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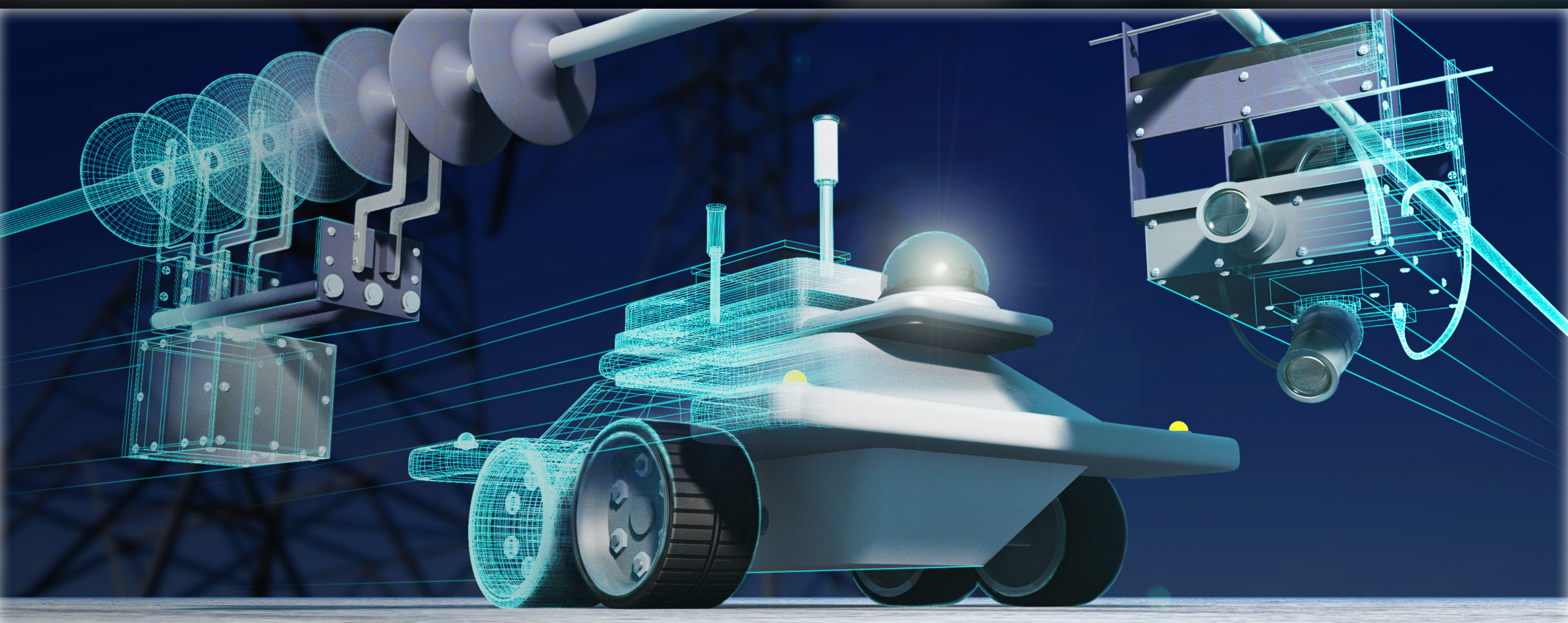
EPRI JOURNAL

Robots Take on Tough Tasks in Transmission and Distribution



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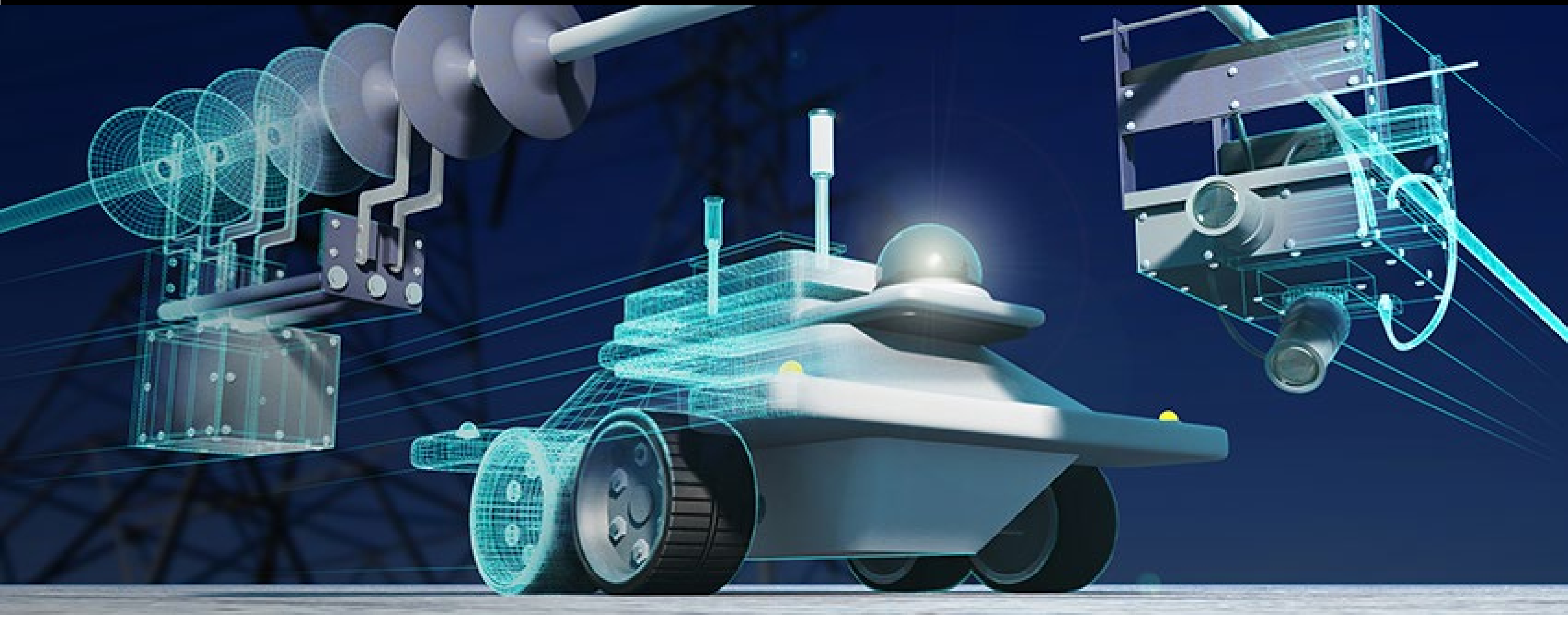


Robots Take on Tough Tasks in Transmission and Distribution

By Brent Barker

Czech playwright Karel Capek coined “robot” for human-like creatures in a 1921 play, adapting an old Slovakian term for forced labor, *rabota*. Made from “chemical batter,” his robots disappeared into the annals of science fiction. But the term stuck and entered the English language in 1923.

Today’s robots are anything but chemical batter and are specialized to carry out tasks too dangerous, cumbersome, remote, or complex for humans to handle. They range from large, multi-arm robots used in automobile assembly to bomb-disabling robots used by police and military to nanorobots used in medicine for delivering drugs through the bloodstream.

For more than two decades, the electric power industry has explored robots’ potential for critical tasks. In transmission and distribution, EPRI has investigated robots able to:

- Glide along shield wires to inspect overhead transmission lines
- Maneuver inside underground vaults to inspect electrical cables
- Climb on and inspect overhead porcelain, glass, and polymer insulators
- Inspect substation components and protect them from intruders
- Swim through the oil inside large transformers to inspect the core

TRANSMISSION LINE ROBOTS

Overhead transmission lines are among the electric power utilities’ most widely dispersed assets. In the United States alone, they traverse tens of thousands of miles—many of them in remote areas. Inspection is needed once or twice a year to assess component aging and right-of-way clearance. Historically, crews conduct visual inspections or use cameras and other instruments as they walk rights-of-way, climb structures, or travel in helicopters. While critical to system reliability, the work is time-consuming, costly, and sometimes dangerous.

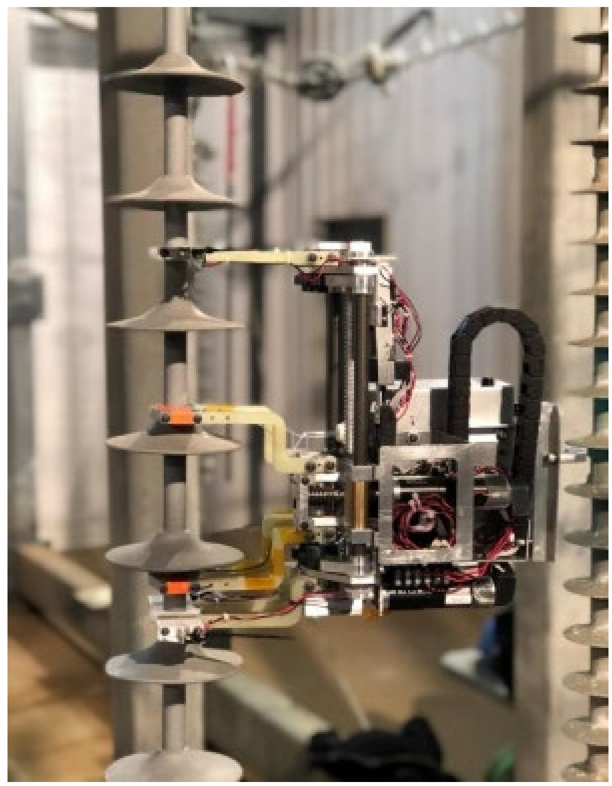
Following nearly two decades of research and testing, EPRI developed an autonomous transmission line inspection robot named “Ti.” It glides along the shield wire above energized conductors, covering an average of 3 miles per day. Bypass systems help Ti get around obstacles and transmission towers.

"We're deploying Ti in Ohio on a 75-mile segment of a 138-kilovolt transmission line operated by American Electric Power," said Andrew Phillips, EPRI vice president of transmission and distribution infrastructure. "When it is up and running in early 2019, it will be the world's first fully autonomous transmission line robot. It draws energy from the transmission line's electromagnetic fields at key points to charge its batteries, glides along the line taking photos and various readings, and sends them in real time to workers. It can complete the 75-mile line in five weeks."

