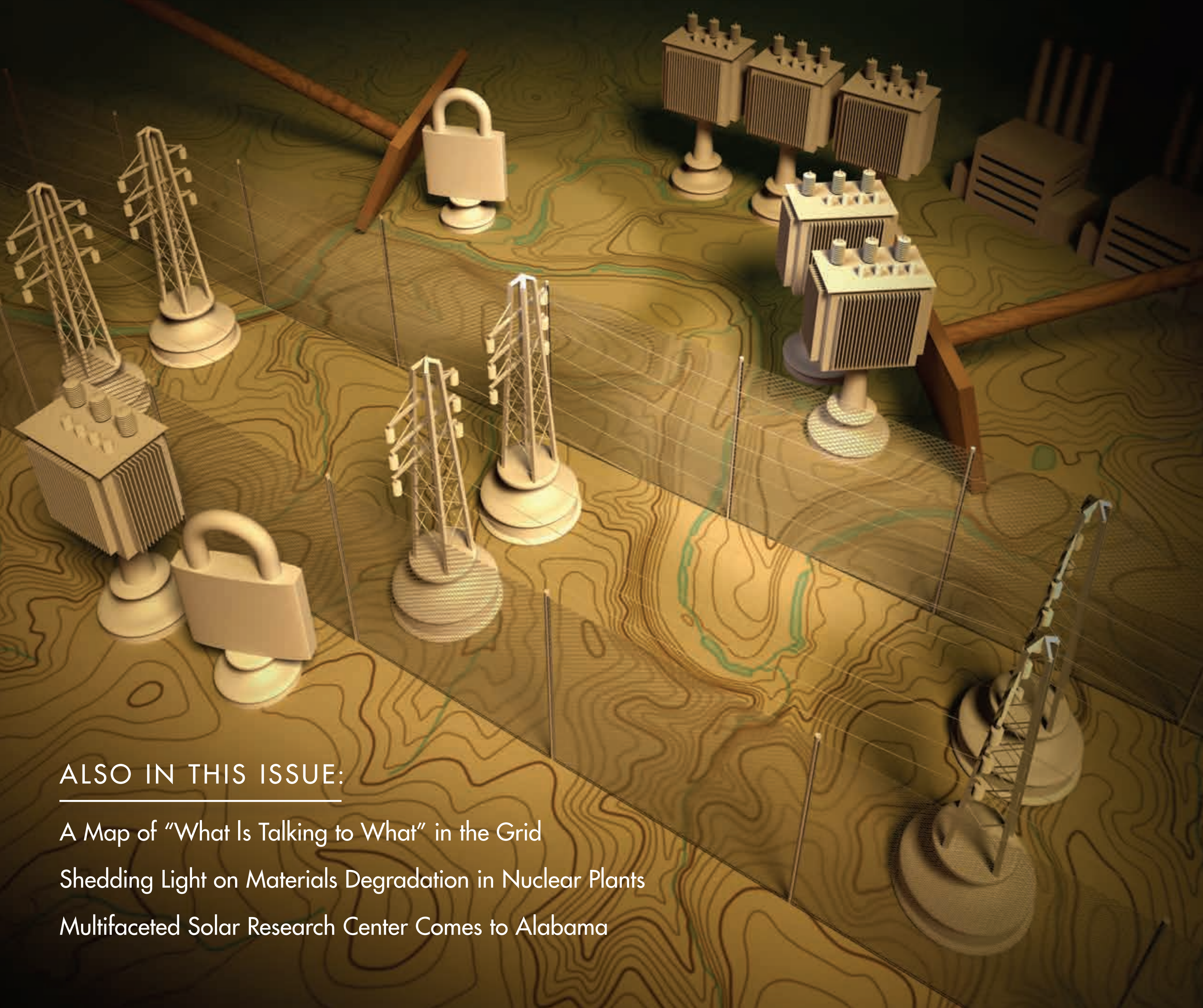
Beyond Speculation and Sci-Fi:

Researchers Help Drive Plans and Technologies to Secure the Grid



ALSO IN THIS ISSUE:

A Map of "What Is Talking to What" in the Grid

Shedding Light on Materials Degradation in Nuclear Plants

Multifaceted Solar Research Center Comes to Alabama

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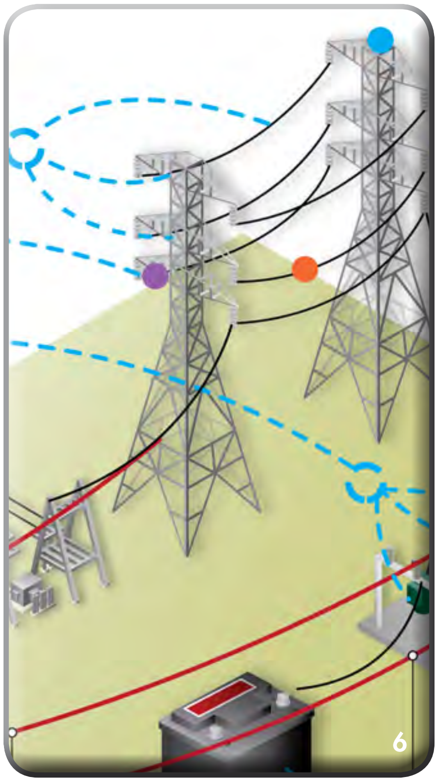

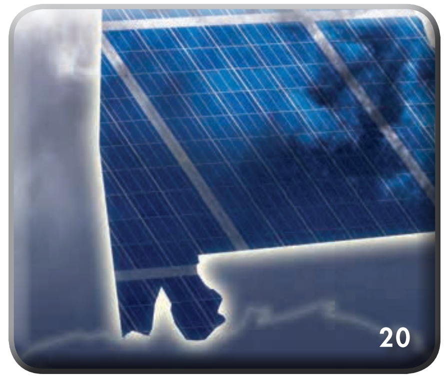

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VIEWPOINT

by Mike Howard, President and CEO, EPRI

From the R&D Perspective: Let's Take a More Concerted Approach to Safety

If you pause to ponder the modern electricity system, you can readily understand why the safety of our workers and the public is front and center, 24/7. Consider the power lines that crisscross every part of the landscape, carrying hundreds or thousands of volts. Power plant components must safely contain and deliver superheated steam at many atmospheres of pressure. Nuclear materials with high and low levels of radiation must be handled and stored to levels of safety agreed to by operators worldwide. Line crews must respond in conditions that drive other people to seek shelter, working under tremendous physical and mental demands. Construction and major modification projects introduce challenges of heat stress, confined spaces, and heavy equipment.

Much of EPRI's work ultimately supports the safe production, delivery, and use of electricity, but beginning in 2015, we are taking a much more concerted approach. This past May, we organized the first EPRI Occupational Health and Safety Research Conference in Charlotte, North Carolina, convening 28 organizations and 65 participants. Reflecting the wide-ranging safety issues in the power industry, the conference featured presentations from academic, industry, and EPRI researchers in four tracks: worker safety, work organization and ergonomics, worker exposure, and emerging occupational safety issues.

In 2015, we will establish the Safety Research Center of Excellence to spearhead new power industry safety research and provide greater visibility for the occupational health and safety components of our current research. We will also host a conference to continue discussions and reports in these areas. The center will catalog safety-related work, equipping industry stakeholders to identify and locate EPRI research and enabling collaboration across EPRI. It will identify and recruit individuals and organizations with expertise in designated fields to participate in research, and develop an EPRI "safety stamp" to designate projects that include significant occupational health and safety-related research across our research portfolio.

You can read more about this specific safety work in the *Innovation* department of this issue of *EPRI Journal*. You can

also see how the drive for safety touches every aspect of our research portfolio. Consider the following examples:

Metallurgical testing of irradiated components from a decommissioned Spanish nuclear plant is providing a once-in-a-plant-lifetime opportunity to understand how and at what rate damage occurs and what parameters influence its severity in key plant components. This will contribute significantly to knowledge that is essential for nuclear plant safety.

For many people, confidence in nuclear power was shaken by the unprecedented events at Japan's Fukushima Daiichi nuclear plant. To enhance plant safety, EPRI selected components to be shaken (literally) to simulate high-frequency earthquakes. These tests will help plants conduct effective seismic evaluations mandated by the U.S. Nuclear Regulatory Commission and will be used in full seismic risk evaluations. There are important ramifications for both worker and public safety.

Advances in sensors and robotics are enabling us to develop machines to do critical inspections and measurements on transmission lines. Maintenance staff then use the information on asset condition to schedule and implement maintenance. With the advent of ever taller wind turbines, power generation workers are learning to appreciate what their colleagues in transmission have long known: any technology that helps you keep your feet on the ground contributes to safety. Researchers are actively searching for and deploying inspection technologies to do just that.

EPRI has developed a framework that utilities can use to characterize so-called high-impact, low-frequency events and then assess vulnerabilities, impacts, and probabilities, and develop mitigation measures. The framework is versatile and can be applied to events as different as hurricanes and cyber attacks. When utilities can develop good business cases for technologies and procedures to protect against such events, reliability and resilience are improved, and public safety is measurably enhanced.

The feature graphic titled "What Is Talking to What" provides a good overview of where the smarter, more interconnected grid is heading. Better sensors, better communication, better data and information—all of these combine to improve worker and public safety.

Wherever you look in the power system—from strategy to create a more resilient grid to the microscopic degradation of materials—safety is in the big picture and in the details. At EPRI, we are actively reaching out to leaders, researchers, and workers to broaden our thinking and sharpen our focus on safety.

Michael W. Howard
President and Chief Executive Officer

SHAPING THE FUTURE

Innovative approaches to upcoming challenges

Controllable Seal Concept Shows Promise for Decreasing Nuclear Plant Shutdowns

A conceptual design of a controllable seal for water-circulating pumps in nuclear power plants shows potential to reduce plant shutdowns and maintenance costs. In collaboration with Georgia Technology Research Corporation, Duke Energy, and Southern Nuclear, EPRI in 2014 completed a feasibility study and plans to build a prototype in 2015.

Controlling Leaks in Coolant Pump Systems

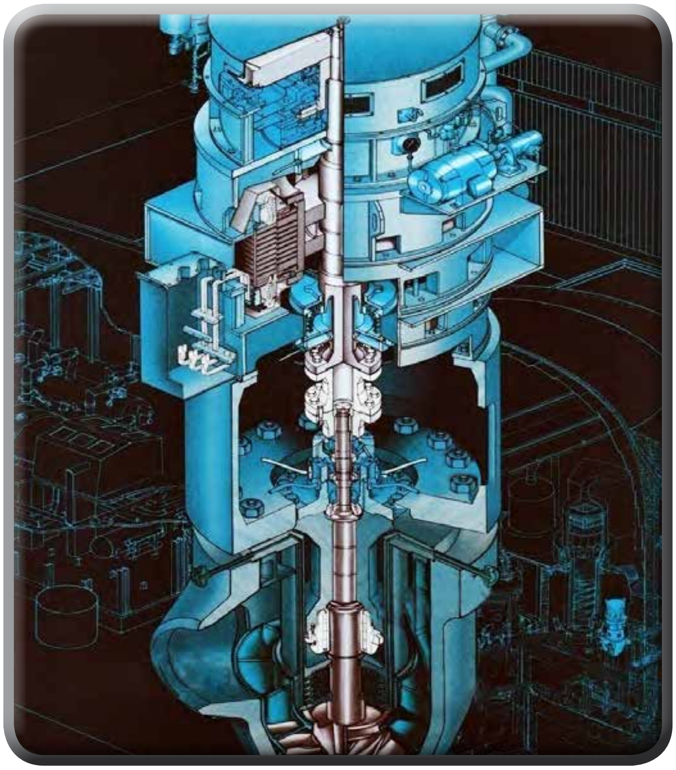
In pressurized water reactor nuclear plants, reactor coolant pumps circulate water that transfers heat from the fuel in the reactor core to a steam generator. Mechanical pump seals control water leakage. To ensure seal reliability and durability, it is critical to avoid excessive leakage, which can happen as a result of seal wear, chemical deposition, or changes in water properties. If leakage rates are too high, plant operators typically must shut down the plant for a week to repair the seal. Such events happen a few times per year across the U.S. fleet, with typical costs of $500,000 for seal repair and $1 million for replacement power for a lost day's output.

To avoid this, EPRI researchers are investigating the feasibility of a coolant pump seal in which leakage can be controlled while in service. The idea is to adjust the seal's shape, changing the thickness of the lubricating film between seal faces to reduce leakage to an acceptable level.

As part of a recent study (3002002344), EPRI developed three conceptual designs for such a seal. In two of the designs, the seal, made of either stainless steel or carbon graphite, has several internal chambers containing *hydraulic fluid*—an incompressible material that can change the seal's shape when subjected to certain pressures. In the third design, a carbon graphite seal is bonded to a piezoelectric crystal, which can change the seal's shape when a controlled voltage is applied.

Researchers simulated the behavior of these three designs through a modeling analysis. Results showed that while all three options are feasible, the model indicates that the carbon graphite seal with hydraulic-fluid-filled cavities may be best able to control leakage over the largest range.

EPRI is also considering the feasibility of hardware- and software-based control systems for the seals. Researchers envision control using a *fuzzy logic system*—one that would control the seal based on a set of "if-then" rules involving human decision making. They modeled such a system for use with the seal, and it demonstrated excellent control. EPRI is pursuing patents for the controllable seal concept.



A reactor coolant pump with traditional seals

The Path to Commercialization

While the concept shows promise, much work remains before it can be implemented in nuclear plants.

EPRI is reviewing, manufacturing, and testing material samples for the controllable seal—a process expected to be complete by 2015. "We are looking at composite materials, since the seal cannot be made from traditional materials," said EPRI's Gary Boles, who manages the seal research.

If viable materials are identified, EPRI will build and test a prototype in 2015. Collaboration with component manufacturers and utilities will be essential to ensure that the seal is compatible with coolant pumps and other equipment, complies with rigorous industry standards, and is commercially viable.

Applicability to Other Industries

While the controllable seal concept was originally intended to address leakage problems with reactor coolant pumps in nuclear plants, it can potentially be applied in other industries, such as petroleum and chemical processing, where high-pressure fluids are pumped and seals are used to control leakage.

For more information, contact Gary Boles, gboles@epri.com, 704.595.2781.

EPRI Informs Industry Electrification Strategies to Reduce Emissions and Benefit Society

"Use more electricity…. Produce less emissions."

