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EPRI JOURNAL

Ushering in the Digital Worker Generation

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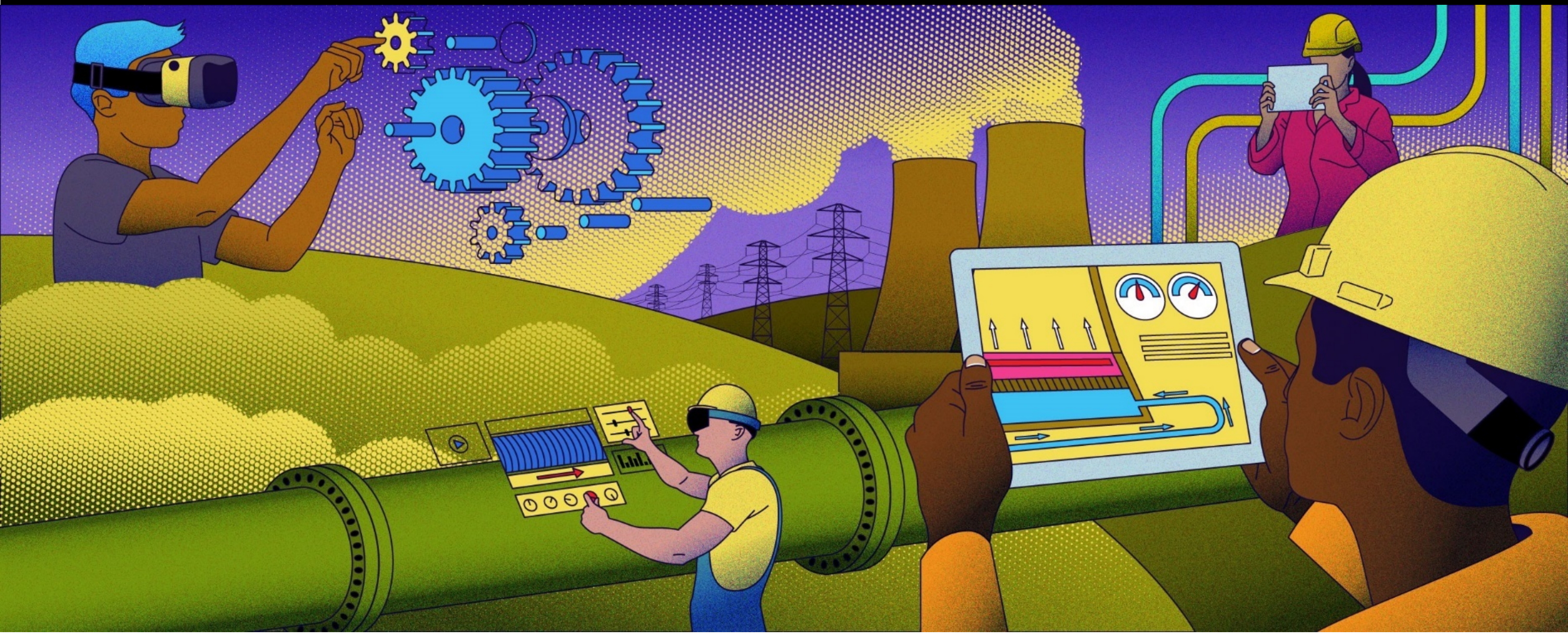


Ushering in the Digital Worker Generation

New Innovation Hub Coordinates Digital Technology Research Across the Electric Power Industry

By Mary Beckman

For nearly a decade, experts in EPRI's Power Delivery and Utilization sector have been developing applications with augmented reality (AR) that utility workers can use to perform tasks on electricity transmission systems. When workers view equipment wearing glasses and headsets, descriptions, instructions, and other vital information are displayed in virtual space over the equipment. Workers use AR tools to identify transformers and other assets, assess storm damage, and report broken poles. Others remind them when to wear fire-retardant clothing at a substation.

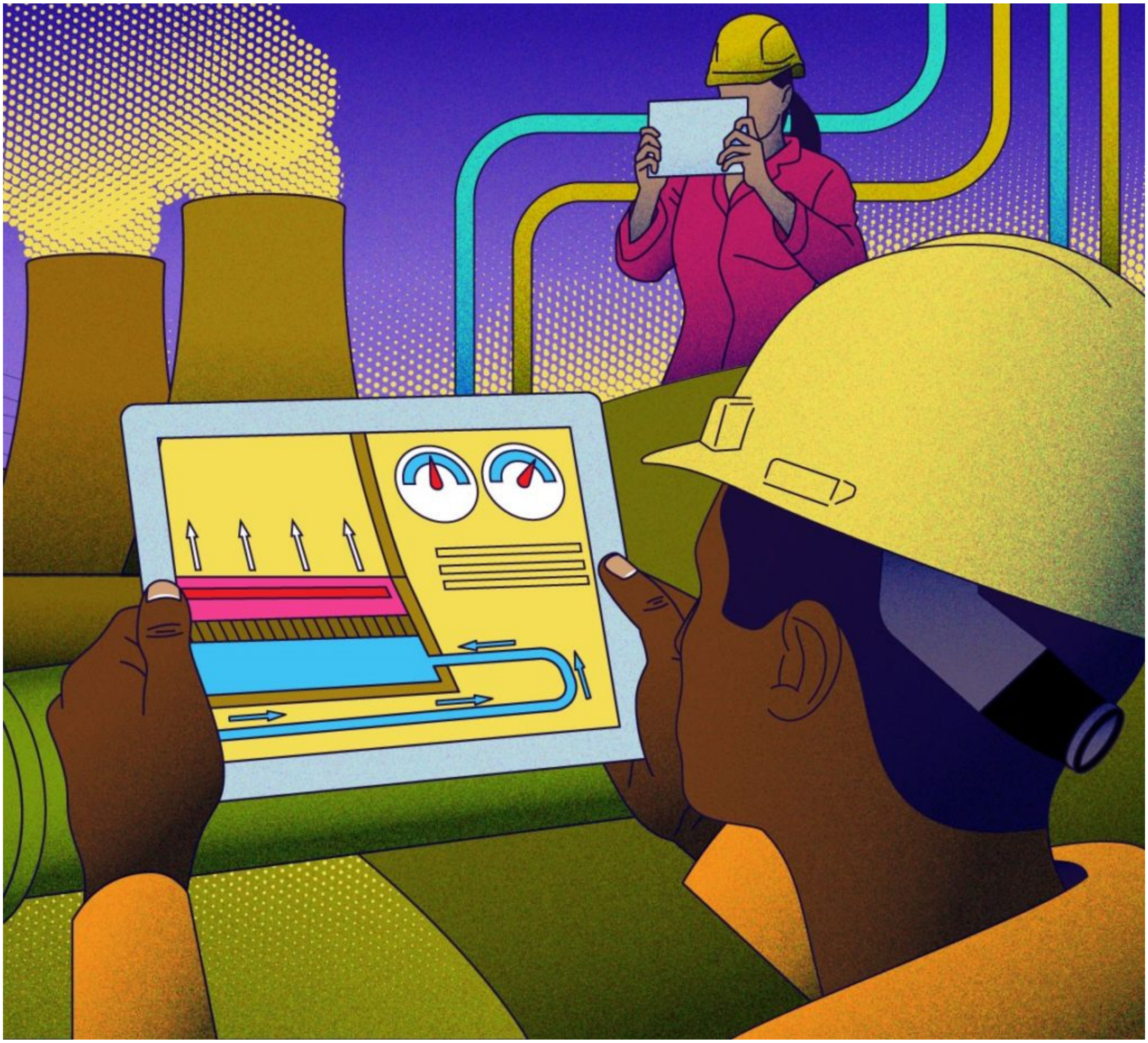
Meanwhile, in EPRI's Generation and Nuclear sectors, researchers are developing digital applications for workers to use in inspecting, maintaining, and repairing power plant equipment. Technicians put aside pen and paper and use a tablet or iPad to guide their work and enter data on the spot. The information is transmitted wirelessly to a central software program instead of being written on a paper form and stored in a file cabinet. According to EPRI Principal Technical Leader Nick Camilli, more than half of operating nuclear plants in the United States have transitioned to mobile platforms (such as tablets) and are using them to execute 70–85% of work orders.

These projects merely scratch the surface of how EPRI is advancing "digital worker" technologies in the electric power sector. These technologies include mobile communications, wearable computers, smart glasses, AR, virtual reality, imaging tools, and other digital technologies workers can use to perform jobs more safely, efficiently, and effectively. Widespread deployment of these technologies can improve communications, data access, real-time observations, task execution, troubleshooting, and decision making.

EPRI technical leaders from its four sectors are spearheading the Digital Worker Innovation Hub to facilitate collaboration and sharing research and best practices among various research areas. The focus is on practical applications near-term and evaluating emerging technologies.

"We are formalizing our strategy and defining how to work together across the institute to facilitate learning and to speed technology development," said Matt Wakefield, EPRI's director of information and communication technology. "We also want to make sure the technologies we use—as cool as they may be—are the right ones for the job."

Among dozens of applications under development at EPRI: mobile field guides for inspecting cooling towers and steam condensers, AR-based verification for transmission switching orders, virtual reality training for turbine maintenance, AR graphics to show hazardous areas in switchyards, and electronic work packages. Researchers are also looking at the human health implications of these technologies, such as how AR impacts ergonomics and workers' awareness of their surroundings.



"These technologies are relevant whether you work in transmission, distribution, a power plant, or are evaluating the safety of your workers in the field," said Wakefield. "EPRI's expertise in all these areas puts us in a good position to maximize what we learn in different sectors and not duplicate efforts."

"EPRI is unique in that our collaboration with hundreds of utilities can provide us with information on equipment specifications, operating tolerances, and work processes," said EPRI Engineer Micah Tinklepaugh. "These can guide the development of the most useful applications and technologies."

As part of the Innovation Hub, EPRI is developing a comprehensive Digital Worker project database and setting up laboratories where researchers and industry stakeholders can test technologies, discuss needs, and brainstorm new applications. An interest group provides a forum for utilities to strategize, plan, and implement technologies. Insights from these activities can inform a broader power industry strategy on Digital Worker technologies.

"We want to establish EPRI as the go-to for power companies," said EPRI Senior Technical Leader Matt Buck. "When they need Digital Worker technologies to solve a particular problem, we want them to say, 'Let's call EPRI and see what they're doing.'"

A HUB FOR SHARING AND TESTING

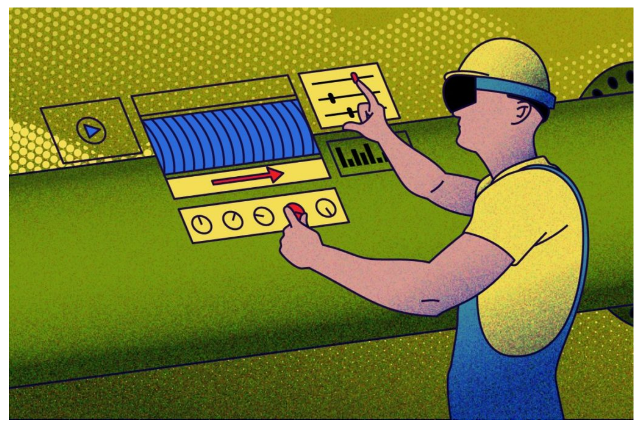
Drawing on internal surveys and EPRI reports, Buck, Wakefield, and Tinklepaugh are gathering information about Digital Worker projects across the institute and organizing an online database to serve the interests of various groups. It can provide project details—who manages the research, how it's funded, and what deliverables are planned. For utilities, project overviews and contact information can encourage collaboration. For the public, it can provide general descriptions of new technologies that EPRI and utilities are developing to enhance electricity service.

