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RENEWABLES: BIRDS, BATS, WASTE, AND NOISE

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ELECTRIC POWER RESEARCH INSTITUTE

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EPRI Investigates Environmental and Human Health Aspects of Large-Scale Wind and Solar Plants

By Chris Warren

It's becoming more common for airplane passengers to enjoy the impressive sight of vast, glassy blue "lakes" of solar panels on the earth's surface. For birds, however, these glassy lakes can be deadly.

"Birds can perceive solar photovoltaic plants as water and may attempt to land on them for a dip or drink," said EPRI Senior Program Manager Naresh Kumar. "Some limited research suggests that they can be wounded or killed by the force of the impact. There is a need to conduct additional research to fully understand the risks."

The so-called "lake effect" associated with solar panels is one of many potential environmental impacts of large-scale renewable energy plants that EPRI is examining as part of a new set of research initiatives. As countries install more solar panels and wind turbines in diverse places and habitats, the need becomes more pressing to understand these impacts, and EPRI is attempting to get ahead of the related issues.

In 2017, EPRI launched two new research steering committees focused on environmental aspects of wind and solar. They provide platforms for electric utilities to identify research priorities; share best practices and research results; and engage with experts, regulators, renewable energy companies, non-governmental organizations, and the public.

Efforts focus on quantifying environmental benefits of renewables and clearly understanding possible environmental concerns so that they can be mitigated—enabling continued deployment of these technologies.

"When people talk about solar and other renewables, they typically don't think of environmental issues. They think of them as emissions-free technologies," said Kumar. "However, we know that every new technology can have some environmental impacts. We're trying to foresee potential issues sooner rather than later so that we can identify solutions."

What to Do with Millions of Solar Modules?

The International Energy Agency (IEA) projects that global solar photovoltaic (PV) capacity will grow from 300 gigawatts at the end of 2016 to 4,500 gigawatts in 2050. China is projected to lead the way at 1,731 gigawatts, and the United States and India are expected to have 600 gigawatts each. Consider these figures along with the fact that solar modules typically last 20 to 30 years, and it's clear that in coming decades large numbers of panels must be recycled or disposed of. According to the IEA, cumulative global panel waste in 2050 could reach 60 to 78 million metric tons, well above the estimate of 43,500–250,000 metric tons for 2016.

The European Union regulates PV module recycling and disposal, with manufacturers of PV panels required to finance the collection and recycling costs. While the United States lacks PV-specific regulations for disposal or recycling solar modules, federal regulations require plant owners to determine whether the modules must be disposed of as hazardous waste, which is more expensive than shipping them to a standard landfill.

While there is still time before large numbers of modules reach the end of their life, regulatory uncertainty in the United States is driving some utilities to seek answers now. "Even though waste volumes are not yet high, they exist and are accumulating, and some utilities are eager to figure out how to deal with end-of-life issues," said EPRI Principal Technical Leader Stephanie Shaw, who is working with EPRI Senior Technical Leader Cara Libby in EPRI's Generation sector to study solar module recycling and disposal possibilities. "Because it's not clear whether panels are considered hazardous waste, utilities are seeking guidance about what to do with them."

To help inform the industry, a 2017 EPRI-Arizona State University study examined aspects of module recycling in Europe, including volumes of solar panels, how they are collected, and how recycling facilities process them.

"We highlighted what has worked and what has been challenging," said Shaw. "It's an educational piece and a potential model for a recycling system in the U.S."

In a second project, EPRI and the National Renewable Energy Laboratory collected data from European recycling facilities to evaluate the energy intensity of module recycling and expected returns from reselling glass, plastic, and other module components recovered during recycling. EPRI expects to use these data to perform a life cycle assessment for PV panels.

A third project launched this year seeks to provide clarity on whether PV modules meet the federal definition of hazardous waste. According to U.S. Environmental Protection Agency (EPA) regulations, a hazardous waste determination is made for a device by crushing a part of it, soaking it in water and acid, and measuring the concentration of metals that leach into the water.

It's not clear which part of a module should be tested: the solar cells, the electronics, the junction box, or the semiconductor material. "In this project, we're going to crush samples from different modules and test them at two test labs," said Shaw. "We're looking for variability in the results and examining what drives that variability."

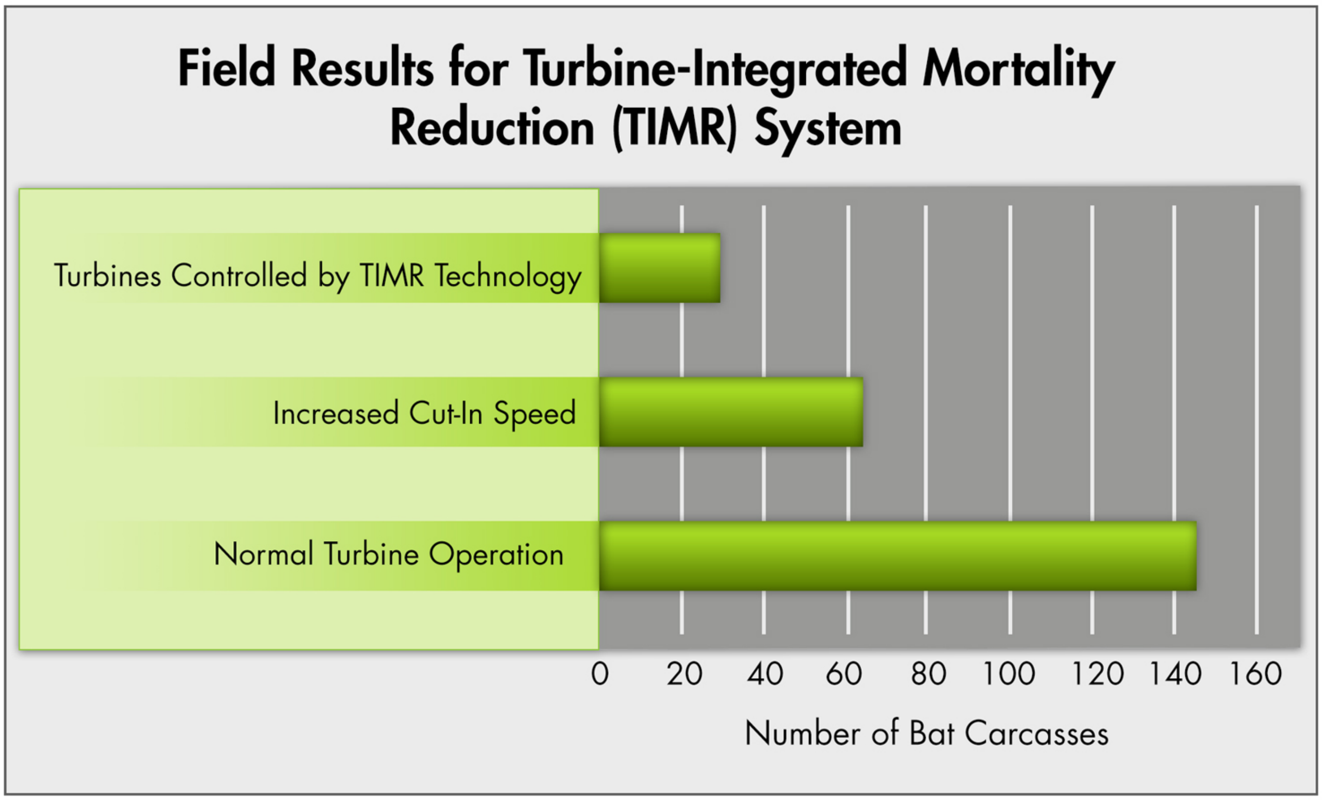
Making Wind Farms Bat-Friendly

A recent academic study* estimated that collisions at wind energy facilities in the United States and Canada killed 840,000–1.7 million bats between 2000 and 2011. Bats are important pollinators and help control insect populations, providing significant economic value to agriculture. In addition, a disease known as white-nose syndrome has caused certain bat populations to collapse, increasing the possibility that more bat species will require federal protection under the Endangered Species Act. These factors, along with a U.S. Department of Energy study that envisions wind energy supplying 35% of the nation's electricity by 2050, have prompted increased concern about bat mortality at wind farms.