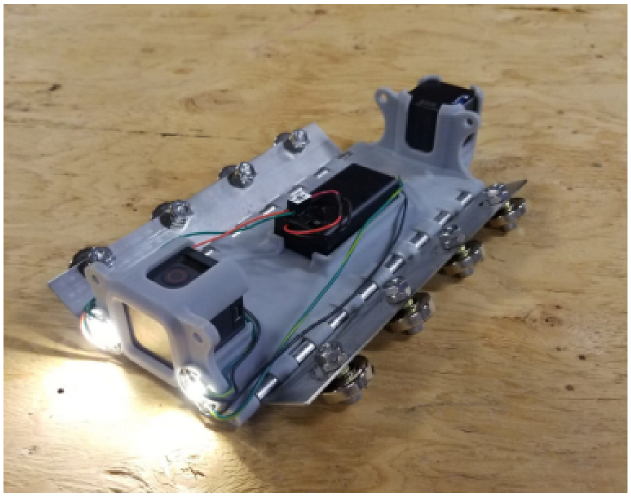
EPRI's transmission line inspection robot.

Evaluation of a security robot at EPRI's Lenox test facility.

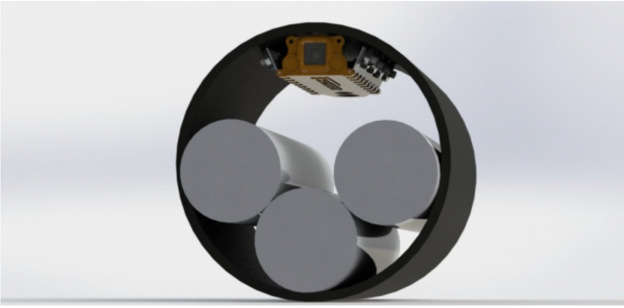
An infrared camera image taken at night by a security robot at EPRI's Lenox test facility. It shows a person behind a fence and energized transformers on a utility pole.



Lab testing of EPRI's insulator inspection robot prototype.



EPRI's robot prototype for inspection of underground transmission cables that run through pipes.



A mockup of EPRI's underground cable inspection robot with a section of pipe and cables.

Ti's high-definition visual and infrared cameras inspect rights-of-way and components and determine clearances between power lines and trees. Its electromagnetic interference detectors can locate discharges such as arcing. Other instruments planned for future deployments: lightning sensors, vibration sensors for windy areas, and leakage current sensors for coastal areas where salt can contaminate components. If speed is required—for example, to pinpoint the source of a recent outage—Ti can move up to 5 miles per hour.

"We're working on a configuration similar to a railway roundhouse that would enable the robot to move to another transmission line as it goes through a substation," said Phillips. "This will greatly increase its usefulness and value."

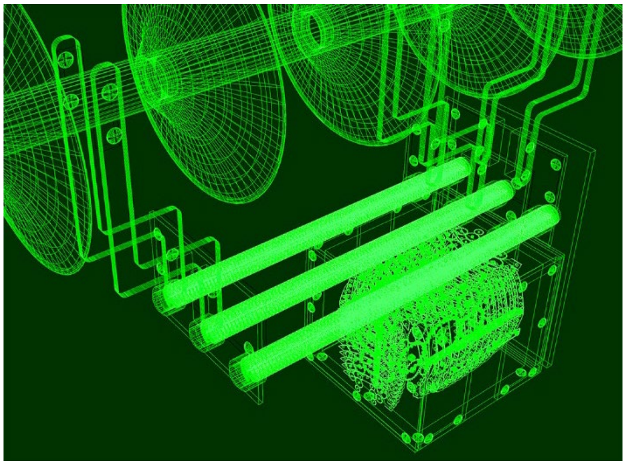
EPRI is examining Ti's costs and benefits such as improved safety and data quality. By pausing in one spot, the robot can capture better quality images than those taken from a helicopter flying at 30 to 60 miles per hour. "Ti can eliminate the need for detailed helicopter inspections, reducing risk," said Phillips.

TRANSMISSION INSULATOR ROBOTS

Research on insulator robots is driven by the need to mitigate safety risks posed by defects in polymer insulators, which are 3 to 15 feet long depending on the power line's voltage. "Polymers are the predominant insulator material today, and the problem is that you can't see an internal defect affecting electrical performance. You need an electrical tester that makes direct contact with the insulator," said EPRI Senior Project Manager Erika Willis.

EPRI has developed and commercialized the Live-Line Working Non-Ceramic Insulator Tool, which can identify conductive defects. However, workers must manually apply the tool using a hotstick. Holding a 10-foot long fiberglass hotstick that sways with the weight of an instrument on the end can be taxing on the body, especially if the worker is up high in a bucket truck battered by wind.

"EPRI's concept is a robot integrated with the Live-Line Working Non-Ceramic Insulator Tool. It crawls up the insulator, collects readings with the tool, then crawls down, where you pull the tool off and get your results. It tells you if the unit is acceptable," said Willis.



When EPRI lab-tested the robot with 10 different insulator configurations, the robot's measurements proved more consistent than manual hotstick measurements. "But a lot of work is needed before the robot can be confidently applied in the field for all insulator designs," said Willis.

EPRI is working with Southwest Research Institute to adapt that robot to work with porcelain insulators. Other enhancements under development include extending the arms and grip hands, extending the length of the robot, and incorporating advanced sensors to improve data quality and processing speed. “We can pack a lot more into a small robot and put cameras on every single arm,” said Willis.

UNDERGROUND CABLE ROBOTS

Because most parts of underground cable systems are buried, visual inspections are conducted at discrete points: inside underground vaults known as *manholes*, at substations, or structures at junctions with overhead lines. Manholes are points of vulnerability, requiring regular inspections to assess the condition of cables, cable splices, joints, supports, and other equipment.

The confined space inside manholes presents challenges to thorough inspection. To avoid sending inspectors into the manhole, some utilities will maneuver a camera with a light source from the surface.

EPRI is analyzing robotic techniques for inspecting underground transmission cables to improve worker safety and reduce outages. “We’re investigating commercially available systems, their limitations, and how they could be adapted for underground cable use,” said EPRI Engineer/Scientist David Kummer. Challenges include image clarity, navigation, robot retrievability, and signal strength inside the manhole.

“We’re evaluating drones for inspecting the joints and other components in manholes,” said Kummer. “We have completed a test to determine imaging capabilities and understand the challenges when maneuvering in a manhole. Next we’ll test commercially available drones designed for confined space applications.” Kummer’s team is using a shipping container to build a mock manhole for testing these systems.

EPRI is examining systems in which three-phase cables are contained within a steel pipe and pressurized with oil. “We are evaluating a robot that can move inside the pipe and through the oil to inspect the cable,” Kummer said. A few manufacturers make robots designed for gas or water line inspection, raising the question of whether they can navigate effectively through oil and in a pipe containing a cable.

In EPRI’s Charlotte facility, Kummer and his team have built a robot prototype and mockups of pipes containing defective cables. “The robot measures 2 inches high by 11 inches long by 4 inches wide, carries two cameras, LED lights, and uses magnetic wheels to hold itself against the inside of the pipe so it doesn’t contact the cable,” he said. “In our laboratory, we manually pulled the robot through 20-foot sections of pipe with mocked-up cables to assess the imaging limitations. We identified many, but not all, of the defects implanted in the cable,” said Kummer.

EPRI is continuing to evaluate these and other technologies, including underwater robots.

ROBOTS FOR SUBSTATION SECURITY

Because substation security still relies largely on gates, guards, lights, and motion detectors to thwart theft, vandalism, and terrorism, EPRI is evaluating robotic technologies to bolster security.

“Today, there are at least a half-dozen commercially available, autonomous robots. EPRI is working with utilities on lab tests and field tests in operating substations. Only a few appear to be practical for continuous 24/7, 365-days-a-year outdoor duty, performing reliably in freezing winters and blistering summers in places as different as California, Texas, Minnesota, and New York,” said EPRI Senior Program Manager Kevin Berent.

Terrain is just as important as weather. According to Berent, “We are looking for robots that are rough and tough; can move through coarse gravel, dirt, snow, and mud; and can handle difficult terrain with minimal maintenance.”

Maintenance, especially in remote areas without personnel, can be challenging. “A lot of the robots have batteries that need to be exchanged. Some batteries are rechargeable, but reliable charging technology is not there yet in the models we’ve seen,” said Berent.