EPRI is setting up Innovation Labs in Charlotte and Knoxville where researchers can develop, test, and demonstrate new technologies. Each will be equipped with AR headsets, virtual reality tools, iPads, and other digital devices. The labs will also showcase areas in which utility staff and other industry stakeholders experience the technologies firsthand, learn about the benefits, and provide feedback to the developers. Additional labs are planned in Palo Alto and Washington, D.C.

"Talking to people and finding out how these technologies are working for them is important," said Tinklepaugh.

For example, visitors can experience a new EPRI virtual reality program that trains technicians in performing Terry Turbine maintenance. Using handheld controllers, visitors manipulate tools and disassemble and reassemble the turbine in a virtual environment.

"It's life-size," said Buck. "You move around and reach into different areas to remove nuts and bolts and different parts of a small steam turbine."



CAN UTILITIES USE DIGITAL WORKER TECHNOLOGIES TO SAVE MONEY?

To help utilities make the business case, EPRI is planning research to quantify the value of Digital Worker technologies—whether through reduced worker time, increased accuracy, or cost savings. A recent EPRI study found that line workers trained in the field with an AR app installed routers on utility poles 48% faster than workers who learned the task by reading instructions on index cards.

Another study found that an AR app could cut in half the staff time for storm damage assessment relative to conventional pen-and-paper. Based on this result, the app could potentially reduce restoration time for a typical four-day outage by 12 hours, saving customers more than $8 million.

SAFETY ASPECTS OF AR

Digital Worker technologies present opportunities to improve job performance, but are they safe? For example, can the extra weight of an AR headset cause muscle strain? Can AR distract personnel working at high elevation, near high-voltage equipment, or in other potentially hazardous environments? According to an EPRI literature review, there has been little research on AR's safety implications.

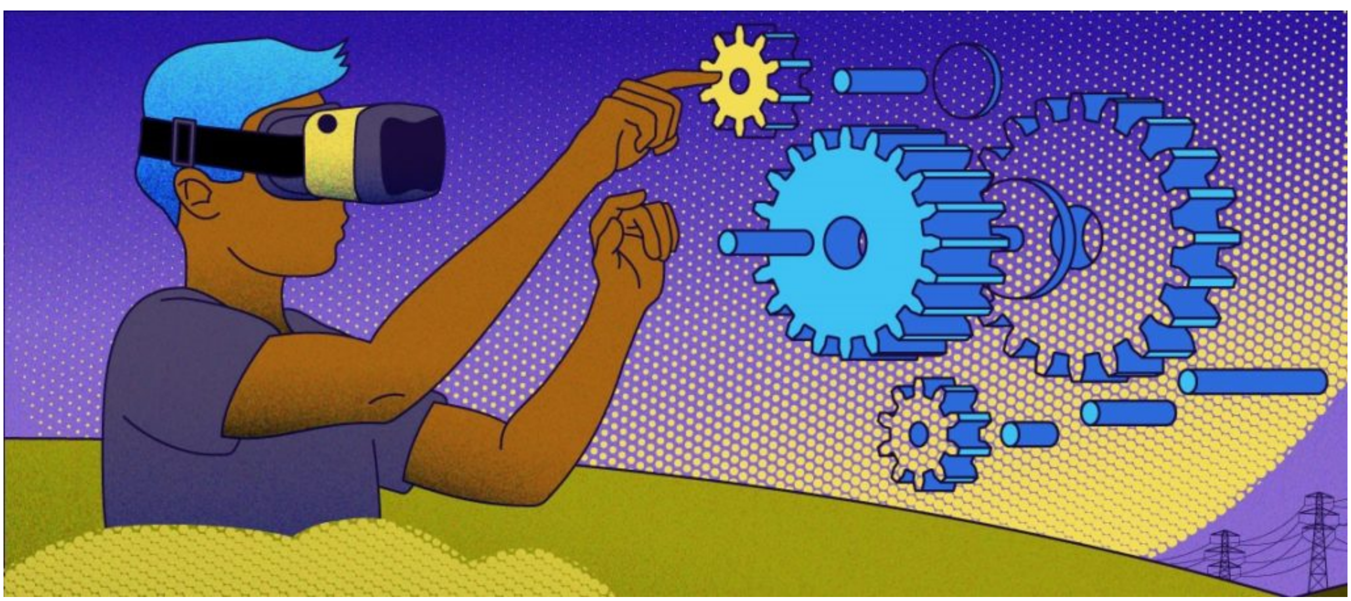
In a first-of-its-kind field study at We Energies' Elm Road Generating Station, EPRI and Marquette University evaluated the effects of two AR devices—a full-face shield and a smaller helmet-attached unit—on 12 plant personnel as they performed routine inspection tasks. The study is being conducted through EPRI's Occupational Health and Safety Program, part of EPRI's Energy and Environment sector.

"The workers liked the smaller devices more because they could easily flip them out of their field-of-vision to see their surroundings," said EPRI Principal Technical Leader Eric Bauman. "They also preferred the option of using speech to control the screens. Some noticed arm strain when they used hand gestures to control the screens."

Researchers found that a full-face shield AR device may reduce blink rate, which can lead to eye strain. While no increase in neck and shoulder strain was observed, the tasks were brief—less than 30 seconds. An in-progress EPRI study on utility personnel performing 20-minute manhole tasks (using the same two AR devices) is expected to shed more light on AR's potential impacts.

"EPRI is getting ahead of these ergonomic and safety issues before large-scale AR deployment occurs," said Bauman. "AR manufacturers can use the results to improve the design of future AR devices."

"This type of study had never been done before, so we had to design the experimental protocol from scratch," said Richard Marklin, a Marquette University mechanical engineering professor who is working with EPRI on this research. "The study will help lead the way for other researchers to investigate these issues further. Ultimately, the research can inform utilities' occupational safety and health guidelines for AR, such as the recommended type of AR device, duration of use, and frequency of breaks.



CAPTURING 'TRIBAL' KNOWLEDGE FOR THE YOUNGER GENERATION

Digital technologies can help save, store, and integrate decades of equipment maintenance data along with the knowledge of retiring utility staff. For example, one AR app enables a substation worker to direct an iPad's camera at a component and access extensive information on its repair history and status. The app warns the worker if she is standing too close to the equipment or is in a high-voltage zone.

"These apps can incorporate tribal knowledge that a worker can take into the field," said Buck. "It's like having an expert looking over your shoulder."

As an additional benefit, digital worker technologies' "coolness" may help attract young, technologically engaged recruits.

"Relative to other technology industries, utilities may have an undeserved reputation as a boring place to work," said Wakefield. "We've generated some excitement among workers who regularly use digital technologies to find nearby restaurants or constellations in the sky. The younger generation has grown up with these technologies and knows how to use them already. That may help bring them to this industry."

According to Wakefield, it's too early to predict how digital technologies will transform the electric power industry, but it's not too early for vendors to develop commercial solutions.

"Some digital worker technologies could be game changers," he said. "The opportunity to improve the way we do business is really exciting."

EPRI Initiative to Train the Next Generation of Digital Workers

With a $6 million award from the U.S. Department of Energy, EPRI has launched the Grid-Ready Energy Analytics Training (GREAT) with Data initiative. In collaboration with utilities and universities, EPRI plans to develop professional training and university courses to enhance Digital Worker skills for the electric power industry in four areas: data science, cybersecurity, information and communication technologies, and integration of distributed energy resources such as solar, energy storage, and electric vehicles. The project will also develop certifications, credentials, qualifications, and standards for the training and education. Training includes live, in-person instruction and computer- or cloud-based digital training modules. Target audiences include engineering, applied mathematics, and computer science students and professional engineers, executives, data scientists, and other workers in the power industry.

KEY EPRI TECHNICAL EXPERTS

Matt Wakefield, Micah Tinklepaugh, Matt Buck

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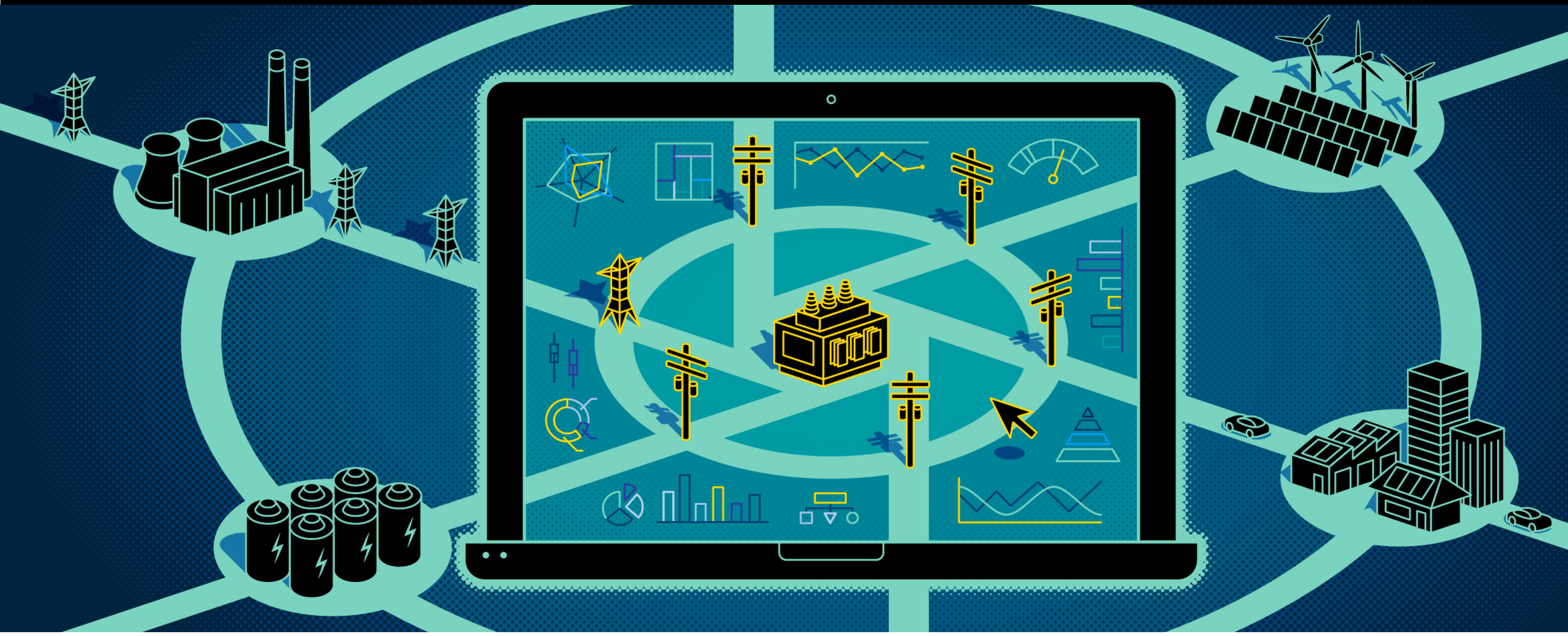


Distribution System Planning Gets a Makeover

EPRI Develops Tools to Help Distribution Planners Navigate the Complexity of a Changing Grid

By Chris Warren

Solar, electric vehicles, energy storage, and other distributed energy resources (DER) are transforming how we generate and use energy. For power distribution planners, this poses significant challenges for integrating extensive deployment of DER while operating the system safely, reliably, and cost-effectively. EPRI is working on new tools to help planners with the transition.