At first glance, this cause-effect statement may seem like an impossibility, thanks to the countless "use more, produce more" messages drilled into our collective environmental consciousness. But it's entirely feasible with *electrification*—switching to electric alternatives of everyday technologies, such as automobiles, forklifts, furnaces, boilers, and long-haul truck equipment. Research by EPRI and others continually demonstrates that decarbonizing the electric power sector and then electrifying other carbon-intensive sectors is the most efficient and cost-effective means to reduce emissions of greenhouse gases and criteria pollutants. The counterintuitive idea here is that electrification decreases overall emissions by raising power sector emissions.

EPRI is examining electrification strategies, with progress in several coordinated research efforts, including work with electric utilities to explore electrification opportunities and broader analyses of electrification's environmental and economic benefits.

Utility Engagement

An initial task is to engage power companies in evaluating specific electrification opportunities. Staff in EPRI's Power Delivery and Utilization research area are working with 19 companies across the country—including major public and investor-owned electric utilities and cooperatives—to reduce customer emissions and improve company productivity through electrification.

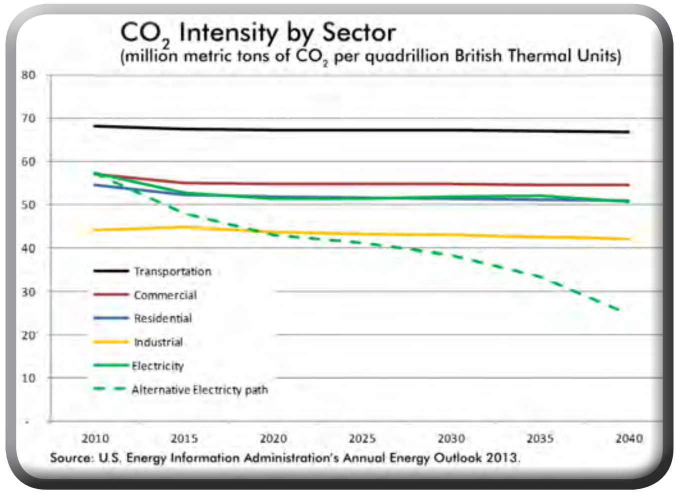
Researchers developed an analytical framework to quantify the potential for electrifying fossil-fuel-powered end-use technologies in residential, commercial, industrial, and transportation sectors within company service territories. They also created an electric technology database, reference guide, and a tool to support decisions about electrification technology measures.

EPRI applied these tools and data to conduct customized electrification case studies for each participating utility. Researchers are screening technologies for technical, economic, and market potential for specific customers.

After the screening process is complete, EPRI will conduct detailed analyses of the most promising technologies and develop business cases for deployment. Building on this groundwork, EPRI in 2015 will launch a new program, Electrification for Customer Productivity.

Economic and Environmental Analyses

Electrification strategies are most effective when they appropriately inform—and are subsequently aligned with—the regulatory process. As such, EPRI is coordinating the utility end-use evaluations with economic and environmental modeling that can yield insights for regulators.



The solid lines in this chart show the projected CO_2 emissions intensities of the transportation, commercial, residential, industrial, and electric power sectors in the United States. The dotted green line shows a projection used as a proxy for potential future CO_2 regulation in which the power sector dramatically reduces its emissions intensity through deployment of advanced generation technologies. The projection, from the U.S. Energy Information Administration's Annual Energy Outlook 2013, assumes a fee on CO_2 emissions that starts at $15 per metric ton in 2014 and increases by 5% per year through 2040.

EPRI's Energy and Environmental Analysis group started an effort to assess the net value of electrification to the utility, business customers, and society at the national and regional levels. With the recent development of powerful analytical tools such as EPRI's US Regional Economy, Greenhouse Gas, and Energy Model (US-REGEN), various electrification scenarios and strategies can be evaluated. The group plans to utilize data on the economic and environmental attributes of specific technologies in various sectors both before and after electrification, identifying impacts such as economic efficiency, energy efficiency, air emissions, water use, and productivity improvements.

Integrating these analyses, the group will produce a report that describes the economy-wide potential of electric technologies, evaluates policies that discourage electrification, and demonstrates how the electric power sector can help society cost-effectively reduce emissions.

Applying the results of the utility engagement work to economy-wide modeling tools will help inform the industry's development of electrification strategies.

For more information, contact Allen Dennis, adennis@epri.com, 865.218.8192, or Francisco de la Chesnaye, fdelachesnaye@epri.com, 202.293.6347.

WHAT IS TALKING TO WHAT...

The electricity grid is rapidly changing, with the growth of intelligent loads (such as water heaters, thermostats, and electric vehicles) and distributed energy resources (such as storage, rooftop and large-scale solar with smart inverters, and combined heat and power plants). To integrate these loads and resources for safe, reliable, affordable, and environmentally responsible electricity, robust communications among many different parts of the grid are needed. Such "talking" can help grid operators to assess and balance energy supply and demand, manage grid voltage, isolate faults, prevent outages in high-demand periods, and increase awareness of grid component health. While some communications are already happening, others are in early deployment or envisioned for the future.

The following pages provide a map of many of the conversations among central generation, transmission, distribution, and customers.

Power plant operator adjusts the set point of the plant's automatic voltage control system to meet the power delivery needs of the transmission system operator. As load varies, the control system maintains plant output voltage at that setting.

Purpose: Maintain system voltage.

The transmission system operator tells operators of large-scale thermal, solar, and wind power plants to ramp power up and down and adjust the plant's substation voltage.

Purpose: Balance energy supply/demand; manage voltage and thermal limits.

Conductor and connector sensors transmit data to utility personnel on temperature, current, disconnected/downed lines, and line sag or bend.

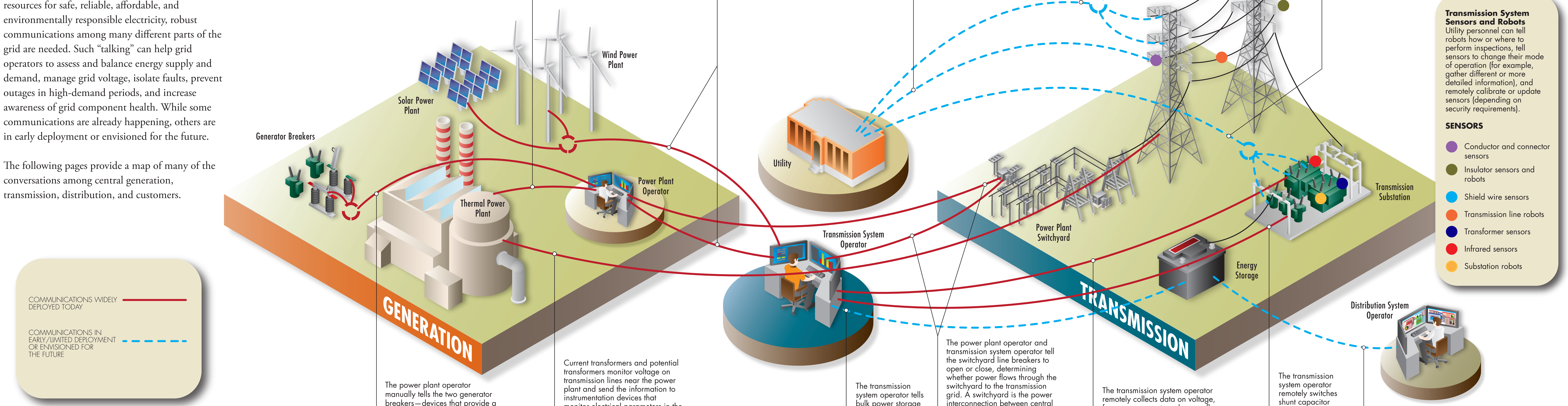
Purpose: Increase awareness of components' condition and rating; conduct dynamic line ratings (which indicate a line's ability to carry power at any moment in time within design limits); address line motion; schedule and implement maintenance; identify equipment at high risk of failure.

Utilities receive data from many different sensors and robots on transmission lines. Examples include shield wire sensors (data on lightning and fault current), transmission line robots (data on visual inspections, location of conductors in space), insulator sensors (data on insulator contamination), and insulator robots (data on electrical conditions). While not shown on the diagram, unmanned air vehicles that inspect aboveground lines, imaging and sensors for security, and underground transmission line sensors and robots are also under development.

Purpose: Increase awareness of components' condition; implement maintenance; security.

Utilities receive data from several different sensors and robots in transmission substations. Examples include infrared sensors (data on degradation of all substation assets), transformer sensors (data on vibration, transformer oil condition, internal discharges, movement of the transformer core, and aging), disconnect sensors (data on temperature and inclination of the disconnect arm), substation robots (visual and infrared information on substation components), and imaging and sensors for security (not shown on diagram).

Purpose: Increase awareness of components' condition; implement maintenance; security.



The power plant operator manually tells the two generator breakers—devices that provide a dual pathway to connect the plant with the grid—to open (which stops energy flow) or close (which initiates energy flow).

Purpose: Control power flow to the grid; protect the plant from damage in case of a voltage mismatch with the grid or plant shutdown.

Current transformers and potential transformers monitor voltage on transmission lines near the power plant and send the information to instrumentation devices that monitor electrical parameters in the plant. These devices check the grid voltage against a set point, and if it is unacceptable, this can also send a signal to open the generator breakers, stopping energy flow.

Purpose: Control grid voltage and current flow; protect the power plant from damage.

The transmission system operator tells bulk power storage systems to charge or discharge energy.

Purpose: Balance energy supply/demand.

The power plant operator and transmission system operator tell the switchyard line breakers to open or close, determining whether power flows through the switchyard to the transmission grid. A switchyard is the power interconnection between central generation plants and grid transmission.

Purpose: Isolate a section of the switchyard for maintenance; segregate the switchyard from a part of the grid that is scheduled for maintenance or damaged; protect the power plant and grid from further damage.

The transmission system operator remotely collects data on voltage, frequency, current, and power flow through monitoring devices called *remote terminal units* (which interface with supervisory control and data acquisition, or SCADA, systems) and synchrophasors installed in substations.

Purpose: Balance energy supply/demand; identify disturbances; maintain voltage and thermal limits; protect equipment; prevent outages.

The transmission system operator remotely switches shunt capacitor banks.

Purpose: Regulate transmission voltage; reduce line losses.

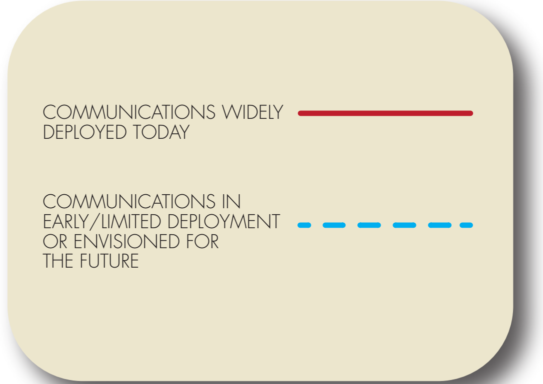
Distribution system operator tells the bulk power storage system to charge or discharge energy.

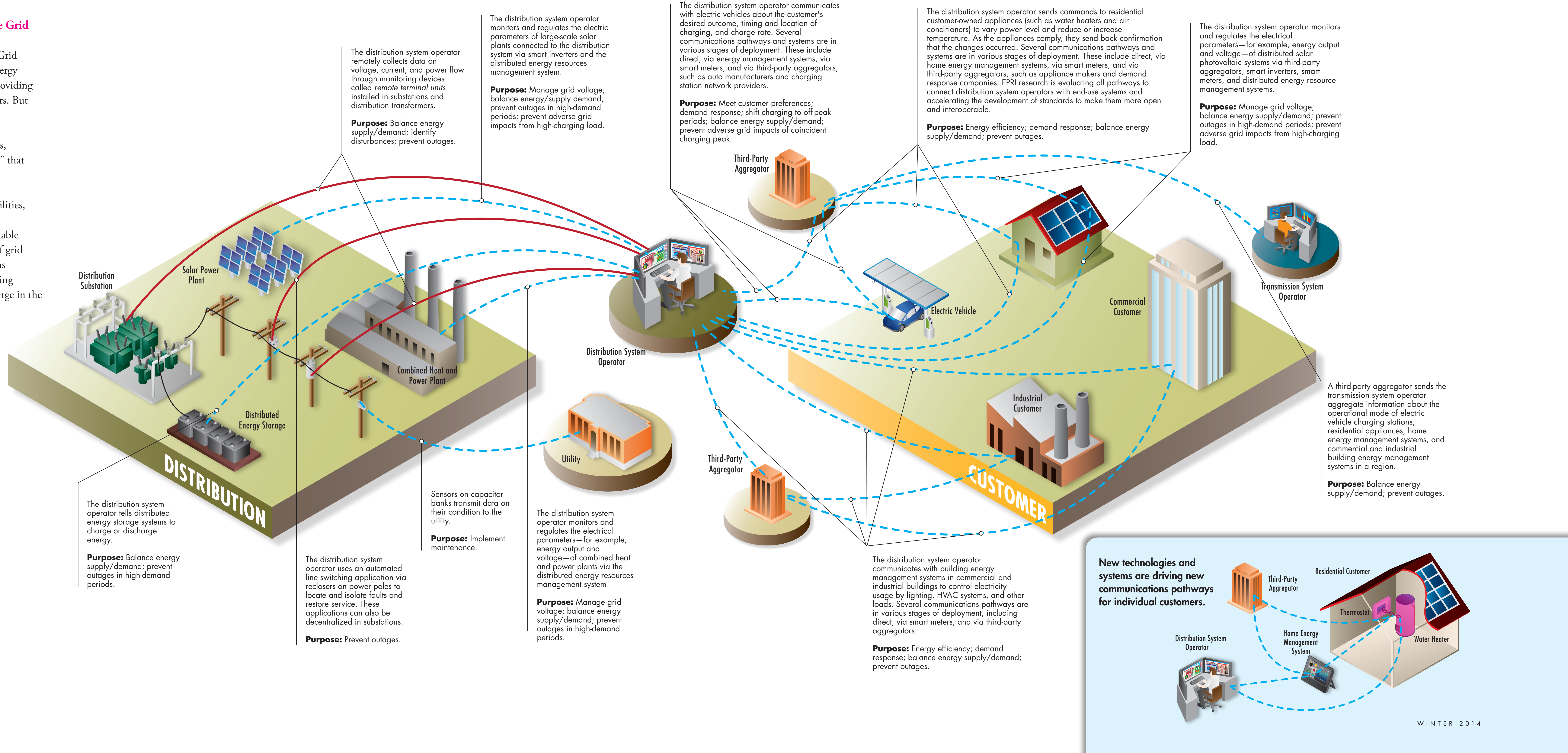
Purpose: Balance energy supply/demand; provide support to distribution system.

