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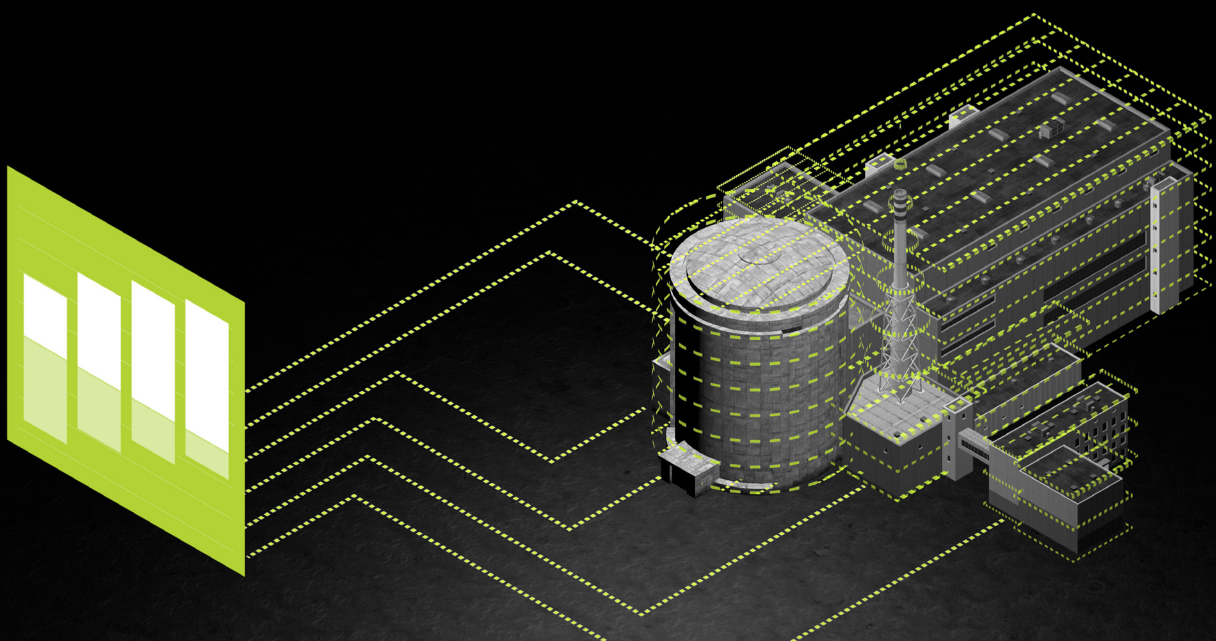
EPRI JOURNAL

Can Nuclear Power Become More Economical and Help Address Climate Change by Modernizing Old Plants?



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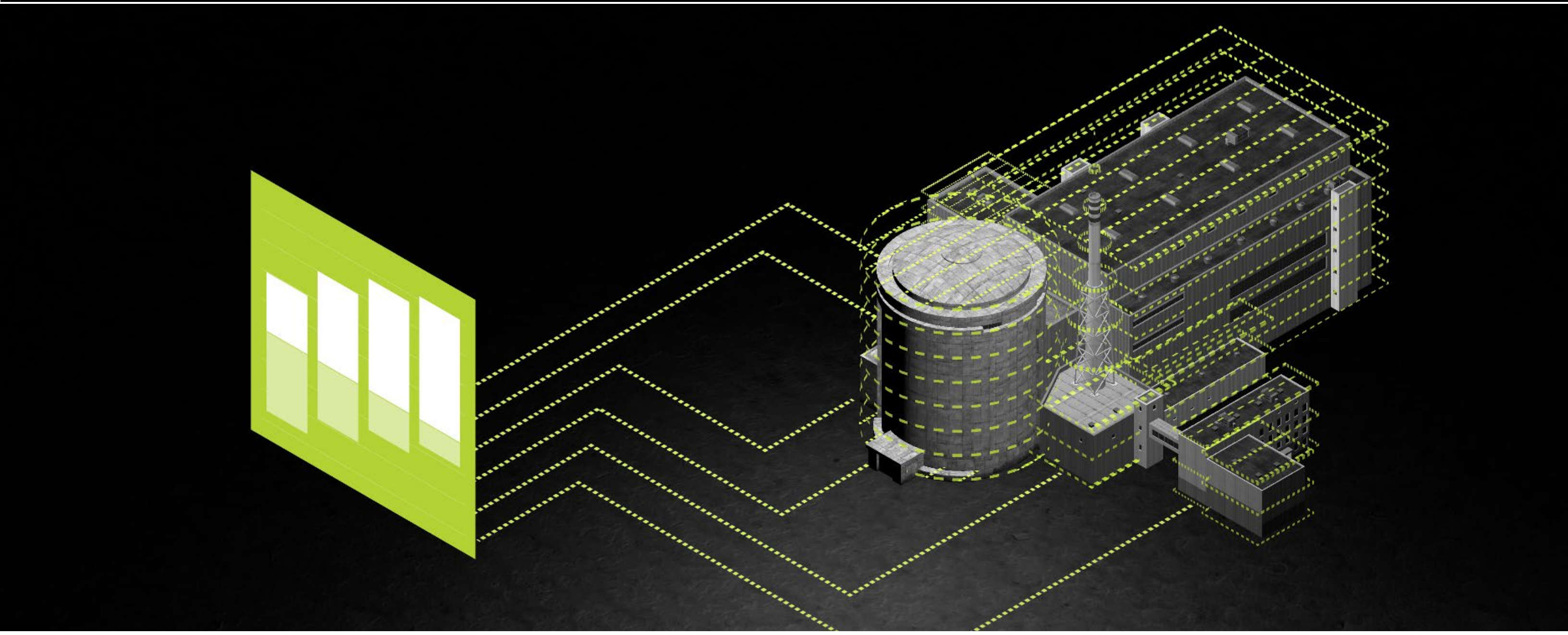


Can Nuclear Power Become More Economical and Help Address Climate Change by Modernizing Old Plants?

Preliminary EPRI Analysis: 25% or More Cost Reduction May Be Viable for Many Plants

By Brent Barker

Facilitating Industrywide Innovation

EPRI is facilitating a new nuclear industry initiative to reduce non-fuel plant operating costs through the application of existing modern technologies. A preliminary EPRI analysis points to the feasibility of a 25% cost reduction for many plants in the United States. "The Nuclear Plant Modernization Initiative was started so that a single organization—EPRI—could help consolidate the modernization activities in progress or planned by various research organizations, industry groups, utilities, and vendors," said Mark Sartain, Dominion vice president.

Nuclear power offers significant potential to address climate change, generating 11% of the world's electricity and about 30% of its low-carbon power. But this potential is jeopardized by competitive disadvantages stemming from low electricity load growth, growing renewable deployment, and cheap natural gas. Many nuclear plant owners face a competitive disadvantage—or are concerned that they will face this in the future. In the United States, for example, costs of single-unit and multi-unit sites average about $40 and $30 per megawatt-hour, respectively. In contrast, market power prices in most parts of the country range from $25 to $30 per megawatt-hour.

A plant may retire if its cost to generate power is greater than the cost of purchasing power on the open market. Indeed, nine U.S. plants are slated to retire over the next three years, potentially eliminating significant carbon-free gains. Nuclear now accounts for more than 50% of the carbon-free power in the United States.

A key driver of nuclear plant operation costs is skilled labor for manual inspections and compliance activities.

"Nuclear plants have used very labor-intensive processes for the simple reason that they worked," said EPRI Senior Program Manager Robert Austin. "But they were developed when the industry was not under cost pressure. With today's economics, this business model no longer works. Plant viability is on the line. Similar economic drivers are present in most parts of the world."

To remain viable, nuclear plants' operating costs must decline, or revenue must increase—whether through sales of process heat or through policies that provide credit for zero-carbon power. "Utilities have more immediate control over the costs, and there are research and technology opportunities that can help with costs, so why not start there?" said Austin.

Because the nuclear industry has focused for three decades on enhancing safety, reliability, and availability, it has not fully modernized. As a result, operating costs have not fallen substantially. Meanwhile, industries such as pharmaceuticals, information, metals, chemicals, petroleum, and other commodities have harnessed advancing technologies to drive down costs significantly. The same is true for non-nuclear power generation, such as solar photovoltaics, wind turbines, and fossil-fueled power plants.

"Automation, digital controls, artificial intelligence, and virtual reality tools offer great potential to reduce the resources and paper burden needed to accomplish many tasks at nuclear plants, enabling reductions in staffing," said Mark Sartain, Dominion vice president and member of EPRI's Nuclear Power Council.

"Most nuclear plants in the world are not particularly digital," said Austin. "They still use manual work processes and either analog controls or antiquated digital controls. These plants are less economically competitive as a result."