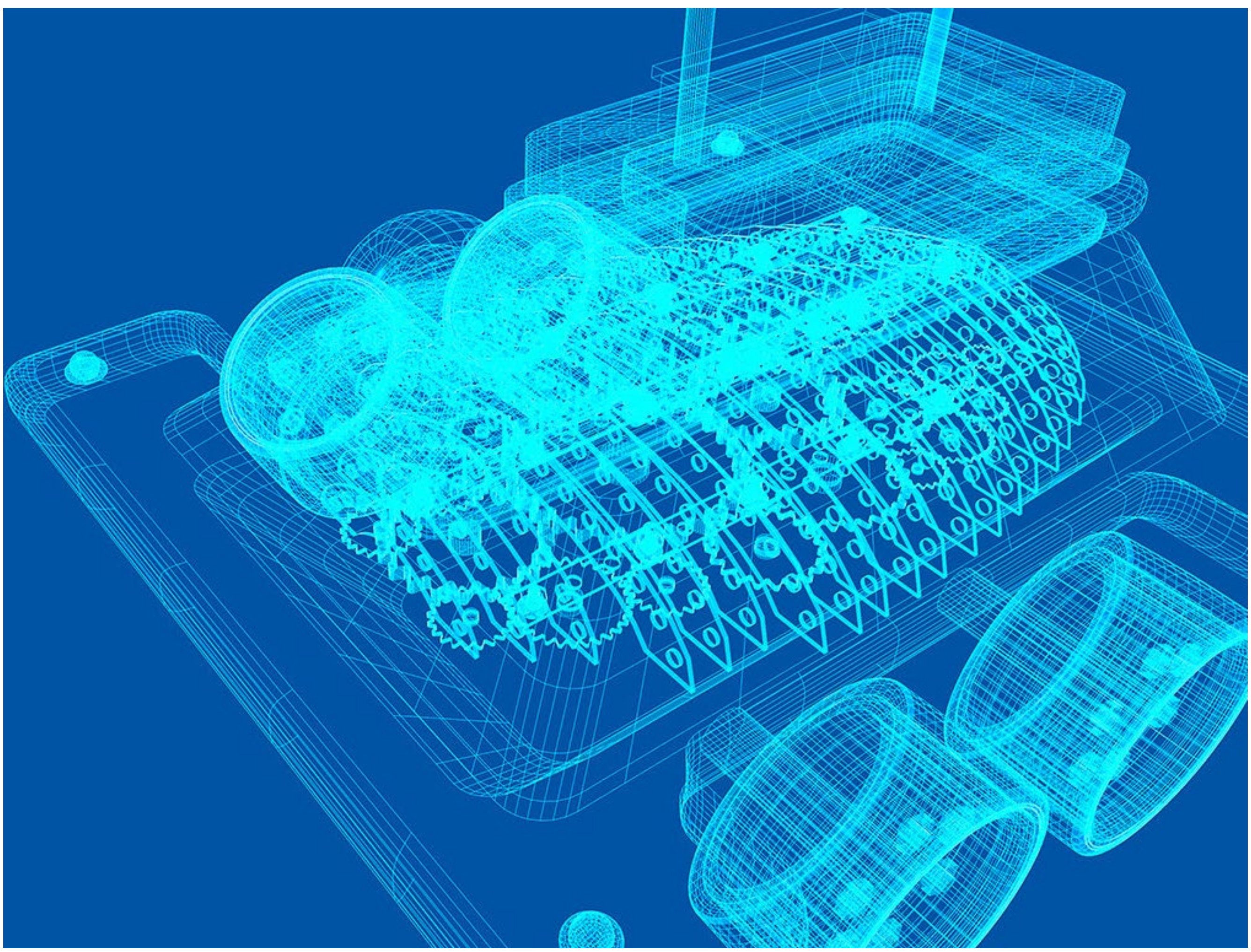
Mobility and size can help intimidate intruders. "Research shows that something moving around and as big as a riding lawnmower can have a deterrent effect, reducing crime. It can't look like a toy. If the robot can directly engage an intruder in real-time via a microphone, speaker, video cameras, and flashing lights—all the better," said Berent.

Multipurpose robots could enhance the business case for substation security. "A security robot that uses an infrared camera to detect trespassing at night could possibly use the same camera to check if equipment is running hotter than it should be," said Berent. "We're considering several possibilities. Could the robot be used to assist with maintenance? Could we add sensors to detect leaks of sulfur hexafluoride?"

SUBSTATION INSPECTION ROBOTS

Robots offer potential value for substation inspection, including visual inspections and sensor-based monitoring of equipment condition, such as temperature, the presence of coronas, and oil and sulfur hexafluoride gas leaks. In 2019, EPRI Principal Technical Leader Poorvi Patel will identify applications and benefits and review commercially available technologies.

"After identifying promising technologies, we plan to do laboratory demonstrations in our new 138-kilovolt test substation, followed by utility field demonstrations," said EPRI Senior Technical Executive Luke Van der Zel. "The objective is to evaluate sensor payloads and robot performance." The next step is to develop a technical specification and application guideline for utilities.



TRANSFORMER ROBOTS

Substation robots may also be used to inspect inside large transformers. Today's inspections have significant shortcomings. "One approach involves lowering a camera or endoscope inside the transformer, but the range of access is limited," said Patel.

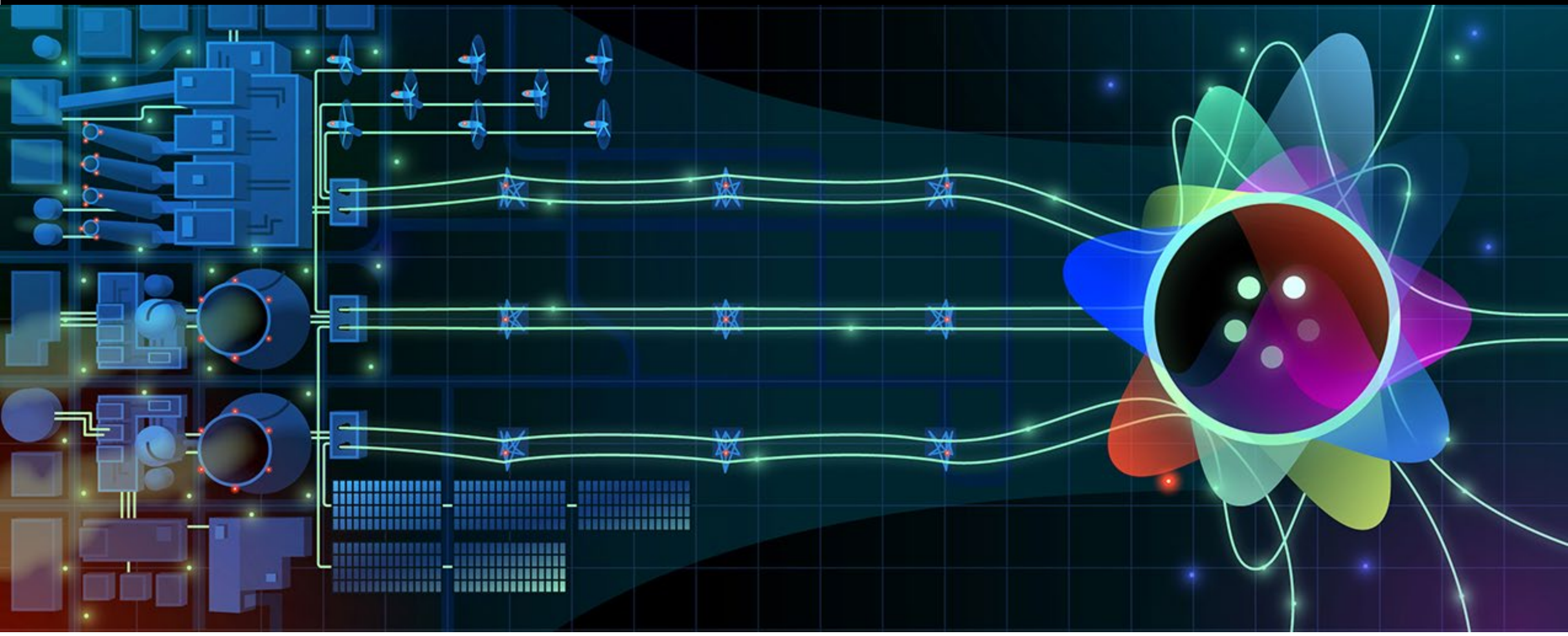
The second approach is to drain the transformer oil—tens of thousands of gallons—and then send a person inside. After inspection, the oil is replaced. "It is time-intensive because it involves entry into a confined space and reprocessing of the oil," said Patel.

EPRI has evaluated various commercially available robots for transformer inspections and identified and lab-tested promising options, then field-tested those with utilities. Guided by operators positioned outside the transformer, the robots swim through the transformer oil collecting video and still images of the interior. This eliminates the need for someone to enter the transformer.

EPRI's controlled, repeatable lab research provided insights on the robots' maneuverability, image and video quality, and ability to reach different sections of the transformer.

KEY EPRI TECHNICAL EXPERTS

Andrew Phillips, Erika Willis, David Kummer, Kevin Berent, Luke Van der Zel, Poorvi Patel, Drew McGuire



Can Artificial Intelligence Transform the Power System?

By Chris Warren

Once a subject for science fiction writers, artificial intelligence (AI) has gone mainstream. Today it can be hard to get through a TV commercial break without seeing an ad about how AI is going to transform logistics, healthcare, or even the work of baseball statisticians. Name an industry or a pursuit, and there's a good chance that someone believes AI is set to revolutionize it.

Given significant interest in the electric power industry, EPRI is already pursuing more than 20 initiatives to explore AI's potential and limitations. Two projects are investigating how AI can support the use of drones for inspecting transmission and distribution infrastructure. Drones can capture far more images of conductors, insulators, and structures than a person on foot or traveling in a truck—especially across rough, roadless terrain. EPRI is evaluating and enabling AI algorithms that can be trained to recognize malfunctioning equipment and examine thousands of images to pinpoint problems requiring repairs—with limited human intervention.

EPRI collected 7,000 images of transmission and distribution assets and identified which were functioning properly and which were not. With technical support from EPRI staff, nine AI vendors used the data to write algorithms that could distinguish between the two.

"We used a new set of drone images that the vendors' algorithms had not 'seen' before to test how well they could automatically identify defects," said Andrew Phillips, EPRI vice president of transmission and distribution infrastructure. The algorithms performed better than random guessing but made many mistakes—a promising start given the relatively limited number of images on which the algorithms were based. "The data sets Google or Facebook use for their algorithms are in the millions," said Phillips. "Ours was in the thousands."

A drone collecting images of substation equipment during an EPRI field test.

This work provided important lessons that are guiding future EPRI collaboration with AI companies. "We learned how to 'curate' the data," said Phillips. "This involves assessing the quality of the images and detailing what they mean—for example, this image shows a good insulator or conductor and this image shows a bad one. This enables us to train the algorithms properly. We also learned how important it is to collect a lot of images—the more data, the better." Now, EPRI is working with power companies to collect and curate many more images so that vendors can train algorithms with larger data sets.

This and other AI projects have prompted EPRI to launch an initiative to improve collaboration between the AI and the electric power industries to meet the power system's unique needs. EPRI technical staff will identify promising research areas and organize educational workshops for AI companies and researchers. They also will work with utilities to gather, curate, and secure data.