Communications Infrastructure for the Future Grid

Communications technology can enable Integrated Grid applications—such as management of distributed energy resources and monitoring of grid asset health—by providing connectivity to devices, utility workers, and customers. But big gaps in communications performance remain. In particular, utilities typically use separate, isolated communications networks for individual applications, resulting in "accidental communication architectures" that don't meet the needs of new applications.

Through field demonstration projects with several utilities, EPRI is investigating the deployment of *field area networks*—ubiquitous, high-performance, secure, reliable networks that simultaneously enable a broad range of grid applications. The idea is to provide a communications infrastructure that can integrate today's rapidly evolving technologies and even completely new ones that emerge in the future.





BEYOND SPECULATION AND SCI-FI:

Researchers Help Drive Plans and Technologies to Secure the Grid

THE STORY IN BRIEF

EPRI's new Physical Security research program is helping transmission owners and operators protect critical infrastructure assets against possible attack and meet emerging federal requirements.

A staple of modern fiction is the post-apocalyptic tale, in which modern civilization is brought to its knees by natural disaster or sensational terrorist attacks that cripple the electric transmission system.

From René Barjavel's 1943 classic science-fiction novel *Ashes, ashes* to William R. Forstchen's 2009 bestseller *One Second After* to the NBC television series *Revolution*, the link between pervasive, permanent power outage and social devastation has captured the public's imagination.

Perhaps this explains why, in the wake of an April 2013 rifle attack on Pacific Gas & Electric's Metcalf transmission substation south of San Jose, California, it has become increasingly difficult to distinguish fact from speculation when it comes to threats to the grid.

Indeed, the speculation surrounding the unsolved, highly publicized incident at Metcalf, which serves the technologically iconic Silicon Valley, could supply plot lines for a variety of novels or movies.

In a presentation to the California Public Utilities Commission in June, Pacific Gas & Electric's senior substation director, Ken Wells, explained what happened. Between approximately 1:00 and 1:50 a.m., one or more saboteurs accessed telecommunications vaults near the substation and severed fiber-optic cables, knocking out cell-phone and landline telephone service in the area. With one or more rifles, they blasted critical substation components from outside the substation's chain-link fence. While security cameras captured sparks from the bullet barrage on video, the perpetrators stayed out of the cameras' view.

The attack damaged ten 500-kilovolt transformers, seven 230-kilovolt transformers, and six circuit breakers. Pacific Gas & Electric control-center operators remotely disconnected the damaged equipment and transferred load to other substations, preventing a power outage. Despite the scale of the attack, no customers lost electric service.

"Our electric system contains significant redundancies," said Wells. "This is the benefit of having an interconnected system and the resiliency of the grid."

The assault, in which no one was injured, cost the utility approximately $15 million. It took 27 days to repair, restore, and replace the damaged equipment and to ameliorate environmental damage from a mineral oil spill.

"From a security perspective, it shifted the paradigm," said Wells. "This event was clearly a game changer for Pacific Gas & Electric and the industry."

The Shots Heard Around the Industry

The shots fired at Metcalf have echoed far and wide. Many industry and intelligence experts, regulators, and lawmakers have characterized the Metcalf event as an act of domestic terrorism and a possible dress rehearsal for bigger events. Others have speculated that disgruntled employees or vandals were behind the attack.

Regardless of the actors or their motives—which remain the subject of an ongoing FBI investigation—the Metcalf incident has triggered far-reaching consequences for the electric power industry that will shape the future physical security of the grid.

"After 9/11, there was a heightened awareness of physical security and there were measures to better protect critical assets, but most incidents at the time had to do with things like copper theft and vandalism. The Metcalf attack changed the picture," said Gerry Cauley, chief executive officer of the North American Electric Reliability Corporation (NERC), the organization that regulates bulk power system reliability.

"It got everyone thinking about what if something like this were organized on a larger scale. Even though Metcalf was an

Substation attack: The purple-highlighted regions in this Google Earth image of PG&E's Metcalf facility indicate damaged areas.

isolated incident, it was a very serious one," he added. "The physical security threat is real."

In March, the Federal Energy Regulatory Commission (FERC) ordered NERC to propose mandatory reliability standards requiring transmission owners and operators "to take steps or demonstrate that they have taken steps to address physical security risks and vulnerabilities related to the reliable operation of the Bulk-Power System."

"The goal is for the industry to focus on protecting the most critical infrastructure facilities from cascading types of events," said FERC Director of Electric Reliability Mike Bardee. "We left NERC a fair amount of flexibility on how to develop the standard."

In response to FERC's order, NERC filed its Physical Security Reliability Standard in May, after 86% of NERC's more than 400 voting members from the electric power industry approved the proposal.

New Requirements and Standards

NERC's proposed standard represents the industry's first mandatory physical security requirements, with six essential elements:

1. Risk assessments to identify critical transmission facilities
2. Independent third-party review of those risk assessments
3. Notification to the transmission operator of these facilities
4. Mandatory threat and vulnerability assessments for critical facilities, conducted by transmission owners and operators
5. Development, documentation, and implementation of physical security plans to protect critical facilities
6. Independent third-party review of threat and vulnerability assessments and security plans

Cauley estimates that the standard would apply to "a few hundred" U.S. substations and control centers—a small fraction of the country's tens of thousands of transmission facilities. It applies to owners and operators of transmission stations and substations operated at 500 kilovolts or higher, certain 200- to 499-kilovolt facilities, and other facilities identified as critical.

In July, FERC issued a Notice of Proposed Rulemaking requesting a few modifications to the NERC proposal, such as allowing government authorities to add or subtract critical facilities. Comments on FERC's notice were due in September. On November 20, FERC approved the NERC proposal.

The primary concern of regulators and the industry, said NERC chief Cauley, is more serious damage that could interrupt power and take weeks or months to restore. "My worst-case scenario is long-term outage," he said. "I think the most important thing we need to worry about is having sufficient spares of critical equipment and the necessary capability to deploy it." In that context, Cauley pointed to the importance of EPRI research on spare equipment, such as readily deployable module recovery transformers. Working with the U.S. Department of Energy and the U.S. Department of Homeland Security, EPRI has already designed, tested, and installed a prototype recovery transformer that can be quickly transported to avert such long-term outages.

Cauley also is concerned about the media's representation of the industry's current security. "There's a general lack of knowledge on how seriously the industry already takes physical security," he said. "Every major power company has a security plan and relationships with law enforcement. A lot is being done."

Collaborative Activities Underway

The same month of the Metcalf attack, EPRI and the North American Transmission Forum (NATF) agreed to address security and explore collaborative opportunities. NATF's members own and operate most U.S. transmission assets.

"There is great synergy between EPRI and the Forum," said NATF President and Chief Executive Officer Tom Galloway. "EPRI has great capability for research and long-term solutions, and the Forum provides confidential venues that promote the

A Grid-Resiliency Framework for High-Impact, Low-Frequency Events

EPRI's new Physical Security program is focused on protecting the grid against—and helping it recover from—direct physical assaults and intentional electromagnetic interference attacks, which use noise or signals to disrupt electrical or electronic systems. Through its Transmission Resiliency supplemental research project, EPRI also conducts research on other high-impact, low-frequency events, including electromagnetic pulse attacks caused by detonation of a nuclear device, coordinated cyber and physical attacks, and intense weather or natural events, such as severe geomagnetic disturbances, tornadoes, hurricanes, wildfires, earthquakes and tsunamis, and ice storms.

As part of the supplemental project, EPRI is developing a framework for characterizing high-impact, low-frequency events; assessing vulnerabilities, impacts, and probabilities; and developing and assessing mitigation measures. In 2015, researchers will test the framework at utilities and develop business cases for them to adopt technologies and procedures to cost-effectively protect against such events.

As part of an emergency drill with the U.S. Department of Homeland Security, EPRI, and others, the modular recovery transformer at this Texas substation was successfully deployed in just five days.

candid and detailed information sharing needed for timely development and implementation of superior practices."

According to Galloway, the vital interface between the public, regulators, and industry is improving. "We are balancing an effective sharing of threat and vulnerability information among those with a valid need to know, while rigorously safeguarding that information from those seeking to do harm," he said.

In an important first step, EPRI and NATF sponsored the Physical Security Summit at EPRI's Charlotte, North Carolina office in August 2013. More than 90 representatives from utilities and government—including the White House, FERC, NERC, the Departments of Energy and Homeland Security, and others—participated in two days of discussions about recent physical security threats, system vulnerabilities, and mitigation approaches and technologies.

A high-level leadership team will direct joint activities and establish key deliverables, such as a detailed research plan. Working groups will focus on topics such as characterization of physical security events, vulnerability and risk assessment, and development and evaluation of mitigation strategies for system hardening and speedy recovery.

NATF's security practice group, which includes about 200 experts, leads monthly webinars on security threats, superior mitigation practices, and compliance with standards.

"We are looking at physical security as a key [part] of an overall effort on transmission resiliency," added Galloway. "We are viewing this holistically and taking an all-hazards approach."

EPRI, in close coordination with industry, has launched a Physical Security program to help grid owners and operators understand and meet their new requirements, and provide them with a technical basis to explore, develop, and deploy security plans and technologies. The program builds on EPRI's existing Transmission Resiliency supplemental project, which focuses more broadly on high-impact, low-frequency events (see sidebar, p. 12).

The Physical Security program will focus on several key tasks:

- **Develop threat characteristics** to benchmark threats to which transmission assets may be exposed by considering types of weaponry (physical and electromagnetic), magnitude and frequency, and knowledge and intent of the actors.
- **Assess component and facility vulnerability** to determine the exposure of transmission assets to such threats, the likelihood of attack, and impacts.
- **Identify, evaluate, and develop mitigation technologies** with a focus on hardening (fences, shielding), surveillance and alarms (image recognition, motion detection, thermography), and recovery (critical equipment spares and law enforcement collaboration). EPRI will evaluate the approaches' effectiveness, cost, impact on operations, and ability to support grid resiliency.
- **Conduct conferences and workshops** for EPRI members to share experiences and discuss vendor technologies and research results.

According to EPRI Senior Technical Executive Richard Lordan, the research aims to achieve enhanced security and resiliency in the context of affordable, reliable power. EPRI will assess the value of countermeasures not only for reducing physical security risk, but also for decreasing risk from other high-impact, low-frequency threats and for enhancing grid performance.

The program will work to extend potential benefits beyond transmission owners and operators to include public and utility employee safety as well as local, state, and national security.

Because the probability of physical grid attacks is uncertain, transmission owners will be challenged to determine a prudent investment level for physical security, said Lordan. NERC's Cauley agrees: "This is really difficult, because [the events] are so rare." As part of the program, EPRI is working with intelligence experts to help improve understanding of their likelihood.

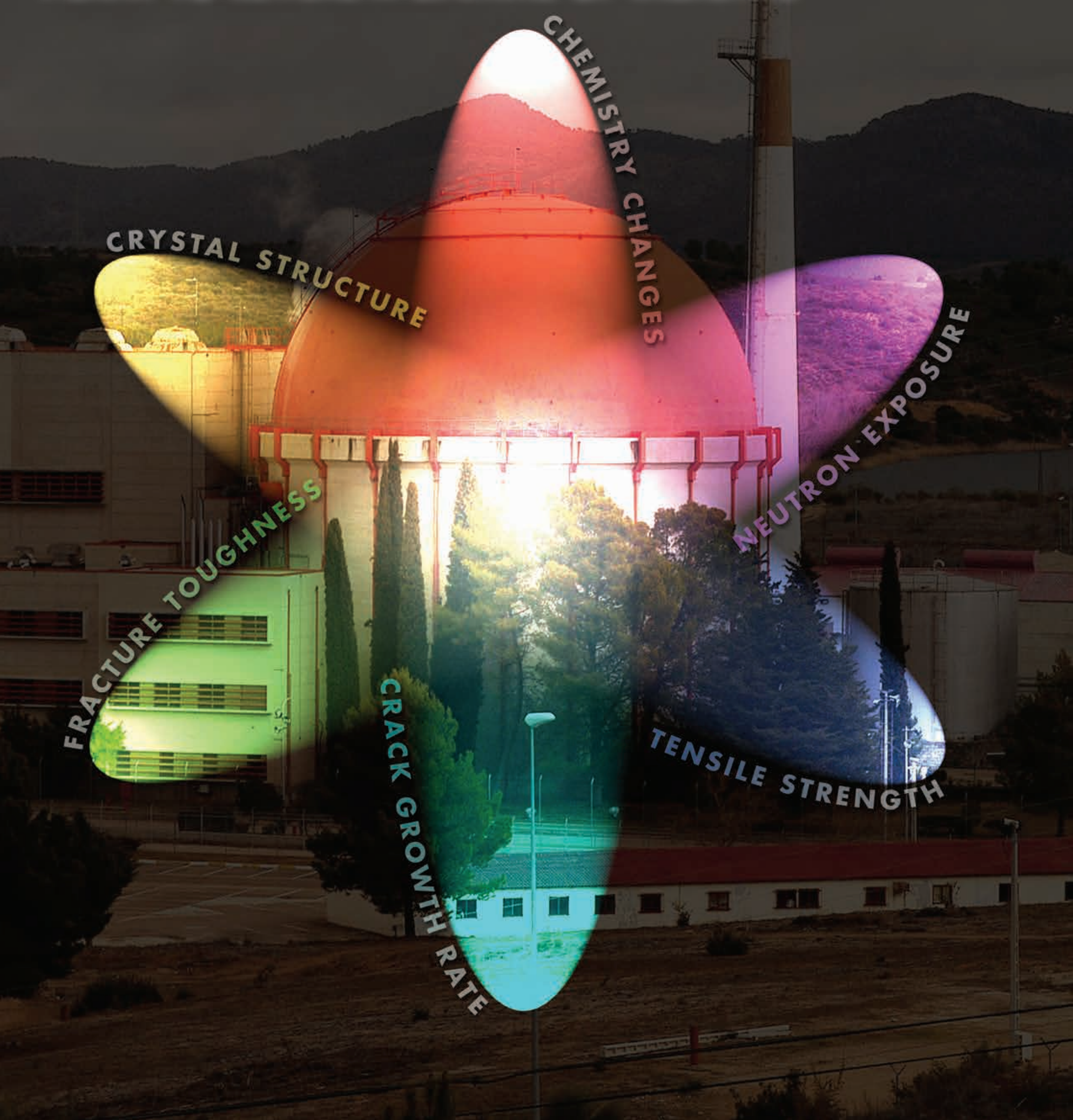
So far, such events haven't happened in reality nearly as often as in the world of fiction. One can only hope that it stays that way.