According to Austin, a two-unit, 2,000-megawatt nuclear plant typically employs about 1,000 workers. "Most of the work is inspections and other tasks required for regulatory and industry compliance," he said. "The reality is that many of these tasks can be done by digital controllers and computers. Many industries have already made this transformation. For example, coal plants have reduced their staff from hundreds to about fifty."

"The good news is that more automated power plants offer enormous economic potential—much greater than many in the industry realize," said Austin.

THE NUCLEAR PLANT MODERNIZATION INITIATIVE

Recognizing this potential, nuclear industry stakeholders came together in 2018 to launch the Nuclear Plant Modernization Initiative, with a vision to preserve nuclear power as a carbon-free, safe, reliable energy resource. Participants include EPRI, its member utilities, the U.S. Department of Energy's Light Water Reactor Sustainability program, plant owners' groups, the Nuclear Energy Institute (NEI), and the Institute of Nuclear Power Operations (INPO). EPRI facilitates the initiative under Austin's leadership.

In this initiative, EPRI and other organizations such as the Light Water Reactor Sustainability program are studying the feasibility of reducing non-fuel operating costs through the application of existing modern technologies. "Modernization does not require heavy construction or major changes such as replacing the reactor core, building a new reinforced building, or laying a lot of concrete," said Austin. "It primarily entails the installation of digital process controllers, computers, and servers. I don't see any technology barriers that would prevent nuclear plants from reducing their operating costs by 50%. But this is an assertion that EPRI needs to validate through research and testing."

A cost reduction of this magnitude could be sufficient to return many plants to economic viability. Potential savings span components throughout the plant. For example, installing sensors and simple analytics for continuous online monitoring of vertical pumps could reduce annual maintenance costs by $25,000 per pump. If applied to the hundreds of similar pumps in a typical plant, aggregate savings over 20 years could exceed $50 million.

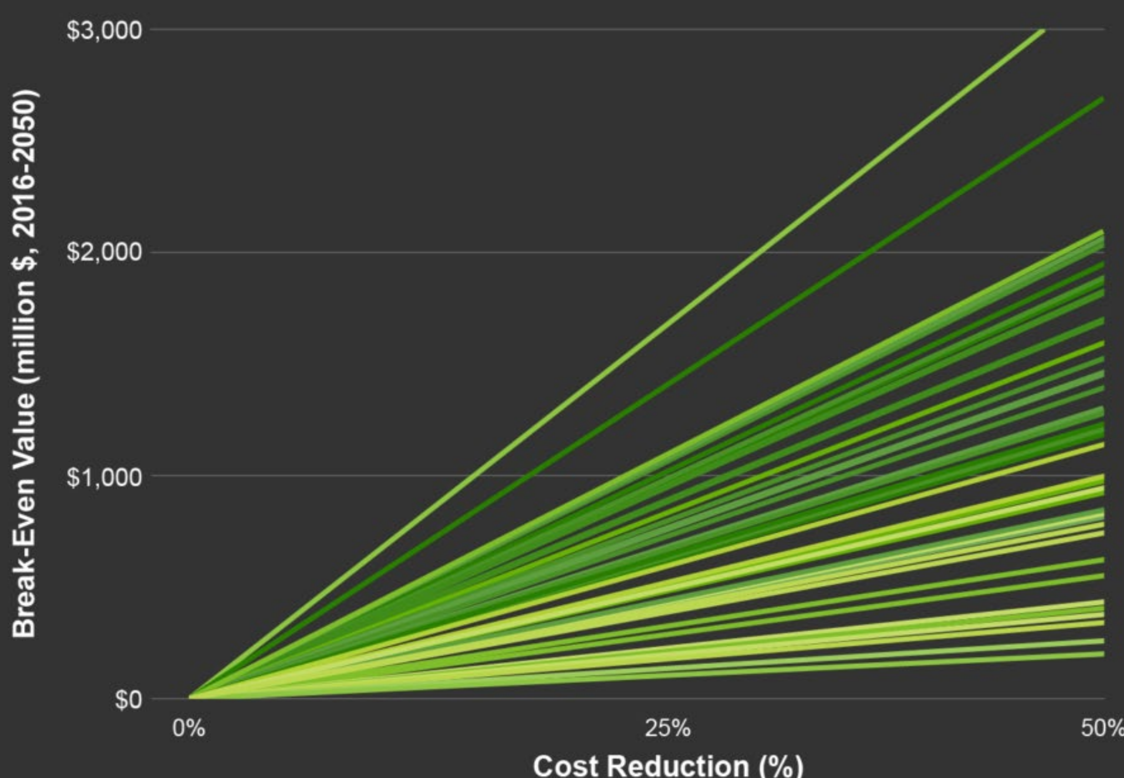
"The Nuclear Plant Modernization Initiative was started so that a single organization—EPRI—could help consolidate the modernization activities in progress or planned by various research organizations, industry groups, utilities, and vendors," said Sartain. "The purpose is to help avoid duplication or omission of important topics, identify new R&D opportunities, and disseminate results through reports and other deliverables."

The initiative's goals include:

- **2019:** Assess the feasibility and economic viability of modernization with existing technologies.
- **2020:** Identify deployment methods, inform regulatory solutions, and identify plants for demonstration. Publish a plant modernization handbook to help guide interested utilities.
- **2021:** Further develop the methods with conceptual designs and detailed business cases. Add case studies to the handbook.

BREAK-EVEN VALUES OF NUCLEAR PLANT MODERNIZATION

Using EPRI's U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model, researchers quantified a break-even value* for modernization investment at every U.S. plant, given a specified percentage reduction in operating costs. Initial estimates suggest that many nuclear plants can justify investment of more than $100 million to modernize and reduce costs by up to 25%. These approximations are based on publicly available plant cost data and reveal the wide variation in break-even values across the fleet. Modeling of future electricity costs in each plant's region was based on various assumptions such as natural gas prices, growth of renewables, and carbon dioxide emissions policies. Plant owners and operators can refine these estimated break-even values using their proprietary data or other plant-specific assumptions.



*The break-even value is the investment amount that would be paid back completely by reduced operating costs. This value was calculated by discounting the annual savings over each plant's remaining life to determine the savings' present value.

Source: EPRI

A WORTHWHILE INVESTMENT FOR MANY PLANTS?

As part of the initiative, EPRI analyzed the economics of modernizing the U.S. nuclear fleet. "The goal of the analysis is to offer preliminary estimates of the economic implications rather than precise figures," said EPRI Principal Technical Leader John Bistline. "Plant owners and operators can refine these estimates using their proprietary data or other plant-specific assumptions."

Using EPRI's U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model, researchers have quantified a break-even value for modernization investment at every U.S. plant, given a specified percentage reduction in operating costs. This involves discounting the annual savings over a plant's remaining life to determine the savings' present value.

"Initial estimates suggest that many nuclear plants can justify investment of more than $100 million to modernize and reduce operations and maintenance costs by up to 25%," said Bistline. Justifiable investment for some U.S. plants could reach $500 million for a 25% cost reduction and $1 billion for a 50% reduction. Future EPRI research will compare these break-even costs with cost estimates for specific modernization technologies and improvements.

Given the significant potential for modernization, some plants slated for closing could become more economically competitive. "Following the work of the Nuclear Plant Modernization Initiative, utilities and other stakeholders should have more information through which to consider the future of a particular plant's operations," said Bistline.

A SUITE OF 12 ENABLING PROCESS IMPROVEMENT AND TECHNOLOGY AREAS

Participants in the modernization initiative identified 12 process improvement and technology areas most important for achieving cost reductions of 25–50% when integrated as a suite at many plants:

- **Digitalization**, including integrated digital controls, virtual reality, and artificial intelligence
- **Wireless connectivity** throughout the plant
- **A common information model** enabling data exchange among different software and compatibility among databases
- **Analytics** that examine large data sets for patterns and correlations
- **Automated work planning** and management software
- **Continuous equipment monitoring** to inform condition-based maintenance, rather than scheduled maintenance
- **Risk-informed engineering and decision making** to inform a level of rigor for a task based on its importance for safety and reliability
- **Real-time, automated water chemistry monitoring** and analysis
- **Continuous, automated radiation monitoring** in critical areas of the plant
- **Enhanced physical security** using monitoring technology and real-time data processing
- **Enhanced emergency planning** for worker and public safety
- **Continuous monitoring of critical plant structures** and real-time analysis of anomalies

Ongoing EPRI research in these areas will be integrated into the modernization initiative. For example, a new EPRI guide informs utilities on deploying integrated digital controls cost-effectively while addressing safety and hazards. Other EPRI tools integrate maintenance cost analysis and monitoring to inform efficient maintenance tasks.

"We are looking at technologies and processes used in other parts of the electricity industry. For example, many non-nuclear generation facilities use remote monitoring, and a Common Information Model Standard is used in the transmission and distribution sector," said Austin. "EPRI's research spans various generation sources, energy and the environment, power delivery and utilization, and nuclear, and we can draw on work in all these areas."