SKYROCKETING DISTRIBUTED RESOURCES

According to the Solar Energy Industries Association (SEIA), cumulative solar photovoltaic capacity in the United States at the end of 2018 was 62.4 gigawatts—about 75 times more than was installed at the end of 2008. A significant portion of the new capacity is connected to the distribution grid. For the third quarter of 2018, SEIA reports that residential and commercial projects totaled about 1.1 gigawatts while utility-scale projects accounted for nearly 700 megawatts.

Planners expect that electrification of transportation is likely to offset much of the load reductions driven by ongoing efficiency improvements, and very rapid electrification could result in some load growth. The International Energy Agency projects the number of electric vehicles in use globally to grow from 3.1 million in 2017 to 125 million by 2030.

MANY NEW ISSUES TO CONSIDER

Traditionally, planners analyze distribution feeders' current and future state to identify actions needed to accommodate load growth. How do new neighborhoods and commercial facilities impact distribution equipment and system operation? Could transformers or power lines be subjected to power flows causing them to exceed their thermal ratings? Planners must then determine system upgrades needed for reliable system operation.

As DER are deployed extensively and bi-directional power flows become more common, projecting grid conditions becomes increasingly uncertain and variable. "It is becoming more difficult for planners to examine all the options and scenarios manually," said Jason Taylor, a principal project manager at EPRI. "For a single feeder, they may need to decide where to deploy storage or other DER, what size to use, whether it addresses future load projections, where to upgrade grid equipment, and many other issues. Examining one issue at a time is time-intensive."

Planners' existing tools, processes, and methodologies cannot be used to examine all these issues quickly.

"Before you had bi-directional flow, planners could use rules of thumb and industry standard calculations to inform their decisions. The analytics were well-known and hadn't changed in 50 years," said Jeff Smith, who manages EPRI's distribution planning and operations research team.

Bi-directional power flow is also changing how different parts of the electric system coordinate. Historically, frequent communication among distribution, transmission, and generation planners was unnecessary because the flow of electricity was predictable: Central power plants generated electricity, transmission lines delivered it to the distribution system, which in turn delivered it to businesses and houses. In some cases today, generation from DER on the distribution grid is exported to the transmission system.

"DER connected to the distribution system may be providing bulk system services," said Smith. "If distribution and transmission planners continue working in silos, we can't assume any longer that the systems will work in concert."

"We cannot plan for distribution circuits apart from other planning activities anymore," said Will Lowder, Duke Energy's project director for energy storage. "We have to find a way to share our information across generation, transmission, and distribution because we will have a significant impact on each other. That is a huge driver for new long-term planning tools."

ALTERNATIVES TO INFRASTRUCTURE UPGRADES

DER connected to the distribution system present new options for meeting load growth beyond adding transformers, capacitors, and substations. "New energy resources could be valuable to both the distribution grid and the bulk power system," said Taylor. "If properly designed and connected to the distribution system at the right locations, they may offer cost-effective alternatives to expensive infrastructure upgrades. However, existing planning tools and approaches are not designed to consider these options."

"In some locations, connecting solar to the grid can cause technical problems in the distribution system, particularly if a feeder's hosting capacity has been exceeded," said Smith. "But the flip side of the coin is that DER can provide valuable grid services such as offsetting peak demand and providing voltage control if they're located where those services are needed."

Enhanced distribution planning can help utilities invest effectively. "Utilities have limited budgets for capital investments and operations and maintenance, and regulators scrutinize these budgets," said Smith. "Smart, coordinated planning helps utilities get the most out of every dollar they spend by realizing the most value from existing grid assets and new DER. In some cases, this can help them to avoid investment in new assets. Regulators welcome these cost-containing efforts."

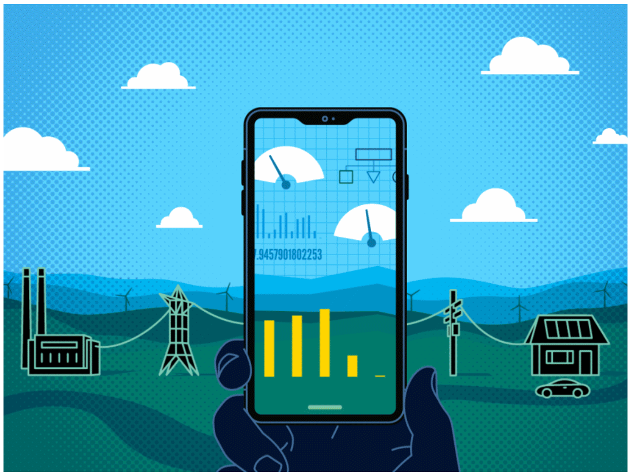
Indeed, integrated distribution resource planning has been spearheaded in states where DER has grown most rapidly, including Hawaii, New York, and California. This recognizes the changing connections between distribution and transmission systems and encourages collaboration to make the best investments. It's a significant departure from traditional distribution and transmission plans separately addressing their respective objectives and time horizons.

DISTRIBUTION PLANNING 2.0

In 2018, EPRI launched a two-year initiative to modernize distribution planning and to develop new tools and procedures that can help utilities:

- Automate the design and evaluation of traditional and non-traditional planning alternatives
- Determine DER's positive and negative effects on distribution systems
- Optimize investment across multiple planning timelines

- Evaluate how DER, increasing electrification, and changing customer demand may affect infrastructure investment
- Support integrated generation, transmission, and distribution planning



Researchers will develop tools (including software that vendors can build on and commercialize) to automate distribution planning, equipping planners to evaluate rapid DER deployment.

As a first step, EPRI is collaborating with utilities to identify gaps in planning tools and processes and to determine data collection necessary to guide future work. "Utilities will help us to define the capabilities the industry needs—both near-term and long-term," said Smith.

The initiative expands on EPRI's existing suite of planning tools, including:

- OpenDSS: Comprehensive distribution analysis tool that supports DER integration and grid modernization
- Distribution Resource Integration and Value Estimate (DRIVE): Evaluates feeder hosting capacity

"With input from our member utilities, we're going to add new capabilities to the DRIVE and OpenDSS tools," said Smith. "We will help vendors incorporate our tools' features and our knowledge of distribution planning into the software they develop."

"As solar, energy storage, and other DER technologies advance rapidly, distribution planning processes and tools need to keep pace," said Smith. "This can enable planners to effectively evaluate all the options and design a system that provides customers with safe, reliable, cost-effective services."

REINVENTING PLANNING AT DUKE ENERGY

Duke Energy and EPRI are building a set of advanced planning tools to enable the utility to assess DER impacts and to automate functions that today are manual. For instance, the tools would automatically assess numerous factors relevant to a proposed battery installation, including its expected operating life, optimal location and size, and impacts on distribution, transmission, and generation.

The tools will factor data on future rooftop solar, predictions for future electric vehicle penetration, and changes in load and generation portfolios. "The more automation you need, the more precise your data has to be," said Clif Cates, who oversees distribution planning at Duke Energy. "The data we used in the past is not real-time enough. We need precise data that can be shared among transmission, distribution, and generation."

According to Cates, Duke Energy's efforts to make its planning more holistic and dynamic required planners from different groups to meet regularly and to integrate distribution and transmission plans. "It's challenging work, but it has helped the groups to understand one another better so that everyone could map out a shared direction," he said.

Other power companies can benefit from this pioneering work. "We are building one of the first case studies on integrating transmission, distribution, and generation planning," said Cates.

KEY EPRI TECHNICAL EXPERTS

Jeff Smith, Jason Taylor

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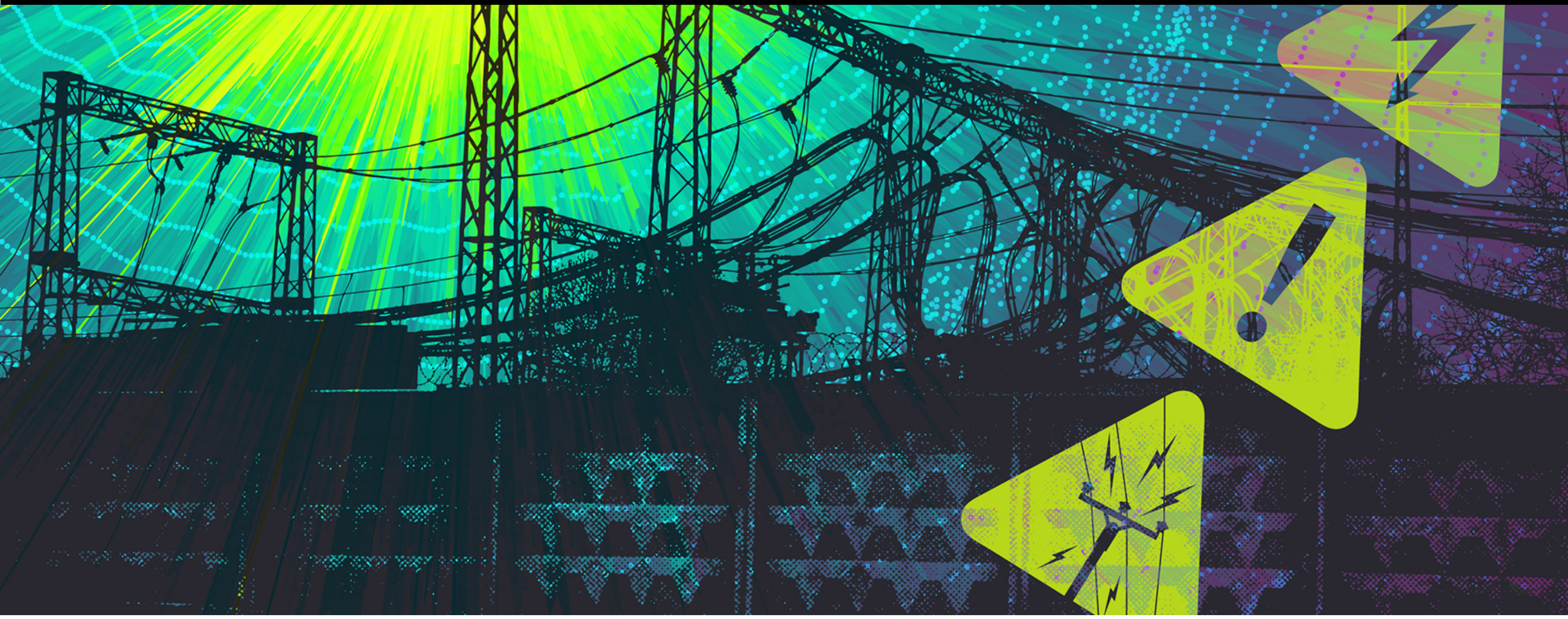

A "Deliberate Approach" To Electromagnetic Pulses

New EPRI Research Outlines Possible Impacts and How to Protect Against Them

By Chris Warren

An EPRI study has found that a high-altitude electromagnetic pulse (HEMP) is unlikely to cause nationwide and long-lasting blackouts as a result of damage to critical substation assets, though the potential exists for substantial disruption of transmission systems. The study also highlighted steps that can be taken to protect grid assets against the worst impacts of HEMPs. Additional research and investigation are needed to understand potential HEMP impacts on power plants, distribution systems, renewable energy systems, and other parts of the grid—as well as other critical infrastructure sectors that support grid operations such as natural gas, water, and telecommunications.