This article was written by Garrett Hering. Background information was provided by Richard Lordan, rilordan@epri.com, 650.855.2435.

Richard Lordan manages EPRI's Physical Security research.

THE ZORITA PROJECT:

MATERIALS EXTRACTED FROM A SPANISH NUCLEAR PLANT TO REVEAL A LIFETIME OF INSIGHTS



When the *Wilson Gaeta*—a sleek, 88-meter long cargo ship—left the port of Santander, Spain on July 19, 2013, it was carrying an inconspicuous gray, sheet-metal container. Inside this container was a potential treasure trove for nuclear industry stakeholders around the world.

Few if any of the crew of the *Wilson Gaeta* were aware of its contents and would not have recognized them as treasure if they had seen them. The container's lead-lined cask held 70 kilograms of highly irradiated metal meticulously cut into strips and removed from Spain's Jose Cabrera Nuclear Power Plant reactor. These metal strips contain insights from nearly 40 years of exposure to high-energy neutrons and gamma rays at the Cabrera Plant, widely known as *Zorita* because of its location. They were bound for the Studsvik laboratories in Sweden, where scientific teams will work to unlock these insights and understand the precise nature of the materials' degradation.

As the *Wilson Gaeta* carried its cargo toward Sweden, hundreds of people and dozens of organizations celebrated the home stretch for seven years of complex planning, negotiations, and contracting by EPRI and others. Soon, laboratory testing could begin.

More nuclear plants are turning 40 years old—a milestone representing the original licensing period for U.S. plants. As of December 2013, 44 plants around the world had reached or exceeded this age, and their number will double by 2020. As plants continue to age, operators need additional information to manage degradation of irradiated materials. The Zorita project aims to fill a critical knowledge gap regarding impacts of long-term radiation on materials. Precise characterization of material properties after prolonged exposure will enable nuclear plant owners to make better-informed decisions about asset operations, maintenance, and continued investment. Such knowledge also can help the world's utilities and regulators evaluate nuclear plant life extensions.

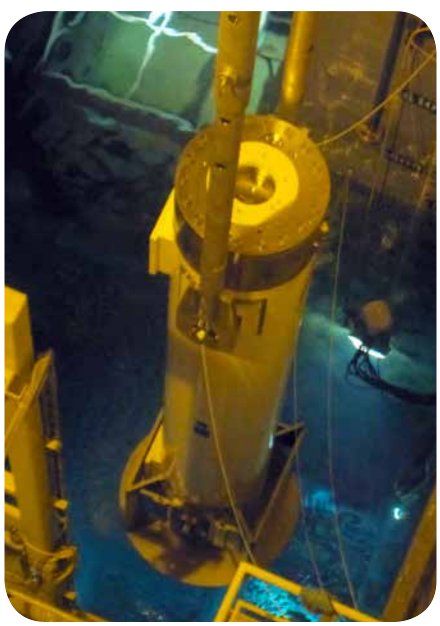
THE STORY IN BRIEF

Under EPRI's guidance and coordination, an international team has extracted irradiated reactor materials from a closed nuclear plant in Spain and shipped them to a Swedish laboratory for analysis. The research will advance understanding of potential materials degradation from long-term radiation exposure, enabling nuclear plant owners to make better-informed decisions about operations, maintenance, and continued investment.

A Rare Opportunity

When Zorita closed in 2006, many international nuclear stakeholders saw its decommissioning as the perfect opportunity to study the effects of long-term radiation on reactor materials (see sidebar, p. 17). "These opportunities are really rare," said Kurt Edsinger, director of materials at EPRI. "It's extraordinary to find a reactor that has the material you want under the conditions you want—from a plant being decommissioned by a utility that is willing to take the time to remove the material and give it to you." Edsinger added that the utility, Union Fenosa, also was willing to provide critical background information to support the research—the operating history, cycle by cycle, including temperature and *fluence* (a measure of neutron exposure), along with knowledge of the makeup of the original material.

Successfully executing the research would require coordination among many utilities, regulators, and vendors from different countries—a difficult



The cask with irradiated materials is lifted out of the fuel pool (left) and then loaded into the container (right).

The container with the cask was loaded onto a truck, which transported the materials to the port of Santander, Spain.

task considering that the materials extraction and transport would have to occur in the context of a nuclear plant decommissioning. "The general feeling during any decommissioning is that this is a very large project with tight schedules and defined budgets—there is no time for science," said Edsinger.

Many in the nuclear industry believed that if any organization could manage such an international project, it would be EPRI. From 2007 to 2013, EPRI Principal Technical Leader Rick Reid worked to convene the stakeholders, define their roles in the project, and gain agreement about how it would move forward.

As EPRI developed and guided the project, interest grew among people and institutions all over the world. Seeing the work's value, they began to contribute their influence and resources. EPRI members and the U.S. Nuclear Regulatory Commission (NRC) provided expertise and funding. Spanish regulator CSN provided approval and support that were critical in bringing to the project the Spanish nuclear utilities and Enresa, which is responsible for nuclear waste management and decommissioning in Spain. Enresa and UNESA, the umbrella organization for the Spanish nuclear utilities, funded part of the material extraction. Also providing funding are European utilities such as Tractebel and AXPO, Swedish regulatory agency SSM, and five Japanese utilities. Mitsubishi Heavy Industries is conducting additional characterization of the materials.

"Like the other program participants, the NRC was interested in characterizing the performance of reactor pressure vessel internal materials irradiated to fluence levels representing some 40 years of commercial reactor operation," said Matt Hiser, materials engineer with the NRC. "The Zorita materials are unique. Most existing knowledge of the performance of materials irradiated to these levels has been obtained from test reactors. However, the conditions in test reactors are not as representative as commercial reactor conditions."

Hiser added that NRC's interaction with EPRI focuses primarily on technical aspects of the project to help ensure that materials tested and the test conditions are representative of commercial reactor conditions for reactor pressure vessel internals. The collaborative agreement between the organizations allows the industry and the regulator to jointly obtain technical data, which NRC will then use to independently assess the data's regulatory implications.

Extracting Samples and Collecting Operational History

Extracting the test samples became an adjunct to decommissioning. The Spanish utility, Union Fenosa, transferred ownership of Zorita to Enresa, which hired subcontractors to perform various decommissioning services. Westinghouse was contracted to cut the reactor internals into smaller pieces. EPRI arranged separately with Westinghouse to cut the samples from the larger pieces after they had been excised from the reactor and moved to the fuel pool.

Westinghouse took eight strips from the one-inch thick *baffle plates*—the parts that are bolted together and arrayed around the fuel assembly. "The longest sample taken was about four feet long," said Reid. "Once in the fuel pool, our strips were cut out and set aside, and the rest of the plate was transferred to the waste disposal liner."

In metallurgy, as in toxicology, the key to establishing cause and effect is the *dose-response relationship.* In this case, *dose* is radiation, and *response* is the degradation of structural materials. The plant operations log can shed much light on historical radiation levels and is therefore essential in understanding material performance under high-radiation conditions.

"As part of the project, engineers had to determine with a high degree of accuracy the radiation exposure of the material over time," said Reid. "This is based on the operational history of the plant, the fuel loading for each cycle, and the precise location of the material. Because the parts of the baffle closer to the fuel have more exposure, we took sections with different neutron exposures." Reid added that the heating of materials from radiation exposure also can have significant effects on material degradation, so researchers had to characterize the heating of the various baffle samples. "The material with the highest neutron exposure has the highest peak temperature during operations," he said.

Long-Term Radiation Exposure and Materials Degradation

The energy created during neutron bombardment in a nuclear reactor displaces atoms from their positions in the crystalline lattice of materials, leaving open spaces known as *vacancies.* These vacancies typically are filled by other atoms that have been knocked loose, but sometimes they remain. Alternatively, some atoms end up in *interstitial positions*—in the middle of lattices not normally occupied by atoms. Vacancies and interstitials are the origins of much of the damage that ultimately affects the mechanical properties of metals.

"Sometimes the vacancies stabilize and don't get filled up," explained EPRI Principal Technical Leader Rick Reid. "You can get a whole bunch of these vacancies fusing together to create a void—a physical pocket. If the region of damage is large enough, swelling can occur."

EPRI Senior Technical Leader Jean Smith added, "If you have a certain percentage of swelling in a large plate, it can induce forces on neighboring components. For example, a bolt that swells is going to affect the plate it is supporting, creating stresses not only on itself but on other components."

Bolts in the reactor core interior have been known to shear off under the stress of swelling. "There have been a few cases at nuclear plants where the head of the bolt came off, but there is enough conservatism built in that such a condition won't lead to a structural problem," said Reid. "The affected plant could continue to operate, and the bolt would be replaced in the next maintenance outage."

Testing in Sweden

The materials arrived at Studsvik on July 26, 2013.

The objective of the metallurgical testing is to understand how and at what rate damage occurs and what parameters influence its severity. "Because of the nuclear safety culture that underpins our work, we want to know if material damage might plausibly get to the point where there is potential risk to the safety of the plant," said Reid. "The Zorita plant operated for its design life, with no failure in any of those materials. These reactor structural materials are not highly susceptible to failure, but damage can and does occur."

Testing will focus on both macro and micro levels. At the macro level, direct mechanical tests will characterize the materials' *fracture toughness* (ability of a material containing a crack to resist fracture), ductility, and crack growth rates from stress corrosion cracking. Micro-level tests will examine their crystalline structure and chemistry changes and pinpoint where and how degradation begins.

Tests completed in 2014 include *tensile strength,* which tests how much stress a sample can take without breaking or deforming. Crack growth rate testing is underway, with all tests scheduled for completion by 2016.

Degradation Management

Insights from the Zorita project offer great potential to inform operations and maintenance activities at aging nuclear plants. Benefits are likely to reach many countries and accumulate over decades.

"It's hard to quantify the value of Zorita, but it's incredibly important," said Edsinger. "The smarter you get in terms of the real performance of the reactor materials, the more you can optimize the way you do inspections, manage material degradation, and even operate the plant."

The results will advance understanding of materials' susceptibility to various degradation mechanisms. This will enable engineers to assess which components need to be inspected, determine inspection frequency, calculate how quickly cracks may grow, and evaluate mitigation techniques. EPRI will develop guidance for appropriate inspection techniques and intervals to identify problems before they impact plant safety or operation.

"Utilities and regulators around the world are asking all the same questions about how to better manage life extension of nuclear plants," said Edsinger. "The Zorita project will provide many important answers."

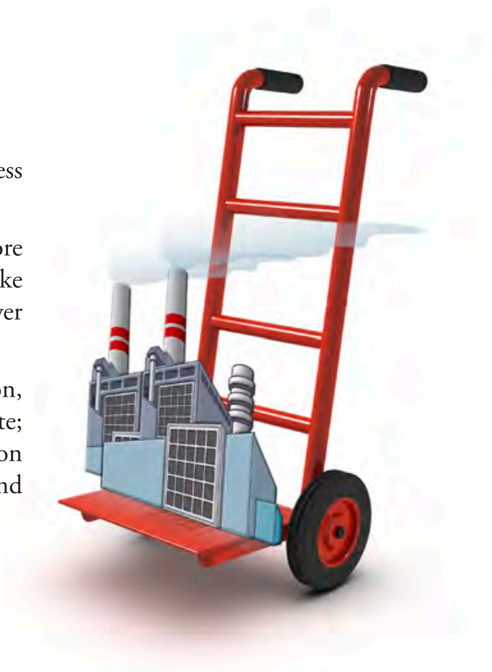
This article was written by Brent Barker. Background information was provided by Rick Reid, rreid@epri.com, 704.595.2770; Kurt Edsinger, kedsinge@epri.com, 650.855.2271; and Jean Smith, jmsmith@epri.com, 650.855.8775.

Rick Reid is a principal technical leader at EPRI, where his research focuses on nuclear plant water chemistry control and decommissioning technologies.

Kurt Edsinger is the director of pressurized water reactor and boiling water reactor materials at EPRI. This area includes near-term efforts to resolve current issues and basic R&D to address longer term issues.

R&D Quick Hits

Express Delivery: The Surprising Economics of Relocating European Gas-Fired Power Plants



Relocating a gas-turbine combined-cycle plant from Europe to South America costs 58% less than building a similar new plant in South America, according to an EPRI study.

With high natural gas prices in Europe, gas-fired plants often run at low levels and therefore yield less income from power production. Depending on the relocation costs, it may make economic sense to move the plant to regions such as South America, where significantly lower natural gas prices can lead to higher plant utilization.

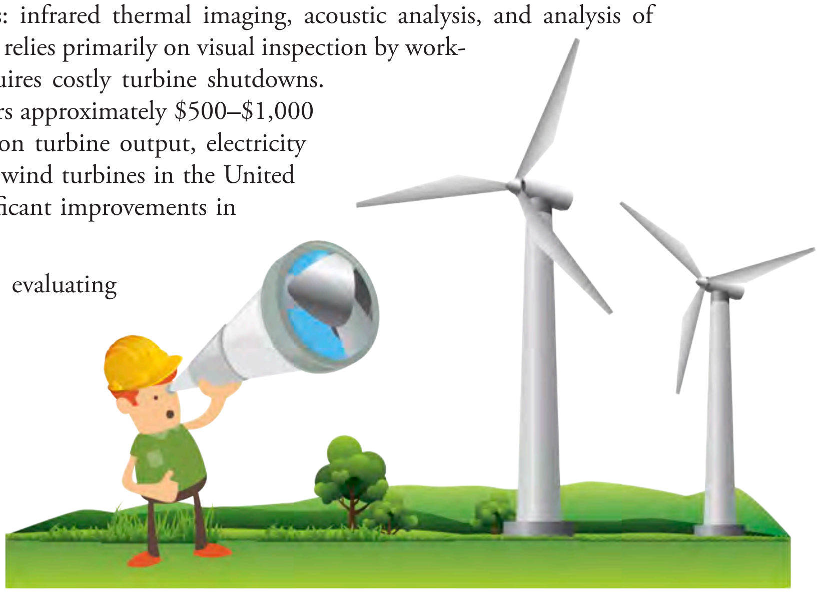
Factors that significantly affect the economics of relocation include the plant's age, condition, and warranty status; labor costs for dismantling and installation; permitting at the new site; and shipping costs. The report's authors recommend that plant owners considering relocation conduct their own detailed cost comparisons. To download the study, go to www.epri.com and enter product ID 3002003656 in Search.