In addition to the cost reduction, replacing analog electronics with integrated digital controls offers these benefits:

- Operators can remove obsolete analog components that can be replaced only through costly reverse engineering.
- Industrial digital controllers work more effectively than analog counterparts and can enhance reliability and safety in various plant systems.
- Fewer critical components are needed, enhancing reliability.
- Single-point vulnerabilities can be designed out of systems.

Some U.S. plants are upgrading digital controls to reduce maintenance costs and staff. Sartain says that some power companies have created remote monitoring and diagnostic centers to streamline data collection and analysis. "Advanced digital technologies in the physical protection area have led to reductions in security staffing."

RETIRE OR MODERNIZE?

The initiative is moving quickly. Most of the technology is already proven in other industries, and cost savings can be estimated. EPRI expects to complete portions of the feasibility studies this year. Plans for 2020 and 2021 include completing business cases and demonstrating the technology suite at several U.S. plants.

"Success will be utilities seeing the benefits and committing to modernize their plants to support safe, reliable, competitive, always-on carbon-free electricity to extend their service to 80 years and beyond—with some utilities deciding to modernize a plant that they had previously decided to retire," said Sartain.

Most tasks to be automated have been carefully prescribed and refined by regulation over decades. NEI is leading efforts with the U.S. Nuclear Regulatory Commission to review and update appropriate regulatory requirements that support the use of modern processes and technology and maintain safety and reliability.

If many plant owners and operators conclude that the economics are compelling, how fast could the technology transformation take place?

"Much of this depends on individual plant circumstances, but it is likely that plants would employ a phased approach spanning multiple years and outages," said Sartain. "Some upgrades would be implemented with the plant online, some would require outages, and some would be a combination of both. Depending on the scope of modernization, implementation schedules could be optimized to minimize outage duration."

"It could be that the cheapest way to guarantee and expand carbon-free electricity generation is modernizing existing nuclear power plants," said Austin. "Other industries have reduced their costs in this fashion. Why not nuclear?"

Department of Energy Shifts Focus to Plant Modernization

The U.S. Department of Energy's Light Water Reactor Sustainability program works to extend the life of the nation's nuclear reactor fleet.

"In previous years, this objective was primarily met by providing the technical bases to support Subsequent License Renewal applications," said Program Manager Alison Hahn. "The program has now redirected its efforts toward plant modernization, which we define as science-based, technology solutions that can improve the performance of the current labor-intensive business model." Areas of focus include:

- Modernize or replace out-of-date instrumentation and control technologies
- Demonstrate advanced condition-based monitoring techniques and technologies
- Develop approaches to mitigate aging of materials in plant components
- Enhance capabilities for analyzing and characterizing performance of plant systems
- Diversify nuclear power plant outputs to include non-electricity products such as process heat
- Assess enhancements and regulatory requirements to improve physical security

KEY EPRI TECHNICAL EXPERTS

Rob Austin, John Bistline

EPRI JOURNAL

A New Template for the Integrated Grid

How a Revised National Standard for Distributed Energy Resources Could Change the Power System

By Cassandra Sweet

Facilitating an Industry Paradigm Shift on Grid Integration

EPRI played an instrumental role in the collaborative effort to craft the new IEEE 1547 standard, which outlines technical specifications for the interconnection and interoperability between distributed energy resources and the electric power grid. Now, EPRI is working with more than 20 utilities on applying the standard. "EPRI has been helpful in facilitating this high-stakes conversation between transmission and distribution grid operators," said Andrew Levitt, senior market strategist at PJM. "These are not easy topics to discuss."

The widespread deployment of rooftop solar and other distributed energy resources (DER) is a game-changer for the electric power industry. The U.S. Energy Information Administration reports that small-scale solar systems generated 60% more power in 2018 relative to 2016. Utilities and regulators now seek new tools to help integrate these resources with grid planning and operations.

An important initial step is to define the requirements and capabilities at the interface between distributed resources and the power grid. This is the objective of the revised national standard IEEE Standard 1547™. (*IEEE*, which stands for the *Institute of Electrical and Electronics Engineers*, is an international technology standards organization.) A year after IEEE published a fully revised version of the standard in April 2018, utilities and regulators have started adopting its technical specifications for the interconnection and interoperability between DER and electric power systems. Originally published in 2003, IEEE 1547 is the only national standard of its kind, establishing uniform DER requirements for performance, operation, testing, safety, and maintenance.

A key contribution of the revised standard is its technical specifications for smart inverters. In 2020, IEEE is expected to publish related compliance test procedures to establish interoperability for inverters and other equipment used to connect DER with the power grid (IEEE Standard 1547.1). By 2021, manufacturers are expected to commercialize components that comply with the revised standards and respond to dynamic grid conditions. This can help increase the distribution grid's hosting capacity and make DER integral with grid operations.

Drawing on its technical expertise and relationships with utilities and other stakeholders, EPRI played an instrumental role in the collaborative effort to craft the new standards. The four-year undertaking convened more than 100 technical experts from all corners of the power industry. EPRI personnel led three key expert groups that crafted the technical specifications at the heart of the standard's revision. These groups focused on voltage control, ride-through, and communication interfaces and protocols. EPRI staff provided independent technical input, facilitated discussions, helped resolve more than 1,500 comments during the standard's balloting stage, and helped review and edit the final draft.

"Because the new standard represented a paradigm shift in how to integrate DER with the grid, there was a lot of feedback from distribution and transmission system planners and operators," said EPRI Principal Technical Leader Jens Boemer. "EPRI collaborates with them on a regular basis, and this helped facilitate the standard's revision. However, as EPRI is an independent research institute, we do not endorse a particular entity's actions or lobby for a certain viewpoint. We facilitate the transfer of research and the consideration of all stakeholders' perspectives, including the public and other non-utilities."

As part of a two-year project, EPRI is working collaboratively with more than 20 utilities on applying the standard. This includes training utility staff and developing general and company-specific recommendations for DER interconnection and interoperability requirements and functional settings. EPRI is also helping to inform industry stakeholders on the standard's application through EPRI-U courses (see list at end of article), webinars, and other outreach. In addition, EPRI continues to facilitate discussions among distribution and transmission system planners and operators on mutually acceptable ways to implement the standard. Drawing on years of laboratory testing, EPRI is also informing the test procedures in IEEE 1547.1.

AN IMPORTANT TOOL FOR UTILITIES

Some utilities view the standard as an important tool for managing and optimizing energy resources and to enhance grid operations.

Xcel Energy, one of the participants in EPRI's project, is evaluating the new standard and working with state regulators in Minnesota and potentially Colorado to weigh in on interconnection standards. In addition to Minnesota and Colorado, Xcel Energy serves customers in Michigan, New Mexico, North Dakota, South Dakota, Texas, and Wisconsin.

"The percentage of DER is relatively low across our entire service territory, but we're starting to see DER clusters, such as 5-megawatt solar gardens in Minnesota and entire communities in Colorado that installed rooftop solar," said Patrick Dalton, distributed energy resources engineer at Xcel Energy. "It's likely that the future power system will have a higher penetration of DER, and we want the right capabilities and tools to operate that system."

The standard provides utilities with technical specifications to integrate more DER capabilities without adversely impacting the reliability of the transmission or bulk electricity system, Dalton added.

"A SENSE OF URGENCY" FOR STATE REGULATORS

IEEE 1547 is being scrutinized by regulators in states that are prioritizing grid modernization. Because the standard is not plug-and-play, regulators need to base decisions on local challenges, conditions, and needs. They can work with regional power industry stakeholders to specify DER capabilities and communication protocols for DER interfaces.