EPRI and Normandeau Associates developed a technology that can shut down individual turbines briefly when a large number of bats are nearby. The Turbine-Integrated Mortality Reduction (TIMR) system determines the risk of bat mortality by combining weather data with real-time information on bat activity. It uses ultrasonic microphones mounted on a turbine's nacelle to detect bat calls. Bats are most active at low wind speeds.

"High bat activity is what leads to high mortality rates at turbines," said EPRI Principal Technical Leader John W. Goodrich-Mahoney. "By linking real-time bat calls with weather conditions, the software can determine if the risk of bat activity is high and shut down a turbine for 30 minutes. If the risk stays high, the turbine will continue to shut down in 10-minute increments. The turbine starts up automatically when the risk falls below a certain level."

To test the technology, EPRI organized a 2015 field study at We Energies' 145-megawatt Blue Sky Green Fields Wind Energy Center. To maximize generation while reducing bat mortality, researchers configured the software to communicate with the SCADA system that operates the turbines, automatically triggering turbine shutdowns when there was a high risk of significant bat activity. During the summer and fall bat migration seasons, 10 turbines operated normally, 10 used the TIMR system, and 10 operated at increased "cut-in" speeds. There is evidence that raising cut-in speeds reduces bat mortality because bats typically don't fly during high winds.



The team compared bat mortality among the three sets of turbines and found that the set equipped with the TIMR system saved the most bats by far. "Compared to the normally operating turbines, the system reduced bat mortality by 83%," said Goodrich-Mahoney. "For the endangered *Myotis* species, the reduction of mortality was 90%. It was the first time that particular species had experienced such a steep reduction."

Over the four-month study, all turbine curtailments occurred between July 15 and September 30 when bat activity was high. With the TIMR system, the turbines operated nearly 50% longer than if their operations had been curtailed at certain wind speeds—a common practice among some utilities to reduce bat mortality.

EPRI is collaborating with the American Wind Wildlife Institute to help make wind power operators aware of the technology. EPRI plans to test the technology at other wind facilities.

Health Impacts of Wind Turbine Noise?

Concerns regarding human health impacts of wind turbine noise have been significant enough that press coverage now uses the term "wind turbine syndrome." Originally coined in a non-peer-reviewed book describing anecdotal evidence of health effects related to noise exposure, the term refers to a collection of symptoms that includes headaches, nausea, dizziness, and sleep problems.

Despite the emergence of the "syndrome," there is no credible evidence that wind turbine noise can lead directly to health problems. "The scientific literature clearly shows that it can be associated with annoyance," said EPRI Principal Project Manager Annette Rohr. "Indirect health effects are possible. There's some evidence that turbine noise can disrupt sleep, which can lead to health problems."

Rohr says that specific research is needed to understand potential connections between turbine noise, annoyance, and health problems. "Past research shows that many factors influence whether an individual is annoyed," she said. "It's difficult to isolate the impacts of turbine noise."

For example, some studies indicate that financial benefit can reduce annoyance. "If residents have turbines on their property and are benefiting financially from them, they are less likely to be annoyed," said Rohr. "But they may be annoyed if they're not getting that benefit and at the same time feel a loss of control over their environment."

For the New York State Energy Research and Development Authority, EPRI examined potential links between turbine noise and health impacts at a 126-megawatt wind facility in Wethersfield, New York. Researchers monitored turbine noise inside and near the facility for nine months and surveyed nearby residents on their reactions to the noise. Noise measurements about three miles from the farm served as a control.

The results indicated that noise levels in and near the farm were at times higher than in rural areas without turbines. They varied considerably, depending on wind speed and seasonal conditions, but generally were within limits recommended by the World Health Organization and the EPA. Louder noise did not correlate with greater annoyance reported by residents. A total of 12 survey participants (about 20% of all respondents) reported being concerned about the health effects of wind turbine noise and attributed symptoms such as headaches, fatigue, stress, and sleep disturbance to the noise. However, as with annoyance, researchers found no relationship between the sound intensity experienced by participants and the likelihood of concern about health effects. New York and other states may use the results as they consider siting new facilities and adjusting noise ordinances.

Rohr hopes to launch a study examining health effects of extremely low-frequency sound known as infrasound that has been hypothesized to drive symptoms. The work would use a controlled laboratory environment to expose people to wind turbine noise with and without infrasound, while monitoring blood pressure and heart rate variability.

Insights on potential health impacts of wind turbine noise can inform state and local noise ordinances that specify permissible wind facility locations. "The potential ramifications for both new and existing wind facilities could be significant," said Rohr.

*Arnett, E. B. and E. F. Baerwald, "Impacts of Wind Energy Development on Bats: Implications for Conservation." In *Bat Evolution, Ecology, and Conservation*, 2013.

This article has been amended to correct data cited from Arnett and Baerwald.

Key EPRI Technical Experts

Naresh Kumar, Stephanie Shaw, Cara Libby, John Goodrich-Mahoney, Annette Rohr

From Schwarzenegger's Cyborg to Power Plant Technicians

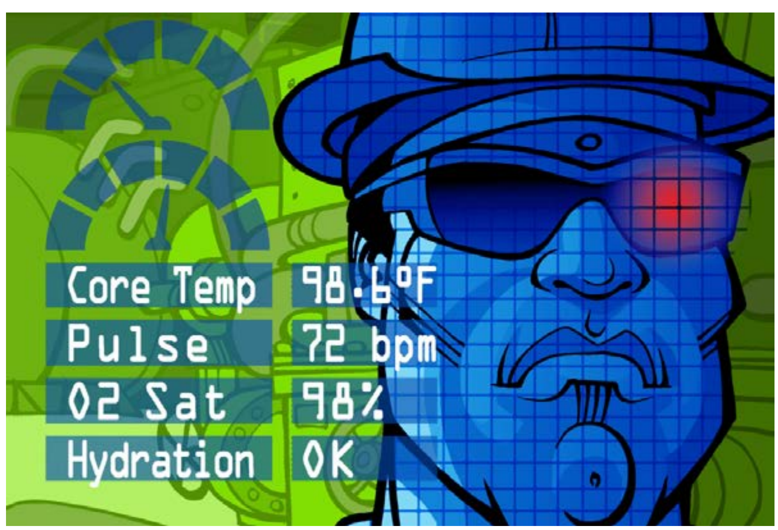
Augmented Reality Is on the Verge of Reality in the Electric Power Industry

By Chris Warren

It wasn't just Arnold Schwarzenegger's classic one-liners ("I'll be back" and "Hasta la vista, baby") that made 1984's *Terminator* such a huge blockbuster. Also driving its quick ascension into the cultural zeitgeist was the futuristic technology built into Schwarzenegger's cyborg character.

In one memorable scene, the audience experiences Schwarzenegger's point of view as he approaches and enters a biker bar and looks at motorcycles, people, and other objects. A red-tinted screen is filled with real-time information describing the objects he encounters—including their height and weight—along with quantitative assessments that, presumably, only a cyborg could understand.