No Climbing Required: New Device Allows for Accurate (and Less Exhausting) Wind Turbine Blade Inspection from the Ground

EPRI and Digital Wind Systems, Inc. have successfully demonstrated a new wind turbine blade inspection technology at a Duke Energy wind farm. The project showed that the technology, known as SABRE™, can detect a range of surface and subsurface blade defects, including broken adhesive bonds, cracks, lightning damage, and delamination. Equally important, operators can safely inspect turbines from the ground while the turbine is operating, and for most applications can complete an inspection in less than 30 minutes.

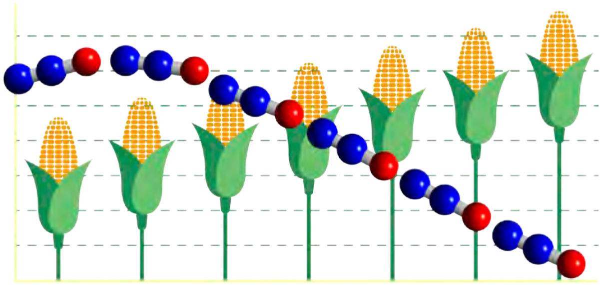
SABRE™ combines three complementary sensor technologies: infrared thermal imaging, acoustic analysis, and analysis of high-speed, high-contrast photography. Currently, the industry relies primarily on visual inspection by workers who climb the turbines, which is time-intensive and requires costly turbine shutdowns. According to preliminary estimates, SABRE™ can save operators approximately $500–$1,000 per inspection in avoided lost power production, depending on turbine output, electricity prices, and time required for visual inspection. With 110,000 wind turbines in the United States and Europe, the industry as a whole could realize significant improvements in cost, efficiency, safety, and reliability.

EPRI is planning additional field demonstrations and is evaluating SABRE™'s potential use in offshore wind farms.



Connecting Corn and Climate Mitigation: EPRI Demonstrates Greenhouse Gas Offsets from Agricultural Fertilizer Reductions

The world's first trade of greenhouse gas offsets from agricultural nitrous oxide emissions reductions used an accounting methodology developed by EPRI and Michigan State University. In June, the American Carbon Registry issued the offsets to a Michigan farmer for reducing emissions by curbing the amount of nitrogen fertilizer used to grow corn. The use of the offsets culminates seven years of work to improve scientific understanding of emissions and develop the methodology.



The methodology's successful demonstration also broadens offset options available to electric companies by enabling fertilizer-reducing offset projects on agricultural lands they own or which are located in their service territories. The climate mitigation impact potential is significant because nitrous oxide has a high global warming potential: each ton of nitrous oxide emitted is equivalent to approximately 300 tons of carbon dioxide.

To complete the demonstration project, EPRI and Michigan State validated the new methodology with an existing offsets certification program, identified a project site and farmer, and worked with a third-party organization to validate the project and verify the resulting emissions reductions. The EPRI report on this project is available for download at http://epri.co/1025399.

Not Just for Leftovers: Microwaves Offer New Possibilities for Nuclear Plant Inspections

Microwave imaging can be used to assess the condition of difficult-to-inspect rubber expansion joints in nuclear power plants with high resolution, according to preliminary EPRI research. Expansion joints absorb vibration and relieve strain in plant piping systems.

Traditional inspection techniques are ineffective for expansion joints because of their complex shape and challenges with inspecting rubber materials. Imaging tools for rubber often use X-rays and can potentially add to worker radiation dose. Ultrasound techniques are inadequate for detecting water in the joints. Many plant operators, therefore, forego inspections and replace the joints every five years, resulting in unnecessary maintenance costs. The three-dimensional microwave images can characterize a joint's internal structure, detecting water and other flaws. EPRI plans to design a microwave probe that matches the joint's shape, making inspection easier.

As nuclear plants age, operators increasingly evaluate parts not originally designed for inspection. Microwave imaging may also be applicable to metals and to other nonmetallic materials—such as high-density polyethylene—that are expected to gain greater use in the future. EPRI has fabricated several nonmetallic and metal samples for inspection to identify the technology's strengths and limitations and evaluate such uses in nuclear plants within three years.

Next Stop for the App Revolution: The Grid

Thanks to advances in microprocessor and software technology, the term *app* may soon be just as popular among grid operators as it is among smartphone users. What if grid devices—everything from smart meters and sensors to capacitor banks and smart inverters—were open platforms onto which utilities could load various applications? Equipment could function more flexibly to meet specific needs.

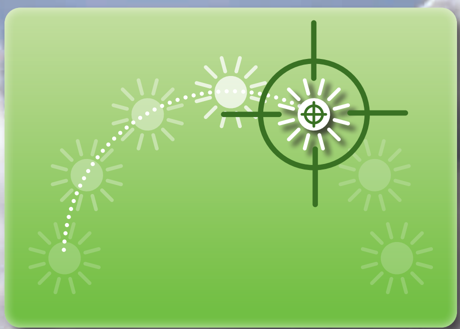
EPRI is investigating the concept of such an open platform, through which manufacturers, app developers, and even utilities could make apps to perform functions, spurring innovation. Examples of future apps for smart meters might include power quality monitoring, billing data collection, and outage notification, as well as emerging functions such as response to stalled HVAC compressors.

Today, manufacturers build a fixed set of functions and services into grid devices, similar to older (and largely obsolete) cell phones. With an open platform, apps could be compatible with many devices, extending their service life as utilities upgrade their functions over time.

EPRI is working with utilities, meter manufacturers, and other technology companies to develop specifications for an open application platform for smart meters.
The EPRI report on this work is available for download at http://epri.co/3002002859.

A Southern Slant on SOLAR:

Multifaceted Research Center Comes to Alabama



ARRAY ORIENTATION AND TRACKING

ACCELERATED MODULE AGING

SHORT-TERM SOLAR FORECASTING

There are plenty of things that people from Alabama point to with pride, but their hot, muggy climate typically isn't one of them. Novelist Harper Lee once described days so humid that "men's stiff collars wilted by nine in the morning." More recently, fellow Pulitzer Prize–winning writer Rick Bragg wrote about how the Alabama sun "did not shine down, it bored into you, through your hat and hair and skull."

While the region's climate has been front and center in American literature, its role in solar power generation is more obscure. Alabama has its fair share of hours and days when the sun isn't out at all, with an average annual rainfall that's nearly double the national average. Even so, there is ample sunshine—and potential for solar power generation—in Alabama and across the U.S. Southeast. But maximizing that solar energy can be challenging because of the region's climate. Humidity may be as tough on solar photovoltaic (PV) systems as on shirt collars, reducing their efficiency and longevity. High temperatures among the hottest in the United States also take their toll on PV module efficiency.

THE STORY IN BRIEF

The viability of renewable energy resources is much like the value of real estate—location is everything. But when it comes to solar, there's more to consider than just how much sunlight is available. EPRI is working with industry partners at a new facility in Alabama to evaluate the performance of different configurations for solar photovoltaic arrays in the U.S. Southeast's high heat, humidity, and precipitation. The knowledge gained from this research will help utilities design, manage, and integrate solar assets.

Enter the Southeastern Solar Research Center, a facility in Birmingham at the 52-acre engineering campus of the Southern Research Institute (SRI). The Center is the product of collaboration among EPRI, which is conducting the first of several research rounds, Southern Company, and SRI, a nonprofit organization involved in everything from preclinical drug R&D to energy and environmental studies. Completed in May 2014, the Center is the first of its kind in the Southeast in its PV research scope and collaborative nature.

Southern Company, the country's fourth-largest electric utility company, serves broad areas of the Southeast. It is funding much of the work and hopes to get other power companies to join in the coming months. Solar currently makes up a tiny fraction of Southern Company's 45-gigawatt generation portfolio. It has been slow to grow in the region for various reasons, including abundant, inexpensive fossil fuels, lack of government incentives, and climate.

"Our investment in renewable generation has increased in recent years, and with that our solar R&D program has grown," said Steve Wilson, Southern Company's general manager of research and development. "Which solar panels are right for the location? What's the best way to install and operate them? A number of questions need to be answered as renewable portfolios grow."

EPRI staff Chris Trueblood and Daniel Foster install components for the Center's soiling measurement station.

Array Orientation and Performance

Currently, the Center features five identical PV arrays, each with its distinct orientation and tracking method: south-facing at a 10° fixed tilt; south-facing at a 30° fixed tilt; southwest-facing at a 30° fixed tilt; horizontal single-axis tracking; and dual-axis tracking (see photo, p. 23). Signs posted nearby indicate the pluses and

EPRI technician Daniel Foster aligns a pyranometer (an instrument that measures solar irradiance) for one of the 30° fixed-tilt solar arrays.

minuses for each array. "Higher expected summertime energy, lower expected annual energy," one reads. Aside from the differences in orientation and tracking, the PV systems are identical.

The first research phase will evaluate how various orientation and tracking methods affect module performance in the Southeast. "It's pretty well understood that to get the best output, you need to point the solar panel at the sun," said EPRI Senior Project Engineer Chris Trueblood, with a laugh. "That said, it's not always cost-effective or practical to do that." He added, "Maybe your roof doesn't face perfectly south or doesn't have the optimum tilt. Depending on when your place gets the most sun and how much sun it gets, it might be more economically beneficial to go with a fixed-tilt mechanism than a dual-axis tracking system, which is always pointed at the sun but may be more expensive to install and operate."

Researchers will investigate how to optimize sun exposure at times when customers need power most. "In Southern Company's service territory, customer load is higher in the afternoons and early evenings, but that's when the sun is already past its peak," said Trueblood. "If you rotate the system so it's optimized for afternoon sun exposure, then you'll get more solar power in the hours that matter most to the area's power system."

The Center is investigating how power production from multi-oriented arrays varies over the course of a day and how that varying production aligns with a utility's load curve. Such insights could help power companies better integrate increasing levels of solar generation into grid operations.

Understanding the Module Aging Process

Consider the average day for a solar module in Alabama: Baked by the sun. Parboiled by the humidity. Battered by wind and rain. Researchers have many questions about how the Southeast weather affects PV modules over time. For example, to what extent do PV arrays degrade after 10, 15, and 20 years when subjected to relentless daily weather cycles in warm, humid climates? What are the points of physical and electrical failure?

Rather than wait decades for answers, researchers are subjecting PV modules to stresses that simulate years' worth of abuse in a matter of months. SRI is well equipped for such research, having done similar work for the automotive industry and the U.S. Department of Defense. PV modules are placed in environmental chambers with humidity up to 98%, then frozen and returned to a warm, muggy state. This cycle is repeated many times. They are also exposed to high-intensity ultraviolet rays to assess degradation of the protective materials that encase modules.

After the modules are sufficiently "aged," they'll be installed and tested in the Alabama sun. "A lot of researchers do the aging studies, and they do the field studies, but most don't couple the two," said Michael Johns, vice president of engineering at SRI. With identical modules made by a single manufacturer, he added, "we'll be getting field data side by side with the baseline data, so we'll be able to show how these perform versus baseline."

EPRI intends to advance the science of PV module accelerated aging research. "Today's aging processes don't give researchers an accurate 'years aged' indicator," said Trueblood. "It's not possible to say with confidence that a given set of aging protocols effectively ages a module by 'X' years for a Southeastern climate." The researchers aim to develop such an aging indicator, providing a deeper understanding of the long-term performance and lifespan of PV modules.

An increasing number of power companies own solar assets. Knowledge gained from this research can provide them with more certainty about the value of multi-decade solar investments and inform planning and budget decisions. "We'll have a better idea of how well existing aging protocols replicate the Southeast environment and hope to be more confident in predicting the life of solar assets," said Will Hobbs, a research engineer at Southern Company.

Sky Imagers, Self-Cleaning Cells, and Robots

Another important issue for solar power in the Southeast is variability in electricity production due to intermittent clouds. Variability will be a major concern for

Southern Company and other utilities as they deploy more solar. "If you put a small PV system in your backyard, and clouds are coming and going all day long, you're not impacting the grid," said Trueblood. "But if the whole community started putting solar on rooftops or building large solar farms, and you have a significant penetration of solar, the utility could be impacted."

In regions with more constant sun such as the U.S. Southwest, utilities can use hourly or daily weather forecasts to get a good idea of how much sun they will get and how much power will result. In regions where clouds come and go more frequently, gauging the availability of solar power can be more difficult. "We currently don't have a way to correlate solar irradiance on the panel with what the sky looks like at any given moment," said SRI's Johns.

The Center is investigating a possible solution: a sky imaging system developed at the University of California, San Diego. The device, which looks a lot like a laser printer with a mirrored dome on top, records visible sky conditions and uses the images to generate short-term solar forecasts. This allows researchers to make use of solar power forecasts minutes before the power is generated. In the future, the pinpoint precision of real-time localized solar forecasts can help utilities mitigate solar power's variability as they integrate PV systems with energy storage and other dispatchable generation resources.

Researchers recently installed a soiling measurement station to compare the performance of a PV module exposed to the elements (including dust, dirt, and pollen) with an adjacent self-cleaning solar cell. The station will provide insights on the cost-effectiveness of PV module cleaning, informing maintenance decisions by large solar plant owners. Southern Company has developed and deployed a robot to inspect solar modules and identify failures through thermal and other imaging methods. There are plans to test other technologies, such as advanced energy storage systems and smart inverters.

The results of this research are expected to have many benefits for utilities as PV penetration rises in their service territories. Analysis of PV array orientation and performance provides much-needed statistics on how well variable solar power aligns with customer load shapes and can help maximize solar production and investment. Quantifying module aging informs PV system design and capital purchases, while short-term forecasting enables utilities to integrate distributed energy resources more effectively into their grids.

"We want to develop the Center for the long term," said Trueblood. "It's not just a one- or two-year project where we close out the project and everything gets decommissioned. We want to see it grow and succeed. And we're reaping the benefits of everything we do there."

Sun, Air, and Water in the South

According to Steve Wilson, Southern Company's general manager of research and development, the investment in the Southeastern Solar Research Center is part of ongoing research on emerging technologies by Southern Company and EPRI. This includes work at the U.S. Department of Energy's National Carbon Capture Center to reduce greenhouse gas emissions from coal and natural gas–based power plants, and research at the Water Research Center near Cartersville, Georgia, to improve the quality of water that power plants return to waterways.