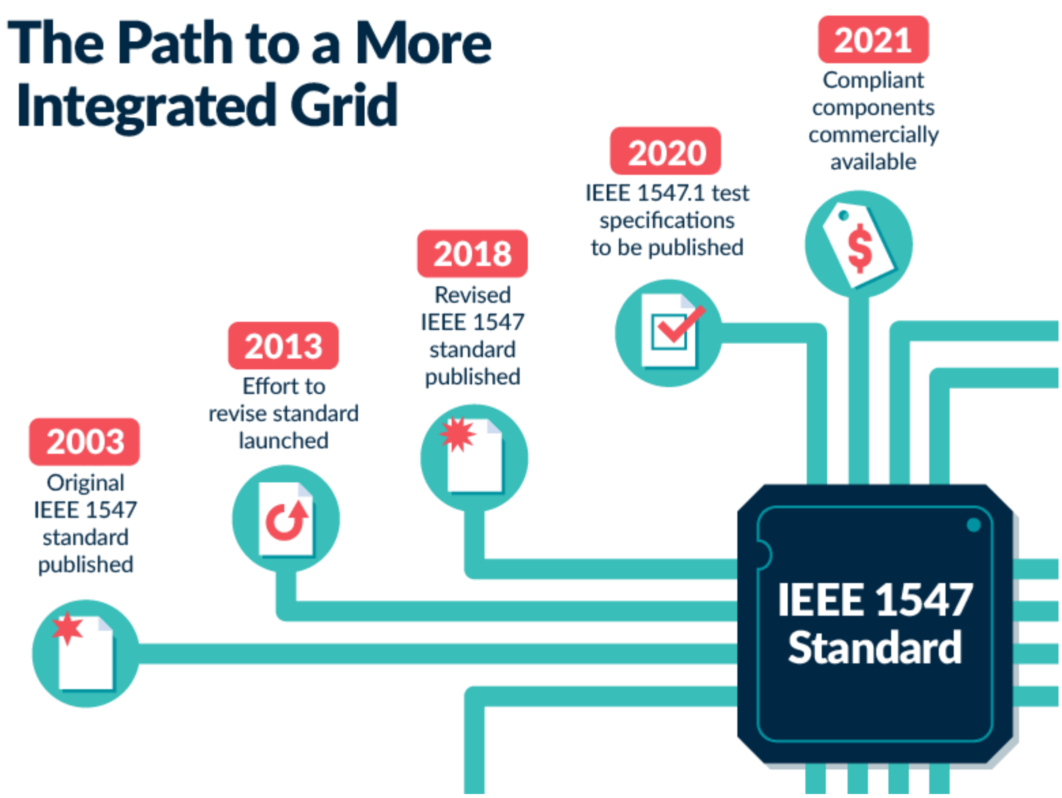
"These stakeholder discussions can take one to two years," said Boemer. "This creates a sense of urgency to start the process now, particularly if the regulator wants to implement the new standard when compliant smart inverters become commercially available in 2021."

The Minnesota Public Utilities Commission is incorporating the revised standard into its statewide technical requirements for utilities and DER, according to Michelle Rosier, the Commission's distributed energy resources specialist.

"In Minnesota, we don't yet have a high level of penetration of DER, but we want to get this standard in place so that we're prepared," Rosier said.

IEEE 1547 requires many smart inverter capabilities, including:

- Monitoring and communicating grid status, receiving off-site operation instructions, and making autonomous decisions to maintain grid stability and reliability.
- Directing rooftop solar arrays or other energy resources to "ride through" or stay online during brief frequency or voltage disturbances. (Historically in the United States and other countries, DER have been required to trip [turn off] automatically during disturbances. If large numbers of DER stop feeding power into the grid simultaneously, outages and other grid disturbances may result.)
- Changing the amount of power exchanged with the grid.
- Directing DER to reconnect to the grid in stages after an outage to avoid power spikes.
- Responding to deviations in local grid voltage by adjusting reactive power (a function known as volt-VAR).



Many regulators are considering these and other inverter requirements. They will have to decide whether grid operators can use customers' smart inverter functions to bolster the grid. While such an arrangement is technically possible, there are questions to consider: How often would a utility use its customers' voltage or frequency support capabilities? Would customers be paid a fee for each use? If so, how much?

"IEEE 1547 is a foundational building block that encourages a new discussion about how utilities use these capabilities—for example, as a substitute for existing equipment and methods or as a backup for worst-case scenarios," said Rosier. "Regulators will have to decide which of these new capabilities and functions are the safest, the most reliable, and in the public's interest." This is where EPRI's independent, fact-based research can serve crucial and specific needs.

California and Hawaii, which have high penetrations of rooftop solar, have established their own DER interconnection standards. These are similar to—though not as aggressive as—IEEE 1547, which requires greater reliability and interoperability of DER with the grid.

States not expected to have significant DER penetration in the next several years can prepare for unexpected DER deployment by revising their DER interconnection requirements now.

"States that use IEEE 1547 as a blueprint to adopt new DER interconnection rules can future-proof their grids for expected and unexpected DER deployment," said Boemer. "They can build DER capabilities now and use them when DER penetration reaches a significant value."

What constitutes a "significant" DER penetration depends on regional grid characteristics. EPRI has developed a model and other tools that can help regulators and transmission planners with this assessment.

COORDINATION AMONG TRANSMISSION AND DISTRIBUTION SYSTEMS

Like many power companies and regulators, transmission system planners and operators view IEEE 1547 as one way to enhance how DER interact with the grid. Successful adoption of the standard will require coordination among distribution and transmission planners and operators, who often have competing needs. For example, during grid disturbances, distribution operators may want DER to temporarily suspend feeding power into the grid to help keep line workers safe. In contrast, transmission operators may want DER to feed into the grid without interruption to help with voltage control and to support system reliability.

"The standard provides a framework to facilitate conversations among transmission and distribution system planners and operators to specify DER capabilities and settings," said Boemer. "It even introduces a new DER ride-through mode called momentary cessation, which can ease the tension between transmission and distribution."

DER connected to the distribution system can have an aggregate impact on the upstream transmission system. For example, if 500,000 rooftop solar arrays in a regional distribution system trip offline simultaneously as a result of a transmission fault, Boemer cautions that the transmission system could experience a significant power imbalance. To address this risk, the updated 1547 standard requires DER to remain connected to the grid during frequency and voltage deviations.

"Otherwise the transmission system operator may need to increase operating reserves or lean on other regions for grid support, which may not be technically feasible or cost-effective," said Boemer. "Transmission faults occur so regularly that tripping of DER should be minimized as much as possible."

PJM Interconnection, the regional transmission organization that coordinates power across 13 states (plus Washington, D.C.) in the U.S. Mid-Atlantic and Midwest, is closely watching the new standard.

PJM is concerned about existing grid settings that require DER to trip offline in response to a grid disturbance, especially in New Jersey and North Carolina, where distributed solar is growing.

"If we continue business-as-usual, the concern is that a disturbance on the transmission system could cause DER across a portion of New Jersey to trip offline at the same time," said Andrew Levitt, senior market strategist at PJM. "By 2021, you could see as much as 1,000 megawatts tripping offline at the same time."

Some power industry stakeholders contend that a DER ride-through requirement is unnecessary because widespread tripping of distributed generators has never occurred in the United States. They point to ride-through's potential adverse impacts such as unintentional islanding.

While these concerns are to be taken seriously, there have been instances of large transmission-connected renewable power generators tripping offline and destabilizing U.S. and Australian transmission grids. In August 2016, while the Blue Cut wildfire raged in southern California, a series of faults on a 500-kilovolt transmission line prompted several large solar farms to trip offline, resulting in the loss of 1,200 megawatts of power, according to a report by the North American Electric Reliability Corporation. During a strong storm in September 2016 in South Australia, the sudden loss of electricity from several wind farms triggered a widespread blackout, according to a report by the Australian Energy Market Operator. A recent analysis suggests that large numbers of distribution-connected solar systems may have tripped or ceased power output in California in 2018.

To be sure, PJM has procedures and equipment to maintain power flow if substantial generation suddenly trips offline. But with more widespread DER, a ride-through requirement for DER can help avoid power losses.

"Large power plants are required to stay online under certain conditions," Levitt said. "It would be good if DER have the same requirements—for example, they're not allowed to trip offline under certain circumstances for a short period."

While PJM does not have authority to regulate DER, it has been educating state regulators about the standard's potential benefits and recently hosted a workshop and formed a task force for regulators and distribution and transmission engineers to discuss DER ride-through settings associated with the new standard.

EPRI also is facilitating discussion of these issues among power industry stakeholders through numerous webinars and workshops. It is working with its utility members and smart inverter vendors to investigate ways to minimize the likelihood of unintentional islanding. It also hosts a series of workshops where utilities share experiences regarding smart inverter integration, lessons from demonstration projects, and best practices.

"EPRI has been helpful in facilitating this high-stakes conversation between transmission and distribution grid operators," said PJM's Levitt. "These are not easy topics to discuss."

Five Ways EPRI Is Helping the Power Industry Standardize the Use of Smart Inverters

1. Development of first-of-its-kind test procedures for smart inverter interoperability and communications with the grid (IEEE Standard 1547.1).
2. Development of tools and open source software to help manufacturers meet new requirements for communications between solar and energy storage systems and the grid (SunSpec Modbus, IEEE Standard 2030.5 and IEEE Standard 1815—DNP3).
3. Development of a model that can aggregate distributed energy resources for transmission planning studies.
4. Laboratory and field evaluation of smart inverters' advanced grid support functions and interoperability in accordance with IEEE 1547.
5. Development of an open test bed to assess functional capabilities, interoperability, performance, grid impacts, and benefits of commercial Distributed Energy Resources Management Systems (DERMS).

KEY EPRI TECHNICAL EXPERTS

Jens C. Boemer

How to Modernize the Nuclear Fleet? EPRI Looks at Technology, Economics

For a machine to be designated a "workhorse," it must do hard work, reliably, and over an extended period. Nuclear power plants have earned this designation by virtue of their reliable operation and sizeable contribution to baseload power generation around the world. A question emerges for these workhorse plants, most of which have operated for decades: Can they compete as modern machines, or will they prove uneconomical and uncompetitive?

