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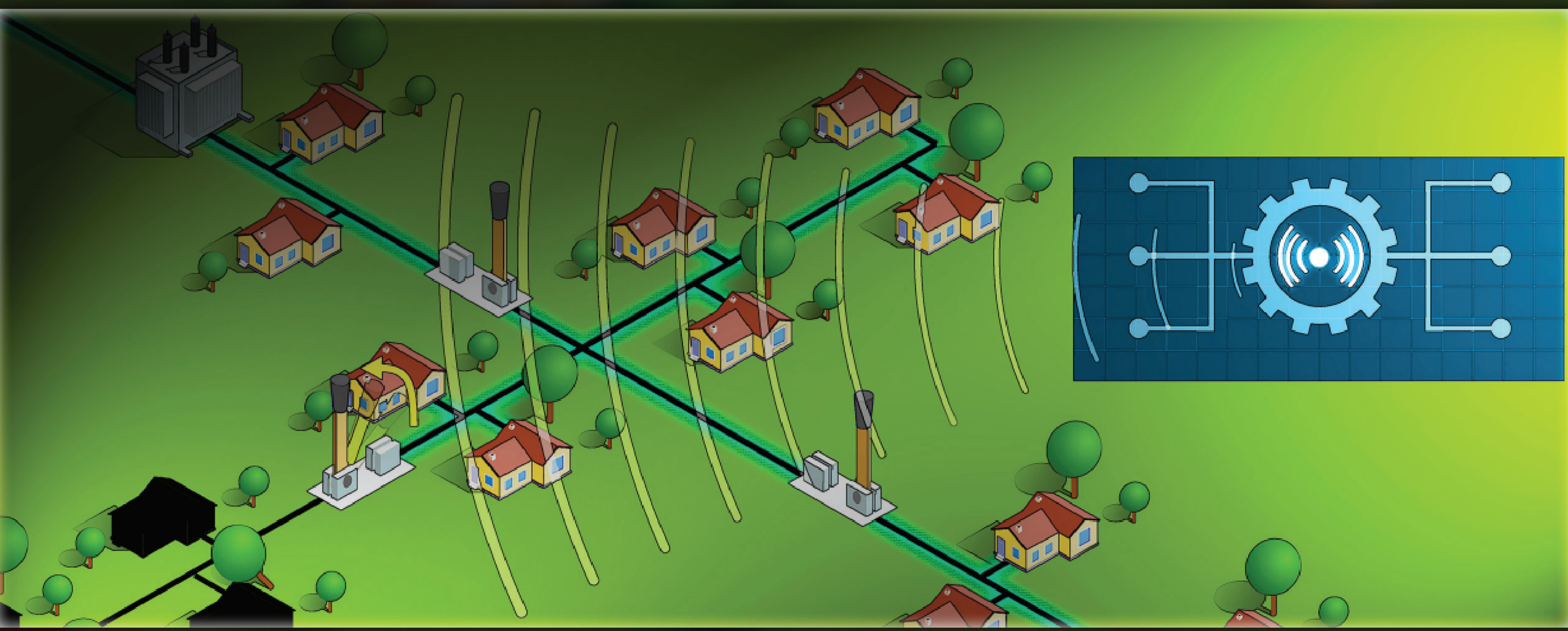
EPRI JOURNAL

Orchestrating the Distribution System



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The Challenge of Setting Company Climate Goals

Electrification 2018: Enthusiasm and Opportunity

Cyber Security: From "The Grid Edge" to "The Grid on Edge"

How Electrification Can Benefit Low-Income Consumers

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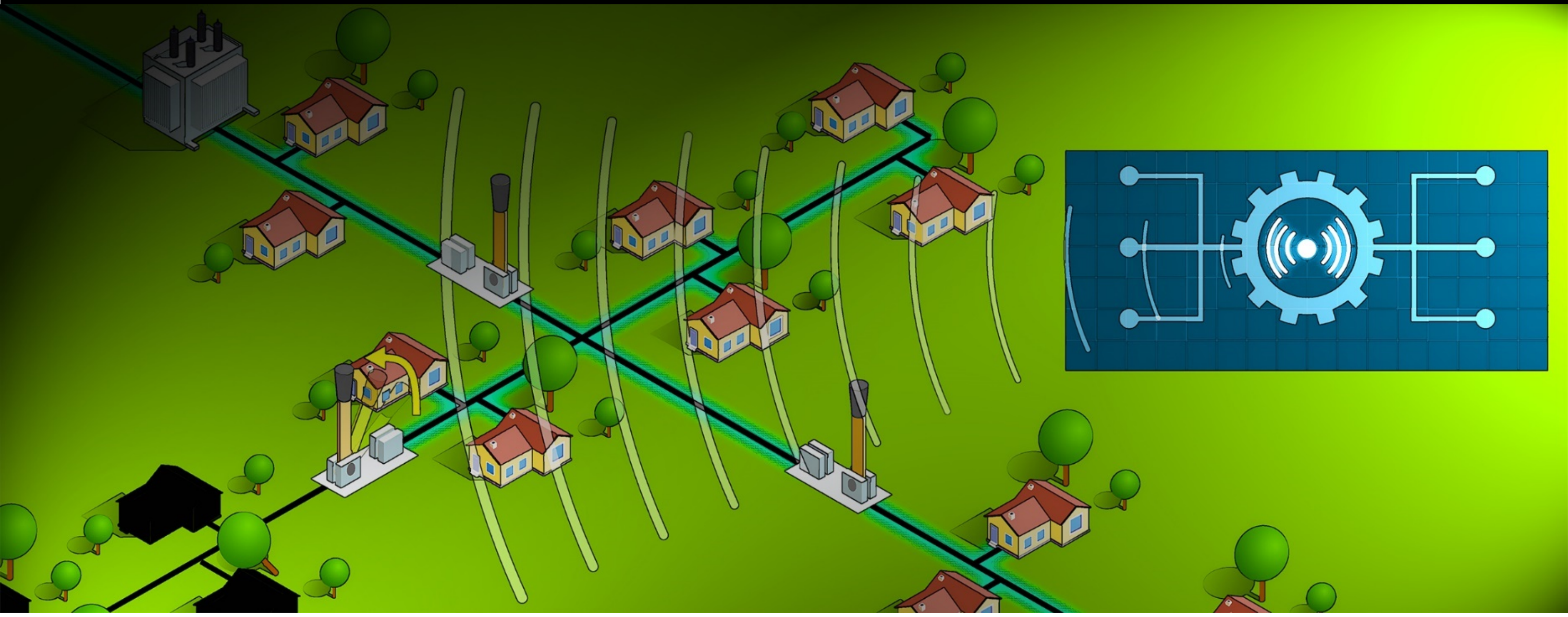