Solar arrays with different orientation and tracking methods at the research center

This article was written by Robert Ito. Background information was provided by Chris Trueblood, CTrueblood@epri.com, 865.218.8118.

Chris Trueblood, a senior project engineer at EPRI, conducts laboratory and field tests of distributed solar photovoltaic systems to evaluate power output variability, utility interactive inverters, and system performance in various environments.

FIRST PERSON *with Ted Craver*

Building a Plug-and-Play Distribution System

Ted Craver is chairman, president, and chief executive officer of Edison International and is a member of the EPRI Board of Directors. In this interview, Craver explains Southern California Edison's recent investments in its distribution system for greater reliability, resiliency, and integration of distributed energy resources and other technologies.

EJ: Speaking at the Edison Electric Institute in June, you said that Southern California Edison has focused recent investments on distribution infrastructure to create a "plug-and-play" network that integrates increasing distributed energy resources, electric vehicles, and other assets. Please explain the thinking behind that.

Craver: The distribution system is at that critical intersection between the electric system and our customers—homeowners and businesses. Most reliability issues that any customer would experience arise in the distribution system. Likewise, the ability to meet customer needs and allow for more customer choice and involvement in how they consume and manage their electric usage comes at that intersection with the distribution system.

Our strategy emphasizes capital investment on the distribution side to facilitate distributed energy resources—which is really another way of saying "Facilitate customer choice and involvement, and ensure that reliability and power quality requirements are met." And of course, as technologies evolve, our customers' demands for higher levels of reliability and higher power quality continue to go up. That's really what we mean by "plug-and-play"—providing a power network that customers can plug any device into and have it work seamlessly, whether it's an electric vehicle, solar, batteries, or technologies we haven't even thought of yet.

EJ: It's an expanded look at reliability for customers.

Craver: The reliability point has always been there. But the industry mostly thinks in terms of reliability measures such as SAIDI [System Average Interruption Duration Index] or SAIFI [System Average Interruption Frequency Index]. Those definitions are based on outages lasting more than 5 minutes. As technologies evolve, as our customers evolve, their tolerance for even momentary outages decreases. Momentary surges, dips in power, or faults can disrupt customer manufacturing processes, many of which are computerized. Even our homes nowadays are geared to digital clocks, so there's a big impact on reliability just from small fluctuations in the grid.

Our need to invest in the distribution side—to make sure it's more robust, more resilient, and has high power quality—is really paramount because that's what our customers need.

EJ: Talk specifically about those investments that make distributed energy resources and the integrated grid more possible.

Craver: A big part is introducing digital monitoring and control devices directly into the distribution system. The electric system was designed contemplating one-way flows of electricity—from big central stations transmitted across high-voltage transmission lines to the distribution system and then to individual homes and businesses. These are relatively predictable flows. Placing distributed energy resources at the terminus of the distribution system creates two-way flows of electricity. At times, electricity could flow back into the grid all the way to the transmission system. Deploying digital monitoring and control devices, advanced control systems, and automation in the distribution system helps us dynamically manage these much more complex, less predictable flows. We're extending the level of sophistication we've had for many years at the transmission level to the distribution level. The system needs to be much more dynamic, flexible, and resilient, and that's what we're investing in.

EJ: As you build this plug-and-play network, what are the challenges related to communications technology and cyber security?

Craver: As is the case in so many other industries, it's a bit of a double-edged sword. The more responsive and dynamic and flexible a system needs to be, the more you need to introduce digital monitoring and control devices. Of course, once you go from a largely electromechanical system to a more digital system, you potentially open cyber-security vulnerabilities. As part of this, we need to ensure that all this new equipment in the distribution system is robust from a cyber-security standpoint.

To that end, Southern California Edison oversees an enterprise-wide cyber-security program to protect its electricity

"Our strategy emphasizes capital investment on the distribution side to facilitate distributed energy resources—which is really another way of saying 'Facilitate customer choice and involvement, and ensure that reliability and power quality requirements are met.'"

infrastructure from cyber threats. The program uses leading-edge cyber-security technology to protect the confidentiality, availability, and integrity of its information technology system and grid-control operations. Along with the entire electric industry and in partnership with several government agencies, we are actively engaged in transferring advanced cyber-security technologies from best-practice leaders in other industries—including the defense and intelligence industries—to secure the electric grid.

You mentioned communication; all these devices require much faster, real-time communication. They are generating enormous amounts of data that in many cases need to be analyzed automatically. So there are much greater communication needs for the distribution system as well. This includes how we will communicate with field devices, field personnel, and customer meters. The traffic on our current networks is so high during the day that we wait until nighttime to download information from our customer smart meters. If we want to make better use of our smart meters, we will need more bandwidth to gather data continuously. We are reviewing our field communications systems for opportunities to consolidate several different networks we use to achieve greater bandwidth.

EJ: This must have huge implications for your workforce and the skills that you have to bring on board.

Craver: Very much so. We're spending quite a bit of time on this. For instance, the operators in our roughly 40 distribution system operation centers must have much more computer training and experience working with digital devices. Even the technicians doing work at the substations and line work must be able to work with more sophisticated equipment than they have in the past. It requires that we upgrade and update the capabilities of our people as well as our tools and capital resources.

EJ: Where are you focusing R&D for a more flexible, connected, and resilient grid?

Craver: Our advanced technology laboratory is in the process of determining how to cost-effectively convert our distribution system's 4,500 radial circuits into a more networked system, and then how to put automation in those circuits to allow them to be much more dynamic and flexible. Once the circuits are more networked, there are technologies that can be deployed to monitor the direction of electricity flow and isolate faults automatically to avoid even momentary outages.

Of course, to get the biggest bang for our research dollar, we do a lot of work with EPRI. EPRI is a terrific partner in this area.

EJ: What's your thinking on how the utility should interact with electric vehicles?

Craver: Electric vehicles could be considered as mobile storage devices that can pull energy from the system and in the future put energy back into the system. Our view is that by managing how additional forms of electrification such as electric vehicles use the system, you can make the system more efficient.

Like every electric system, our system at Southern California Edison is built to handle the needle peaks in usage. For us, that is when our customers have high air conditioning use in the summer. Largely due to our moderate weather the rest of the year, our electric system is utilized on average 48%. That means there is a lot of infrastructure sitting idle when not being used to meet those needle peaks. If electric vehicles are being charged in off-peak periods, then we're able to improve the utilization of our infrastructure. We have a tremendous opportunity with electric vehicles because they're really not used that much—none of our vehicles are, whether they're gasoline-powered or electric. So if you can charge them in those idle periods in times when you can make better use of the existing infrastructure, you're making the overall cost of the system lower.

"We're extending the level of sophistication we've had for many years at the transmission level to the distribution level."

"Our advanced technology laboratory is in the process of determining how to cost-effectively convert our distribution system's 4,500 radial circuits into a more networked system, and then how to put automation in those circuits to allow them to be much more dynamic and flexible."

EJ: What are your plans for deploying electric vehicle charging stations?

Craver: The California Public Utilities Commission originally wanted third parties to provide the charging infrastructure and precluded utilities from participating in this area. It has been slow to develop, so the commission is beginning to re-examine that approach. We're going to make an application to the commission to supply an important part of that charging infrastructure, particularly in high-use areas—businesses, shopping malls, city halls, multi-unit housing, universities—places where a lot of people stay for a period of time. We seek to deploy charging systems to fill part of the overall charging need in our service territory and to spur market adoption in support of California's climate change goals.

To make our program customer-friendly, we plan to qualify multiple charging equipment vendors so our customers can choose equipment that is best suited to the charging needs at their location. We will also advise customers on the size and location of charger installations to control costs and ensure effective integration onto our distribution system.

EJ: What are your plans for deploying energy storage?

Craver: California has a mandate for the state's three investor-owned utilities to put into the system 1,325 megawatts of storage by 2020. As part of that mandate, the state specified a percentage that would go into homes and businesses, a percentage that would go into the distribution system, and a percentage that would go into transmission and generation. Our share of that is 580 megawatts. We can own and put in our rate base 290 megawatts. We do intend to do that.

We expect that virtually all the utility-owned storage that we introduce into the system will be on the distribution side in the substations and circuits. We won't seek to do much on the transmission, generation, and customer levels. Our research has led us to conclude that the distribution grid offers the best value opportunity and cost-benefit tradeoffs for energy storage projects. We're primarily a wires business—we don't own much generation. Adding storage to the distribution system allows us to more easily integrate customer-owned generation and energy efficiency and demand response programs. That's really the natural role for the utility because we own the entire distribution system.

EJ: How have you changed your approach to customer engagement?

Craver: That's an emerging area, and quite a bit more needs to be done. We are starting a different type of dialogue with our customers—one that's more focused on the value that we bring to our customers beyond simply providing a commodity. California is clearly moving toward time-of-use rates, so there will be more variability in rates. That will change the way customers think about when they use electricity and how much they use. Engagement with customers about customized electricity packages is still in the early stages.

EJ: How does the growth of distributed energy resources affect Edison's future generation planning?

Craver: We have a "Preferred Resources" pilot program that grows out of the closure of our San Onofre Nuclear Generating Station. California policy establishes a strong preference for the use of energy efficiency, demand response, renewables, and distributed generation—otherwise known as *preferred resources*. As part of the pilot, we've also included energy storage, since storage may serve as a means to address potential intermittency of some of the other preferred resources such as wind and solar. One of the areas of greater load growth in our system is in parts of our Orange County territory. To address that growth without the San Onofre plant while maintaining reliability of that area, the pilot will use preferred resources to reduce the net growth of local electrical need.

We're still in the early stages of this multi-year pilot, but one thing we have learned so far is that preferred resources do not naturally appear in the system where they are needed most or in the right amounts. For example, we need distributed generation in our Orange County pilot region to meet customer growth. However, these resources tend to be developed in other areas of our service territory with less expensive real estate costs. We're currently working with solar developers and our customers to increase the development of distributed generation where it is needed most.

Pioneering Earthquake Research Yields Positive Results

After two years of investigation, EPRI has found that high-frequency earthquakes—those characterized by rapid back-and-forth movement—do not adversely impact the function of most parts in nuclear power plants. The findings will help utilities more accurately assess their plants' earthquake vulnerabilities.

Heightened Safety Focus

In the aftermath of the 2011 earthquake and tsunami that caused a meltdown at Japan's Fukushima Daiichi Nuclear Power Plant, the utility industry has targeted certain areas and components for additional safety-related research. As part of that, EPRI began studying the potential impact of high-frequency earthquakes, which involve 20–30 ground movements per second. Such earthquakes are more commonly associated with the Midwest and Eastern United States. Low-frequency earthquakes, such as those common in California, are characterized by ground movements as slow as two to three times per second (also expressed as 2–3 hertz).

While many studies have examined how low-frequency earthquakes impact buildings and big tanks, relatively little research has been devoted to how high-frequency temblors could affect nuclear plant components. "If the ground moves 20 or 30 times a second, it doesn't move very far, and these small displacements don't damage buildings," said John Richards, an EPRI principal technical leader who spearheaded the research project. "But it is possible that such high-frequency vibrations could upset the operation of small electrical components in a nuclear power plant. That is what we set out to test."

The Good News

For its testing, EPRI selected more than 150 components, including a range of switches and relays that perform tasks such as turning motors on and off and monitoring temperature and pressure. The components were placed on shaker tables to simulate high-frequency earthquakes and then inspected. While previous seismic studies have largely been in the range of 4–16 hertz, the bulk of EPRI's tests took place at 20–40 hertz, and some were as high as 64 hertz.

Researchers found that 75% of the parts worked without any problems at all shaking rates, including rates far above those of real earthquakes. Importantly, all the parts showing adverse impacts under high-frequency conditions also had impacts in previous low-frequency tests. For example, electrical contacts in

A shaker table test setup for parts called contactors*, which are used to start and stop motors*

some parts bounced during both high- and low-frequency tests—an effect known as *contact chatter.* "This study indicates that there is no unique high-frequency sensitivity," said Richards.

At the outset of this investigation, researchers knew that some parts are sensitive to low-frequency earthquake motions. If it is necessary to use these parts in a nuclear plant, they are carefully evaluated to ensure that the way they are used does not prevent the plant from shutting down safely during a large earthquake. This new study did not identify any unique high-frequency sensitivities, which is critical information for helping utilities identify parts of concern and determining whether they have acceptable seismic capacity.

In the near term, data from the tests will help nuclear power plants with post-Fukushima seismic evaluations mandated by the U.S. Nuclear Regulatory Commission. "Long term, the data will be applied in plants doing full seismic risk evaluations to assess the ability of parts to withstand earthquakes," said Richards.

For more information, contact John Richards, jrichards@epri.com, 704.595.2707.

New Safety Research Center of Excellence Will Boost Industry Collaboration

In 2015, EPRI will establish the Safety Research Center of Excellence to spearhead new power industry safety research and provide greater visibility for current research.

As part of this initiative, EPRI in May organized its first Occupational Health and Safety Research Conference in Charlotte, North Carolina, convening 28 organizations and 65 participants. Reflecting the wide-ranging safety issues in the power industry, the conference featured presentations from academic, industry, and EPRI researchers in four tracks: worker safety, work organization and ergonomics, worker exposure, and emerging occupational safety issues. A 2015 conference is being planned to continue discussions and reports in these areas.

A poignant reminder of safety's primary importance came at dinner on the first night of the conference. Chuck Evans, a Tennessee paper mill worker who lost both of his legs below the knees in a 2008 industrial accident, gave a talk on the personal responsibility involved in safety. "He talked about how an accident like his impacts so many other people, including his family, his co-workers, and his company," said Chris Melhorn, senior program manager, Energy Delivery and Use, Health Environmental Sciences, who organized the conference with a committee representing EPRI's four research sectors.

A Clearinghouse and Convener for Safety Research

Avoiding accidents such as the one Evans experienced is at the core of EPRI's initiative to launch what will be a virtual center, to serve as a clearinghouse for expert knowledge and resources covering critical issues and topics—including compliance with U.S. Occupational Safety and Health Administration (OSHA) regulations.

Much of EPRI's research has a safety component. The center will catalog this safety-related work, equipping industry stakeholders to identify and locate EPRI research and enabling collaboration across EPRI.