The plants are getting a fresh look today from owners and operators, regulators, legislators, advocacy groups, financial institutions, and researchers such as EPRI. Many stakeholders are reappraising them as a foundation for sustained decarbonization—both on their own and in conjunction with renewables. They are also appraising plants' economic contributions, local environmental footprint (quite compact), and many other societal benefits.

Economic forces shaping the future of these plants include:

- Natural gas prices and the cost of gas-fueled power generation (relatively low)
- Carbon reduction (not established as a priority at the federal U.S. level)
- The cost of solar, wind, and other renewable alternatives
- Technological options and economics of nuclear plant modernization

Mike Howard, President and Chief Executive Officer, EPRI

According to the World Nuclear Association, nuclear power provides more than 10% of the world's electricity.

EPRI Journal highlights our recent white paper, *The Economics of Nuclear Plant Modernization in U.S. Markets*, which examines a range of data and assumptions regarding plant operations and economics. Its initial estimates suggest that many nuclear plants could justify investments of more than $100 million to modernize and reduce non-fuel costs by 25%. In some regions, a cost reduction on that order—or higher—may be necessary to remain affordable. This suggests that it would be worthwhile for plant owners and operators to take a closer look and assess the economics of modernization to reduce non-fuel costs at their facilities.

EPRI Journal also reports on our Nuclear Sector's Plant Modernization Initiative, which is examining how plant owners and operators could equip their facilities with updated technologies and improved processes to improve economics. The initiative has identified 12 areas with significant potential to reduce non-fuel costs at many plants. These include digitalization, wireless connectivity, analytics, automated work planning, risk-informed engineering and decisions, and continuous monitoring of structures and equipment.

One area of focus for plant modernization that can be appreciated by anyone who has ever had to put air in a car's tires is the concept of condition-based maintenance versus interval-based maintenance. The most familiar example I can offer is the difference between checking air pressure in all four of your car's tires every month (interval-based) in contrast with adding air only when your dashboard indicator tells you the pressure has dropped in one of your tires (condition-based). The latter takes less of your time, and time is money.

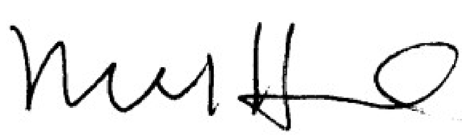
With sensors, data analytics, and communications networks, plant operators and maintenance technicians can focus on the right actions, in right priority, at the right time. Sensors and communications can give you direct readings of analyses can provide far-ranging insights for projecting and prioritizing needed actions. These add up to much more efficient, lower-cost operations.

One of the overarching challenges of our times is to understand as best we can—and as fast as we can—the interplay among rapid technological advancements and economic drivers. Some nuclear plants today face economic conditions that call into question their continued operation. The near-term closing of such plants could call into question society's prospects for decarbonizing energy production, delivery, and use.

This brings an urgency for determining how technology can enable an economically viable nuclear fleet for the near- and long-term benefit of society. Plant modernization may be an appropriate choice for some plants but may not work for others. Investments in certain plants may not be justified as a result of a particular market's economics. Nevertheless, modernization has much to offer in maintaining nuclear power as a safe, reliable, affordable generation option positioned to make a substantial contribution to decarbonization. It can also help provide a bridge to future nuclear power technologies for our electric system and the people who operate it.

The "modern" expectation of energy is that it be sustainable, affordable, reliable, and always available. There are important opportunities to make nuclear plants modern in the affordable sense and to continue their "workhorse" contribution to societies in every part of the world.

Mike Howard



President and Chief Executive Officer, EPRI

EPRI JOURNAL

A Critical Time for Innovation in Nuclear Energy

The Story in Brief

In June 2019, EPRI, the Nuclear Energy Association, International Atomic Energy Agency, the U.K.-based National Nuclear Laboratory, and Korea Hydro & Nuclear Power (KHNP) are co-organizing the Global Forum on Innovation for the Future of Nuclear Energy in Gyeongju, South Korea. KHNP is hosting the forum. In this interview with the *EPRI Journal*, KHNP President & CEO Mr. Jae-hoon Chung discusses the state of the nuclear power industry, how KHNP is innovating, and why it's important for industry leaders to attend the Global Forum.

EJ: WHY IS THIS A PIVOTAL TIME FOR THE GLOBAL NUCLEAR INDUSTRY?

Chung: Nuclear power is at a crossroads. Across the globe, the cost of constructing new plants continues to rise, and existing plants face growing economic challenges from other energy sources. While the industry has taken significant steps to address safety issues raised by the Fukushima accident, nuclear plants still face competition from other generation sources.

But the fact remains that nuclear energy is a clean, zero-carbon energy source, and it can assist in humanity's response to climate change. I believe now is a very critical time for the nuclear power industry to make far-reaching, innovative changes to secure competitiveness.

KHNP President & CEO Mr. Jae-hoon Chung

EJ: WHAT ROLE DOES INNOVATION PLAY IN THE NUCLEAR INDUSTRY?

Chung: Innovation in technology, business models, culture, processes, safety procedures, regulations, and supply systems can reduce costs of design, construction, and equipment. This can help nuclear power plants recover from their economic challenges and become economically competitive with other power sources.

EJ: HOW HAS KHNP INNOVATED IN RECENT YEARS?

Chung: KHNP is pursuing innovative improvements in automated diagnosis for predictive maintenance using what we call “4th industrial revolution technology” such as big data, machine learning, virtual reality, and other advanced technologies. With automated diagnosis, plant operators use sensors to monitor equipment defects, conduct comprehensive analysis of these defects, and take measures to prevent plant outages.

Over the next three years, KHNP plans to significantly expand its application of automated diagnosis, implementing wireless sensors and big data for main equipment in the fleet. KHNP also operates intelligent live video monitoring at our construction sites to enable prompt responses if and when a safety accident occurs.

EJ: WHY IS THE GLOBAL FORUM IMPORTANT FOR THE INDUSTRY’S FUTURE?

Chung: The forum will provide a first-ever venue for leaders across the global nuclear industry to explore innovative technologies and processes under development or deployed in operational plants, learn what is hindering widespread deployment, and determine ways to move those innovations forward in the near future.

In particular, I hope this forum will strengthen international cooperation among nuclear industry leaders, government and regulatory agencies, technology providers, researchers and academia focused on applied research, and innovators from other industries. This can enable more effective implementation of innovative technology and processes in nuclear plants.

Mr. Chung discusses plant operations at a KHNP facility.

EJ: WHAT DO YOU HOPE PARTICIPANTS LEARN ABOUT KHNP WHILE ATTENDING THE FORUM IN SOUTH KOREA?

Chung: KHNP is a global and domestic energy partner. We are honored to host this forum near KHNP headquarters and to have an opportunity to showcase the Shin-Kori nuclear power plant, the site of the first Korean-designed Advanced Pressurized Reactor-1400 (APR 1400). The APR 1400 is an advanced, seismic-enforced design utilizing cutting edge technologies, including a digitalized control room and man-machine interface system.

We look forward to sharing South Korea's progress with nuclear power plant development, with the hopes that it will help advance technological innovations across the globe as well as strengthen the relationships needed to make those advancements. This is an opportunity for KHNP to introduce global nuclear power leaders to innovations that have reduced construction costs and improved operating performance at our plants.

EJ: WHAT WOULD YOU SAY TO FELLOW NUCLEAR LEADERS WHO MAY BE CONSIDERING ATTENDING THIS FORUM? WHY SHOULD THEY ATTEND?

Chung: This Global Forum will be a special opportunity for leaders to deeply explore innovative improvements and changes for the better of the industry, and strengthen relationships across all the critical stakeholders that make implementing those innovations possible.

This forum could be one of the most important that leaders participate in this year to overcome the deployment barriers of innovation in nuclear. I urge nuclear plant leaders, regulators, researchers, governments and tech providers (both in and outside the industry) to come to Gyeongju in June. Improving the state of the nuclear industry for the future is a joint effort.

In Development

How Can the Power Industry Help the Monarch Butterfly?

By Mary Beckman

Extracting Value from R&D

A group of utilities are developing a plan to enhance monarch butterfly habitat on their transmission line rights-of-way by adjusting vegetation management practices. "EPRI research on the causes of the monarch's decline and potential solutions is helping to inform the utilities that are involved in developing the monarch plan," said Tim Lohner, PhD consulting environmental specialist at American Electric Power (AEP).

Monarch butterflies spend their winters in fir forests on a dozen mountaintops in central Mexico, their colorful wings turning the trees orange. They make their way north, many toward the Great Lakes, to breed in the spring and summer.