Building on earlier work, the report provides analysis of potential transmission grid impacts and cost-effective mitigations. (It does not examine impacts on generation, distribution, and end-use loads.) EPRI worked closely with HEMP experts at the U.S. Department of Energy, the Defense Threat Reduction Agency, and the Lawrence Livermore, Sandia, and Los Alamos national laboratories.

Researchers modeled the voltage surges that digital protective relays can be exposed to as a result of E1 pulses. A detonation 125 miles above the earth's surface can generate an E1 pulse spanning an area of approximately three million square miles. However, impacts diminish with distance from the ground zero location and can vary depending on the location of the electronics.

"We modeled these electric fields and incorporated them into a power grid model to assess equipment exposure to voltage and current surges," said EPRI Senior Program Manager Randy Horton, who oversees HEMP research.

Through laboratory testing, EPRI measured the effects of E1 pulses on equipment such as digital protective relays. In one set of tests, researchers simulated E1 pulses directly hitting equipment and recorded when the equipment was damaged or disrupted. In a second set of "direct injection" tests mimicking voltage and current surges in the cables feeding into equipment, researchers recorded the levels of E1-induced surges that caused damage or disruption.

"The modeling told us what the equipment could be exposed to during an event while the lab testing told us the exposure levels that the equipment could withstand," said Horton. "By evaluating these two sets of results, we were able to determine if damage or disruption could occur."

Results indicated that E1 pulses have the potential to damage digital protective relays spanning an area as large as an entire electrical interconnection. The severity and extent of damage depends on the location of the equipment and the strength of the electric field produced by a HEMP. Some equipment may fail completely, while other components may be disrupted or unaffected. E1-related damage to digital relays and other controls could hamper recovery efforts and long-term grid operations. E1 pulses are unlikely to cause an immediate, interconnection-wide blackout, though more research is needed to gauge how damaged digital relays could affect power system stability.

Assessment of E2 impacts indicated that damage to the transmission system is not expected to occur. Assessment of E3 impacts indicated that a regional blackout (multiple states) is possible, but immediate, widespread transformer damage is not expected to occur.

Other findings:

- A moderately powerful E1 pulse could disrupt or damage approximately 5% of digital protective relays in the transmission line terminals of an interconnection while a more severe E1 could disrupt or damage about 15%.
- Viable options to mitigate E1-related damage include shielded cables with proper grounding; low-voltage surge protection devices and filters; grounding and bonding enhancements; and reserve supplies of digital protective relays and communication equipment.
- Viable protections against E3-related damage are similar to protections against geomagnetic disturbances and include keeping replacement transformers on hand and blocking or reducing the flow of geomagnetically induced currents.

"Overall, we found that a HEMP's potential impacts on the transmission system are real and of concern, and they can be mitigated by several approaches that are outlined in our report," said Horton. "Our findings do not support the belief that HEMPs can cause nationwide blackouts lasting for years."

In 2016, EPRI launched research on HEMPs to investigate concerns that a HEMP attack could result in long-term blackouts. It aims to provide utilities, regulators, and policymakers with a technical basis for assessing the potential impacts and for making decisions about mitigation options.

At the time, some stakeholders advocated that utilities deploy measures that the U.S. military uses to protect electronics in key facilities from a HEMP attack. "Those measures were never designed to be used in a substation and are very costly," said Horton. "Before regulators and policymakers required utilities to follow those military standards, power companies wanted to better understand the possible impacts and hardening measures."

In February 2017, EPRI released its first publicly available study to thoroughly examine potential impacts of E3 on large power transformers in the electric transmission system. It concluded that even though an E3 pulse could generate significant currents in tens of thousands of transformers, the likelihood of widespread and long-lasting blackouts from E3 alone was small. A December 2017 study evaluated E3's potential impacts on voltage stability in the transmission system. Both studies have since been updated with new data from Los Alamos National Laboratory.

The objective of EPRI's ongoing HEMP research is to inform stakeholders, including utilities that are investing in mitigations and regulators that are crafting policies and rules for hardening substations and other transmission infrastructure. "We are building a technical basis for informing decisions," said Horton.

EPRI has launched a demonstration project to design and implement hardening measures at more than a dozen utility substations across the United States.

"We are taking a deliberate approach," said Horton. "Through our upcoming field tests at substations, we can improve understanding of costs, identify unintended consequences, provide engineering solutions, and help address long-term asset management."

"We also see broad benefits from communicating our findings with other critical infrastructure sectors such as gas, water, and telecommunications," said Horton. "To date, we have looked at HEMP impacts only on the transmission system, so we don't want people to conclude that EPRI has solved the HEMP problem. A HEMP would not just hit the transmission system. It would hit everything, and we want to be prepared. We are also planning to investigate impacts on generating facilities and other utility infrastructure across the energy system."

KEY EPRI TECHNICAL EXPERTS

Randy Horton

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Going Local with Electrification

Expanding on Its Landmark U.S. National Electrification Assessment, EPRI Investigates Opportunities at the State and Provincial Level

By Chris Warren

EPRI's U.S. National Electrification Assessment concluded that electrification is likely to increase in the future, leading to various potential benefits including cost-effective, economy-wide CO_2 reductions—and it has now emerged as something of a launch pad for 17 utilities in 13 states and 1 province to assess electrification's potential for their region. The trend is clear: Electrification in the United States has increased from 3% of final energy use in 1950 to more than 20% today. The assessments are bringing a local focus to the big questions that have emerged with respect to electrification, cost, efficiency, emissions, and other areas of broad social concern.

As part of the National Electrification Assessment, researchers used the U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model to examine four scenarios regarding the role of electricity in America's future energy system. The study varied assumptions for technology costs and performance (such as the pace of electric vehicle price declines) and carbon prices reflecting potential climate policies. In the "conservative" and "reference" scenarios, no price is levied on CO_2 emissions. The "progressive" scenario put an energy-system-wide price of $15 per ton on CO_2 beginning in 2020, with the price rising 7% per year. The "transformation" scenario priced CO_2 at $50 per ton beginning in 2020—also with a 7% annual increase—and estimated that electricity would account for nearly 50% of final energy use by 2050.

U.S. National Assessment key insights:

- While final energy use has generally risen throughout history and most analyses project increasing final energy consumption for decades to come, all four scenarios in EPRI's assessment show a sustained decrease as a result of enhanced energy system efficiency and electrification. This is driven by improved efficiency in end use technologies, such as lighting and internal combustion engines, along with a shift from non-electric to electric technologies that tend to use one-quarter to one-half as much energy to provide the same or better service.

- All four scenarios demonstrate how electrification can curb carbon emissions. The reference scenario, with no carbon policy, projects a near 20% reduction in CO_2 emissions between 2015 and 2050 as a result of efficiency gains and increased electrification. In the transformation scenario, emissions over the same time period decrease by about 70%.
- Increasing natural gas, wind, and solar generation have lowered the carbon intensity of electricity generation in the United States by 28% since 2005. All four scenarios project continued growth of wind and solar generation, driven by price declines and current state and federal policies.
- To enable electrification, manufacturers will need to innovate and lower technology costs, and companies will need to provide the charging and other electric infrastructure.

The assessment includes a menu of policy, research, regulatory, and market actions that are needed to harness the societal benefits outlined in the scenarios.

To expand on the national assessment and provide practical and actionable insights for the power industry, EPRI has embarked on similar analyses at the state level. "Power companies operate at the state level, which can have varying energy market dynamics, energy resources, building stock, climate, air quality, emissions policies, and economics," said Francisco de la Chesnaye, the EPRI senior program manager who directs energy system analysis. "Targeting these in our next round of assessments will lead to more actionable results."

EPRI has launched assessments with 17 utilities in 13 states and 1 Canadian province, including California, New York, Georgia, Alabama, Pennsylvania, and Ontario. Research questions include:

- What is the value of efficient electrification?
- What are the drivers of efficient electrification?
- As electrification expands, how will electricity demand change across various sectors, geographic areas, and end uses?
- At the state level, what will electricity generation, transmission, and end-use energy consumption look like in the future?
- What research is needed to enable efficient electrification and inform effective electrification policies and utility programs?

Research participants can draw on their knowledge of state attributes and dynamics to inform more effective modeling. "We work collaboratively with the participants to customize our models so that they more accurately represent their state's electricity and energy end-use systems," said de la Chesnaye. "Within EPRI, this effort crosses research boundaries. We're involving our experts in energy and environmental analysis, air quality, energy utilization, and grid operations."

HOW ASSESSMENTS ARE DONE

The two-year state-level assessments are quantifying unique local characteristics that can impact electrification opportunities. These include end-use energy demand in the transportation, industrial, commercial, and residential sectors. "You need to understand each state's economic makeup," said de la Chesnaye. "For example, how does consumption in manufacturing compare with that of the service sector? How are buildings heated and cooled? Is natural gas available? It very much matters where you are in the country because the performance and economics of heat pumps versus natural gas furnaces vary by climate zone."


KEY TAKEAWAYS FROM EPRI'S U.S. NATIONAL ELECTRIFICATION ASSESSMENT
EPRI's U.S. National Electrification Assessment concluded that electrification is likely to increase in the future, leading to various potential benefits including cost-effective, economy-wide CO_2 reductions.
FOUR SCENARIOS EXAMINED IN THE STUDY
CONSERVATIVE
Slow decline in technology costs
REFERENCE
More rapid decline in technology costs
PROGRESSIVE
More rapid decline in technology costs plus moderate carbon price
TRANSFORMATION
More rapid decline in technology costs plus stringent carbon price
Percentage Change, 2015–2050
Total Final Energy
20%
22%
27%
32%
All four scenarios project falling final energy.
Electric Load
All four scenarios project electric load growth.
24%
32%
35%
52%
Natural Gas Use
Natural gas use continues to grow in all four scenarios based on its operational flexibility and an assumed ongoing low cost.
33%
40%
31%
18%
Economy-Wide Emissions
19%
20%
57%
67%
All four scenarios project significant emissions reductions.
CO_2
Electricity Portion of Final Energy, 2050
32%
36%
39%
47%
Source: EPRI

The assessments consist of four tasks:

1. Use the US-REGEN model to quantify the potential extent of efficient electrification in participant-defined scenarios with various assumptions for technology cost and performance, policies (such as greenhouse gas emissions targets), and other factors.
2. Examine the impacts of various electrification levels on air quality, greenhouse gas emissions, and water quality. This can inform environmental policies.
3. Assess how new loads and resources associated with electrification could impact transmission system operations and planning.
4. Provide utility-specific guidance on how to implement technologies and programs cost-effectively to realize benefits of electrification.