For example, OSHA has recently set exposure limits for a harmful welding fume known as *hexavalent chromium.* These fumes are a concern in the electric power industry, and several EPRI members have expressed interest in more detailed investigations. If such work were to ramp up in coming years, members involved in welding research in EPRI's Generation and Nuclear sectors can use the center to learn about the Environment sector's research on exposure to welding fumes. Should it be necessary to change the composition of welding rods to eliminate exposure to hexavalent chromium, research would need to test weld integrity and characterize any new fume exposures.

Accident victim Chuck Evans gives a talk at EPRI's first Occupational Health and Safety Research Conference.

The center will also identify and recruit research participation of organizations and individuals with expertise in particular fields.

The center's approach reflects that of EPRI's member power companies. "Safety is something that is approached corporate-wide in electric utilities," said Melhorn. "It's not done exclusively in generation or in transmission and delivery. It's top down on the corporate level, and that is where we are headed."

While details of the center's operations and research are still under development, Melhorn envisions an advisory structure comprising staff from different EPRI research sectors and member companies. New York Power Authority's Vice President for Environmental Health and Safety John Kahabka, who urged companies to be more collaborative in their safety research in the conference's keynote talk, will lead the center's member outreach.

Also under development is an EPRI "safety stamp" to designate projects that include significant occupational health and safety-related advantages throughout EPRI's research portfolio.

For more information, contact Chris Melhorn, cmelhorn@epri.com, 865.218.8013.

New Research Center Begins Studies to Help American Eels Safely Navigate Hydroelectric Facilities

EPRI's Eel Passage Research Center has started desktop and laboratory studies investigating ways to ensure safe downstream passage of American eels around hydropower facilities. While the binational effort is focusing on the Canadian-American border along the St. Lawrence River, insights from the research may advance eel protection initiatives elsewhere in the United States and Canada and in many other countries. Field research is planned for 2015.

The American Eel: Unique Among Migratory Fish

Unlike salmon and other *anadromous* fish species that migrate upstream to reproduce, the *catadromous* American eels swim upstream as juveniles and then migrate downstream as adults to the Sargasso Sea in the Western Atlantic to spawn and die. "Their life cycle is reversed," said Paul Jacobson, a senior technical leader at EPRI, who directs the virtual Eel Passage Research Center. Historically, eels supported important commercial fisheries and constituted the majority of fish biomass in many headwater streams. Eels also are important predators and prey in coastal and estuarine areas. The eel's unique biological characteristics and ecological importance were key factors driving the center's formation in 2013.

During this downstream migration, the larger adult eels are more vulnerable to turbine blades, and a portion of the adult population dies as they attempt to pass through hydroelectric facilities. "Adults also have greater reproductive value than young upstream migrants because they've already survived 20 years or more and are migrating to reproduce for the first and only time," said Jacobson. With a significant decline in abundance over much of the species' range, turbine mortality has become a concern.

The center is a binational collaboration seeking to identify and develop economically, biologically, and operationally effective methods for safely passing downstream migrating eels around hydroelectric facilities on the St. Lawrence River. Because one of the region's largest hydropower projects spans the United States/Canada border, involvement of entities from both countries is essential. The technical committee guiding research activities includes representatives from generation companies such as New York Power Authority, Ontario Power Generation, Hydro Quebec, and Duke Energy, as well as state, provincial, and federal resource management agencies from the United States and Canada.

The American eel

A Focus on Behavioral Approaches

Current methods to aid downstream eel passage are impractical and ineffective for the large hydroelectric projects on the St. Lawrence River. Screens covering water intakes rapidly collect large amounts of debris, and plant shutdowns are costly.

As an alternative, the Eel Passage Research Center is evaluating ways to influence eel behavior. "We are investigating stimuli like light, sound, and electricity to guide the fish to places where they can be collected and trucked or barged around the projects," said Jacobson. "Our objective is to develop such guidance devices and deploy them along the river near hydropower facilities."

In 2014, the center initiated laboratory water-channel experiments to evaluate eel responses to several stimuli. Work also is underway on a white paper examining previous research on light's influence on eel behavior and advances in lighting technology.

EPRI is planning two studies for 2015. One will use sonar technology to assess the downstream movement of eels in the St. Lawrence River. For the second project, researchers will build a model to characterize the river's water movement patterns—such as velocity, turbulence, and shear—near hydropower projects. Researchers suspect that eel behavior is influenced by these patterns and that manipulating them may help guide the eels around facilities.

The center will continue to identify and conduct additional research projects through the end of its first five-year term in 2017.

International Applications

While the center's work is focused on the St. Lawrence River, the results may help eel conservation efforts in other rivers in the American eel's range, which extends from the north coast of South America to Canada. Insights also may benefit European eels in Europe, Scandinavia, and the British Isles.

For more information, contact Paul Jacobson, pjacobson@epri.com, 410.489.3675.

A Decade of Work on Transmission Line Sensors Comes to Fruition

Although he knows the importance of laboratory work, Dr. Andrew Phillips is not the sort of engineer who believes in endless indoor tinkering.

Since he began EPRI's research and development on wireless transmission line sensors in 2003, Phillips' belief in the importance of getting out in the field and testing new technologies has only increased—especially when those demonstrations ended in failure, as is often the case. "Failures are the only things you ever learn from in this world," said Phillips, EPRI's technical director of transmission and substations.

After plenty of setbacks over a decade-plus of lab and field work, Phillips and his colleagues have developed 11 sensors designed to tackle many challenges that come with monitoring and maintaining transmission lines. For example, the most useful measurements generally need to be done on energized conductors or insulators, which poses challenges and risks for line workers. Today, Phillips and his team have sensors capturing data at 18 different utility sites.

"We don't have a lot of ways to measure what is happening in the field and solve problems," said Phillips. "If you have a problem on a line or if you want to bring back data on a line, there hasn't been a toolbox to go out and do it."

Three Sensor Applications

According to Phillips, the sensors will have one of three basic applications when utilities deploy them. One is to conduct *dynamic line ratings*, which provide the grid operator with a measurement of a transmission line's ability to carry power at any moment in time within design limits, accounting for factors such as wind and temperature. This enables utilities to make adjustments to line current.

The second application is to provide real-time information on assets so that operators know when they are at high risk of failure. "For example, if conductors over 14 lanes of highway start getting too hot, the sensor can report that they may fail," said Phillips.

The third is to provide information that enables utilities to fix problems that are rarely observed in person by maintenance personnel. "It's for when you don't know what's happening in the field," said Phillips. "Like the conductors are galloping [low-frequency motion] and crashing into one another, and there are outages." With the right sensors, utilities can diagnose far-away problems and design solutions.

A sensor that measures conductor temperature, current, inclination, and vibration

A Spectrum of Development Stages

Of the 11 sensors under development, one is already being manufactured. It monitors a conductor's temperature, current, and inclination (bend or sag). The others are in field demonstration, laboratory testing, or are about to begin lab testing.

Phillips expects to see a new sensor commercialized annually for the next few years.

Currently entering the demonstration phase at member utilities are sensors that measure lightning currents and geomagnetically induced currents, as well as a sensor that detects and mitigates power surges.

Making Sensor Data Useful

EPRI is applying equal rigor to developing ways to use the data generated by sensors. "Making sensors that measure things without a parallel effort on algorithms that interpret the data and turn it into knowledge is not that helpful," said Phillips.

Usable knowledge from algorithms enables utility personnel—from field and maintenance staff to asset managers to grid operators—to determine appropriate actions. For example, EPRI has developed an algorithm that analyzes data from its *leakage current sensor* (which detects undesirable current flowing across an insulator's surface) and alerts utility personnel via e-mail to the risk of a *flashover* (an electrical breakdown that creates a short circuit across an insulator).

For more information, contact Andrew Phillips, aphillip@epri.com, 704.595.2728.

Thermosyphon Cooling System Boasts Water Savings Up to 78% in Field Test

In a year-long pilot test completed in 2013, a power-plant cooling technology known as a *thermosyphon* demonstrated great promise to save water in plant operations. The results come at a time when water use in the electric power industry is receiving increasing attention.

Water Research Center: A Focus on Plant Cooling Systems

Reducing water use in power plant operations has become a top priority for utilities as a result of diminishing water resources and increasing demand for water in many economic sectors. Power plant water withdrawal permits can be stalled or blocked in regions with scarce water supplies, and the industry is under increasing scrutiny from investors to use water more responsibly.

To address these challenges, Georgia Power worked with EPRI and Southern Research Institute in 2012 to launch the Water Research Center at the coal-fired Plant Bowen in Cartersville, Georgia. The center tests a range of technologies that boost water-use efficiency in electric power generation. A key focus is reducing evaporative water losses from cooling systems, which typically account for 90% of water consumption in thermoelectric power plants.

"Because power plants use a substantial amount of water for cooling, advanced cooling technologies will be important in the years ahead as we face supply challenges from regulations, droughts, and growing populations," said Richard Breckenridge, who manages EPRI's Water Management Technologies program.

The first project in the center's cooling focus area was a performance evaluation of the Thermosyphon Cooler Hybrid System, developed by Johnson Controls, Inc.

How the Thermosyphon Works

Many U.S. thermoelectric power plants use closed-cycle cooling systems to cool heated water through evaporation in a cooling tower and then recycle the water to produce more electricity. The water lost from evaporation must be replaced by water withdrawals known as *make-up*.

The thermosyphon cools hot water exiting a plant's steam condenser before it reaches the cooling tower, reducing evaporative water losses in the tower. Heat is transferred from the hot water to a refrigerant in the thermosyphon's evaporator, generating a refrigerant vapor that flows by natural convection into its condenser. As fans move cool ambient air over the condenser coils, the vapor's heat is transferred into the air. The technology has few moving parts and requires energy only for the fans.

The pilot thermosyphon evaluated at Plant Bowen

Researchers installed a pilot-scale thermosyphon upstream from Plant Bowen's Unit 4 cooling tower. An additional, small cooling tower was deployed to collect data on air and water cooling. From August 2012 to October 2013, a web-based control system remotely monitored thermosyphon and cooling tower parameters such as water temperature, water flow rate, and ambient humidity. Researchers used the data to calculate water use in the cooling towers and water savings from the thermosyphon.

Results revealed monthly water savings ranging from 34% to 78%, even in months with average ambient temperatures above 70°F. Water savings increased with higher fan speeds—but at the cost of greater power consumption. However, 40–50% of the water savings was achieved without an economic penalty. The thermosyphon required zero maintenance during the year-plus evaluation. Findings are detailed in the report *Performance Evaluation of a Thermosyphon Cooler Hybrid System at the Water Research Center at Plant Bowen* (3002001594).

Full-Scale Demonstration

In 2015, EPRI plans to begin a three-year evaluation of a full-scale module thermosyphon cooler at a plant in the western United States. Researchers will analyze the module's performance and investigate ways to improve the technology's water-saving performance and cost effectiveness.

For more information, contact Richard Breckenridge, rbreckenridge@epri.com, 704.595.2792.

Field Tests Aid Development of a Better Way to Calibrate Emissions Monitoring Systems

EPRI researchers have completed field tests on a device that could make power plant emissions monitoring systems more efficient.

The Problem: Increasing Emissions to Measure Emissions

Consensus has emerged that the current method for calibrating power plant continuous emissions monitoring systems is flawed.

To ensure that these systems properly monitor emissions such as sulfur oxides and nitrogen oxides, plant operators use *reference gases* to calibrate the equipment. But this method does not allow measurement of particulate matter, an important—and regulated—component of fossil power plant emissions.

The problem, said Chuck Dene, EPRI's manager of air emissions monitoring and control, is that "you can't put particulate matter in a bottle and feed it into a monitor to calibrate it." Instead, said Dene, operators usually have to make time-consuming, expensive modifications to emissions control equipment to emit additional particulate matter and use that measured amount for the calibration. "It's obviously not desirable to increase emissions to calibrate an instrument," he said.

The Quantitative Aerosol Generator: A Cleaner Approach

Dene and EPRI Environmental Controls Engineer Cassie Shaban are testing an alternative method at power plants in Alabama, Michigan, and Pennsylvania and in the laboratory: a *quantitative aerosol generator*, or *QAG*. EPRI is developing the device to create an aerosol that closely mimics particulate matter emissions and can be delivered to the monitoring systems in specific amounts for calibration. Because it's done outside the plant's stack, no additional emissions result. The burdensome equipment modifications are no longer needed.

Developing an effective aerosol generator is not simple. Plants use different monitors from various manufacturers, and those differences affect the type of aerosol needed. The aerosol also must match the size, mass, and optical characteristics of the flue gas particles. And to be usable in the field, the equipment can't be bulky.

EPRI has evaluated several designs over the past four years. Through field tests, researchers have improved the aerosol generator by reducing its size and power consumption and incorporating a commercially available nebulizer. At the Monroe power plant in Michigan, a quantitative aerosol generator was used to calibrate four different kinds of monitors. At Pennsylvania's Bruce Mansfield facility, three tests were completed on instruments for three different units. All of the tests have identified the importance of matching the device's particle size distribution with particulate matter expected in the stack.

The quantitative aerosol generator (the white cylindrical device) delivers aerosol to an emissions monitoring system for calibration.

Additional tests will follow on a different type of particulate matter monitor in a Missouri plant. "I think we are now close to a device that is ready for commercialization," said Dene.

Engagement with the EPA

Field tests are also intended to demonstrate the technology's effectiveness to the U.S. Environmental Protection Agency (EPA). "We embarked on the field testing to develop a body of data that could be presented to EPA to show that this technique works and that it can be repeated from site to site," said Dene.

EPRI has engaged EPA because "it does us no good to come up with a calibration approach that is not acceptable to EPA," explained Shaban. EPRI met with EPA officials to solicit feedback on the technology's development path. One idea under discussion is to use the device to certify particulate matter monitors at the manufacturer.

"The EPA understands that it's not desirable to continue with the current calibration approach," said Shaban. "The quantitative aerosol generator is one of a few ways to approach this, and it's the one that has the least impact on emissions."

For more information, contact Cassie Shaban, cshaban@epri.com, 650.855.2345, or Chuck Dene, cdene@epri.com, 650.855.2425.

TECHNOLOGY AT WORK

Member applications of EPRI science and technology

EPRI Guidance Helps FirstEnergy Improve Circuit Card Reliability in Nuclear Power Plants

With the help of EPRI technical guidance, FirstEnergy Nuclear Operating Company (FENOC) has implemented new practices that enhance the reliability of its nuclear plant circuit cards, boosting plant safety and potentially saving millions of dollars in avoided power output reductions.