Three decades later, augmented reality is moving steadily from science fiction to becoming a tool that utilities can use to work more efficiently, cost-effectively, and safely, and EPRI is leading a multifaceted research effort to advance the technology.



"When Schwarzenegger walks into that biker bar and information is overlaid on what he sees, it's spooky how close that is to what we envision right now in the electric power industry," said Matt Buck, an EPRI senior technical leader who is developing digital and augmented reality tools to bolster power plant operations and maintenance. "Here's what we're imagining for plant technicians: They view equipment through augmented reality–enabled smart glasses, which automatically overlay information about the components and provide various indicators of condition and performance."

From Fast Food Joints to Utilities

EPRI's augmented reality research is investigating and assessing diverse potential applications in the electric power industry—from power plant operations and maintenance to transmission and distribution line work. EPRI's cross-sector research encompasses laboratory work, field tests with utilities, and technology assessments and development, with potential application in EPRI's nuclear, generation, power delivery and utilization, and energy and environment sectors.

EPRI Technical Executive John Simmins spearheaded EPRI's augmented reality efforts in 2011, shortly after EPRI switched from blackberries to iPhones. "Like any nerdy guy, I downloaded apps right and left, and one was an augmented reality app to locate fast food restaurants," he said. "You looked at your phone, and it would tell you there was a McDonald's 2.4 miles away. I was talking with a colleague and I asked, 'Why couldn't we overlay utility data on reality?'"

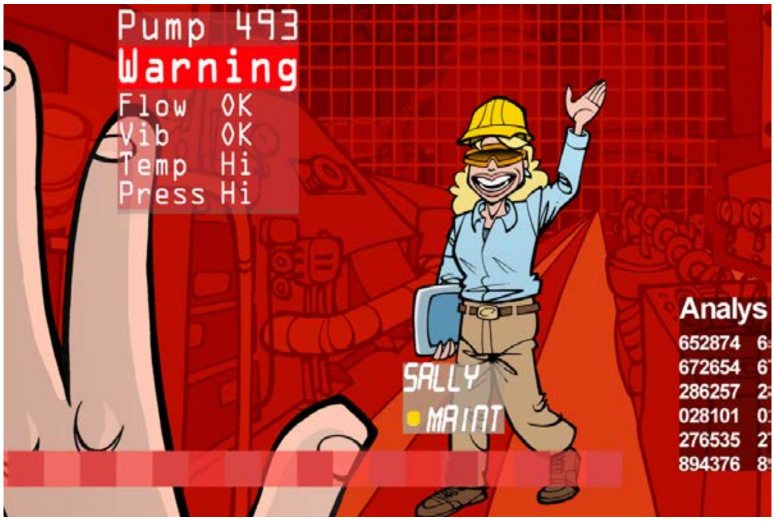
Simmins' first project collaborated with four utilities in successfully demonstrating that utility workers could view grid components through augmented reality glasses or helmets along with information about the equipment's specifications and maintenance history. Now, Simmins is collaborating with 10 utilities to identify applications such as worker safety and storm response. EPRI is assessing the necessary capital investments, quantifying the potential benefits for utility operations, and analyzing cost effectiveness.

"We help utilities identify and document their applications and then develop tests to measure efficiency gains and reductions in human errors," said Simmins. "For example, if a worker saves 15% of his time completing a task with augmented reality, what does that mean in dollars and cents?"

Con Edison Pursues Safety and Efficiency

New York's Con Edison is working with EPRI to test various uses for augmented reality and sees potential for bolstering worker safety and grid operations and maintenance. One application under investigation is substation switching. When done incorrectly, this task can put workers at risk, disrupt electricity delivery, and result in large maintenance expenses.

Augmented reality equips workers with a second set of eyes to prevent errors and point them to the right piece of equipment. "You can look at the switches and see that the one that should be operated is lit up," said Simmins. "If you're not in the right substation—which does happen—you don't see any switches light up."



Another promising application is substation inspections and maintenance. "When you make a round of inspections at a substation, it would be good to have the relevant maintenance history and equipment specifications when you look at a transformer, circuit breaker, disconnect switch, or other piece of equipment," said Sergo Sagareli, a senior engineer at Con Edison.

Do No Harm

While augmented reality shows promise for reducing human errors and increasing productivity, it is essential to demonstrate that workers can safely wear the technology's glasses and helmets.

Marquette University Mechanical Engineering Professor Richard Marklin, who has long collaborated with EPRI on ergonomics research, is working with EPRI Senior Technical Leader Eric Bauman to understand more precisely the impacts on workers of using augmented reality equipment.

"Is it safe to use this technology? Does it affect workers' health and safety, and if so, how?" said Bauman.

Research focuses on muscle and skeletal strain as a result of extended use of glasses and helmets, eyestrain, and situational awareness.

"When you look at an augmented reality display for a long time, there is the potential for dry eyes, eye strain, and muscle strain in the neck," said Bauman. "With situational awareness, the concern is that you become so focused on the display or alerts that you could forget that you're at elevation in a power plant or standing next to energized equipment."

At a test site, Bauman and Marklin plan to monitor 10 electric utility workers equipped with augmented reality helmets and glasses as they complete three typical utility tasks. In the glasses and helmets, a tiny camera aimed at the workers' pupils will detect blinks and other indicators of eye strain. Future tests may involve gauging balance problems after extended use of augmented reality equipment.

In other research, EPRI is developing and testing wearable technologies to enhance worker safety. These include sensors to monitor workers' heart rate and temperature and alert them to danger of a heat stroke. Other sensors can alert workers to nearby hazards such as construction zones, energized equipment, and moving vehicles. EPRI is assessing what is important to monitor and how to interpret the information. While the research is still early, Bauman believes such wearable technologies offer the potential to improve safety of augmented reality use.

From Pencil and Paper to Augmented Reality

The current approach to equipment inspections and repairs in power plants is low-tech. "Many coal and natural gas plants still use paper and pencil," said Matt Buck. "When workers inspect equipment, they often make a written note if something needs work and wait until they get back to a PC before they enter a work request."

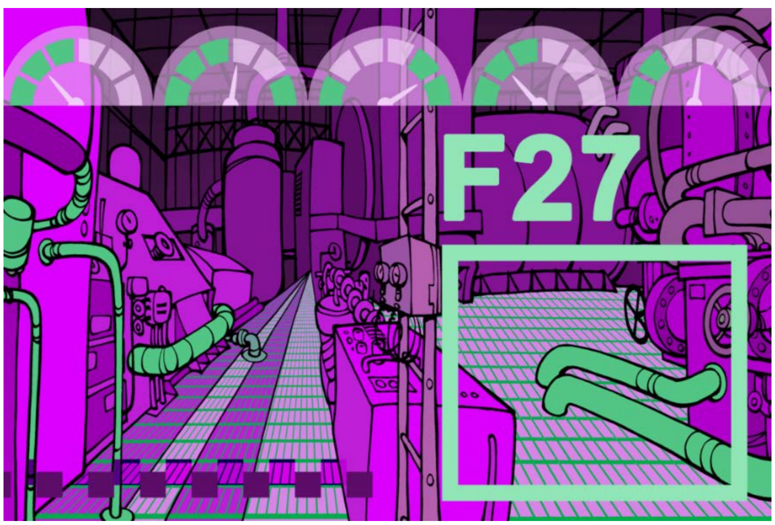
Recognizing that the younger generation of workers is more digitally inclined, utilities are eager to upgrade this approach with augmented reality and other digital technologies. "If you put a young guy in a power plant and hand him a clipboard and tell him to write stuff down, he'll look at you like you're crazy," said Buck.