EPRI's AI initiative broadly aims to support the power industry in providing safe, reliable, affordable, and clean energy. "AI has the potential to improve the affordability of electricity," said Neva Espinoza, EPRI director of cross-sector technologies and components. "It can improve reliability by identifying high-risk, malfunctioning assets. It also can enhance safety by providing utilities with information needed to replace or repair those assets before they fail."

AI is poised to be critical in developing and operating the Integrated Grid and its combination of centralized power with distributed energy resources such as solar, battery storage, wind, and electric vehicles. For example, it offers the potential to forecast solar and wind generation more accurately based on weather, helping grid operators balance generation and demand.

More broadly, can AI help make an increasingly distributed, multi-directional, complex power system work seamlessly? "Real-time integration of all the diverse technologies in the power system relies on data and communications," said Espinoza. "AI tools are vital because they can process data and react quickly. The old physics-based models we have relied on for the past century can't do that."

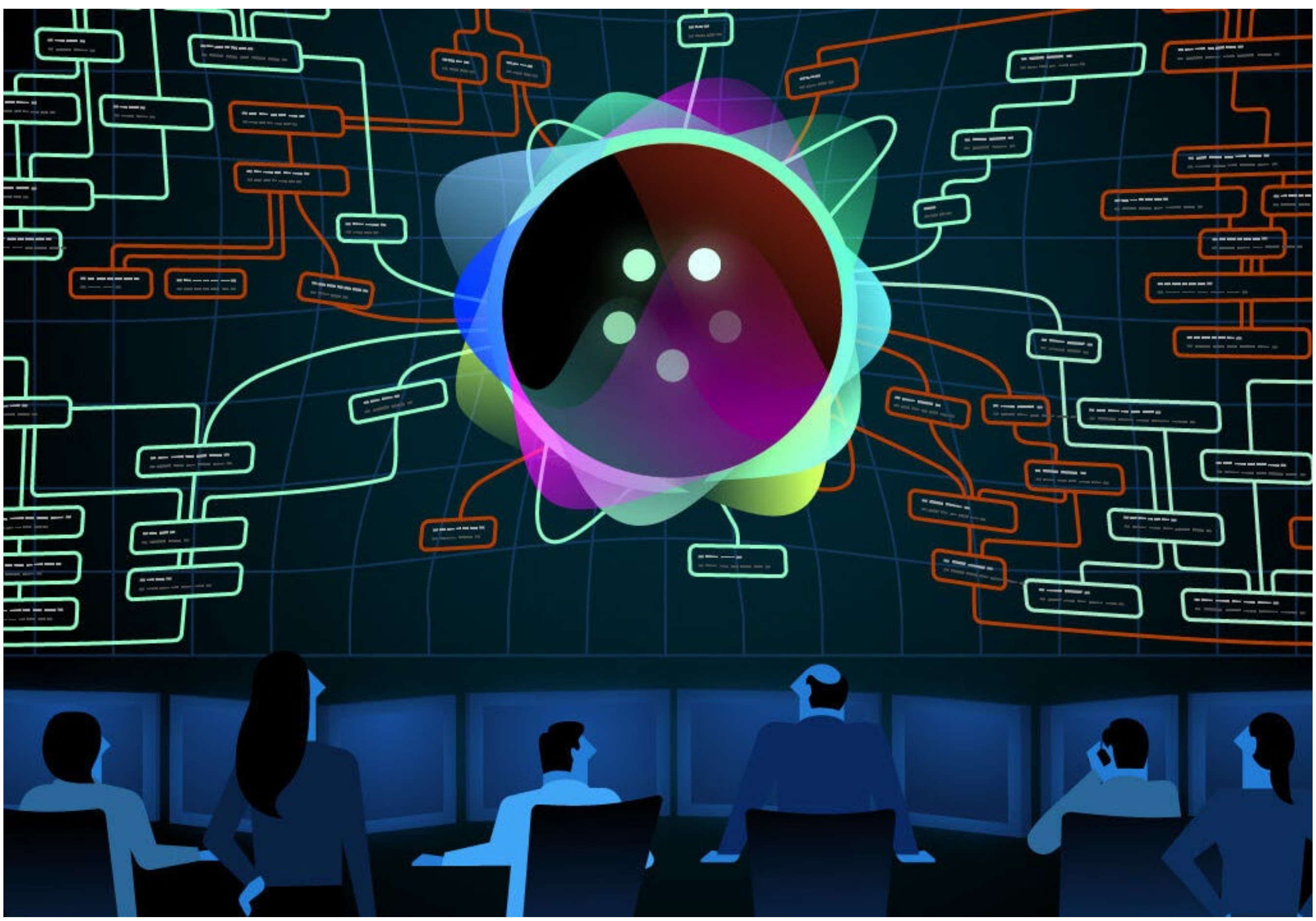
Increased reliance on AI comes with risks. As data, communications, and AI become more important in forecasting, planning, and operating power system assets, security becomes vital. EPRI will focus substantial research on addressing potential vulnerabilities that arise from increased use of AI.

A BRIDGE BETWEEN AI ORGANIZATIONS AND THE POWER INDUSTRY

Along with the exponential increases in computing power and data collection, the power industry is focused on widespread AI deployment. “Many industries, including ours, have been collecting and storing large quantities of data for a significant amount of time,” said Phillips. “Now, AI tools are becoming available to work with this data, with the potential to provide solutions in many areas.”

EPRI is also working to create a common understanding of power systems’ unique characteristics. “AI companies have math and computer science expertise, but they often lack the physics background to understand why power system assets degrade and fail,” said EPRI Technical Leader Lea Boche. “As EPRI engages them, one of our first objectives is making them aware of the challenges utilities face and the related physics.”

Educating the AI industry—which encompasses large companies such as IBM and Google as well as startups and university researchers—also involves conveying a broader understanding of how regulations and business models can affect the development of AI solutions. For example, cloud applications are often central to AI solutions, but most utilities face regulatory restrictions on their use. “This is beginning to change as the benefits of cloud applications grow more apparent,” said Boche. “We want to help streamline the work that AI vendors do by helping them to understand the utility industry better.”



One technical expert in each of EPRI's four sectors will serve as a facilitator, understanding each sector's main challenges and identifying AI companies with potential to contribute solutions. "This person will facilitate collaboration among AI stakeholders and EPRI experts," said Espinoza.

Through ongoing workshops and newsletters, EPRI will communicate each sector's priorities to AI companies. "We're going to identify data sets with potential AI applications and publish white papers to outline an AI vision for the power industry," said Espinoza.

DATA, DATA, AND MORE DATA

Because AI solutions are built on extensive, quality data, EPRI is preparing to collect such bodies of data from utilities. "Power companies want to work together and share data because they know they will benefit from it," said Boche.

EPRI is uniquely positioned for this as a result of close collaboration among its subject matter experts and its utility members. "This effort requires many companies to submit data, which needs to be curated. This in turn requires subject matter experts—EPRI's strength," said Phillips. "EPRI can provide additional value by taking the responsibility of collecting and curating the data."

Data from a single utility may be insufficient for such tasks. Drawing on its engineering expertise, EPRI can collect and curate data for the power industry and provide the large, high-quality data sets needed for AI solutions.

To prioritize and focus AI research, EPRI will identify the 10 data sets most valuable for power system AI applications, drawing on input from utility executives. Each data set in the "EPRI10" may represent hundreds of different applications.

"The 10 data sets will span the power sector from end use to distribution to transmission to generation," said Phillips. "We are working with utility executives to make sure the applications can give us the biggest bang for the buck."

The data collected and analyzed as part of this effort can inform all of EPRI's research priorities, not just those for AI. "It can provide a solid foundation for our day-to-day R&D moving forward," said Espinoza.

EPRI's Data Analytics Initiative

AI research can draw on insights from EPRI's Data Analytics Initiative, which examines the complex policy, legal, and IT issues with respect to data security, governance, use, and ownership.

"When we collect data from a utility, we need to have in place all the things that touch that data including legal contracts and terms and conditions of use," said Neva Espinoza, EPRI director of cross-sector technologies and components.

In this initiative, EPRI has defined its approach to cleansing, cataloging, security, privacy, management, control, and access. These will be audited as AI research proceeds. A secure, flexible data analytics platform can help enable the collaboration needed to develop AI solutions while protecting EPRI data sets.

KEY EPRI TECHNICAL EXPERTS

Andrew Phillips, Neva Espinoza, Lea Boche

EPRI JOURNAL

The Next Frontier for Sustainability

New EPRI Program Helps Utilities Make Sustainability a Core Part of Their Business

By Chris Warren

Over the past two years, Harun Asad has arranged workshops, guest speakers, visits to solar farms, and other activities for the 30-plus members of the Sustainability Leadership Council at the New York–based utility Consolidated Edison (Con Edison). As the company's head of corporate sustainability, Asad launched the leadership council—comprising department directors—"to reinforce and amplify the strategy of integrating sustainability into the core business and operations."

At quarterly meetings, the group discusses topics such as sustainability's connections with long-range utility planning, affordability for customers, supply chain, and electrification. The solar farm visits demonstrated more tangibly the importance of sustainability to Con Edison's core business.

"It was an opportunity for them to touch and feel renewables and experience firsthand that their business is not just poles and wires," said Asad. "In fact, Con Edison recently acquired $1.6 billion in renewable energy assets."

The Sustainability Leadership Council is one of numerous indicators of how Con Edison is elevating sustainability. The company's long-range strategic plan clearly articulates how investments and initiatives impact sustainability, and the very definition of sustainability has expanded since Con Edison began focusing on it two decades ago.

"The lens in the beginning was just environmental, and then it grew into environmental, health, and safety," said Asad. "We have since graduated to a much broader lens that adds economic and social responsibility dimensions."

BUILDING ON A DECADE OF WORK

This progression aligns with trends across much of the electric power industry. Indeed, 2018 marked the tenth year of EPRI's Energy Sustainability Interest Group (ESIG)—a group of 45 power companies collaborating with EPRI to develop tools and resources for establishing and enhancing company sustainability programs.