But this familiar North American species is in trouble: Almost a billion strong in the mid-1990s, the population has declined by more than 80%. Researchers believe that one cause is the loss of milkweed, the prairie plant species on which monarchs feed and breed. Other possible factors include loss of winter habitat in Mexico and California and pesticide use. By June 30, 2019, the U.S. Fish and Wildlife Service is expected to decide whether to list monarch butterflies as endangered or threatened under the federal Endangered Species Act.

A 2017 study by several federal agencies and universities found that about 125 million acres of monarch habitat in the United States need to be restored to support a winter population in Mexico large enough to avoid extinction. While the results indicate that agriculture has the largest role to play in the monarch's recovery, they also point to other land uses, including city landscaping and transmission line rights-of-way.

The study identified 10.7 million acres in transmission rights-of-way as potential monarch habitat—about 8.5% of the total needed for monarch restoration and a potentially meaningful contribution. Tim Lohner, PhD consulting environmental specialist at American Electric Power (AEP), estimated conservatively that utility conservation efforts on these land corridors could yield enough milkweed for more than 12 million monarchs, or about 5% of a fully recovered population.


A monarch feeding on milkweed.

"With electric power companies managing millions of acres of habitat across North America, they can support conservation of monarchs and other pollinators," said Jessica Fox, senior technical executive for EPRI's Power-in-Pollinators Initiative. "They have numerous types of property, including rights-of-way for transmission and distribution lines, solar and wind power plants, acreage around nuclear and fossil plants and substations, and undeveloped land."

EPRI is exploring ways to improve and conserve habitat for bees, insects, and butterflies on power company lands. Although monarch butterflies aren't the most important species from a food pollination perspective, they are familiar and capture the public's imagination. They can call attention to other, lesser known pollinators that are important for our fruits, nuts, and honey.

"The monarch is a culturally iconic species," said Fox. "Everybody can recognize it, even a five-year-old."

EPRI is working with the Xerces Society—a scientific group and one of the petitioners for the monarch's endangered species listing—to investigate causes of the monarch decline and identify conservation efforts to help improve the butterfly's prospects. EPRI also is surveying utility land managers to identify potential power industry contributions and barriers to conservation. Preliminary survey results indicate that these will likely depend on the type of property, site conditions, and legal requirements for maintaining the land.

"Power companies own some lands and manage others via easements and lease agreements, which can be difficult to navigate in some cases when initiating new land management practices," said Fox.

Regulatory requirements may present barriers. For example, permits for some hydropower facilities require power companies to keep vegetation mowed to a trim six inches. But suitable milkweed habitat needs to be approximately two feet tall for the plants to bloom. At substations, the North American Electric Reliability Corporation (NERC) requires a safe distance between vegetation and equipment. Changes in these and other rules may be useful to accommodate and encourage monarch habitat restoration.

"The butterflies migrate throughout our lands," said Lohner of AEP, which has a nearly 200,000-square-mile service territory in the Midwest.

AEP and other utilities are developing a plan (known as a candidate conservation agreement with assurances) with the University of Illinois at Chicago, the Fish and Wildlife Service, and others to preserve or enhance monarch habitat on up to 18% of their transmission line rights-of-way and easements by adjusting vegetation management practices.

"EPRI research on the causes of the monarch's decline and potential solutions is helping to inform the utilities that are involved in developing the monarch plan," said Lohner.

EPRI's Fox is looking beyond the monarch to a broader set of declining pollinator species.

"It is important to support the long-term resiliency and stability of ecological systems, and that means looking beyond the listing decision this summer," Fox said. "Last year the rusty patch bumblebee was under consideration for listing. Next year it might be a different butterfly or bee. We plan to investigate several broad strategies: connecting habitats to avoid isolating populations, supporting diverse species and landscapes to improve ecological health, and recovering declining pollinator species."

KEY EPRI TECHNICAL EXPERTS

Jessica Fox

A Partnership to Drive Decarbonization with Nuclear Power

By Chris Warren

If you listen to the talk in some circles, you could assume that nuclear power is circling the drain. But if you look at what people are doing, there's a strong case being made for nuclear to play a critical role in creating a carbon-free economy.

"Look at the United Kingdom. They are building new nuclear power plants—and creating a market that supports new plant construction—and also building a lot of wind farms and solar. China is talking about doubling its generation and transmission capacity, and nuclear is part of the strategy along with renewables," said EPRI Vice President and Chief Nuclear Officer Neil Wilmshurst. "In Japan, even after Fukushima, the government is talking about 30 percent nuclear in the future. The nuclear industry in North America has challenges, but around the world it is playing a critical role in addressing climate change."

All of this raises this question: What is critical to the success of this new wave of nuclear power? The answer is accelerated innovation, which has been hampered by a lack of collaboration among nuclear power companies, regulators, and governments. "If you bring industry, regulators, and governments together, there's a much greater likelihood that you can come to a common understanding about the barriers to innovation and commit to working together to eliminating them," said Wilmshurst.

Enter the memorandum of understanding (MOU) between EPRI and the Nuclear Energy Agency (NEA) to advance global nuclear research. Within the framework of the Organisation for Economic Co-operation and Development, the NEA facilitates cooperation among its 33 member countries to help implement safe, economical, environmentally sound nuclear power. Signed in 2017, the five-year MOU aims to help the NEA and EPRI better understand and prioritize nuclear energy research needs, including the perspectives of nuclear utilities, governments, and regulators in research priorities.

"The NEA has traditionally worked more with government and regulators, while EPRI is a globally recognized and sought-after resource for the nuclear industry," said Wilmshurst. "This agreement strengthens NEA's connection with the industry. We have all this technical knowledge of what is possible with nuclear. If regulators and governments can better understand the innovation possibilities, they are more likely to work productively with the industry to advance nuclear power development."

"The evolution of nuclear technology is an integral part of global safety," said NEA Director-General William D. Magwood, IV. "The sector has to evolve. While meeting all required levels of safety, nuclear plants must be more flexible and cost-efficient in order to meet societal needs. EPRI understands the existing and emerging challenges of nuclear plant operations. Its collaborative research activities complement the scope and relevance of our work. As such, EPRI and the NEA can together address the technical and strategic challenges of bringing new technologies to market as required for the safe and effective use of nuclear energy."

The MOU enables EPRI and the NEA to develop joint events, seminars, workshops, and training. It facilitates exchange on research activities in various fields of nuclear energy, including safety, operational experience, waste management, economic analysis, and technology development. This includes topics such as the development of accident-tolerant fuel.

"Through this partnership, EPRI and the NEA can also effectively engage public and private stakeholders to adopt a collective approach to solving identified common issues, while respecting their respective natures and obligations," said Magwood. "For example, we are currently leading efforts to ensure the worldwide availability of a material and fuel testing facility, a key concern for both regulators and industry."

In June 2019, EPRI and the NEA—along with the International Atomic Energy Agency, Korea Hydro & Nuclear Power, and the United Kingdom's National Nuclear Laboratory—are organizing the Innovation for the Future of Nuclear Energy forum in South Korea. The event will convene utility leaders, regulators, academic researchers, policymakers, and entrepreneurs from other industries.

Participants will learn how other industries overcame barriers to innovation, identify ready-to-use or almost-ready innovative technologies for deployment, develop consensus on promising areas deserving more attention, and lay the foundation for continued collaboration following the forum. "This is the starting point," said Wilmshurst. "We will build on what we learn at the forum to help nations harness nuclear power to achieve their energy and climate goals."

EPRI JOURNAL

Drones and AI Converge for Power Delivery Inspections

EPRI Investigates How These Technologies Can Make Inspections Safer, Cheaper, and More Effective

By Chris Warren

Improved inspections of power delivery infrastructure can help reduce the risk of outages by pinpointing equipment that needs to be repaired or replaced. Today's inspections require a lot of time, people, and equipment. "It's a combination of aerial inspections from helicopters and fixed-wing aircraft, climbing poles, using bucket trucks, and walking inspections," said EPRI Senior Technical Leader Dexter Lewis. "Utilities use a different mix of those depending on the power line's importance, budgets, and timing."

Utilities can use helicopters to reach remote areas and cover more territory, but sending inspectors into the air has safety risks. Utilities are exploring drone technologies to deliver the benefits of aerial inspections while enhancing worker safety. "With alternatives that keep humans on the ground, you can reduce risk," said Lewis. "There's also an opportunity to reduce costs and time of inspections while improving the quality of the information gathered."

With the emergence of relatively inexpensive drones and artificial intelligence (AI), EPRI is investigating their application for transmission and distribution inspection, building on prior EPRI research on the use of unmanned aircraft to capture images.

"One lesson we have learned from our drone research is that we need an automated system for processing the large number of images that drones can capture," said Drew McGuire, an EPRI distribution systems program manager. "While we were investigating ways to use drones to improve inspection, interest in AI among utilities increased, and the two technologies have converged into a great opportunity. If drones capture a large volume of high-quality images of transmission and distribution equipment, AI can analyze them for signs of breakage, deterioration, and other problems."