In 2015 and 2016, Buck and his EPRI colleagues published guides to encourage greater use of mobile devices in power plant operations and maintenance. In 2017, he organized the first "digital worker" interest group—a forum for utilities to discuss current efforts to implement mobile technology for field workers, share experiences and best practices, and assist EPRI in determining research priorities.

These efforts pointed to various ways to manage work more accurately and efficiently. For instance, if a worker determines that a piece of equipment is malfunctioning, instead of taking notes he can scan a tag to initiate a work request. The worker might photograph the component, helping those who will complete the repair to bring the right tools. “You can begin and end the work electronically,” said Buck.

Buck views such digital work management as an essential precursor to implementing augmented reality in power plants. EPRI is examining potential uses of the Microsoft HoloLens*, a headset that superimposes augmented reality images in a person’s field of vision. Researchers constructed mockups of pipes, valves, and other power plant equipment and used the HoloLens to overlay images with information to identify components, menu options for various tasks, and detailed directions on how to accomplish those tasks. A worker wearing the HoloLens headset sees the equipment along with this information and may make selections based on her job responsibilities.

“If you click on a component, a drop-down menu will give you the choice to enter a work request, see assigned work, perform an inspection, and do a lock out/tag out on the equipment,” said Buck. “The vision is a much more human version of Schwarzenegger’s cyborg, walking through a power plant and using the information to diagnose and fix problems.”



Buck recognizes that it’s one thing to make such a tool work in a controlled environment with equipment mockups, but that it’s quite another to implement it in dynamic, diverse field situations.

“In a power plant, there is a lot of rotating equipment, piping, valves, and other diverse components,” said Buck. “How do you incorporate the necessary information so that the device will recognize all this equipment? That is a big jump. You need a lot of computing power that can sit on your nose or head and is lightweight enough that it remains comfortable even with extended use.”

It will take time to develop headsets into a field-ready tool. In the meantime, Buck and his colleagues are working on an augmented reality application that enables workers to hold an iPad in front of a component and view all the same information. They expect it to be ready for field testing in 2018.

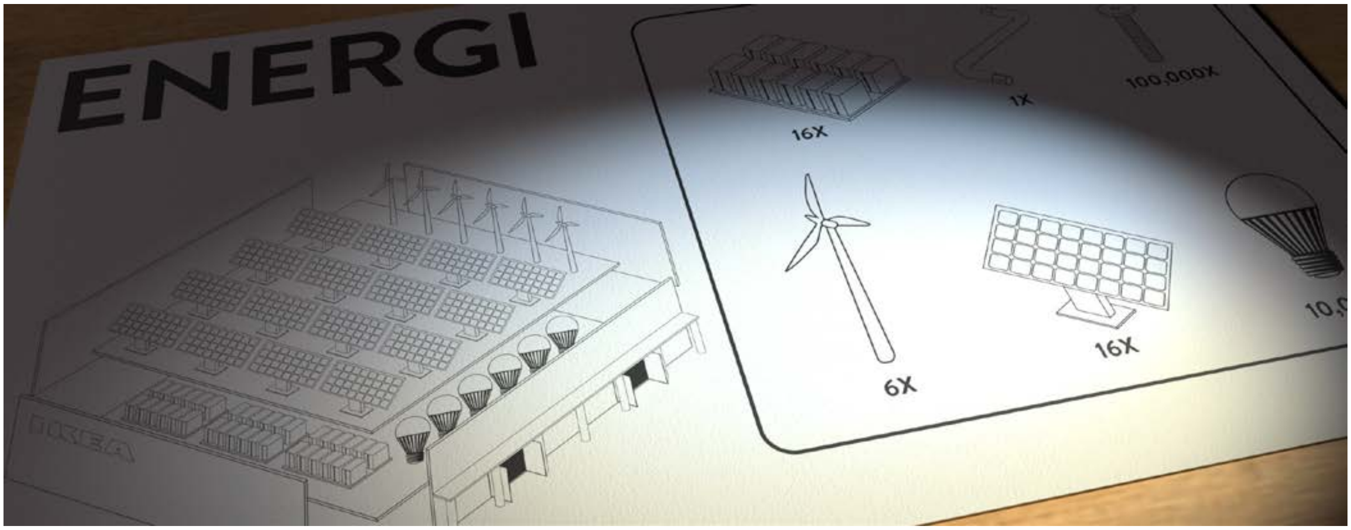
“We have to walk before we can run,” said Buck. “But in the not-too-distant future, augmented reality could become a standard tool for utility workers in the field.”

*Microsoft HoloLens is a registered trademark of Microsoft Corporation. *EPRI Journal* is an independent publication and is neither affiliated with nor authorized, sponsored, or approved by Microsoft Corporation.

Key EPRI Technical Experts

Matt Buck, John Simmins, Eric Bauman

First Person—Energy at IKEA: For the Bottom Line



IKEA Pursues Solar, Fuel Cells, Geothermal, LEDs, and Much More

The Story in Brief

"We have a global goal of producing as much energy as we consume by 2020," says Joseph Roth of IKEA's U.S. Expansion/Property Public Affairs. Roth speaks with *EPRI Journal* about what drives IKEA's renewable energy and efficiency initiatives and how it works with electric utilities to achieve its goals.

EJ: At a high level, what is your company's energy vision—both as a consumer and producer of energy?

Roth: As an energy consumer, IKEA is a retailer with very large buildings that require electricity for air conditioning, display lights, refrigeration for our food operations, and much more. As an energy producer, we're investing in renewable energy generation for our buildings. That said, we rely on the grid for a portion of our consumption and for backup power. The level of grid reliance varies from location to location. As renewable technologies advance, we expect to continue growing on-site generation but still anticipate that our buildings will rely on the grid for backup. We recognize the grid's value as a safety net.

While we are an energy producer, our focus remains on our core retail business. Our energy generation activities are aimed at supporting our locations and our commitment to minimizing impacts on the environment. Our locations remain connected to the grid, and our on-site generation does not result in excess power.

EJ: What are IKEA's goals with renewable energy and energy efficiency? How will IKEA reach them?

Roth: Reflecting our Swedish heritage, IKEA has a strong respect for the environment. We have a global goal of producing as much energy as we consume by 2020. Our strategy is focused on investing in renewable energy at our buildings wherever and whenever possible as well as off-site to enhance our energy generation. Currently, 90% of our U.S. stores, distribution centers, and offices have rooftop solar, for a total of approximately 42 megawatts of generation capacity. We have four stores with solar water heating, two stores with geothermal for heating/cooling, and we own two off-site wind farms in the U.S.

Globally, IKEA evaluates locations regularly for conservation opportunities. We integrate innovative materials into product design; take steps to conserve water, forests, and other natural resources; and flat-pack goods for efficient distribution. Sustainability efforts in the U.S. include recycling waste material; incorporating energy-efficient HVAC and lighting systems, recycled construction materials, skylights, and water-conserving restrooms into buildings; eliminating plastic bags from the check-out process; selling only LED bulbs in our lighting department; and using only LEDs for exterior and interior lighting. IKEA has installed electric vehicle charging stations at 30 stores, with more planned.

"We have a global goal of producing as much energy as we consume by 2020."

EJ: What drives these initiatives?

Roth: The Swedish respect for the environment is ingrained in our culture and incorporated into day-to-day business. As a privately-held company, IKEA has flexibility to pursue innovative energy and sustainability initiatives. We evaluate potential initiatives from a return-on-investment perspective, assessing the economics of proposals and the potential impact on a location's—or the company's—bottom line.