With the first task already completed for several state-level assessments, a significant takeaway has emerged. "The power sector in a state can help drive down CO_2 emissions from that state's economy in a cost-effective manner," said de la Chesnaye. "That is a key message and insight for policymakers, the public, and power industry stakeholders."

Another early insight: While many differences are emerging among state analyses, the national finding that electrification can provide significant value to society remains consistent across current projects. State-level electrification can reduce greenhouse gas emissions, final energy consumption, and energy costs.

"As in the national assessment, the state-level studies are showing that transportation is the most cost-effective, near-term opportunity for efficient electrification," said de la Chesnaye. "The potential contribution of the building and industrial sectors varies widely by state and tends to occur later."

A key factor for each state is its climate zone (or zones) and the related impact on electric technologies' performance. "Temperature affects not only the efficiency of heat pumps, but also the performance of batteries for electric vehicles," he said. "Battery performance in turn affects the economics of operating an electric vehicle and its cost-competitiveness with vehicles powered by internal combustion engines."

EPRI aims to expand the assessments to more states and more countries. "We hope to offer this cutting-edge capability to as many power companies as we can so that they and their customers can realize the many benefits of efficient electrification," said de la Chesnaye.

KEY EPRI TECHNICAL EXPERTS

Francisco de la Chesnaye, Geoff Blanford, Tom Wilson

Anchoring the Digital Worker

In the May/June *EPRI Journal*, we report how technical leaders from across the institute's research sectors are spearheading the Digital Worker Innovation Hub to focus on digital technologies that assist workers in performing their jobs more safely, more efficiently, and more effectively. These can be tools to improve communication and data access and enhance real-time observations, troubleshooting, and decision making.

The hub can also:

- Facilitate collaboration related to practical applications near-term and for evaluating emerging technologies
- Develop a comprehensive project database
- Set up laboratories where researchers and industry stakeholders can test technologies, discuss needs, and brainstorm new applications
- Provide a forum for strategies, plans, and technology implementation
- Inform a broad power industry strategy on digital worker technologies

EPRI recognizes "digital worker" as a big and promising concept, with expanding possibilities in the power sector. Here are a few points and examples that may help us to appreciate those possibilities.

HUMAN-DIGITAL OR DIGITAL HUMAN?

We should avoid thinking of digital workers either as digitally optimized humans or human-enhanced technology.

Fujitsu coined a definition for "digital workforce" to include "any process which can be completed through human interaction with technology and a structured decision-making process" and with "the potential to be improved through automation."

This calls to mind "machine learning," and those who work in engineering and technical disciplines can readily fit the definition of a digital ("automated") workforce with hundreds of tasks extending across systems' design, planning, and operations. But can automation serve as an effective anchor for digital worker thinking? Is that concept big enough?

MOBILITY MATTERS

With that in mind, here's an aspect described in Deloitte Insights by Michael Brinker and Jeff Schwartz that applies to the 70% of workers they describe as "untethered"—for whom mobile devices are "unleashing new levels of productivity, efficiency, and collaboration." The key is that "companies are starting to move 100 percent of their IT applications onto mobile platforms for workers who are not behind a desk. That's enabling employees to do everything on one platform. They're not splitting time between a mobile device and some remote PC. It's 100 percent mobile. That's the big trend we see now. We think in the next five to 10 years the 100 percent mobile employee will be the majority."

This also calls to mind EPRI's work in augmented reality and virtual reality—perfect examples of untethered applications for untethered workers.

At this event, experts from utilities and all four EPRI sectors will share lessons from research on promising Digital Worker technologies. Contact Matt Wakefield for technical questions and Maria Becker for logistical information.

FOR THE DIGITAL WORKFORCE: FLUX AND FLEXIBILITY

Earlier this year, lexology.com reported that Siemens Group and its general works council representing workers agreed on a EUR 100 million Fund for the Future for continuing education for workers. The law enables federal support for workers while they're employed, decoupled from unemployment or restructuring, and it allows both employees and employers to be reimbursed for educational and re-training expenses.

A driving force for the change is "digitalization" of both white collar and blue collar jobs. The article reports that "15% of existing German jobs will be eliminated over the next decade, and 30% of all jobs will change significantly. The federal government forecasts that more new jobs (2.1 million) will be created than current jobs (1.3 million) eliminated through digitalization."

Given Siemens' important technological and industrial place in the power sector, it is readily apparent that the changes faced by its workforce will be affecting the construction, operations, and maintenance of power facilities worldwide.

O&M (& EYES & EARS & DATA & SPEED & OUTSIDE SUPPORT)

Digitalist Magazine highlighted "kilobyte-rich" radio frequency identification (RFID) tags, which are poised to make a fundamental upgrade from their basic "position finder" function in industrial facilities, to become tags with "so much storage capacity that they will act like transponders and actually tell people what to do."

As described, these "eyes and ears" for information technology will change operations and maintenance (O&M) profoundly. The article reports: "As BCG Consulting points out, technicians will identify any problems with a machine from a stream of real-time data and then make repairs with the help of augmented-reality technology supplemented, if necessary, by remote guidance from off-site experts. In this way, downtime per machine will be reduced from one day to an hour or two."

It is remarkable to consider how digital workers' concerted capabilities will combine data in real time with virtual reality while bringing in outside expertise and support—all with unprecedented speed and precision.

HOW WILL THE DIGITAL WORKFORCE TAKE SHAPE?

The Harvard Business School Digital Initiative hosted Melissa Valentine and Michael Bernstein from Stanford University in 2016 to discuss their research on the use of crowdsourcing to accomplish "complex work"—using organizational structures that could be reconfigured based on need.

In a word, the digital workforce may be developing the capability to "morph" digitally to create products specific to needs in certain settings—then disband when the job is done.

They describe a system that "creates crowd organizations, which automatically hire diverse online experts from massive online labor markets to populate computational structures inspired by organizations (roles, teams, and hierarchies), and then continuously reconfigure these structures to responsively adapt the crowd workers' activities."

They describe the upshot as "digitally networked organizations that flexibly assemble and reassemble themselves from a globally distributed online workforce to accomplish complex work…."

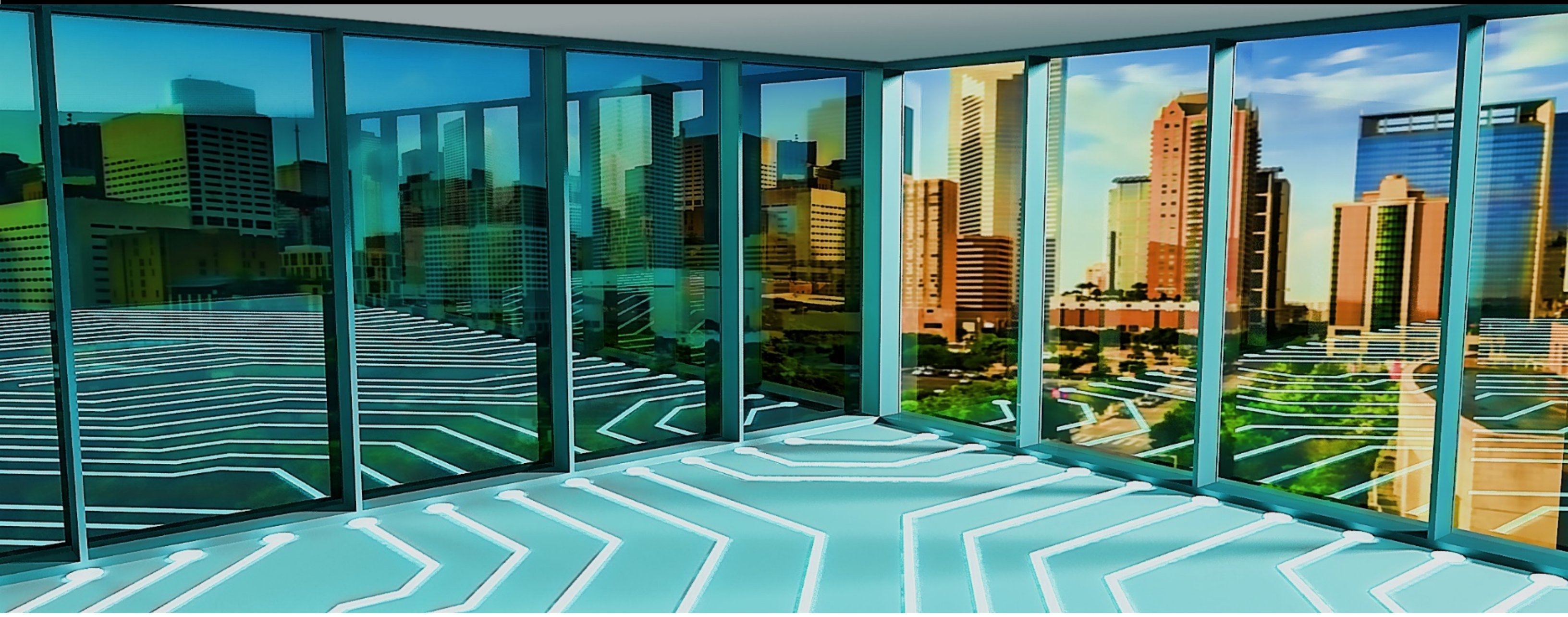
For workers and companies whose work has been grounded in power delivery, transmission, and distribution systems, the assets have been the anchor. Workers' knowledge, insights, and skills have been shaped and honed by those assets.

Which brings us to this point: Perhaps the common element of digital workers and digital workforces is that they are "digitally anchored." As our work becomes increasingly digitally anchored, it will require us to navigate our professions and technical disciplines in new ways. If we approach the digital workforce or digital worker understanding the true scope and potential, then we can realize significantly greater opportunity, challenge, and reward.

Mike Howard

President and Chief Executive Officer, EPRI

EPRI JOURNAL



How Windows Can Remake the Power Grid

The Story in Brief

Stephen Selkowitz, recently retired as department head and a senior advisor for building science at Lawrence Berkeley National Laboratory, is one of the world's foremost experts on windows and building façades. His conversation with *EPRI Journal* reveals that the potential for emerging window technologies to transform power grid operations is much larger than most realize. He points to the significant reductions in energy consumption and peak demand that are possible. Utilities can play an important role in this window revolution.

EJ: EXPLAIN HOW TODAY'S WINDOWS AND BUILDING FAÇADES RESULT IN SIGNIFICANT ENERGY LOSSES. WHERE ARE THE OPPORTUNITIES FOR ENERGY SAVINGS?

Selkowitz: Each year in the United States, windows are responsible for about 30 percent of the energy used to heat and cool buildings—about 4.1 quads—at a cost of $50 billion. This consumption is a result of thermal heat losses and gains across windows, air leakage, and transmission of solar heat into buildings.