EPRI has collected about 7,000 images of transmission assets and curated them—in other words, labeled the components in the images and identified whether they were operational or defective.

"We gathered images from utilities across the country," said McGuire. "Then, we shared the curated images with AI developers and researchers and educated them about transmission inspections. We showed them what they should look for and what the inspection criteria are. This enabled them to train AI algorithms to identify assets needing repair or replacement."

EPRI tested these algorithms using a data set that had not been previously used to train the algorithms, enabling the researchers to better understand potential real-world performance. The accuracy of the algorithms' predictions was promising, considering that this was the first time many of them had been used to evaluate transmission infrastructure. "It indicates that this is a worthwhile endeavor, and we see a great opportunity to accelerate the maturity and performance of this technology," said McGuire.

EPRI is collecting additional images that the AI vendors can use to continue training the algorithms and enhance their performance. The goal is to match or surpass the effectiveness of traditional inspection methods while lowering costs and increasing the speed.

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

"As the technologies improve, our testing can provide objective, statistically valid insights into how well they work," said McGuire. "Maybe they're good at detecting broken insulators but not good at identifying broken conductors. By doing this, we can provide utilities with an assessment of the state of the technology and expected performance while helping AI professionals get better at these applications."

In its similar project for distribution systems, EPRI is compiling and curating thousands of images for AI developers, who will use the images to train algorithms later this year. Long term, EPRI plans to collect and store more than 100,000 distribution and transmission images and use them to train algorithms.

As the sophistication of AI and drones increases, power line inspections may become more autonomous—though a complete inspection revolution is unlikely in the short term. "It's more likely to be small deployments that grow steadily, resulting in incremental improvements in efficacy and reduced operations and maintenance costs," said McGuire. "We might never get to full autonomy, but we're working toward augmented inspections that are safer, more effective, and less expensive."

KEY EPRI TECHNICAL EXPERTS

Dexter Lewis, Drew McGuire

In the Field

Wall-Climbing Robots Inspect Nuclear Storage Casks

Field Tests Demonstrate Robots' Ability to Inspect Facilities That Store Used Fuel

By Scott Sowers

Extracting Value from R&D

EPRI and Robotic Technologies of Tennessee designed robots for inspecting used nuclear fuel storage casks, and nine field tests across the United States demonstrated that the robots can perform high-quality inspections. At Maine Yankee Nuclear Power Plant, the tests showed that casks are robust after their first 20 years of operation. "We can use this result to support our application to the U.S. Nuclear Regulatory Commission to continue using the casks," said Maine Yankee Project Manager Paul Plante.

Robots designed to inspect used nuclear fuel storage facilities have performed well in nine field tests across the United States.

In the 1980s, the nuclear industry in the United States began storing used nuclear fuel in dry cask systems (see this 2016 *EPRI Journal* article for more on the history of used fuel storage). These consist of a basket of fuel assemblies, sealed with a chemically inert gas inside a shielded stainless steel canister, which in turn is placed in a 20-foot-tall concrete overpack or cask (see graphic below). Small air vents in the overpack permit passage of residual heat from the fuel.

Inspection is challenged by the confined spaces (1.75 to 7 inches high) used to access the canister surface. For several years, EPRI has developed and field-tested robots both small and nimble enough to examine the canister surface.

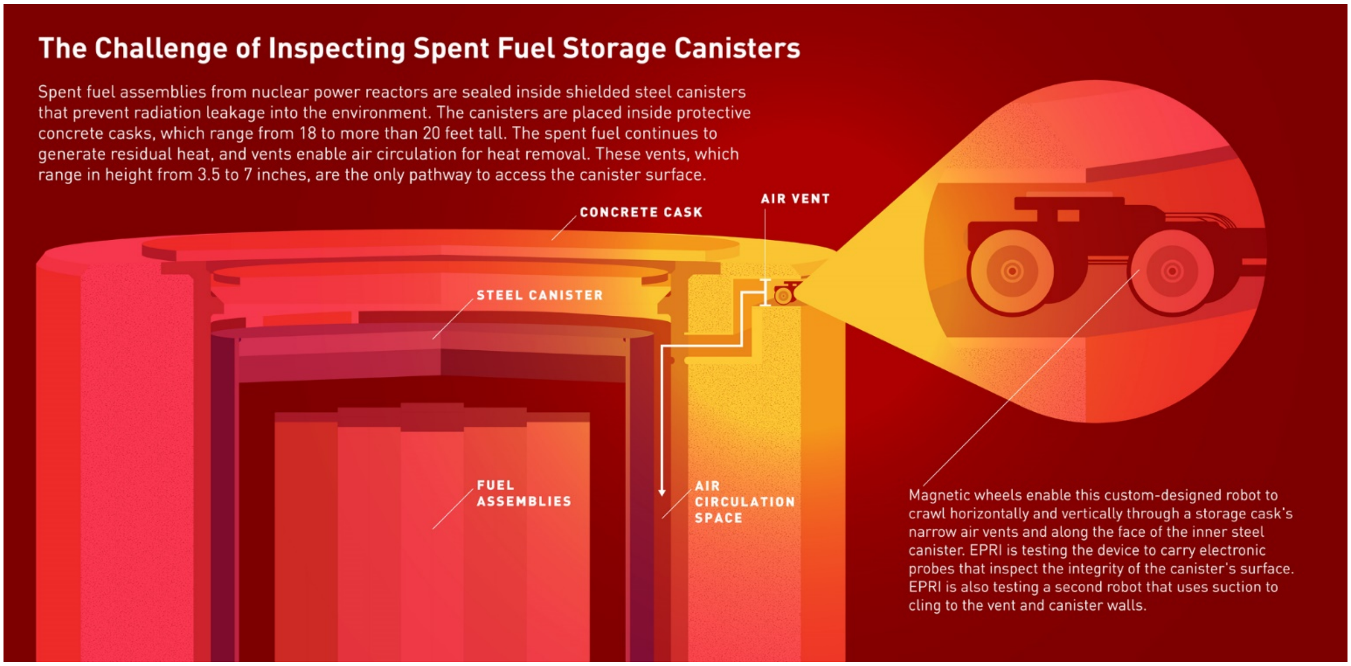
Designed by EPRI and Robotic Technologies of Tennessee, the robots can climb walls and move horizontally to position various nondestructive evaluation tools, including cameras and video systems, eddy current array probes, electromagnetic acoustic transducer probes (often known in the nuclear power industry as *EMATs*), radiation detectors, and temperature sensors. One robot uses magnetic wheels' attraction to the carbon steel liners surrounding the canisters, minimizing contact with canister surfaces. A second robot uses suction to adhere to surfaces, providing the additional benefit of removing dust and debris.

During the field tests, robots successfully obtained high-resolution videos and other data relevant to the canisters' surfaces.

"Our field tests have demonstrated that the robots are robust and can perform high-quality nondestructive examinations of several different designs of dry storage systems," said EPRI Program Manager Jeremy Renshaw. "They can withstand the high temperatures and radioactivity inside casks and operate as designed with no loss of performance, and they are retrieved without any residual radioactivity."

Field test locations included:

- Orano Dry Storage Facility (Aiken, South Carolina)
- Palo Verde Nuclear Station (Tonopah, Arizona)
- McGuire Nuclear Station (Huntersville, North Carolina)
- Maine Yankee Independent Spent Fuel Storage Installation—two deployments (Wiscasset, Maine)
- San Onofre Nuclear Generating Station—two deployments (San Diego County, California)
- Hatch Nuclear Power Plant (Baxley, Georgia)
- Pacific Northwest National Laboratory Dry Storage Test Mockups (Richland, Washington)
- Trojan Independent Spent Fuel Storage Installation (Columbia County, Oregon)
- Vermont Yankee (Vernon, Vermont)



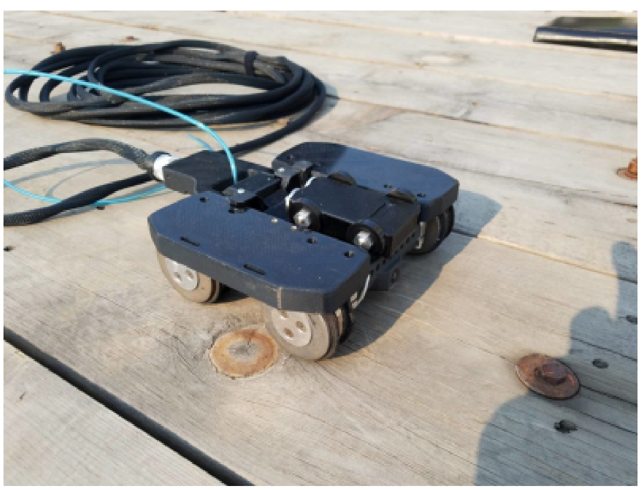
The Maine Yankee, San Onofre, Trojan, and Vermont Yankee deployments tested the robots on canisters loaded with used fuel, while the other sites used empty canisters.