EJ: How does your company work with electric utilities to achieve these goals?

Roth: IKEA partners with various utilities across the country where we have buildings, participating in large customer programs focused on renewable energy, demand management, and energy conservation. We work with utilities to ensure that our solar and geothermal projects serve our buildings' needs while also meeting grid requirements. We recognize that our needs and operations are complex and may present opportunities to implement utility pilot programs. We welcome opportunities to be pioneers in testing new approaches for managing, tracking, or pricing energy use.

IKEA is also open to deploying and testing new generation technologies in collaboration with open-minded utilities. At seven stores, we recently installed fuel cells, all of which are operating smoothly.

"Despite our commitment to renewable energy generation on-site, we recognize the value of staying connected to the grid and the importance of supporting investment in utility infrastructure to ensure continued grid reliability."

EJ: What will your relationships with utilities look like in 5 years? As a customer, what new services and products will you seek from utilities?

Roth: We strive to forge strong and productive relationship with the utilities that serve the areas where we operate. We continually look for opportunities to conserve energy, reduce operational costs, and minimize environmental impacts while also maintaining affordable, reliable utility service. Heating and cooling systems, escalators, and interior and exterior lighting are just a few of the energy efficiency opportunities on our radar.

Utilities can help us evaluate our energy use patterns and identify actions to reduce consumption and costs. As the technology for commercial energy management systems advances, utilities can help us deploy these systems and make optimal use of them.

Despite our commitment to renewable energy generation on-site, we recognize the value of staying connected to the grid and the importance of supporting investment in utility infrastructure to ensure continued grid reliability.

Viewpoint—From Texas Torrents to Generator Island: Insights from a Destructive Hurricane Season

Mike Howard, President and Chief Executive Officer, EPRI

In thinking about the resilience of our power systems, it occurs to me that *resilience* can be considered as *reliability* in response to attack, stresses, or rapid change. For the United States, three distinctive power systems suffered attack from hurricanes in the U.S. Virgin Islands, the Commonwealth of Puerto Rico, and several states in the Southeast.

Hurricane Harvey poured down more than four feet of water on coastal Texas. Hurricane Irma's outage totals were staggering—six in ten Florida customers, a quarter of Georgia's, one in five for Puerto Rico, and about one of ten in South Carolina.

Hurricane Maria destroyed grids on St. Croix, St. Thomas, St. John, and Puerto Rico. One month later, on October 19, only 21% of Puerto Rico's normal grid load had been restored. About 78% of customers were still without power. For the Virgin Islands, the range was stark—with 98% of St. Croix's customers restored and none on St. John, which depended on restoration through an undersea cable.

Mainland restoration proceeded more swiftly, owing to several factors. For example, flood damage differs from damage caused by very high winds. Mutual assistance programs deployed crews and materials relatively swiftly. Florida and Texas utilities had invested in grid hardening and smart grid technologies to help withstand storms and to speed restoration.

We're continuing to learn how a hardened, smarter infrastructure can withstand nature's attacks. We're gaining insights technically, operationally, and financially in repairing such systems. Some of the improvisation now under way in the Caribbean may inspire new approaches for grid hardening, grid resilience, and disaster recovery.

The New York Times reported that Puerto Rico, with its grid destroyed, had become "Generator Island," with generators ranging in size from lawn mower to moving truck. Google received a federal license for its Project Loon to deploy balloons equipped to provide Internet service. Elon Musk's installations of solar power coupled with batteries have drawn significant public attention.

Several key insights emerged from EPRI's Research Advisory Council in October:

- Experience with 2017 hurricanes demonstrated the value of grid sensors, automation, and advanced communication networks.
- What must follow is to rethink grid resilience *and* community resilience. EPRI is leading efforts on zero net energy and other advanced energy communities equipped with technologies to support reliability during severe weather.
- Utilities demonstrated the effective use of social media along with call centers to engage customers and provide outage information.
- Opportunities exist to expand mutual assistance programs to call center operations and inspection drones.

For EPRI, the grid's resilience and vulnerabilities link to many different areas of research. The November/December edition of *EPRI Journal* reports on research and development that demonstrates just how diverse these can be.

EPRI's advanced metering infrastructure (AMI) Industry Status Database includes 75 utilities operating 80 million meters. We're working to make it a comprehensive guide for optimizing AMI. The global market for smart meters will reach $19.8 billion in 2018, and they will continue to grow in importance in storm recovery and system restoration—to name just one important application.

We're working with utilities to investigate augmented reality with grid equipment. Two obviously important areas in the wake of Harvey, Irma, and Maria are worker safety and storm response.

Inside fossil-fueled power plants, our researchers and collaborators in EPRI's I4GEN program are examining the application and benefits of sensors, advanced diagnostics, digital dashboards, and digital worker technologies such as tablets, smartphones, and augmented reality. Ultimately we expect plant operators to process massive streams of real-time equipment data to operate plants more flexibly and reliably in concert with a more dynamic grid.

The *EPRI Journal* interview with IKEA's Joseph Roth provides an important customer perspective as the company seeks to produce as much energy as it consumes in its global operations. He emphasizes the commitment to staying connected to the grid and supporting investment in utility infrastructure. Assuming other large companies pursue IKEA's goal, the technical and financial ramifications are significant for grid resilience and reliability.

Resilient microgrids may require a fuel-based "anchor" generator for baseload power. Fuel cells offer reliable, 24/7, quiet operation along with the highest efficiency and lowest emissions of all fuel-based generation technologies. Many customers may be willing to pay a premium for these attributes.

We also highlight EPRI's Integrated Grid pilot projects, including:

- Entergy's tests of utility-scale solar and lithium ion battery storage systems for smoothing solar's variable output, shifting peak production, and enhancing power quality
- Southern California Edison's evaluation of distributed battery energy storage impacts on its distribution planning, considering grid services, dispatch, and reliability

- New York Power Authority's (NYPA) and Central Hudson Gas & Electric's evaluation of solar and energy storage coupled with smart inverters to minimize the impact of variable power flow in the distribution grid

In the months following these hurricanes, society has focused on rebuilding the grid and the significant work that remains for building more resilient grids and communities. We see opportunity to do this, drawing on what we are learning from the hurricanes of 2017.

Mike Howard

President and Chief Executive Officer, EPRI

In the Field

The Next Generation of Generation

EPRI, Dozens of Collaborators Drive Technology Development to Digitize Power Plants

By Scott Sowers

As fossil power plants operate more flexibly in a dynamic grid, can sensors, data analytics, and other digital tools help them optimize operations and maintenance? EPRI's I4GEN Program is pursuing a range of answers to this central question.

Launched in 2015, I4GEN is advancing diverse technologies to digitize power plants. The I4GEN vision: Sensors deployed throughout the power plant gather massive amounts of real-time data on equipment condition, while automated data aggregation and analysis tools support effective decision making. Fundamental to this is connectivity among plant systems, software, hardware, and staff.

I4GEN has assembled a working group to help drive technology development and share insights. Its 70 participants include utilities American Electric Power (AEP), Duke Energy, Louisville Gas and Electric, Kentucky Utilities, Southern Company, Tennessee Valley Authority (TVA), We Energies, and New York Power Authority. Technology providers include Siemens, which develops hardware and software for the electric power industry, and Emerson, a major supplier of control systems.

The group is using case studies to examine the application and benefits of sensors, advanced diagnostics, digital dashboards, and digital worker technologies such as tablets, smartphones, and augmented reality.