Stephen Selkowitz

In the summer, conventional windows allow heat from sunlight to enter buildings, increasing cooling load. This solar heat gain tends to be the major driver of summer afternoon cooling peaks—usually even a bigger driver than air temperature. In the winter, windows are poor insulators compared to walls and allow heat to leak from buildings, *For U.S. residential buildings, we found that triple-glazed windows can reduce annual heating and cooling energy use by 1.64 quads. If you make the windows even more insulating and add dynamic solar heat gain control, the potential annual savings is 2.25 quads. In this case, windows would enable zero net heating energy consumption, while cooling energy consumption would be reduced by 80%.*

increasing heating loads on HVAC systems. Better window technologies offer numerous energy savings opportunities and improved comfort. High-performance windows can minimize solar heat gain in the summer to reduce cooling loads, admit solar heat and insulate against heat loss in the winter, reduce energy consumption for artificial lighting during the daytime, and reduce a building's peak heating and cooling load.

Windows are unique building elements. Unlike heating, cooling, and lighting systems where the typical design strategy is to reduce energy use to lower levels, windows have the potential to be zero net energy or even net-positive energy. For instance, in northern climates in winter, if windows reduce thermal losses and capture solar gains, they can become net-positive energy.

When people analyze building energy use and inefficiencies, they typically focus on heating, cooling, and lighting systems. These analyses are not often done for windows or building envelopes because they don't consume energy directly. That's why people sometimes overlook the building envelope when assessing energy-related investments. Coming up with the right metrics for windows and envelopes, understanding how to quantify savings potential, and justifying necessary investments have always been a challenge. Unlike HVAC and lighting, which have relatively short lifespans, building envelopes are expected to last the life of the building, making it especially important to design them right at the beginning.

EJ: HOW CAN HIGHLY INSULATING WINDOWS HELP REDUCE ENERGY CONSUMPTION?

Selkowitz: Before the 1970s in the U.S., most windows utilized a single pane of glass. With the oil crisis of the 1970s and dramatic increases in energy costs, double-glazed insulating windows were adopted more widely. These consist of two panes of glass with air in between, but they were still 10 times "leakier" than insulated walls. To improve their thermal performance without a radical redesign, two novel technologies were added: low-e coatings and argon gas instead of air between the panes. These changes doubled the window's insulating value at a modest additional cost. Today, this technology accounts for about 85% of all residential and commercial window sales. It has reduced heating and cooling loads and since its introduction has saved $150 billion in energy costs just in homes compared to conventional double-pane windows. Yet modeling shows that there's a lot of room for improvement. These windows are still responsible for billions of dollars in energy lost each year.

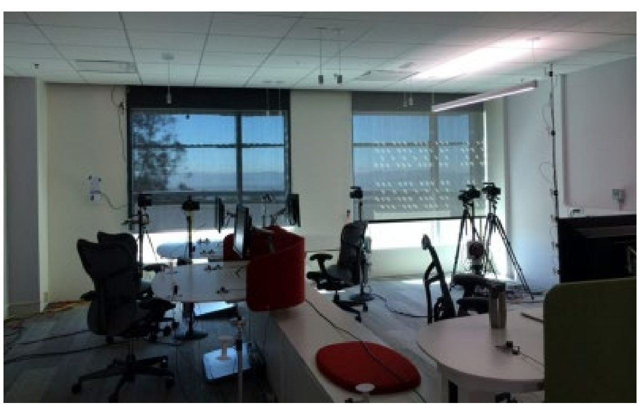
In northern Europe, three-paned windows known as triple glazing technology are now widely used. But U.S. window companies have not gone from double-glazed to triple-glazed because that would make the glass unit wider and heavier, requiring a redesign of the window sash and frame—which in the U.S. is traditionally much thinner than in Europe. This is very expensive and risky for the manufacturers, who see uncertain markets for these innovations.

Unlike heating, cooling, and lighting systems where the typical design strategy is to reduce energy use to lower levels, windows have the potential to be zero net energy or even net-positive energy.

Berkeley Lab has developed a novel triple-glazed window that offers a solution to this problem. A third pane of very thin glass is inserted between the two panes of a double-glazed, low-e window, a second low-e coating is applied, and in the gaps between the panes argon is replaced with krypton, which is more insulating. The window manufacturers don't have to change anything else about the double-paned window. They can use their existing sash and frame. These design changes increase the glass weight by only 10% while doubling the window's insulating value. Depending on climate and orientation, this new window can be close to net-positive energy.

Interestingly, Berkeley Lab patented this window in the 1990s, but at the time, the thin glass sheets needed for the middle layer were unavailable. When cell phone makers initially introduced these sheets, they were too expensive. Since then, the flat screen TV industry has advanced the thin glass production technology needed to bring those costs down—to the point where it is possible to make affordable triple-glazed windows. We're now working across the supply chain to optimize each component and testing prototypes in the lab and field with two window companies—Andersen and Alpen.

This window should be suitable for large-scale manufacturing with a modest increase in production costs. In California, there's an opening for large-scale, scale, near-term market adoption. The state's 2019 residential building code requires a much more highly insulated wall. Installing about 300 square feet of triple-glazed windows gives a building the same rating as installing about 2,000 square feet of the highly insulated wall. Many builders may opt for the windows, assuming they can purchase and install them at a cost lower than the extra wall insulation. There's also an opportunity here for utility rebate programs to subsidize at least the initial market entry of these products in California and other jurisdictions where code changes are underway.

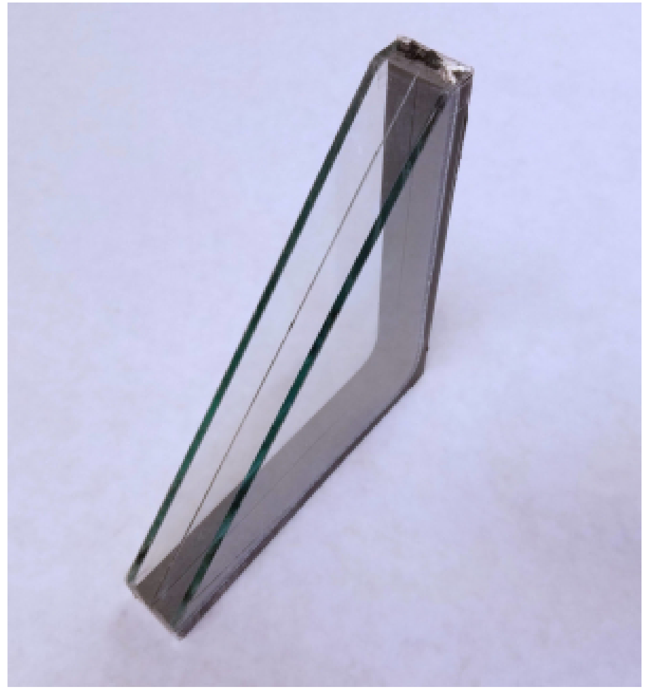


This photo inside FLEXLAB shows testing of technologies for a new Genentech office building, including automated roller shades, dimmable LEDs, and sensors to measure glare, light levels, and energy flows. Genentech staff occupied the space for a period to assess its quality under various weather conditions. Photo courtesy of Lawrence Berkeley National Laboratory.

The Lawrence Berkeley National Laboratory's FLEXLAB enables users to test energy-efficient integrated building systems. In this photo, FLEXLAB is testing fixed shading and high-performance window glazings for a new Genentech office building. Photo courtesy of Lawrence Berkeley National Laboratory.

This photo shows part of a full-scale, 5,000-square-foot mockup of the corner of one floor of the New York Times Headquarters Building. Before purchasing the building, the New York Times Company invested in this mockup to test and optimize various window, façade, and lighting technologies—with technical support from Lawrence Berkeley National Laboratory. These include low-emissivity window glazing to reduce winter heat loss and summer solar heat gain, exterior ceramic rods to diffuse daylight, and interior automated roller shades to control glare, daylight, and solar energy. Photo courtesy of Lawrence Berkeley National Laboratory.

This photo shows testing of shading systems at Berkeley Lab's Advanced Facade Testbed. The room on the left is equipped with an automated external blind system that manages solar heat gain and glare. The center room uses an automated external dual blind system, with a lower portion that controls solar load and glare and an upper portion that redirects daylight inside. The room on the right uses conventional interior manual blinds. The study found that the external systems can reduce cooling loads by 50–85% relative to the conventional blinds. Photo courtesy of Lawrence Berkeley National Laboratory.



A corner sample of Berkeley Lab's triple-glazing prototype. It uses a thin layer of glass that can be inserted in the center of a conventional double-glazed window. Photo courtesy of Lawrence Berkeley National Laboratory.

EJ: WHAT ARE 'SMART' WINDOWS?

Selkowitz: Smart or dynamic windows are another big area of technology development. They have glazings that change their optical properties to admit more or less heat and light from the sun. Typically, they darken and become more absorptive so less sunlight is transmitted. There are three types. Photochromic glazings respond to certain levels of visible sunlight, thermochromic glazings respond to temperature levels, and electrochromic glazings change when a voltage is applied.

Thermochromic windows are commercially available today. When the glass heats above a certain temperature, it will switch from transparent to dark. It works well in some applications, but not so well in others because the switching temperature is fixed—so the windows can't be controlled by the building's energy management system. If you're a utility that's planning a demand response event, you want the windows in a particular location to switch at a particular time to reduce the cooling load. You don't want to wait or be dependent on a change triggered by temperature.

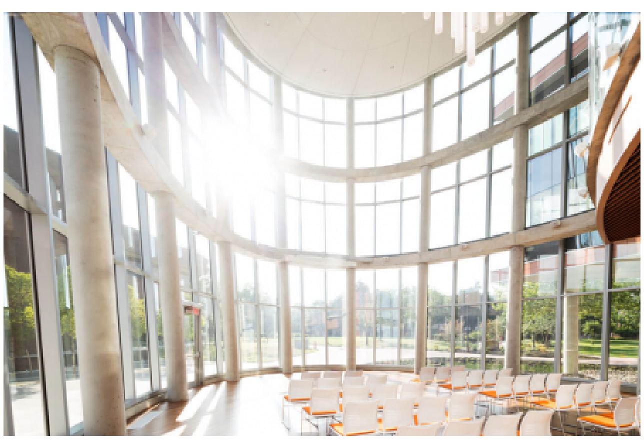
Electrochromic windows are the main player in the smart window field. They are effective at reducing glare and solar heat gain and are well suited to building energy management systems because timing the changes can be controlled with electrical signals. You can continuously optimize the glass properties to reduce cooling load, address peaks, and support smart grid operations.

Electrochromic windows have been commercially available for less than 10 years. They're still well under 1% of the window market but growing quickly. In addition to high costs, a big challenge is how to control and integrate them with building lighting and HVAC systems and demand response controls. Who decides to send the signal to darken the windows, and what drives that decision? A building manager has to consider the window's impacts on heating, cooling, and lighting loads as well as the workers' visual requirements. Typically, the manager wants to solve the visual comfort problem first because the cost of the workers in the building is far more than the energy costs. Should the windows let more sunlight through so that electric lighting can be dimmed, or should they let less sunlight through in order to reduce cooling load? As new buildings and retrofits shift to more efficient LEDs, building managers will probably err on the side of minimizing the cooling load since lighting loads are becoming smaller.

Grid operators also have particular needs that may or may not be aligned with the needs of the building managers and workers. There's a lot of discussion in the window industry about these challenges right now. My view is that real-time optimization of smart windows is too complex to be handled by a human being. It should be automated, but with a local user override option. The solution will require cooperation among window manufacturers and HVAC companies along with input from utilities on their changing grid landscape. Berkeley Lab has demonstrated that using a smart controller to manage electrochromic windows, dimmable lights, solar, and battery storage can flatten and minimize loads during the afternoon and early evening peak periods.