Inspections at the Maine Yankee site confirmed what plant operators had suspected. "We found some coating damage on the inside of the overpack, but no damage on the canister," said Maine Yankee Project Manager Paul Plante. "Because the canister is the boundary that confines the fuel, the observation that it's in good shape suggests that this group of casks are robust after their first 20 years of operation. The overpack is intended primarily for shielding, so coating damage is not a big deal. We can use this result to support our application to the U.S. Nuclear Regulatory Commission to continue using the casks."

One of the robot demonstration sites was Palo Verde Nuclear Generating Station, which manages more than 150 dry storage systems. Photo courtesy of Arizona Public Service.

An operator prepares a robot for testing in a mockup cask at Palo Verde Nuclear Generating Station. Photo courtesy of Arizona Public Service.

At Palo Verde's Energy Education Center, this cutaway version of a cask (showing its internal features and dimensions) was used for a robot demonstration. Photo courtesy of Arizona Public.



This robot uses magnetic wheels that stick to the carbon steel liners surrounding the canisters. Photo courtesy of the 3 Yankee Companies.

To prepare for the robotic inspection at Maine Yankee, researchers installed scaffolding around a cask. Photo courtesy of the 3 Yankee Companies.

A robot climbing a cask wall during a demonstration at McGuire Nuclear Station. Photo courtesy of Duke Energy.

The team that implemented the robot demonstration at Maine Yankee's Independent Spent Fuel Storage Installation. More than 40 people representing 18 companies and organizations participated. Photo courtesy of the 3 Yankee Companies.

The findings from all inspections to date help confirm that cask systems are highly durable and can provide safe storage for decades.

Robotic cask inspection can reduce risk to workers. As robots enter and exit the casks, radiation exposure to personnel is low. Nuclear material doesn't need to be moved, reducing the possibility of mishandling.

Prior to this effort, some plant operators had planned to transport casks to spent fuel pools to perform inspections. Other inspection approaches use heavy-lift equipment to move and rotate canisters. Relative to these approaches, EPRI's robot requires fewer people and less time and reduces costs by about 90% or more.

Meet Another Wall-Climber: The Concrete "Crawler"

The fuel canister inspection robot is not the only wall-climbing robot that EPRI has developed. Since 2011, EPRI has built, demonstrated, and refined a robotic concrete crawler that can inspect concave, convex, and other hard-to-reach surfaces on large concrete structures at hydroelectric, nuclear, and fossil generation facilities. It carries equipment to measure and map specified areas of structures, as well as nondestructive evaluation devices that can inspect deeper concrete layers. In 2013, EPRI and New York Power Authority demonstrated the crawler at a hydroelectric plant.

An inspection team at San Onofre Nuclear Generating Station uses a pivoting arm to lower a robot into a vault containing a dry storage canister. Photo courtesy of San Onofre Nuclear Generation Station.

KEY EPRI TECHNICAL EXPERTS

Jeremy Renshaw

EPRI JOURNAL

R&D Quick Hits

Can Augmented Reality Make People Faster at Their Jobs?

A study by EPRI and Ameren Illinois offers a preliminary answer: yes.

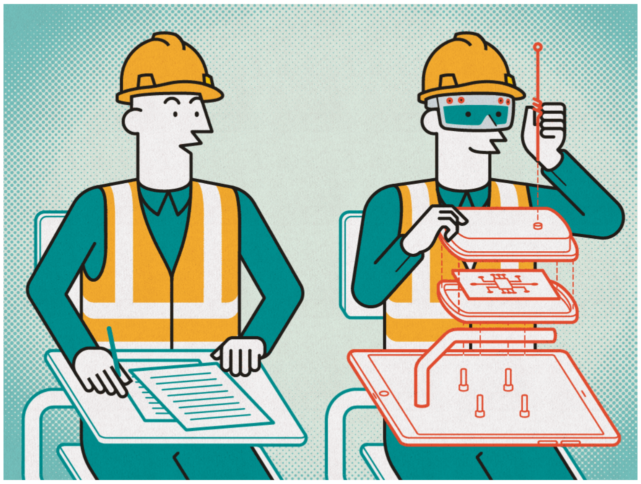
Traditionally, utilities train line workers on tasks by providing paper guides and administering computer tutorials in an office, often months before completing tasks. As smart technologies are widely integrated with the grid, line workers must master more tasks, raising the question of whether traditional training is still adequate. A possible solution is *just-in-time training*. At the work site, technicians view tasks simulated in augmented reality (AR) apps minutes before performing the work.

To test this approach, EPRI and Ameren Illinois evaluated about 50 workers as they completed router installation and maintenance tasks. Ameren provided one set of workers with step-by-step instructions on paper cards. A second group used an AR app to train in the field. Using the app's 3-D animations of the tasks, workers could rotate the router and read additional information about the various steps and best practices. Workers trained on the paper method took an average of 77 minutes to complete tasks while the AR-trained workers took an average of 37 minutes.

The study's authors are careful to point out that this is an initial assessment. More extensive field studies of AR-based training are needed to more precisely characterize potential efficiency gains.

KEY EPRI TECHNICAL EXPERTS

John Simmins, Micah Tinklepaugh



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R&D Quick Hits

EPRI Looks at Machine Learning and Synchrophasor Data to Find Problems on the Grid

In the future, artificial intelligence could help grid operators avoid outages. In a preliminary EPRI study, machine learning techniques showed promise in their ability to accurately identify events on the power grid by analyzing massive amounts of data.

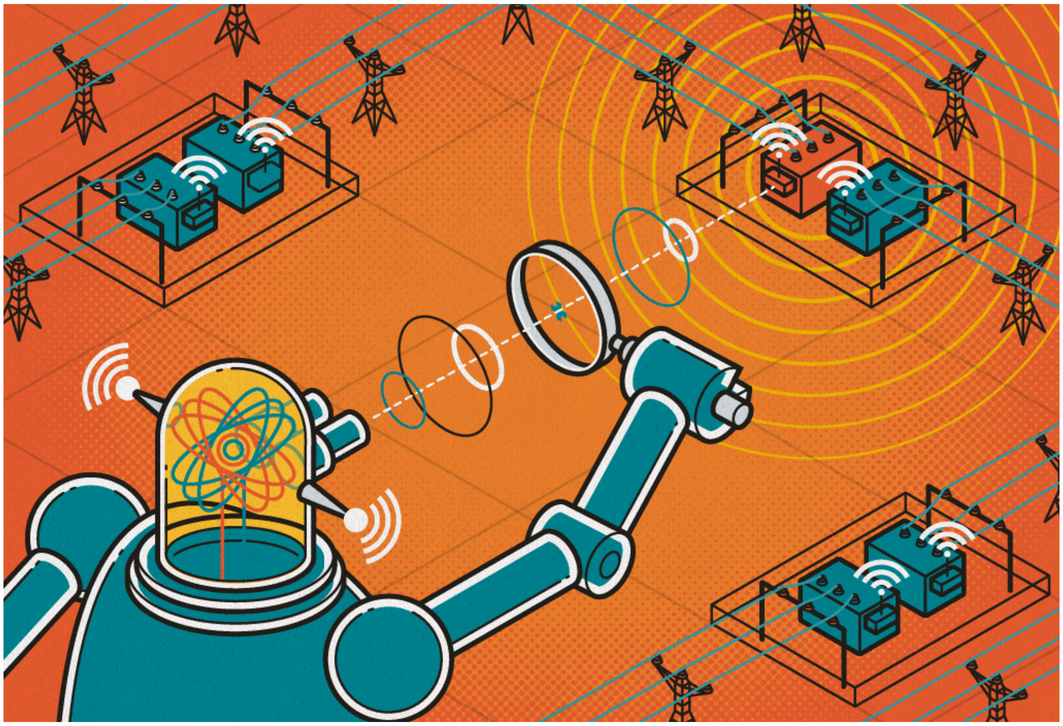
Over the past decade, utilities have deployed thousands of phasor measurement units in grids across the United States. These collect synchronized voltage and current measurements (known as synchrophasors) 10–60 times per second. For grid operators, these data can potentially provide better awareness of real-time conditions, help integrate renewable energy, and help detect and identify problems before they lead to outages. Machine learning seems poised to help utilities make sense of this and other vast data sets.

To analyze the synchrophasor data, EPRI investigated the applicability of supervised and unsupervised machine learning techniques and proposed frameworks that combine them. Supervised learning tends to be more accurate but requires data labeled with grid events. When such data were not available, unsupervised learning was used. Preliminary experiments used simulated data.

EPRI plans to apply the technique to real synchrophasor data and develop software to perform the analysis, with the first version expected by the end of 2019.

KEY EPRI TECHNICAL EXPERTS

Evangelos Farantatos



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