"Sustainability is how a company balances economic, environmental, and social issues and decisions to support the long-term viability of the company itself, the community, and the environment," said EPRI Senior Project Manager Morgan Scott. "EPRI works with members of the interest group to identify priority sustainability issues and investigate how companies are setting goals, using metrics, and disclosing data—these are the building blocks of sustainability programs. We're also providing a regular forum where sustainability managers can share their knowledge and insights."

Over the past decade, the electric power industry's approach to sustainability has expanded from reporting on greenhouse gas emissions, air quality, and other environmental issues to include economic and social considerations. Building on the foundation laid by the interest group, EPRI's new Strategic Sustainability Science program is helping utilities cultivate this broader approach across various departments and in communicating with investors, regulators, advocacy groups, and other stakeholders.

SUSTAINABILITY RETURN ON INVESTMENT

Quantifying the return on investment (ROI) that utilities can expect from their sustainability efforts is one important ingredient in engagement and support. According to Asad, C-level executives and the board of directors at Con Edison are increasingly involved in sustainability programs and investments. Demonstrating ROI can help inform decision making. But this is not easy.

"There is not much literature on best practices to inform sustainability ROI methods," said Asad. "There's a range of potential approaches to capture societal, environmental, economic, and brand values."

EPRI is examining sustainability ROI to help the power industry communicate more clearly about the benefits of sustainability.

"A sustainability manager should be able to walk into an executive briefing and say, 'Here is your sustainability ROI, and this is the value you create—across a variety of areas—when you invest in sustainability," said Scott. "Utilities need that, and right now it's hard to do."

According to Scott, a tool that delivers an accurate ROI should include other types of value beyond just financial considerations, such as environmental, social, innovation, and brand impacts. With this broader framework, EPRI is investigating these questions:

- What is a sustainability investment? Is it an investment to support a sustainability program only, or can it include an investment in other company programs that drive change on a priority sustainability issue?
- How are various sustainability "capitals" incorporated into an ROI calculation?
- How do electric power companies currently assess sustainability ROI?
- How do other industries calculate sustainability ROI?
- How might power companies incorporate sustainability ROI into project evaluation and financial planning?
- Is it possible to calculate a sustainability ROI for the electric power industry? If so, how?

The results, to be published in 2019, can help companies track ROI for specific sustainability investments. This can be quantitative, qualitative, or both. "When we don't have a quantitative ROI, we may be able to evaluate qualitative changes such as an investment's community impacts," said Scott. "Both quantitative and qualitative elements can help us better understand how value is created."

EPRI has also developed the first version of a tool that incorporates sustainability into the financial analysis of investments and projects. "Managers of various utility programs—not just sustainability managers—can use such a tool to generate a sustainability ROI score that can be input into a financial analysis," said Scott. "It can help them drive sustainability in their own work."

EMBEDDING SUSTAINABILITY IN COMPANY OPERATIONS

While continuing to develop tools and resources for utility sustainability managers, EPRI's Strategic Sustainability Science program seeks to engage others. "It's about embedding a triple bottom line mindset into a company's day-to-day operational activities and long-range planning," said Scott. "You have a sustainability program already, and now you want to weave it into the fabric of your corporate culture."

A Sustainability Semantics Project is examining how utilities can use more consistent language and messages when engaging with stakeholders.

"It's all about better communicating sustainability, knowing that words matter," said Scott.

"We have different groups—from strategic planning to investor relations and corporate communications—that talk about sustainability in different forums and with different language," said Con Edison's Asad. "I want the long-range plans, the annual report, press releases, speeches, and all other communications that involve sustainability to be consistent."

Drawing on interviews with and a survey of utility staff, researchers are developing profiles of various internal audiences and characterizing the challenges that sustainability professionals have with respect to communicating sustainability to their utility colleagues. The result will be a "code book" that enables users to search for the most powerful language to use when speaking with specific utility audiences—whether it's someone in corporate communications, operations, or finance.

LOCATION MATTERS

For several years, EPRI has been developing tools to help utilities benchmark their sustainability performance with their peers. Building on this work, EPRI researchers are now looking at how factors such as geography and demographics influence performance. The first topic is water management.

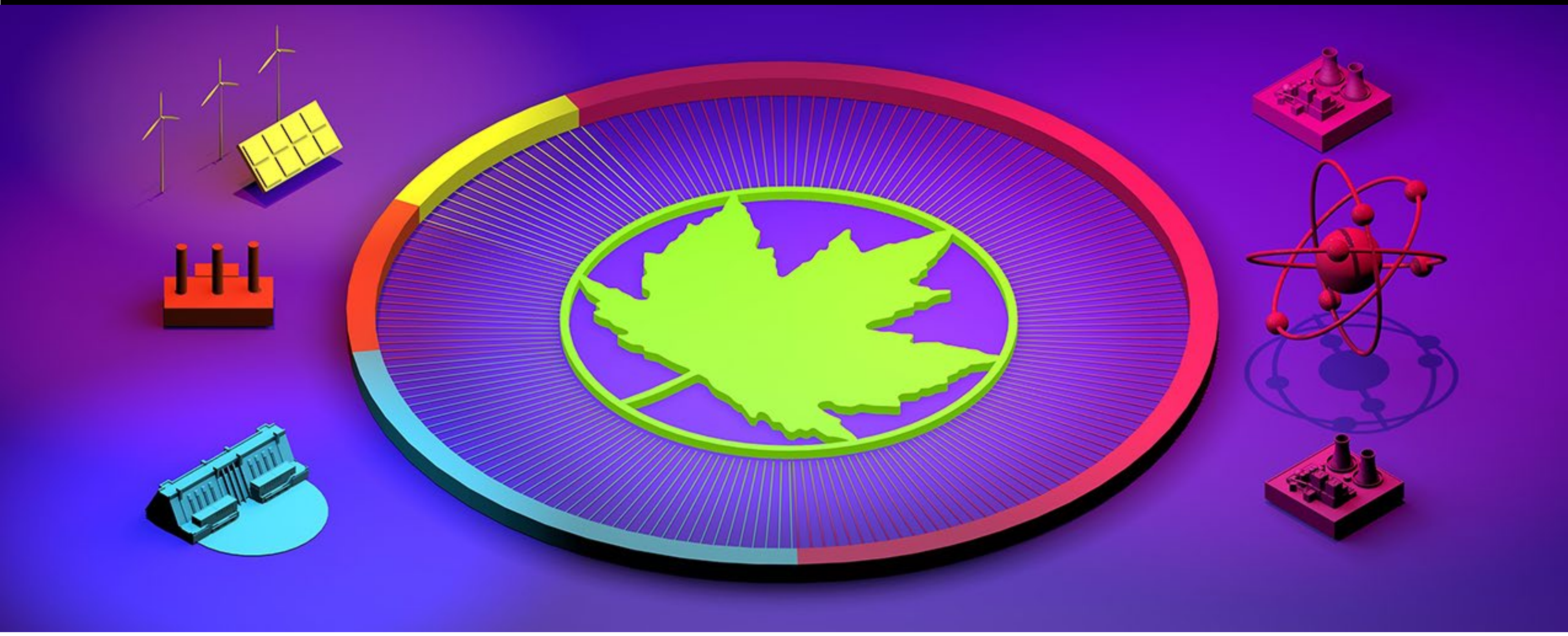
Because today's sustainability benchmarking does not consider geography, a simple comparison of how much water two utilities consume can be misleading. If Company A consumes less than Company B, it may initially lead one to conclude that Company A has a better sustainability performance. But if Company A is located in the southwestern U.S. and Company B is in the northeast, that tells a very different story.

"Even though Company A is consuming less water, it may have much higher water risk or potentially impact the ecosystem far more than Company B," said Scott. "These are things we would not understand from a simple benchmarking of consumption, pointing to the importance of considering context."

According to Scott, EPRI's new sustainability efforts can help utilities meet society's changing expectations regarding sustainability. "We've designed each research area in this new program with the aim of better understanding the technical aspects of sustainability and how utilities can apply them strategically to create value," said Scott. "Power companies can use the results to embed a stronger sustainability mindset in their organizations and to engage with society on how the electric power industry can enable a more sustainable economy."

KEY EPRI TECHNICAL EXPERTS

Morgan Scott



99% Carbon-Free in Ontario

The Story in Brief

"To decarbonize the electric power system, it takes fully leveraging every technology and tool available to you," says Jeff Lyash, President and CEO of Ontario Power Generation (OPG). In this interview with *EPRI Journal*, Lyash discusses the keys to success with his company's decarbonization efforts, nuclear power refurbishment, and customer engagement.

EJ: You previously served as CEO of Progress Energy in Florida, and now you're a CEO for a power company in Ontario where it's much colder. How was the transition?

Lyash: The first winter I was up here, I went to one of our far northern plants at Moosonee on James Bay. There I was reminded that Celsius and Fahrenheit are the same temperature at -40°. It's a colder climate, but you wear the right clothes and get out there and take care of business just like anywhere else.

Jeff Lyash

EJ: OPG's power generation today is more than 99% free of carbon emissions. What has driven the success of your decarbonization efforts?

Lyash: I would start by saying that it takes consensus—among federal and provincial policymakers and business leaders—that decarbonizing electricity is necessary, desirable, and adds value to society. Without consensus, it's very difficult to make progress. Once you have it, decarbonizing the electricity sector is doable technically. Difficult certainly, but doable.

A second lesson is that to decarbonize the electric power system, it takes fully leveraging every technology and tool available to you. People tend to gravitate toward their favorite technology—wind, solar, nuclear, or biomass—but electric power systems are regional in nature. You have to consider the resources in your region—more wind in some locations, more sun in others, more hydro in others. In Ontario's case, it was deploying biomass, wind, and solar; expanding the natural gas fleet; expanding and optimizing hydropower facilities; and continuing to invest in nuclear power.

A third lesson is that these technologies and decarbonization come at a price. It's important to be transparent and fair with customers about the price impacts. Ontario's system operator is evaluating ways to protect consumers from large cost increases.

EJ: Explain how your region's resources have shaped your decarbonization efforts?