Case studies will begin in fall 2017. One is slated to investigate how to improve advanced pattern recognition (APR) software, which collects and analyzes data on pressure, temperature, vibration, and other equipment parameters. Traditionally, plant personnel manually collected data from plant components. APR provides data electronically every five minutes, enabling utilities to promptly identify faults and problems that require maintenance. For many utilities, however, it is a challenge to screen the large volumes of APR data for actionable information.

"APR is a great technology for detecting potential anomalies," said Duke Energy Technical Manager Greg Augspurger. "But after warnings are provided, people must extract insights from the data and recommend corrective actions. Often, changes in operating conditions are detected that do not require corrective action; this still requires human investigation to make the appropriate determination."

According to Augspurger, Duke Energy sees potential in I4GEN to significantly advance data analytics and APR technology application for electric utilities.

As a starting point, EPRI is planning to evaluate several analytic software packages and determine their usefulness in extracting insights from data.

I4GEN is focusing on user-friendly digital dashboards that distill key insights and actions from the oceans of sensor data. Given each power plant's unique set of operating conditions, it would be impractical to build a single interface that works across the fleet.

"The goal is dynamic and reconfigurable dashboards that provide the right data for the right people," said EPRI Principal Technical Leader Susan Maley. "An operator does not have the same dashboard as the financial manager. As new equipment is added, users would want to reconfigure their dashboards."

A challenge to achieving this arises from the fact that power plant systems use various software that communicate in different languages.

“Their interoperability is poor,” said Maley. “They don’t even identify plant components in the same way. We need a single unifying digital platform for the power plant.”

With I4GEN, EPRI and the working group seek to advance a vision of connectivity and communication among power plant systems, hardware, software, and users.

Key EPRI Technical Experts

Susan Maley

Technology At Work

Data Mining Outside the Box

EPRI Databases Offer Broader Insights on Nuclear Plant Performance

By Brent Barker

In medicine, insights on an individual's health can be gained by comparing test results with historic readings and benchmarking them against the results from a larger population of the same gender and age. In a similar way, databases of nuclear power plant operations can be a powerful tool for comparison, investigation, and analysis. Over the past few decades, EPRI has compiled databases on water chemistries at boiling water reactors and pressurized water reactors, plant radiation fields, fuel reliability, and steam generators.

Nuclear plant operators can ask EPRI to interrogate these databases to help them analyze plant problems and benchmark performance against similar plants.

"The data we have collected reveal that every plant is unique and reacts differently to a change. While in one plant a given change may result in beneficial changes to radiation fields, in another plant of the same vintage and design, this may not be the case," said EPRI Principal Technical Leader Carola Gregorich. "We must approach every optimization challenge by first considering the unique attributes of the plant under investigation and then comparing the plant with its own history and other plants' histories."

"Querying multiple databases enables us to look at a problem holistically," said Gregorich, who has become a leader at EPRI in database mining. "If we limit ourselves to just one database such as water chemistry, we could potentially miss the right answer entirely."

A Shutdown Inconsistency at Vogtle

In 2016, Southern Nuclear asked EPRI to interrogate the chemistry database to help explain an unusual reading during a normal refueling shutdown at the Vogtle nuclear plant. As part of the shutdown protocol, several tasks are completed before the reactor head is removed: Control rods are inserted into the reactor pressure vessel, the reactor is cooled down, and hydrogen peroxide is injected into the cooling water to dissolve the radioactivity on the fuel rods and remove it from the coolant. In both Vogtle units, plant operators found a peak release concentration of 8 microcuries per milliliter of radioactive cobalt-58—about double the amount they expected although well within the range of values observed by the pressurized water reactor fleet. The inconsistency presented no risk to the public, but it required a longer time to clean up prior to commencing outage operations.

"Shutdown for refueling is a well-orchestrated, deliberate process with fairly consistent readings from outage to outage," said Gregorich. "Southern Nuclear asked us, 'Should we have been surprised? Why did this happen? What can we do to prevent this going forward? What does the database show?'"

Gregorich and her team interrogated the chemistry database for shutdowns at other plants with similar designs and with steam generators made of the same material. "Of the 183 shutdowns at similar plants, we found 25 with a cobalt-58 release that was at least double the typical reading," said Gregorich. "One of these readings occurred at a Vogtle unit. This was uncommon but not rare."

To investigate the causes of the cobalt-58 spike, other EPRI researchers including Principal Technical Leader Dennis Hussey mined among the various databases and gathered additional data on the Vogtle units from

Southern Nuclear. This eliminated several design and chemistry factors and narrowed the potential causes to four that were presented to Southern Nuclear for consideration:

- Random occurrence
- Several mid-cycle forced outages
- Chemistry changes in zinc injection operations (zinc is injected into the reactor cooling water to reduce radiation fields)
- Shutdown procedures

Future Use of Databases

EPRI is making the databases easier to access for utilities. “We are working on improving the user interface so plant staff can benchmark different parameters at their facilities against the industry,” said Gregorich. EPRI Project Engineer Nicole Lynch led the development of the new interface, which has gone live. Members are using this new functionality.

“Utilities increasingly ask us to assess their operational procedures and potential improvements,” said Gregorich. “By going beyond an examination of just one plant, the databases offer a wider view and a much greater variety of improvement options.”

Gregorich expects that the EPRI databases—and others like it in the nuclear industry—will become even more valuable. “There is a growing turnover of staff in the nuclear industry,” she said. “Experience and knowledge are getting lost. These databases are becoming an important historical archive that will benefit the next generation of staff at operating and new plants.”

Key EPRI Technical Experts

Carola Gregorich, Dennis Hussey, Nicole Lynch

Innovation

The Meter Is Running

EPRI Helps Utilities Tap the Potential of Advanced Metering Infrastructure

By Chris Warren

Twenty years ago, when Ed Beroset worked in the computer industry, he interviewed for a position at an electricity meter manufacturer doing embedded system programming.

"This job description struck me as odd. I looked at the meter on the side of my house, and it was a bunch of gears," recalled Beroset, now an EPRI principal technical leader. "I wondered, 'Why do we need an embedded system?'"

It was a reasonable question. At the time, electricity meters had changed little since the late 1800s, when Oliver Shallenberger invented the first polyphase meter for Westinghouse. That durable device used magnets, coils, and a spinning disk to measure the watt-hours consumed in residences and businesses. The answer to Beroset's question during his job interview: A technological revolution in metering was about to make it cost-effective for utilities to replace millions of Westinghouse-style mechanical devices with electronic meters.

Today advanced metering infrastructure (AMI) is a major focus of policymakers, consumers, and an electricity industry intent on improving the power system's efficiency, reliability, and flexibility. A recent EPRI survey of utility AMI purchases revealed that companies have spent between $100 and $500 on each meter and expect to devote between $54 and $275 per meter for operations and maintenance over the next 5 years. Transparency Market Research projects that the global market for smart meters will reach $19.8 billion in 2018.

AMI presents many opportunities for utilities to enhance grid operations. For example, smart meter data can be used to optimize grid voltage, but EPRI research indicates that only about 10% of utilities use meter data for this purpose. AMI can also support recovery from storms and other events that interrupt service.

In 2015 EPRI launched an initiative to identify innovative uses of AMI data, develop robust standards that promote interoperability among AMI devices, and share best practices.

"Utilities need more awareness of grid conditions between the substation and the consumer, and AMI can help," said Beroset.

Using AMI data, utilities can quickly identify and characterize the extent of power outages. AMI can also help manage sizable electric vehicle charging loads to benefit grid operations. For example, it could guide pricing to encourage charging when solar energy production is abundant, helping balance supply and demand.