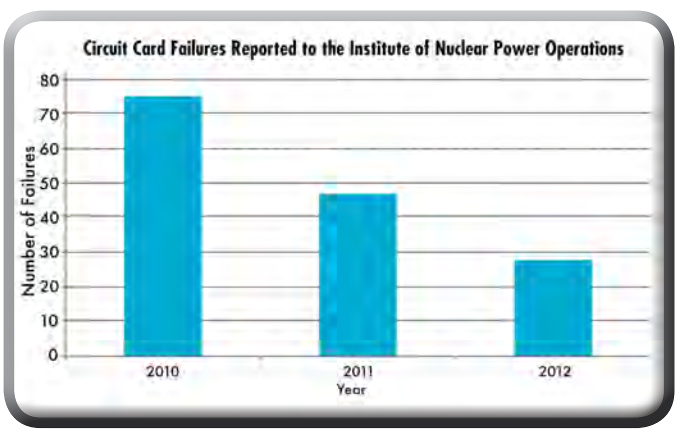
The Gold Card Project

Thirty to forty years after being installed, most printed circuit cards running the vital instrumentation and control systems in U.S. nuclear power plants continue to work well. Yet over the past decade, the nuclear power industry has observed an increased failure rate in these aging circuit cards—a trend that could adversely impact plant safety, performance, reliability, and availability. The cards are vulnerable to degradation from high temperatures, dust, and humidity.

In 2010 and 2011, EPRI published and updated the "Gold Card" report (1022990), which provides information on circuit card degradation mechanisms and failure risks, recommendations and best practices to prevent failures, and guidance on replacing or upgrading the cards to digital technology. Based on findings from across the industry, the report can help nuclear plant operators develop comprehensive reliability programs for circuit cards.

FENOC Implements Gold Card Recommendations

In recent years, the Gold Card report has helped improve circuit card reliability across the nuclear industry, and the number of circuit card failures reported to the Institute of Nuclear Power Operations has dropped each year (see chart below).



Since EPRI initiated its Gold Card project in 2009, the number of circuit card failures has significantly decreased.

FENOC's experience offers an example of this positive impact. At its three nuclear power plants in Ohio and Pennsylvania, circuit cards control virtually all of the plants' safety- and non-safety-related systems, and FENOC completed a detailed gap analysis of its circuit card practices and procedures using the report's 133 recommendations.

A main contributor to EPRI's Gold Card program, FENOC implemented several of the recommendations, yielding quick and substantial benefits. For example, it addressed *infant mortality*—instances in which components fail shortly after being installed—by starting a program that closely monitors new components for 100 hours. The result: 30 defective parts were identified. "Any one of those components had the potential to present an unexpected challenge to operators," said Neil Brooks, instrumentation and controls fleet component engineer at FENOC. "These are components that would either enter us into a limited condition of operation, or potentially reduce a plant's power output by more than 20%. That cost would be on the order of millions of dollars."

As part of an overall update of the company's preventive maintenance guidelines, FENOC changed its fleet-wide definition of refurbishment of circuit cards and power supplies. Focused on extending circuit card life by replacing components that degrade over time, FENOC's approach now includes an examination of circuit pads for discoloration and damage. Other aspects of FENOC's Gold Card implementation efforts include boosting power supply health by testing backup power supplies and aligning maintenance, handling, and planning processes.

FENOC's Brooks believes the most significant value is extending the findings across the industry. "I think the EPRI Gold Card document put into words a lot of tribal knowledge that the more experienced workers knew and put into practice, maybe without thinking about it, and then actually got it out to everybody," said Brooks. "One of the main things is knowledge transfer, so any engineer can pick this up and eliminate many typical circuit card failure mechanisms."

For more information, contact Rob Austin, raustin@epri.com, 704.595.2529.

Con Edison, Bonneville Power Administration Use EPRI Tools for a More Robust Transformer Fleet

Con Edison and Bonneville Power Administration (BPA) have used EPRI analytical tools to more efficiently prioritize repairs and replacements in their transformer fleets, saving maintenance dollars and increasing grid reliability.

EPRI's Expert System Software and Industry-Wide Database

Transformers are both critical and expensive, costing up to several million dollars per unit. Unexpected failure can impact system reliability and stability, with costly outages and disruptive replacement procedures.

Typically, maintenance and engineering staff collect and evaluate data—such as dissolved gas in oil—on hundreds of individual transformers and determine repairs and replacements based on this analysis. Given that most transformers are in good condition, such time-intensive tasks are an inefficient use of relatively scarce resources. What's needed: computer tools for rapidly assessing the current state, future performance, and failure risk of transformers, supporting informed maintenance and capital investment.

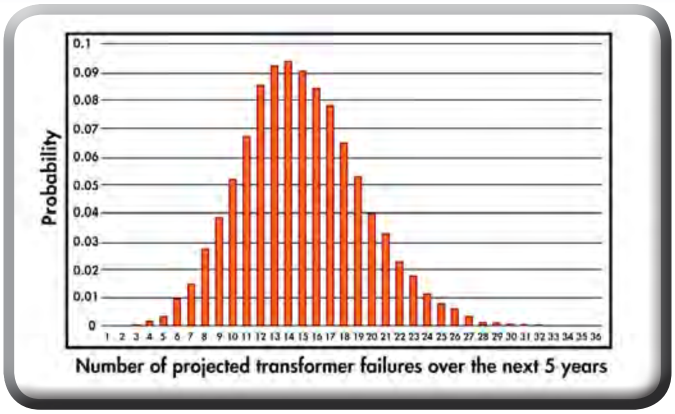
In 2013, EPRI released PTX Expert System Software (PTX) for assessing the condition of a fleet's transformers by crunching data from utility historical records and test results along with each unit's ratings, model type, year of manufacture, and other information. Integrating decades of knowledge of dissolved gas analysis from manufacturers and utilities in a rule-based framework, the software identifies high-risk units for more detailed testing, helping utilities prioritize replacements.

A second tool is EPRI's industry-wide database of transformer performance. Since 2006, EPRI has pooled performance records on 40,000 power transformers from 25 utilities spanning more than four decades—making it the largest database of its kind. The statistically rich dataset enables utilities to predict transformer failures in their fleets with far greater accuracy than analyses based only on their own transformer records. Utilities can focus on transformer attributes such as model and application and use the failure rates to support well-timed capital budget decisions on replacements and spares.

Utilities Implement Tools

Con Edison and BPA rely on staff transformer experts who assess each unit's failure risk based on their knowledge of its history and dissolved gas test data from the utilities' chemistry laboratories.

To supplement these assessments, the utility experts use PTX to analyze their data, confirming potential problems for further investigation—including evidence of long-term aging and short-term repair needs. Results from PTX analyses support their decisions on unit repairs and replacement. When transformers taken out of service were evaluated, their degraded condition was confirmed, validating the software's assessments and demonstrating its ability to help reduce in-service failure.



This chart shows the expected transformer failure rate in a hypothetical utility fleet based on an analysis of EPRI's industry-wide transformer database.

"The PTX tool mirrors the thought process of our experts, and it can analyze much more data—and more quickly," said Con Edison Engineering Manager Matthew Walther.

The database has helped Con Edison's experts understand how its transformer fleet failure rate compares to that of other utilities. They have used it to validate past and existing replacement strategies and will use it to refine future strategies.

BPA has used the database to justify and establish a 10-year transformer replacement program.

Con Edison Expands on PTX

Recognizing the software's potential to support maintenance decisions, Con Edison is working to automate the transfer of transformer data from its laboratory database to the software system. This will help the utility streamline the process and develop reporting capabilities for various stakeholders. The utility is developing an alarm feature to automatically notify key staff about potential problems flagged by PTX. It is also linking the software to its work management database to integrate maintenance histories into their analyses. Long term, Con Edison plans to feed data from online gas monitors on approximately 100 transformers into the software.

For more information, contact Bhavin Desai, bdesai@epri.com, 704.595.2739.

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.

Understanding Electric Utility Customers—2014 Update: Review of Recent Studies (3002001268)

This report is the third in a series reviewing research on how residential customers respond to electric rate structures that vary prices over time. It explores impacts from providing customers with programmable thermostats and information about their electricity consumption.

Performance Evaluation of a Vibratory Shear Enhanced Processing Membrane System for Flue Gas Desulfurization Wastewater Treatment (3002002144)

This report describes the results of a recent field demonstration of a commercially available technology for processing flue gas desulfurization wastewater in power plants. The three-month project at the Water Research Center at Georgia Power's Plant Bowen assessed the technology's contamination removal efficiencies, water recovery, and other operational parameters.

Recommendations for Managing an Effective Cathodic Protection System (3002002949)

This report is the latest in a series of EPRI guides on *cathodic protection*, an essential method for controlling corrosion in metal structures in nuclear power plants. Topics include training and qualification of personnel; communication between cathodic protection system owners and associated plant and non-plant personnel; system configuration; maintenance; data collection; monitoring, surveying, and inspection; performance assessment; troubleshooting; and remediation.

Foreign Material Exclusion Practices in the Field: What Good Looks Like (3002003061)

This video shows work activities on an emergency diesel generator to demonstrate important worker practices that prevent intrusion of foreign material into nuclear plant systems. Utilities can use the video for worker training to support plant safety.

Nuclear Maintenance Applications Center: Video Capture Techniques for Knowledge Transfer (3002003207)

This report provides guidance on using video to document knowledge and expertise from managers, engineers, and other power plant experts before they become unavailable due to retirement or other circumstances. The report provides lessons learned from video sessions that EPRI conducted in developing 3-D animation applications for nuclear plant components.

Cold Weld Repair of Ferritic Components—Case Studies of UK Power Stations (3002003362)

Cold weld repair techniques avoid the need for post-weld heat treatment and reduce repair time, allowing plant operators to return to service quickly. This report describes the successful use of these techniques in the United Kingdom power industry through 13 case studies, providing insights on when they may be viable.

Assessment of Radioactive Elements in Coal Combustion Products (3002003774)

Coal combustion products contain radioactive elements originating from coal, such as uranium, thorium, and their decay products. This report summarizes the current knowledge of radionuclides in coal combustion products and potential radiological impacts. The review did not locate any published studies pointing to significant radiological risks.

Residential Off-Grid Solar Photovoltaic and Energy Storage Systems in Southern California (3002004462)

This study examines the economics and reliability of combined solar photovoltaic-battery storage systems for Southern California residences, concluding that they will be cost-prohibitive for at least the next 10 years.

Understanding the Social Cost of Carbon: A Technical Assessment (3002004657)

The United States government has developed social cost of carbon estimates to value the benefits of CO_2 emissions reductions in federal rulemakings. This study examines the government's social cost of carbon approach and the three models underlying its estimates, identifying opportunities for improvement.

Comments of the Electric Power Research Institute on EPA's Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units [CAA § 111 (d)] (3002004658)

This report contains EPRI's comments on the U.S. Environmental Protection Agency's proposed rule (issued in June 2014) under Clean Air Act Section 111(d) to cut carbon pollution from power plants. The comments assess the engineering, economic, and power sector aspects of the rule.

Robert Lotts
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Pushing the Envelope on Water Conservation in the Desert Southwest

Arizona's Sonoran Desert is a harsh environment: 120-plus degrees Fahrenheit in the summer, with few perennial streams and less than 8 inches of rain per year. In the late 1960s as Arizona faced substantial growth in population and power demand, three utilities—Arizona Public Service (APS), Salt River Project, and Tucson Gas and Electric—began studying the feasibility of building the Palo Verde Nuclear Generating Station, the nation's largest.

The plant's significant cooling water demand in the desert prompted the utilities to commission research that identified effluent from a Phoenix wastewater treatment plant as the most reliable, sustainable water supply. The utilities authorized construction of a 90 million-gallon-per-day water reclamation facility to further treat the wastewater plant's effluent to a quality that cost-effectively met the plant's design requirements. They also built a 36-mile system to transport the water to the nuclear plant. Since the first effluent was delivered in 1982, the plant has used more than 550 billion gallons, saving enough fresh water to meet Arizona's annual municipal and industrial demand. In 2000, APS expanded this use by constructing the 1,000-megawatt Redhawk combined-cycle power plant near Palo Verde.

Both Palo Verde and Redhawk are *zero liquid discharge facilities:* no water is released to rivers, streams, or oceans, and water recovery and reuse are maximized. A key aspect of Palo Verde's water conservation relates to *blowdown*—the mineral-laden water that is periodically drained from cooling towers to prevent equipment damage. While Arizona regulations require 15 *cycles of concentration* (a measure of cooling water reuse) in Palo Verde's cooling towers prior to discharging blowdown to nearby evaporation ponds, pretreatment at the water reclamation facility has allowed plant operators to extend water use to 25 to 30 cycles. This reduces blowdown by approximately 50% and enables smaller evaporation ponds. At Redhawk, a brine concentrator is used to recover blowdown, maximizing reuse and conserving water.

In 2009—nine years into what has become a 14-year drought—APS established its first Water Resources Department, along with a strategic plan to ensure a reliable, sustainable water supply for current and future generation. Several initiatives support the plan, including:

1. Data collection, reporting, and display systems to track water use throughout the generation fleet.
2. Research and development on alternative cooling technologies, alternative water supplies, and treatment technologies to reduce power plant water consumption: For instance, while APS concluded that it is not economically feasible to retrofit Palo Verde and other plants with dry cooling systems (which use air instead of water), the utility used current economic data and information on local environmental conditions to determine that dry or hybrid cooling is feasible for new gas-fired generation.
3. Water infrastructure and well maintenance program: This encompasses groundwater wells, water pumping, treatment, pipelines, and canals. APS is currently evaluating the use of *aquifer storage and recovery systems*—man-made underground basins that can store effluent in shoulder months when excess is available for use in the summer when water demand peaks.
4. Investment in water management staff, infrastructure, technology, and backup water supplies for each power plant: APS will prepare for limited water supplies in the future by securing long-term water contracts with predictable costs.

Numerous studies point to an increasing imbalance between supply and demand, particularly in the seven Colorado River Basin states. APS will continue to improve its water management and carefully evaluate new technologies, while considering their impacts on customers.

APS implemented water conservation strategies in Arizona sooner than in other parts of the country because local conditions demanded them. With growing water constraints even in regions with more precipitation, utilities across the United States almost certainly will find compelling reasons to conserve water in the future and should prepare by observing companies such as APS that already face shortages. Over the next five years, R&D investments in North America should focus on alternative cooling systems, such as dry or hybrid cooling; water treatment strategies that enable more cycles of concentration in cooling systems; and use of alternative water supplies, such as treated wastewater and brackish groundwater.