Lyash: In 2009, Ontario established a feed-in tariff that has since built a sizable portfolio of wind and solar in the province. So we have pressed into wind and solar deployment. However, solar incidence in Ontario is not what it is in Arizona. Wind can be a useful and cost-competitive resource here, but it tends not to be synchronized with peak demand.

Our objective is a low intensity of carbon per kilowatt-hour of generation, not a certain percentage of renewables. That's what I believe the objective should be if the primary focus is addressing climate change. So, we have tried to identify more impactful ways to decarbonize.

We have a strong tradition of hydroelectric power and have invested several billion dollars in expanding the fleet, adding new generating stations and increasing the energy and capacity of our existing facilities. These investments are capital-intensive on the front end but are cost-effective over their 50-, 75-, 100-year lives.

We have preserved and optimized our nuclear fleet, which is a primary source of bulk greenhouse gas–free energy. About 60% of the megawatt-hours consumed by Ontarians every year comes from the fleet.

A turbine being hoisted as part of the refurbishment of Darlington Nuclear Generating Station. Photo courtesy of OPG.

EJ: How does your company plan to drive further reductions in greenhouse gas emissions?

Lyash: The carbon intensity of Ontario's electrical production system is on average about 40 grams per kilowatt hour. This is a very low number. The United States on average is around 350 grams per kilowatt-hour, and Germany is about 550 grams per kilowatt-hour. Zero is not substantially better than 40 when the rest of the world is at 500, so our objective is not driving further emissions reductions. Rather, it is to maintain the low greenhouse gas intensity.

How do we do that? We will continue to expand the amount of energy we get out of our hydroelectric fleet. We have other hydropower projects in northern Ontario that we could bring into service if demand requires it. Over the next couple of decades, optimizing the fleet is going to be important. In Ontario, the river systems that the hydropower stations run on have some flexibility for impounding water and timing its release.

We are refurbishing our nuclear fleet with an eye toward operating these plants for another 30 to 50 years. At our four-unit Darlington Nuclear Generating Station, we are well into a $12.8 billion refurbishment that will make those units long-term players in keeping our carbon intensity low. We're considering new utility-scale small modular reactors and have a license to construct up to 4,800 megawatts of capacity at Darlington when the time and technology are right. We also are working with Canadian Nuclear Laboratories on very small modular reactors (under 50 megawatts) that could be deployed in remote communities and remote mining and other extraction facilities. These will replace diesel generation.

We are engaged in various energy storage activities. I hear some folks say, "We need storage because of the intermittency of wind or solar." That may be true, but I don't think of storage as tied to any particular technology. I think of storage as a technology for synchronizing generation assets with the load profile. We're using storage to help address the off-peak nature of wind and to optimize the performance of our hydropower fleet. At Sir Adam Beck Hydroelectric Generating Stations, we just refurbished our pumped hydro storage facility, extending its life by 50 years. It's one of the largest installations of its type in North America. We have several other pumped hydro storage opportunities that we can pursue when the time is right. And we're looking at grid-scale battery storage to help optimize dispatch.

Most recently, OPG launched a new partnership with Stem to provide artificial intelligence–driven, advanced energy storage systems that will help Ontario industrial manufacturers manage electricity costs.

Natural gas is an important part of our mix—for capacity and energy—and we are investing in natural-gas combined-cycle technology. It's entirely possible down the road for us to implement cost-effective carbon capture on a natural gas generation facility.

We've also looked beyond our borders to participate in low carbon generation. OPG recently entered into a purchase and sale agreement to acquire 100% of the equity of Eagle Creek Renewable Energy, an owner and operator of small hydropower facilities in the United States.

Sir Adam Beck Generating Station, a hydropower facility in Queenston, Ontario. Photo courtesy of OPG.

EJ: What is the role of electrification in decarbonizing Ontario?

Lyash: In addition to keeping our carbon intensity low, we want to use electricity to drive carbon out of other sectors of the economy. In Ontario, about 80% of greenhouse gas emissions comes from transportation, space heating, and industrial. Efficiently electrifying these sectors and displacing petroleum is the lowest-cost approach to take carbon out of the economy.

EJ: As a generation company, what is OPG's role in electrifying these sectors?

Lyash: We play a couple of roles. A company like OPG can be helpful in supporting policy analysis and development and in identifying viable pathways to achieve targets. We can also be directly involved in investing in infrastructure to support electrification. The 60 local distribution companies in Ontario certainly have a role, but OPG's advantage is that we span the entire province. We can help promote conversion of transportation fleets, whether it's public transit across the province, the rail system, or commercial and industrial fleets.

EJ: What lessons can the electric power industry draw from Ontario to make nuclear more cost-competitive in the United States?

Lyash: A big lesson learned for me is that the entities responsible for planning the system have to be clear about the long-term value of these large energy producers and structure the revenue model to support them. For most of the nuclear plants in the United States, the revenue model is broken. Nuclear assets—similar to hydropower—are long-term plays, and their value flows to citizens over their 50-, 75-, and 100-year lives. You have to consider the investment with that long-term future front and center.

You have to be clear about the value of a nuclear plant's tremendous positive environmental impact—no nitrogen oxides, sulfur oxides, mercury, coal ash, and greenhouse gas emissions. Likewise, you have to recognize the benefits to the system—you're getting capacity, energy, and voltage support.

If the project is planned properly, you're generating significant economic development. For example, with the Darlington refurbishment, we developed the supply chain in Canada, so 96 cents out of every dollar we spend on that plant is with local Ontario businesses. The refurbishment and the plant's extended life add $90 billion to Ontario's gross domestic product. No other power project can make that claim.

When it comes to refurbishing or constructing a nuclear plant, the robustness of the supply chain is critical. The Canadian nuclear fleet has a tremendous advantage in that it is a domestic supply chain. I can buy most of what I need from local, high-quality suppliers who have been in the business for decades. It's much harder to do that in the United States.

In today's typical market construct focused solely on short-term capacity or energy gaps, the value of nuclear assets is not recognized. As a result, they struggle to compete with low-priced natural gas and subsidized renewables. Markets with nuclear have to be rate-regulated, which is the case with our Darlington facility. Or, you need a long-term contract. Our Bruce Nuclear Generating Station has a 50-year contract.

Another lesson for me is that to execute these mega-nuclear projects, it takes significant time and effort to clarify the scope, understand the risk, complete the engineering and licensing, and reflect all that in the estimate and schedule. The decision to undertake the project should be made with eyes wide open, without an overly optimistic view of the schedule or cost. You have to be extremely well-prepared and realistic on the front end. The process leading up to the execution of the Darlington refurbishment took 10 years.

Construction of the Peter Sutherland Sr. Generating Station, a hydropower facility completed in 2017. Photo courtesy of OPG.

EJ: Let's turn to your customers now. Why is engagement important?

Lyash: We actively engage with our customers in discussion on important issues such as reliability, power quality, safety, environmental protection, greenhouse gas reduction, prices, and economic development in the province. When I say 'customers,' I don't just mean the people who receive an electricity bill at their house. I mean the business community, academic community, elected officials, policymakers, and thought leaders. Engaging them in meaningful dialog over a long period helps our company make informed decisions and builds public support around them.

EJ: What does effective engagement look like?

Lyash: Every company needs to tailor its own customer engagement approach, because each business is slightly different. We have programs to engage directly with the power industry, federal and provincial government, local boards of trade, chambers of commerce, and economic development organizations. These are aimed at aligning our agendas. We engage with academic institutions on workforce development issues.

We do outreach with indigenous communities because our generation facilities are in their traditional territories. As we seek to expand facilities or develop new ones, we hear and incorporate their views and their advice. As they build an understanding of our activities, we develop trust.

We've also been successful establishing hydroelectric development partnerships with indigenous communities by offering equity ownership and construction contracts for local businesses. For example, for our Peter Sutherland hydropower station, the Taykwa Tagamou First Nation owns 30% of the facility, and we placed $50 million worth of contracts with their businesses. Our two partners on a 50-megawatt solar facility under construction—Six Nations and the Mississaugas of the New Credit—have a 20% share in that facility.

We also bring in community members as apprentices. By the time the project concludes, they have a journeyman card and a marketable skill. The indigenous communities are partners for life on the facilities, and along the way they've helped us understand the site's cultural significance, environment considerations, and community impacts.

EPRI JOURNAL

How Regulators Can Respond to a Fast-Changing Energy Sector

By Garrett Blaney
Outgoing President of the Council of European Energy Regulators

Over the past year, discussion among European regulators about the appropriate response to rapid changes in the energy sector has resulted in a "3D" strategy to guide our future programs and policies:

Garrett Blaney

- **Decarbonization**. Driven by a major downward shift in the cost of renewable energy along with Europe's commitment to address climate change, decarbonization efforts are changing how energy systems are operated, markets priced, and networks managed.
- **Digitalization**. Electricity consumers are gaining access to a wide range of emerging service options based on platforms that have been transformational in other sectors.
- **Dynamic regulation**. Energy regulators need to change as they face fundamental questions about how to respond to decarbonization and digitalization. They need to focus on solving tomorrow's problems before they arise.

In preparation for this strategy, European energy regulators recently issued a report on smart technology development, with a focus on five key technological changes in the energy sector:

- Smart home technologies and the Internet of Things
- Consumer-generated electricity
- Electrical energy storage
- Electric vehicles (EVs) and charging stations
- Blockchain applications

Here, I would like to discuss how energy regulators can consider two of these.

CONSUMER-GENERATED ELECTRICITY

While not new, generation by electricity consumers has grown significantly in recent years, particularly with declining rooftop solar costs. Inadequate consideration of the grid implications in Europe has resulted in challenges for consumers, such as costly retrofits of inverters and the inability to supply their own power during grid blackouts.

Energy regulators must consider strategies that empower consumers to benefit fully from their energy resources. Examples include dynamic retail rates (often known as *wholesale pass-through prices*) and peer-to-peer trading (often using blockchain technologies).

Increasing consumer-generated electricity will change how the grid is managed, and regulators need to engage in a discussion about the future role of distribution system operators for reliable, secure grid operations. This might involve solutions such as consumer participation in wholesale markets, revised network tariffs, and smart inverters.