Utilities' ability to tap AMI's potential is limited by proprietary technology and the lack of communications standards—challenges that EPRI is helping to address. "If all these devices 'speak' different communication protocols, there's a lower probability that they will work together properly," said EPRI Technical Executive Brian Seal. "Utilities end up with fewer choices of new devices and models that can be connected to AMI."

The Wi-SUN Alliance™—a group of utilities, meter manufacturers, and other stakeholders developing common wireless communication standards for AMI and other applications—hosts events where vendors test interoperability of devices. EPRI is unique among participants in that it isn't a buyer or seller of equipment.

“That gives us a unique role to help advance standards that do not favor a particular technology or cater to a particular utility need,” said Beroset.

To date EPRI is the only participant developing an open-source communications protocol to be Wi-SUN CERTIFIED™. This can help drive new applications. “Users won’t have to go through the time and effort to translate the written standards and documents into code. They can build upon the open source code,” said Seal.

To help utilities make the best use of AMI, EPRI in 2014 created the AMI Industry Status Database. It includes 75 utilities operating 80 million meters and information on equipment deployed and applications supported. Utilities can log in at any time and update their AMI data and are using the database to determine how others are applying AMI.

“The vision is that it becomes a comprehensive guide on how to help optimize the value of your AMI,” said Seal.

EPRI is compiling best practices for all aspects of AMI operation and management in a series of guidebooks. One shows, for example, how to evaluate meters and other AMI equipment to determine when they are nearing the end of their useful service lives.

“Meters are geographically dispersed, and it’s expensive and time-intensive to replace a million of them,” said Beroset. “You want to know when to replace them well before large numbers are failing so you have time to plan.”

EPRI also tests how well the devices function, which is particularly important as new designs are unveiled. “If there is a high voltage surge of a certain shape and duration, what does it do to the product? If it gets hot outside, does that shorten the product’s life or cause the display to turn gray?” said Seal. “We are performing testing in these and many other areas.”

Key EPRI Technical Experts

Ed Beroset, Brian Seal

Technology At Work

Capturing the Sun

Dozens of Projects Nationwide Examine How Best to Combine Solar and Energy Storage

By Sarah Stankorb

As more solar power generation comes online, utilities face a growing challenge (and opportunity) to store excess daytime energy for use in the evening, when electricity demand increases. Solar power presents a tremendous potential source of energy but not *capacity*—available on demand and with the flexibility to adjust energy flow as needed. Energy storage devices such as batteries can store solar energy to provide this capacity, but grid-integrated storage remains in development.

EPRI is investigating many aspects of deploying solar and storage. For example: How should solar and storage technologies be combined and configured? Where are optimal locations on the grid? Can the same battery technologies serve sunny desert grids and cloudy northern systems? How can solar generation and energy demand be forecast to support the most effective use of batteries?

To answer questions about solar, storage, and other distributed energy resources, EPRI is leading more than 20 Integrated Grid pilot projects and many more related demonstration projects and initiatives across the United States. Some are supported by the U.S. Department of Energy, while others involve regional collaborations among utilities and other electric power industry stakeholders.

"The research is *not* trying to replace the grid connection with solar and batteries," said EPRI Technical Leader Ben York. "Instead, we want to optimize both so that the grid can operate effectively with distributed energy resources."

Research on how best to combine batteries and solar is being conducted at residential and commercial locations and at utility-scale solar power plants connected to the distribution grid. "It's a matter of scale," said EPRI Senior Project Engineer Steven Coley. "At all levels, you're trying to serve load, either for individual customers or many customers."

There's debate regarding whether distributed or central solar and storage would enable a more efficient, cost-effective grid, and EPRI's demonstrations are testing both models.

"Both models could potentially work in different locations, depending on local weather, electricity demand, costs, incentives, local mandates, and market rules," said Coley. "There's likely not a one-size-fits-all model."

Highlights from EPRI's Integrated Grid pilots include:

- **Entergy**, which serves customers across Arkansas, Louisiana, Mississippi, and Texas, recently installed and integrated utility-scale solar and advanced lithium ion battery storage systems in New Orleans. The utility is testing batteries' ability to optimize the value of solar by smoothing its variability, shifting peak production, and enhancing power quality. Researchers are remotely monitoring and controlling the site and reconfiguring the distribution feeder.
- **Southern California Edison** is studying the impacts of distributed battery energy storage on its distribution planning. Preliminary analysis shows that locating battery storage in a way that increases hosting capacity on the distribution system may enable certain grid services, such as supplying energy capacity to distribution and bulk transmission systems, but there may be constraints on dispatch.

Consider the example of a battery located on a distribution system far from the substation. At certain times, providing its full power capacity to the transmission system may violate distribution system reliability standards.

- **New York Power Authority (NYPA) and Central Hudson Gas & Electric** are evaluating the ability of solar and storage coupled with smart inverters to minimize the impact of variable power flow in the distribution grid. A second NYPA pilot with Consolidated Edison is investigating how to use solar forecasting to predict output fluctuations. Researchers also are exploring how to manage load and demand response to optimize the use of renewable energy and energy storage on the grid.

Key insights emerging from these and other projects:

- Accurate solar forecasting is essential to dispatch batteries appropriately and avoid their overuse and resulting degradation.
- Unique vendor approaches are common, and standards are needed for configuring and communicating with solar-storage systems.
- To cost-effectively integrate large amounts of distributed solar and storage, better tools are needed for analyzing the economics and technical aspects of bulk system and distribution system impacts.
- Accurately valuing distributed solar-storage solutions requires a much better understanding of the value of resiliency and customers' willingness to pay for uninterrupted power.

Key EPRI Technical Experts

Ben York, Steven Coley

In Development

A Corrosion-Free Alternative to Steel Pipes

EPRI Looks at High-Density Polyethylene for Pipes in Nuclear Plants

By Sarah Stankorb

Metallic pipes form the backbone of cooling systems in nuclear power plants. Steel is an affordable, strong, readily available, and well-understood material that has been used in pipes in various settings for 150 years. However, it can degrade when exposed to water, presenting potential plant safety and reliability problems.

Since 2005, EPRI has examined high-density polyethylene (HDPE) as an alternative. Made from petroleum, HDPE is a hard, tough, corrosion-resistant plastic, commonly used for natural gas distribution pipes, municipal water transport, and fire protection systems.

"We have a great opportunity to use this advanced material, HDPE, which undergoes none of the corrosion processes that we see in carbon steel piping," said EPRI Principal Technical Leader Ryan Wolfe. "Before utilities could deploy HDPE pipes in nuclear plants, several technical questions had to be answered. Our research has been aimed at determining whether they are an acceptable alternative to steel pipes."

When utilities initiate projects to use HDPE pipes in nuclear plants, they do so using an American Society of Mechanical Engineers (ASME) Code Case. This Code Case uses extensive EPRI research performed over the past 12 years as a technical basis.

Scratches, Windows, and Joints

When plastic pipes are moved during construction or installation, their surfaces can get scratched by rocks, soil, and debris. One EPRI test is examining the extent and degree of scratching that HDPE pipes can sustain safely.

"The HDPE piping performed well," said Wolfe. For two years, pipes with scratches deeper than what is permitted under the ASME Code were subjected to high pressures and temperatures. No failures were observed. These results are being used to propose updates to ASME Code.

If the manufacturer did not thoroughly mix HDPE pipe ingredients, pipes may contain small transparent regions called "windows." When such pipes are heated and joined, the windows may make the joints more susceptible to cracking. There is neither an established maximum acceptable window size nor a nondestructive technique to detect windows, challenging the use of HDPE in nuclear power plants. EPRI is collaborating with the Plastic Pipes Institute to help address these issues.