A building at Bowie State University with electrochromic windows made by SageGlass. On the right structure, the windows are in their clear state. On the left structure, some windows have darkened. Image courtesy of SageGlass.

The same building at Bowie State University with most of the windows darkened. Image courtesy of SageGlass.



An interior view of the building with the windows in their clear state. Image courtesy of SageGlass.

An interior view of the building with some windows darkened. Image courtesy of SageGlass.

A related important area of smart window technology is integrated façades that control and redirect daylight in commercial buildings. Automated, motorized shading devices can block excessive sunlight and regulate glare. Skylights allow sunlight to penetrate deep into low-rise buildings, and emerging products can direct daylight two to three times deeper than conventional solutions. Artificial lighting can be automatically dimmed in response to changing daylight. In the winter, these components can help maximize solar heat gain and minimize heating energy losses. And in the summer, they can help reduce cooling loads. Control systems are still needed to manage the façade components along with HVAC and lighting systems to keep the indoor environment comfortable and reduce energy consumption.

EJ: THERE'S BEEN A LOT OF BUZZ ABOUT WINDOWS THAT CAN GENERATE POWER FROM SUNLIGHT. WHAT'S YOUR PERSPECTIVE ON THE TECHNOLOGY?

Selkowitz: Power-generating windows have emerged in the last five years and are an exciting addition to the available window options. In the first generation, conventional solar cells were incorporated into glazing, letting some light through and absorbing and converting the remainder to electricity. The newest products provide unobstructed views and daylight. They absorb solar energy in the non-visible parts of the spectrum and convert it to electricity. There are half a dozen startups working on the technology.

We've tested some of these products, and they work. But all of them share a few challenges. Each window needs to be wired to a building electrical network to deliver power. Vertical windows on a building façade receive less solar energy and may be obstructed by other buildings or trees. The see-through products yield just half the power of conventional solar cells. The ultimate impact on the building energy use will depend on how these challenges are resolved.

EJ: WHAT ARE THE BARRIERS TO INNOVATION IN WINDOW TECHNOLOGY?

Selkowitz: Innovation is challenged by the fragmented nature of the window industry. The window makers don't make glass, and the glass makers don't make windows. There are many other companies that make key components: hardware, sash and frame, weather-stripping, and sealants. A complex supply chain is involved in assembling, delivering, and installing units. This can lead to a chicken-and-egg problem. For example, if you ask the glass makers why they don't make a more advanced glazing, they may say that the window makers don't see a need for it. And if you ask the window makers why they don't want it, they may say that it would be too expensive from the glass supplier and that the market doesn't want it. Contrast this with the aircraft and automotive industries, where one entity manages innovation across the entire supply chain from start to finis, including customer sales.

Each year in the United States, windows are responsible for about 30 percent of the energy used to heat and cool buildings—about 4.1 quads—at a cost of $50 billion.

EJ: WHAT ARE THE IMPLICATIONS OF WIDESPREAD ADOPTION OF ADVANCED WINDOW AND FAÇADE TECHNOLOGIES FOR GRID OPERATIONS?

Selkowitz: The potential impacts are significant. Windows are a big contributor to cooling loads, particularly in hot climates and in office buildings with a lot of glass. If you can dynamically control light and heat at the façade and make windows zero net energy or net-positive energy, you can have a big effect on peak demand during the hottest few days of the year. They can significantly impact load shape on essentially every day of the year that there's a cooling load.

There's big emerging potential for heating as well. For example, most of the older homes in California are heated with natural gas. If the state replaces its gas heating infrastructure with electric to help meet its decarbonization targets, utilities may end up with a winter-morning heating peak. Triple-glazed windows could play an important role in reducing those new winter peaks.

In the summer, conventional windows allow heat from sunlight to enter buildings, increasing cooling load. This solar heat gain tends to be the major driver of summer afternoon cooling peaks—usually even a bigger driver than air temperature.

Berkeley Lab has modeled the potential energy savings if all windows were converted to various advanced window technologies. For U.S. residential buildings, we found that triple-glazed windows can reduce annual heating and cooling energy use by 1.64 quads. If you make the windows even more insulating and add dynamic solar heat gain control, the potential annual savings is 2.25 quads. In this case, windows would enable zero net heating energy consumption, while cooling energy consumption would be reduced by 80%.

For commercial buildings, we found that highly insulating, dynamic windows could save 1.62 quads for heating and cooling each year. With integrated façades that use daylight, you can reduce artificial lighting use to save even more and make buildings net-positive energy.

EJ: WHAT ROLE CAN UTILITIES PLAY IN ADVANCING THESE TECHNOLOGIES?

Selkowitz: There are three things utilities can do. First, there's a big need for field demonstrations to monitor and objectively document the performance of window technologies. Utilities can play a crucial role in making those happen. These will probably uncover technical challenges that need to be addressed. Utility-sponsored demonstrations can examine the impacts of advanced windows on load shapes, summer cooling peaks, winter heating peaks, and HVAC system sizing. Successful demonstrations build confidence among building owners and should help utilities with strategic planning.

Number two, utilities can help these technologies bridge the gap between proof-of-concept in the field and standard practice through rebate or other financial incentive programs. With more utility programs supporting these new technologies, other window companies will be more likely to step on the bandwagon and start producing them.
Number three, to maximize market potential, smart window systems must be able to easily communicate and integrate with a wide range of HVAC and lighting systems. Today, each design is tediously optimized and integrated with a "plug and pray" approach. This increases costs and risk and reduces interest in adoption among building owners. Utilities could be a powerful force for standardizing communication protocols by tying adoption of these protocols to rebates and incentives.

EPRI Delves into the Practical Details of Advanced Window Applications

EPRI's Advanced Buildings Program includes research on window technologies and other components of building envelopes, with a focus on cost-effective application and integration in buildings. As part of field demonstrations with utilities, builders, and developers, EPRI researchers are examining the costs and challenges of large-scale adoption of advanced windows and emerging window technologies. This includes the practical details of installing them in high-performance buildings and integrating them with lighting, HVAC, and other building systems.

"As with most customer technologies, when assessing the market potential for a new window technology, you need to evaluate more than just the technology," said EPRI Technical Executive Ram Narayanamurthy, who manages the Advanced Buildings Program. "The overall application costs significantly impact adoption. A new smart window, for instance, may have a reasonable capital cost, but what are the additional integration costs that fall on the builder, and what are the barriers to customer acceptance? Builders may coordinate with multiple contractors to install the new product, or customers may not like how it looks. These are the types of issues that EPRI is investigating to understand how to advance market adoption of these technologies."

One recent EPRI study modeled the costs and market potential of many smart window glazing combinations in different climates and building types. Research plans include investigating potential impacts of advanced windows on peak load, load shapes, energy consumption, and other aspects of grid operations. EPRI-led field demonstrations in advanced energy communities with high-performance buildings can offer insights on such impacts.

EPRI JOURNAL

In Development

Technicians Learn Nuclear Plant Maintenance in the Virtual World

'Overwhelmingly Positive' Response to New EPRI Tool

By Tom Shiel

Innovation with Virtual Reality Training

Dominion Energy staff had an "overwhelmingly positive" response to EPRI's virtual reality training tool for Terry Turbines in nuclear plants, according to Mark Quesenberry, Dominion's nuclear maintenance performance improvement consultant. Dominion was so impressed with the program that it installed virtual reality rooms at its three nuclear plants.

Virtual reality—it's not just for video games anymore.

EPRI's Nuclear Maintenance Applications Center has introduced a virtual reality (VR) program to train nuclear plant workers on maintenance tasks for Terry Turbines. The objective is to provide training that is safer, more engaging, and more efficient than traditional hands-on component training—which involves setting up and maintaining hardware and mockups and sometimes transporting equipment to training sites.

Wearing a headset, the technician enters a virtual environment and uses two handheld controllers to manipulate tools and disassemble and reassemble the turbine. Four modes are available:

- Free-hand: The technician removes parts from the turbine in any order.
- Show-me: The program uses animations to demonstrate the steps of turbine disassembly and reassembly.
- Practice: The technician completes the steps, with key parts highlighted by the program.
- Test: The technician completes the steps with no help from the program other than text descriptions of the steps.

According to EPRI Principal Technical Leader Tom Walker, the program is easier to administer than hands-on training. Its requirements—a headset and a computer with sufficient graphics capabilities—are relatively low-cost and low-maintenance. It can be set up in any room, and there is no need to purchase and maintain spare plant components.

EPRI demonstrated the program for its utility members, and the response has been positive.

“Trainees really enjoyed using the program. They moved parts around, explored all areas of the turbine, and practiced the various steps. In some cases, it was difficult to get them to remove the headset,” Walker said.

The initial response at Dominion Energy was “overwhelmingly positive,” according to Mark Quesenberry, Dominion’s nuclear maintenance performance improvement consultant. Participants enjoyed the experience and recommended expanding the technology’s use.

Dominion was so impressed with the program that it installed VR rooms at its three nuclear plants. Quesenberry said that VR provides training that is safer, easier, and more engaging and cost-effective than traditional methods.

Based on the success of the demonstrations, EPRI is working on a VR application for valve disassembly, repairs, and reassembly.

“Our vision for VR is a virtual showroom with many components. The user would select a component, such as a circuit breaker or an emergency diesel generator, and enter a training room for that component,” said Walker. “Our members are already asking us to add specific components to the virtual showroom.”

VR can help attract the next generation of nuclear plant technicians. “VR is a powerful training tool that can help the industry maintain worker proficiency, especially as the workforce transitions as a result of retirement and other turnover in the next 5 to 10 years,” said Walker.

KEY EPRI TECHNICAL EXPERTS

Tom Walker

Innovation

A New Tool to Address 'Single Point Vulnerabilities'

Nuclear Plant Operators Use EPRI Database to Mitigate Vulnerable Components That Can Cause Costly Shutdowns

By Sarah Stankorb

In a nuclear power plant, a single point vulnerability (SPV) is a component or subcomponent that, if failure occurs, can cause a reactor or turbine to trip and the plant to go offline. Among plants built in the 20th century, about 1% of components are SPVs, with most in the turbine-generator side (not the reactor side) of the plant. For example, if the setpoint of a relay in the main power system drifts too low, the generator could trip, which in turn could cause the turbine to trip. While many SPVs are known to plant operators, others are unrecognized or inadequately mitigated. To minimize the risk of an SPV failure, operators may enhance operational procedures or conduct additional inspections, testing, and preventive maintenance.

Preventing SPV-related shutdowns and eliminating SPVs are vital to safe, reliable plant operations. Shutdowns as a result of equipment failure can be costly. Repair of an easy-to-fix component may require a three-day shutdown at a cost of about $3 million in lost generation revenue.

To prevent unnecessary shutdowns, utilities are using EPRI's new Single Point Vulnerability Analysis Tool to identify SPVs in their plants along with actions to eliminate or mitigate them. The tool draws on a database of SPV data provided by the industry—including identified vulnerabilities, mitigation designs and costs, and successful elimination strategies. Users can compare SPVs in their facilities with SPVs in other plants and learn how those plants mitigated them.