Regulators will need to assess terms and conditions in consumer/supplier contracts to ensure that they do not restrict the consumer's choice of supplier.

Regulators will need to consider how comparison tools for consumers can be adapted to reflect market developments. As customers increasingly sell excess electricity to the grid, regulators must examine their right to relevant information on the bill while avoiding information overload.

EVs AND CHARGING INFRASTRUCTURE

Widespread adoption of EVs is expected to increase electricity consumption significantly—to as much as one-quarter to one-third of consumption for households with EVs. In addition, the new loads may occur at overlapping times, such as when people arrive home from work and plug in their vehicles. Distribution systems in many locations have not been designed for such load increases. To address this, energy regulators can encourage distribution system operators to contract for congestion management services rather than overhaul grid infrastructure. European regulators are working with legislators to promote competition in charging infrastructure markets, help ensure that system operators are technology-neutral, and protect consumers from cyber security incidents.

Regulators need to carefully consider important questions raised by EVs, including:

- How do consumers access information on energy prices as they connect to different charging stations?
- Who pays for grid upgrades needed for fast charging?
- Who protects consumers' interests when technology is changing so quickly?

To navigate the power sector's transformation, European energy regulators will need to cooperate more closely and share best practices with regulators in other sectors—such as telecommunications and consumer protection—as well as with regulators in other parts of the world.

Non-Stick Components for Power Plants?

By Tom Shiel

Advanced coatings under investigation are potential "game-changers" to improve performance of heat exchangers and other power plant components, reducing operations and maintenance costs and emissions.

Heat exchangers play an important role in keeping a power plant's heat rate low, but their tubes can be subject to fouling when contaminants in the coolant water affect their surface conditions.

A coating with non-stick properties similar to those of Teflon™ can potentially reduce fouling and improve heat transfer. Just a 1% heat rate improvement at a typical 500-megawatt power plant can result in more than $500,000 in annual fuel savings and an annual reduction of 40,000 tons of CO_2 emissions.

EPRI and Heat Transfer Research Institute developed a list of attributes needed for an effective heat exchanger coating. These include:

- Non-stick
- Durable
- Compatible with water and steam
- Withstand power plant temperatures and pressures
- Non-toxic to aquatic life (because coatings will contact cooling water released to lakes and rivers)
- Non-toxic to humans (because maintenance workers will contact coatings)
- Compatible with materials in heat exchanger tubes
- Affordable installation, maintenance, and inspection
- Minimal resistance to heat transfer
- Minimal effects on flow inside heat exchanger tubes

The team reviewed manufacturers' claims, scientific literature, and other data for more than 100 coatings, identifying their features, benefits, and limitations. Researchers gathered additional information on the coatings through interviews with manufacturers and coatings users.

"Many of these coatings are still in the university research or initial development stages," said EPRI Technical Executive Sam Korellis.

Based on this analysis, researchers identified eight coatings approaching commercial availability and demonstrating promise to have most of the preferred attributes. The next step is to lab-test these products to quantify their attributes. The team has developed a set of tests for this purpose.

According to Korellis, one challenge will be to simulate power plant conditions in the lab tests, which will be conducted first on metal plates and then on metal tubes.

To mimic conditions typically encountered by heat exchangers, researchers abrade the coated tubes by pumping a high-concentration sand and water solution and pushing brushes or scrapers through them. The coatings will be sprayed with steam and exposed to high temperatures for extended periods. Small coating samples will be analyzed for chemical composition to determine toxicity. Following these and other tests, EPRI will publish a report and continue to collaborate with its funders and the manufacturers to consider potential improvements and applications.

Coatings that perform well in the lab tests will be field-tested on operating heat exchangers, which can be up to 20 feet in diameter and 100 feet long. Testing is expected to take about two years.

Korellis views these coatings as a potential step up from solutions that involve cleaning heat exchanger tubes with brushes, chemicals, and scrapers.

“Coatings could enable us to avoid cleaning and scraping the tubes and losing performance between cleanings,” he said. “The coatings will not last forever, and we’ll eventually need to reapply them, and that’s part of understanding their operations and maintenance costs. If we have to apply them once a week, that would probably be cost-prohibitive. Once a year or longer would be in the range the industry would prefer and could afford.”

“These coatings are potential game-changers for the power industry,” he said. “If proven effective, they could be used on anything from turbine buckets to cooling towers to fan blades and alleviate fouling, contaminated surfaces, and other degradation that affects plants. The U.S. Navy is working with many of the same companies EPRI has identified, as ships and equipment can be adversely affected by fouling and corrosion brought on by exposure to large amounts of sea water.”

“Right now, we’re looking at heat exchanger tubes because they offer potentially large benefits and can provide us with insights on the coatings’ capabilities,” he said. “We’ll proceed to other parts of the power plant based on the results in this project.”

KEY EPRI TECHNICAL EXPERTS

Sam Korellis

Technology At Work

New EPRI Tool Enables Nuclear Plants to Save Millions in Maintenance Costs

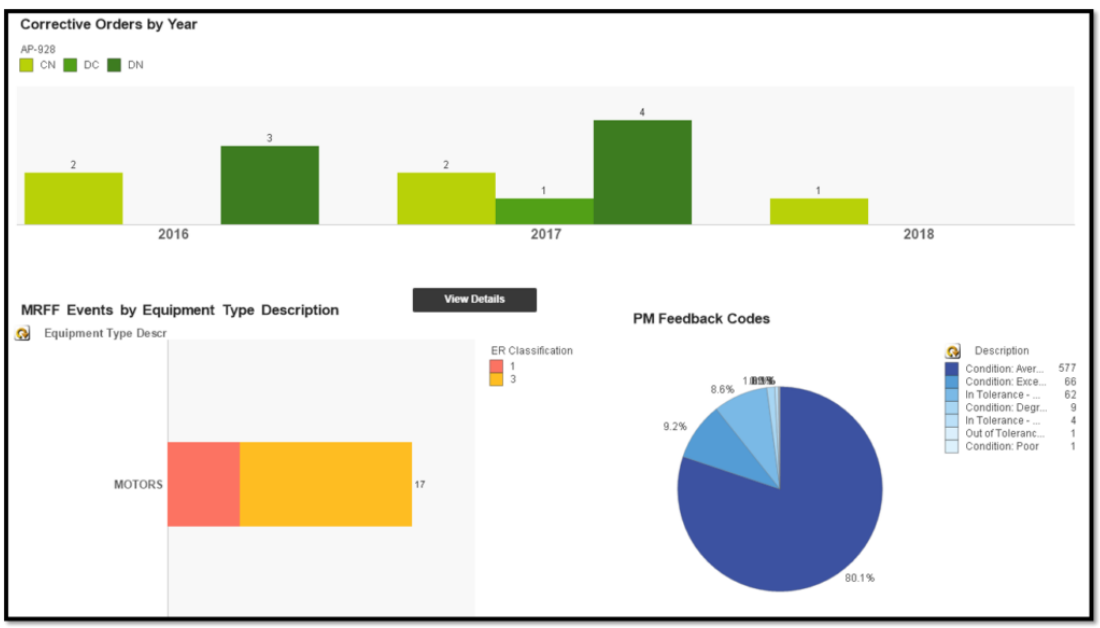
By Sarah Stankorb

Historically, the nuclear power industry emphasized "reliability at any cost," which could result in cases in which more money than necessary was spent on component maintenance for an appropriate level of reliability. Given today's challenging market for nuclear power, the industry is focused on developing maintenance strategies to achieve "the right reliability for the right cost." For example, less frequent inspections of a non-critical heating, ventilation, and air conditioning (HVAC) unit may result in slightly more failures of that component, but with no consequence to safe, reliable plant operations.

The U.S. nuclear industry recently developed a strategic plan called Delivering the Nuclear Promise to drive greater operational efficiency and affordability for customers, while continuing to prioritize safety and environmental protection.

To help nuclear plant operators identify savings opportunities for plant systems and components, EPRI worked with utility members to develop the Work Order Data Visualization Tool. This web application enables utilities to view and track historical maintenance costs (including ancillary costs such as construction of scaffolding) and draw insights about where money is being spent.

Using this tool, utility personnel can readily identify components with the highest maintenance costs and examine strategies that better balance cost and reliability. Previously, it was difficult for utilities to fully assess various costs across their maintenance regimens. When staff at Exelon's Quad Cities plant used the tool, they reviewed more than 30 complex systems with 2,700 preventive maintenance tasks scheduled in a single year. The tool made the analysis more manageable, generating charts, tables, and graphs that enabled Exelon personnel to discern key trends and identify outliers.



A screenshot of EPRI's Work Order Data Visualization Tool.

As a result of insights from the tool, Quad Cities decreased the frequency of some tasks for non-safety-related HVAC equipment, realizing $30,000 in annual savings. Plant staff also determined that certain motor inspections were more frequent than necessary. Using a less frequent, more consistent schedule resulted in annual savings of $75,000. For some systems they addressed unexpected component failures by increasing inspection frequency.

Exelon used the tool along with another application to examine its maintenance strategy for several non-critical components, using 11 years of historical data spanning its nuclear fleet. The company identified its 10 costliest, non-critical components and streamlined unnecessary maintenance for an estimated $80 million in annual savings across its fleet by the end of 2025.

Researchers have collected data from 21 utilities, using the data to develop a separate app for each utility. EPRI plans to develop an automated data upload feature in the tool, further streamlining these analyses. Other plans include:

- Demonstrating the tool's value in analyzing other data sets such as those from electronic work packages
- Expanding its use to new companies
- Developing additional apps to help utilities forecast spending over the next 20 years

KEY EPRI TECHNICAL EXPERTS

Jeff Greene

Innovation

How Quickly Do Solar Modules Age?

EPRI Researchers Speed Up the Aging Process to Better Understand Long-Term Performance

By Sarah Stankorb

When engineers consider the development and procurement of solar energy plants, they typically ask questions: Which solar photovoltaic (PV) modules will perform best in our climate? Which are most likely to continue producing energy well into the future? What certifications, specifications, or performance tests should be requested from module manufacturers? On what science do manufacturers determine their products' claimed longevity?