Also, the ASME Code Case does not address cold fusion in HDPE joints. Fused joints may appear complete on the surface but may be incomplete and weak within the joint, potentially leading to breakage. EPRI found that three nondestructive evaluation methods—phased array ultrasonics, microwaves, and standing torsional stress waves—are effective in detecting cold fusion in HDPE joints.

EPRI also has examined fatigue, creep, and response to fire and earthquakes.

"So far, every time we answer one of these questions, it's one less concern about using HDPE pipe in a nuclear plant," said EPRI Technical Leader Craig Stover.

In 2018, EPRI plans to publish a comprehensive guide for utilities interested in installing HDPE pipes, pending the results of the ASME Code Case.

Key EPRI Technical Experts

Ryan Wolfe, Craig Stover

R&D Quick Hits

A Technical Bridge Across the Pacific Ocean

EPRI Informs Efforts to Extend Nuclear Plant Licenses in Japan

Drawing on decades of technical research on the U.S. nuclear fleet, EPRI research supported a successful effort by a Japanese utility to extend the operating license of three of its nuclear units.

Photo of Takahama Units 1 and 2 courtesy of Kansai Electric Power Company

Many nuclear plants in Japan are approaching 40 years of age—the endpoint of their original licenses. The Japanese regulator has endorsed a framework, similar to the International Atomic Energy Agency's International Generic Aging Lessons Learned (IGALL) program, to support aging management up to 60 years. The IGALL identifies areas in nuclear plants that require aging management programs, providing references (including EPRI research results) to inform the programs' development.

In 2014, the Japanese utilities asked EPRI for assistance in addressing challenges related to license renewal. EPRI brings decades of technical guidance to inform U.S. utilities' aging management programs. After the Japanese utilities identified potential knowledge gaps in their aging management programs relative to the IGALL, they worked with EPRI to identify how EPRI guidance could help fill those gaps.

While conducting this assessment, Kansai Electric Power Company (KEPCO) in 2015 submitted its application to extend the license of Mihama Unit 3 and Takahama Units 1 and 2. In 2016, the regulator approved the extension—the first such approval in Japan. In 2017, two Japanese utilities, KEPCO and the Tokyo Electric Power Company (TEPCO), received an EPRI Technology Transfer Award for the effort. Following KEPCO, other Japanese utilities are using EPRI research and reports as technical bases for their license extensions.

"Working with the Japanese utilities, we found that many requirements in the U.S. and Japan are quite similar, but the details of implementation are dictated by local codes and regulations and by unique data sets and models," said Kurt Edsinger, EPRI's director of R&D for nuclear materials. "This was the first major effort to connect EPRI research with the IGALL approach, and it will likely be repeated as fleets in other countries look to extend the lives of their nuclear plants."

R&D Quick Hits

From Forklifts to Fryers

The Health and Safety Benefits of Electrifying the Workplace

An EPRI Quick Insights brief points to health and safety benefits of efficient electrification in commercial and industrial facilities. Examples include:

- Replacing combustion engine–driven forklifts with electric forklifts can reduce noise pollution, refueling hazards, and worker exposure to carbon monoxide.
- Replacing chemical water treatment with electric processes such as ultraviolet rays and ozone removes harmful chemicals from the workplace and eliminates worker exposure.
- Replacing natural gas fryers and griddles with electric equipment in commercial kitchens reduces ambient temperatures and eliminates exposure to open flames and combustion by-products such as particulate matter and nitrogen monoxide.
- Truck stop electrification can power trucks' heating, cooling, and other equipment, providing an alternative to idling trucks' diesel engines. This can reduce emissions of hydrocarbons, particulate matter, nitrogen oxides, and other pollutants linked to human health problems.

Other benefits of efficient electrification include reduced greenhouse gas emissions and increased energy efficiency, grid flexibility, and productivity.

R&D Quick Hits

A Fuel Cell Future?

The Rise of Microgrids Could Be Good News for Fuel Cells

After decades of high expectations and low adoption, stationary fuel cells may be poised for market growth in distributed generation applications, according to an EPRI Strategic Intelligence Update.

Photo courtesy of Doosan Fuel Cell America, Inc.

Fuel cells offer reliable, 24/7, quiet operation along with the highest efficiency and lowest emissions of all fuel-based generation technologies. But hydrogen fuel management along with fuel cells' high upfront costs, low returns, and slow ramp rates relative to engines, turbines, and other combustion-based technologies have proven to be key barriers to adoption. While those challenges remain significant, substantial improvements to power density and stack life, as well as cost reductions through volume manufacturing, may make fuel cells somewhat more attractive for some niche markets.

A growing awareness and interest in microgrids and distributed generation approaches have also encouraged some customers to take a new look at fuel cells. They are increasingly under consideration as fuel-based "anchor" generators in resilient microgrids, particularly in configurations that provide combined heat and power.

The recent introduction of power purchase agreements for fuel cell generation could eliminate the upfront investment hurdle. Emerging hybrid technologies combine fuel cells with gas turbines and engines to capture unreacted fuel for greater efficiencies and affordability. Another hybrid technology under development couples fuel cells with battery storage to enable dispatchable power and participation in demand response programs.

R&D Quick Hits

The Feeder of the Future

EPRI Simulates a Flexible, Reliable Distribution Feeder with High-Penetration Renewable Resource

In the laboratory, EPRI successfully demonstrated an open architecture to coordinate, control, and dispatch distributed energy resources and to support grid operations. Results suggest that with a robust command-and-control architecture, utilities can use high penetrations of distributed renewables for voltage control, transmission support, and other grid services.

At the National Renewable Energy Laboratory, EPRI built an analog simulator to model a 10-mile distribution feeder connected to hundreds of distributed energy and demand response resources. Standard messages on a recursive network architecture enabled interoperability among the resources, and EPRI software aggregated data from the resources to determine how much power they could supply to or draw from the feeder.

An advanced distribution management system sent requests to the software—such as increase or reduce feeder voltage—that the software fulfilled by controlling groups of resources simultaneously via the recursive architecture. Researchers used this approach to mitigate overvoltage, undervoltage, overload, and other typical distribution grid scenarios.

EPRI's John Simmins (right) led the effort to develop and test the feeder simulator (center) at the National Renewable Energy Laboratory.

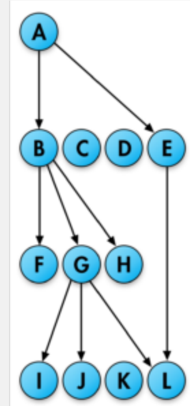
"This research showed how a distribution feeder with high levels of distributed energy resources and demand response could potentially operate in the future," said EPRI Technical Executive John Simmins. "With this architecture, a grid operator can aggregate many energy resources and dispatch them as a group to help balance energy supply and demand, and to maintain acceptable grid voltage."

This approach can be applied to radial grids and mesh networks.

How a Recursive Network Architecture Works

This diagram shows a recursive network architecture that could be used to manage distributed energy resources on a distribution feeder. Each letter represents a network node (connection point) that is connected to generation capacity (such as wind, solar, and energy storage). Each node knows the capacity of and communicates with nodes directly beneath it.

Here's an example of how a grid operator's request for capacity might work: Node A requests 500 kilowatts of capacity from B. Because B has only 200 kilowatts of connected resources, it asks F, G, and H each to provide 100 kilowatts. F and H have 100 kilowatts of connected resources, but G has only 10 kilowatts—so G requests 30 kilowatts each from nodes I, J, and L. The chain of communication fulfills the original 500-kilowatt request.



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