The tool enables users to organize and plot data by plant system, plant design, and component type. It alerts EPRI technical staff to newly identified component vulnerabilities, which prompts research to address them. Because engineers at different plants often use different names for the same components and systems, EPRI incorporated a common information model that helps users find relevant SPVs.

SPV comparisons on the reactor side are most beneficial when made between plants with similar designs—and the tool enables such comparisons. On the turbine/generator side, plant operators and engineers can compare across different designs and still gain insights about their facilities.

For example, consider nuclear plants A and B with similar designs. If plant A shares all its information on SPVs and successful mitigations in the database, plant B can verify that it has identified the same SPVs and that it is using the best mitigation strategies. If plant B has listed an SPV that plant A has not listed, Plant A may have already eliminated that SPV, and plant B may want to consider plant A's elimination strategy.

In 2010, the U.S nuclear power fleet reported 77 scrams (emergency reactor shutdowns). In 2017, there were just 38 scrams. This significant reduction was driven by an industry focus on SPV identification, labeling, elimination, and mitigation. In 2015, EPRI issued an SPV guide that plant personnel have used for process improvements.

Previously unrecognized SPVs caused half of the scrams in 2017, pointing to the benefits of ongoing action to address SPVs. Indeed, this is why EPRI created the tool—to facilitate collaboration among plant personnel.

To help make the database comprehensive, EPRI and the Institute of Nuclear Power Operations (INPO) recently created a system that prompts plant operators to flag SPV-related scrams as part of their scram reporting requirements to INPO.

Along with the tool's release, EPRI plans to provide training to help utilities characterize the technical aspects of their plants' vulnerabilities. A better understanding of what causes vulnerabilities in the first place is needed before an appropriate mitigation strategy can be developed.

The tool is available for use by utilities in the United States and Mexico, and EPRI staff are working with utilities in Canada and China to enter their data. Utilities in United Arab Emirates and South Africa have expressed interest in using the tool.

The industry's knowledge of SPVs and their impacts is maturing, but operators are still on a learning curve. The industry can continue to improve by sharing information through the tool.

KEY EPRI TECHNICAL EXPERTS

Jacquelyn Fraedrich, Mark Woodby

In the Field

Flexibility from the Carolinas to South Africa

EPRI Helps Duke Energy and Eskom Fine-Tune Power Plants for Lower Loads and Other Flexible Modes

By Tom Shiel

Utility Innovation in Flexible Operations: Duke Energy

Among the biggest challenges for flexible operations is to determine how long a power plant can run at a lower level without incurring damage or increasing costs. Duke Energy applied EPRI's systematic approach to reduce minimum generation levels at two coal plants. "EPRI has enabled us to apply technical knowledge to improve our risk projections, cost projections, and mitigation strategies associated with flexible operations," said Peter Hoeflich, Duke Energy's director of analytical engineering.

Peter Hoeflich, Duke Energy's director of analytical engineering, has this advice for utilities just getting started with flexible operations for their fossil power plants: "Prepare to be agile."

Since 2015, EPRI has been helping utilities do just that. EPRI and the 15 power companies in its Mission Profile Working Group have developed a comprehensive online resource that power plant operators can draw upon to identify and address impacts of various flexible modes.

Flexible operations can adversely impact fossil plants in various ways, such as fatigue, compromised environmental controls, and component pitting and corrosion. In 2018, EPRI completed a three-volume report on impacts of flexible operations on boiler components (see Additional Resources at the end of this article). A study on avoiding turbine damage from low-load operation is slated for completion later this year. EPRI is providing utilities worldwide with these and other research results to support reliable, cost-effective service.

"Operating at lower loads or shutting down periodically can mean less revenue for fossil plants," said EPRI Senior Program Manager Michael Caravaggio. "They're being asked to provide the power system with more services while generating less revenue. We need to help utilities use their fossil generation more efficiently."

DUKE ENERGY: OPTIMIZING FOSSIL AND HYDROPOWER FLEETS

As an active participant in EPRI's Mission Profile Working Group since 2015, Duke Energy applied EPRI's systematic approach at two coal plants to reduce minimum generation levels. At the coal plants and a combined-cycle natural gas plant, Duke Energy and EPRI applied lessons from the working group to review design, operations, and maintenance data; evaluate risks to components and systems operating in flexible modes; and develop strategies to minimize those risks.

"As our renewable energy teams predicted growing solar generation in the Carolinas, we recognized that our fossil plants would have to accommodate that generation," said Duke Energy Analytical Engineer Stephen Dean. "We wanted to optimize our fossil and hydropower fleets to benefit our customers. We've built our understanding of flexible operations based on insights coming out of EPRI's working group."

Among the biggest challenges for flexible operations is to determine how long a plant can run at a lower level without incurring damage or increasing costs. "Through collaboration with EPRI, we were able to update our models so they can help us assess the changes under consideration at our plants," said Dean.

This interactive graphic describes EPRI research to enable flexible operations at a typical coal plant.

Through its own research and work with EPRI, Duke Energy has improved the flexibility of several plants and is planning to enhance its entire fleet of fossil and hydropower facilities. One key to the utility's success is discussion among its plant operators and grid operators. These groups needed to determine flexible modes that are both safe for plants and supportive of grid flexibility.

Now, the utility is developing a metric for tracking flexibility improvements across the fleet. It's also training plant operators and developing new procedures for flexible modes.

"EPRI has enabled us to apply technical knowledge to improve our risk projections, cost projections, and mitigation strategies associated with flexible operations," said Hoeflich.

Dean pointed to additional research needs such as:

- Better predict plant impacts of flexible operations
- Assess impacts of energy storage on new power plants and future operations
- Develop techniques to expand plants' tolerances for flexible modes while minimizing impacts on components

ESKOM: LOWERING MINIMUM GENERATION LEVELS

Innovation in Flexible Operations: Eskom

To reduce minimum loads at two coal plants, EPRI and Eskom evaluated different equipment configurations and adjusted steam temperature and flame stability parameters. "We worked with EPRI to review our plant operational parameters, define operating tolerances for flexible modes, and develop methods to enable lower load levels without leading to trips," said Naushaad Haripersad, Eskom's acting senior manager of plant performance and optimisation. "The results allowed us to reduce our minimum generation during testing and have the potential to lead to coal savings during periods of high renewable generation and low electricity demand."

Eskom generates 83% of its electricity from coal-fired plants in providing approximately 90% of South Africa's electricity. Historically, outages at the utility's units result from planned maintenance or emergency repairs. However, as independent power producers develop more renewable generation, flexible operation of Eskom's coal-fired units has become more important. Their current design and operating regimes are not flexible enough for load-following.

Eskom and EPRI collaborated on studies on grid flexibility and plant flexibility—in particular, the load-following capabilities of fossil generation. In 2018, Eskom conducted EPRI-designed tests on units at the 3,450-megawatt Matla Power Station and the 3,510-megawatt Tutuka Power Station to assess how much they could lower minimum generation levels. EPRI and Eskom then evaluated different configurations for equipment (such as pumps and mills) and adjusted steam temperature and flame stability parameters. The aim was to reduce minimum loads while maintaining reliable, stable operations and minimizing risk of unit trips.

"We worked with EPRI to review our plant operational parameters, define operating tolerances for flexible modes, and develop methods to enable lower load levels without leading to trips," said Naushaad Haripersad, Eskom's acting senior manager of plant performance and optimisation. "The results allowed us to reduce our minimum generation during testing and have the potential to lead to coal savings during periods of high renewable generation and low electricity demand."

Eskom is reviewing its plant staff manual on when and how to run plants in various flexible modes.

"The operating staff will have to follow a process—what action to take, when to take it, and how," Haripersad said. "This is a challenge we must address in parallel as we evaluate our plants for flexible operations."

Mission Profile Working Group

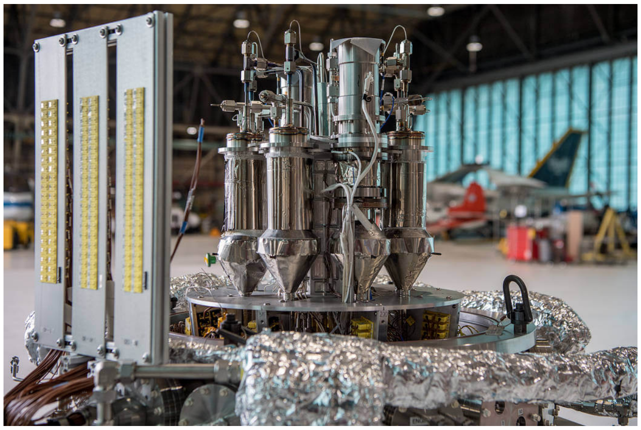
The 15 power companies in EPRI's Mission Profile Working Group have developed a comprehensive online resource (available only for working group members) and a public site to help power plant operators identify and address impacts of various flexible modes. The group draws on industry knowledge about power plant design, vulnerabilities with systems and components, field-proven solutions, and more.

KEY EPRI TECHNICAL EXPERTS

Mike Caravaggio, Merrill Quintrell

R&D Quick Hits

Tiny Nuclear Reactors Could Transform Power Generation for Remote Communities and Military Sites… and Missions to Mars



Nuclear “microreactors” offer unique capabilities for displacing diesel power generation in numerous applications and for supporting critical infrastructure, according to an EPRI Emerging Technologies Brief.

While most commercial nuclear reactors today produce more than 1,000 megawatts of power, microreactors (also known as very small modular reactors) range in capacity from kilowatts to less than 50 megawatts (most are in the 1–10 megawatt range). Unlike their larger counterparts, they are designed for full factory fabrication and rapid deployment, reducing cost and schedule uncertainty. Simplified heat removal and safety systems and stable reactor cores can reduce accident risks, increase fault tolerance, and minimize maintenance and inspection needs—enabling remote deployment and potentially autonomous operation.

Microreactors are well-suited for off-grid remote communities, remote mining and other resource extraction facilities, and military operations that often rely on diesel generators and costly (and sometimes risky) fuel shipments. During outages, grid-connected critical facilities such as hospitals and water treatment plants could continue operations if powered by microreactors in microgrids. Indeed, nuclear fuel’s high energy density—more than a million times that of fossil fuels—could enable years to decades of continuous operation without refueling.

“Nuclear has an unrivalled energy density and other compelling attributes,” said EPRI Technical Executive Andrew Sowder, who authored the report. “However, the power will not be cheap. There will likely be a ‘nuclear premium’ associated with higher capital costs, regulatory compliance, and public acceptance challenges. Justification of microreactor deployment will require compelling business cases and favorable commercial arrangements such as power purchase agreements.”

More than a dozen microreactor technologies are under development by private companies and research groups. In 2018, the U.S. National Aeronautics and Space Administration (NASA) successfully demonstrated a kilowatt-scale microreactor suitable for supporting manned exploration of the Moon and Mars and other space missions. The technology, called Kilopower, uses a novel approach to cool the reactor core (which is about the size of a paper towel roll): Hermetically sealed (airtight) pipes transfer reactor heat to engines that convert the heat to electricity. Heat pipe technology is mature and deployed widely in smart phones, tablets, and oil pipelines.

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 electricity generated and delivered in the United States with international participation extending to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; Dallas, Texas; Lenox, Mass., and Washington, District of Columbia.

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