Solar plant owners and operators seek to predict performance decades into the future, but long-term data are limited. The solar industry is still relatively young, with 90% of capacity deployed in the past seven years. In addition, module designs and components continually change. A better understanding of degradation rates can improve confidence in technology, reduce investment risk, and lower costs.

In a three-year project under the U.S. Department of Energy's Solar Energy Technologies Office [PREDICTS2 program](), EPRI is studying PV module life expectancy and ways to improve predictions of degradation rates.

"Anyone with a financial stake in solar power plants is interested in greater certainty in how modules perform over time," said EPRI Senior Technical Leader Cara Libby, who is leading the research. "Our work is aimed at developing more reliable tests for evaluating the lifespan of solar technologies, so that companies can make these investments with greater confidence."

EPRI is examining how accelerated aging tests mimic degradation observed in PV plants that have operated for many years. This involves determining the optimal set of conditions for module testing.

Dr. Michael Bolen, who manages EPRI research on solar generation, points out that many solar module test regimens are borrowed from the semiconductor industry and are effective at screening for certain failures in the first few years of a module's expected 20-plus year life. They are not effective at predicting life expectancy.

At the Southeastern Solar Research Center, researchers subjected module batches to standard accelerated aging tests listed in International Electrotechnical Commission (IEC) 61215 and Qualification Plus, which include various temperature and humidity cycling protocols. The IEC batch exhibited no decrease in power output. In contrast, modules at a commercial solar power plant under observation experienced a 5% decrease in power over five years. The Qualification Plus batch exhibited a reduction similar to what is typically observed at commercial plants after a few years of outdoor exposure.

The PV modules in this array at the Southeastern Solar Research Center were subjected to accelerated aging tests before being installed outdoors. Photo courtesy of Southern Research.

Based on these accelerated tests, modeling, and performance measurements at other plants, researchers seek to develop calculations for estimating module degradation rates in any climate as a function of exposure to environmental stressors.

"We are trying to better understand how specific stressors lead to degradation," said Libby. "This can help us define better tests for predicting susceptibility to failures from year 4 to year 30 of a module's life."

"New PV modules and other innovations in solar technology enter the market on a regular basis. It is impractical to wait for 20 years of field observations to accurately gauge life expectancy and degradation rates," said Dr. Bolen. "Improved accelerated aging tests are one of many emerging techniques to bolster confidence in new technologies."

The research also may help answer this ongoing question for the solar industry: Do modules degrade at a steady rate over their life, or do various aspects of degradation compound to accelerate degradation?

EPRI is considering additional accelerated aging research on modules from several manufacturers, in different climates, and from power plants of various ages. EPRI also is preparing a report to help solar plant operators optimize maintenance and improve techniques to identify failed or degraded modules.

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number DE-EE0007137.

Are Cracks in Solar Cells a Big Deal?

As part of EPRI's research under the U.S. Department of Energy's PREDICTS2 Program, EPRI conducted electro-luminescence tests on PV modules to better understand the link between module defects and power degradation. In late 2016, researchers imaged modules at an operating commercial PV plant. A year later, they imaged the same modules again, observing 20% more solar cells and modules affected by busbar defects. This surprisingly large increase warrants further investigation of root causes along with continued monitoring to assess performance impacts.

Researchers conducted electroluminescence imaging on PV modules at this commercial PV plant to better understand the link between module defects and power degradation.

In a separate analysis, researchers took electroluminescence measurements on modules at various points during lab-based accelerated aging tests, then imaged the modules again after they were installed outdoors for further monitoring. The first set of field images had 9% more defects than the final lab images—likely attributed to handling during installation. The results demonstrate PV cells' susceptibility to cracking and point to more research to determine whether and how the cell cracks affect the modules' long-term safety and power.

KEY EPRI TECHNICAL EXPERTS

Cara Libby, Michael Bolen

Still Strong at 80 Years Old

EPRI Informs Nuclear Power Industry on Managing Aging Plant Components

By Jordan Russell

Eighty years ago, Superman made his first appearance in DC Comics. In 2018, Exelon's Peach Bottom Atomic Power Station, NextEra's Turkey Point Nuclear Generating Station, and Dominion's Surry Power Station—all in operation for more than 40 years—submitted license renewal applications to allow operation to 80 years. While Superman and nuclear power aren't typically thought of together, they clearly share longevity. Superman's longevity is tied to fan appreciation and ever-changing story lines, while nuclear power's longevity is tied to its demonstrated safe, reliable performance. Today that is combining with a sustained commitment to addressing technical challenges associated with long-term operations.

Originally licensed to operate for 40 years, the Peach Bottom, Turkey Point, and Surry plants have been granted 20-year license extensions to 60 years. The potential benefits of additional life extensions are significant. For example, a second license renewal would enable Peach Bottom to provide safe, reliable, carbon-free power to more than 2.7 million homes and businesses for an additional 20 years.

In the United States, license renewal applications are submitted to the U.S. Nuclear Regulatory Commission where it's anticipated to take approximately 18 months for review and approval. The process requires a systematic plant review, identification of degradation mechanisms, and development of aging management programs to support continued safe, reliable operations. Other countries follow a similar process, pointing to the importance of aging management.

Exelon's Peach Bottom Atomic Power Station. Photo courtesy of Exelon Generation.

"Based on extensive research, we have found no technical barriers to extending the life of nuclear plants out to 80 years and are confident the industry can address any challenges if they arise," said Sherry Bernhoft, EPRI senior program manager.

Superman and nuclear also have strength in common. Nuclear plants have 4- to 7-foot-thick walls of steel-reinforced concrete that can withstand earthquakes, tornadoes, hurricanes, floods, and many other events. To help maintain this strength and structural stability, nuclear plants implement aging management programs. To inform plant owners on decisions related to plant life extension, EPRI has completed aging management research and developed guidance for concrete, concrete biological shield walls, reactor metal materials, and electrical cables.

CONCRETE

Concrete structures are susceptible to degradation from irradiation, alkali silica reactions, and other mechanisms. EPRI has recently developed guidance for identifying and evaluating concrete degradation from alkali silica reactions and implementing aging management programs.

"To help transfer our guidance to nuclear plant operators, we created interactive, engaging training videos* covering topics such as degradation mechanisms, developing an aging management program, and more," said EPRI Technical Leader Sam Johnson.

**It is necessary to create an EPRI U account to view this video.*

CONCRETE BIOLOGICAL SHIELD WALLS

The concrete biological shield wall is susceptible to aging because it is close to the reactor and subjected to radiation and high temperatures. EPRI recently created a step-by-step method for evaluating its ability to provide continued structural support for the reactor pressure vessel.

"It integrates three separate models," said Emma Wong, EPRI senior technical leader. "The first shows how much concrete is expected to degrade, the second shows the impacts of different loads on the degraded concrete, and the third examines how effectively a degraded concrete biological shield wall can support the reactor pressure vessel."

REACTOR MATERIALS

The older a reactor, the longer the materials have been subjected to radiation, which can affect their structural characteristics. EPRI is conducting engineering analyses of reactor materials and developing new guidance for materials inspections in plants pursuing extended operations.

"For boiling water reactors, we have recently developed inspection and evaluation guidance for reactor vessels' internal components operating beyond 60 years," said Robin Dyle, EPRI principal technical executive. "In 2019, we will complete similar guidance for reactor piping and the vessel itself."

With greater than 60% of the world's 440-plus nuclear reactors more than 30 years of age, life extension and aging management will remain essential to support safe, reliable operation over the coming decades.

Perhaps in 2074, we'll be celebrating Superman's 136th birthday and Peach Bottom's 100th birthday.

KEY EPRI TECHNICAL EXPERTS

Sherry Bernhoft, Sam Johnson, Emma Wong, Robin Dyle

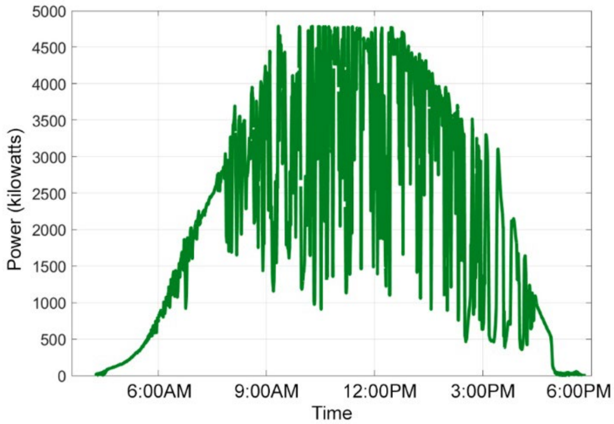
R&D Quick Hits

Can Variable Solar Generation Cause Lights to Flicker?

With Strategically Placed 'Mesonet,' Ameren Missouri Reduces Forecast Error by 40%

An EPRI study of five solar photovoltaic (PV) plants across the United States found that their contribution to flicker was insignificant.

Flicker refers to fluctuation in a light's brightness resulting from rapid voltage variations in the power grid. It is commonly associated with fluctuating industrial loads such as steel mills and electric boilers. Widespread deployment of variable solar generation is expected to increase voltage variations, raising concerns of more widespread flicker and other adverse impacts on power quality.



PV output with high variability at one of the power plants monitored in the EPRI study.

Beginning in 2012, researchers in EPRI's Integration of Distributed Energy Resources program deployed power quality meters at several solar PV plants across the country to measure solar irradiation, power generation, voltage and frequency variation, and other data—including flicker. Analysis of two years of flicker data at a subset of these plants in North Carolina, Arizona, Georgia, and Tennessee indicated that high solar variability did not increase flicker on distribution feeders, even at points close to the solar installations. In fact, higher flicker readings on feeders tended not to coincide with solar variability. The study concluded that cloud-induced changes in PV generation occur too slowly to contribute to flicker.

Key EPRI Technical Experts

Aminul Huque

ELECTRIC POWER RESEARCH INSTITUTE

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI members represent 90% of the electric utility revenue in the United States with international participation in 35 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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