Orchestrating the Distribution System

EPRI Examines New Technologies and Methods to Help See, Manage, and Optimize New Energy Resources

By Mary Beckman

In New York, renewable energy is set to grow by leaps and bounds in the coming decade. By 2030, the Empire State's utilities are required to source 50% of the state's electricity from solar, wind, hydropower, and biomass. According to the U.S. Energy Information Administration, renewables (including hydropower) contributed 28% in 2017. With rising renewable energy, power generation is expected to become more distributed—with enormous implications for distribution system operations.

"New York has very aggressive climate goals that make significant use of clean, distributed energy resources," said Dave Crudele, a program manager in distributed energy integration at the New York State Energy Research and Development Authority (NYSERDA).

Distribution systems across the country, including New York's, were not originally designed for distributed energy resources (DER). Control and operating systems need to be upgraded to better incorporate these new dynamic sources of power distributed along the system.

"Without better awareness and control of distributed resources, many of these resources will not be operating in concert with the distribution system," said EPRI Senior Program Manager Jeff Smith. "The guiding principle here is measurement leads to improvement. If you can measure something, you can understand it. If you can understand it, you can manage it. If you can manage it, you can improve it."

Now, EPRI is working with NYSERDA and three New York utilities to develop software and tools that can help improve awareness of real-time DER operations and make control systems more responsive to them, improving reliability and power quality.

"EPRI has proposed a number of innovative R&D projects to make it easier to have more distributed energy resources on New York's grid," said Crudele.

With increasing rooftop solar, the distribution system has become much more dynamic, with power flowing in multiple directions.

HYBRID CONTROL

The power system in the United States has been designed for one-way power flow: Energy is generated at one end, transmitted to substations, and distributed to customers at the other end. For many years, managing the system was straightforward. Utilities kept track of how much power they generated and how much power users consumed. They used that historical information to forecast and plan.

"You could do that because all the power flowed downstream from the generating station. There wasn't anything going on dynamically on the distribution system, like we see today with distributed energy resources," said EPRI Senior Technical Executive Brian Deaver.

With more distributed, intermittent energy sources such as solar and wind, the distribution system has become much more dynamic, with power flowing in multiple directions. Conventional control systems are not sophisticated enough to manage these flows.

Consider a neighborhood of houses with rooftop solar. On a sunny day when solar panels are producing power, utility control systems are not aware of the generation and may only sense that the houses are consuming a small amount of grid electricity. Consequently, operators may only account for a certain level of demand when routing power through the distribution system. But when a cloud floats over the neighborhood and solar production decreases, many houses suddenly need utility power—and operators are faced with unexpected high demand.

To help manage a grid with intermittent, distributed resources, EPRI is investigating 'hybrid control' approaches that combine existing controls and new methods to perform three functions: pinpoint the location of distributed resources, monitor their energy production, and optimize their contributions to power flow.

The objective is to program a utility's distribution management system (DMS) to coordinate distributed resources with utility infrastructure, local autonomous controls, and centralized controls.

"The way the grid works now, a solar plant's generation may be causing high voltage locally, but the DMS is unable to adjust its output to mitigate the problem. With new control methods and algorithms, the DMS will be able to factor in distributed resources in deciding how to operate the system," said EPRI Senior Project Manager Lindsey Rogers, who leads the hybrid control project.

SEEING IS POWER

Today's grid can't 'see' nontraditional energy resources, such as rooftop solar, wind turbines, fuel cells, and energy storage. In other words, utility operators and control systems have limited ability to measure the real-time output of small generators distributed across the grid.

Orange & Rockland Utilities is working with EPRI to explore how to give the DMS 'eyes' for distributed resources. Researchers are modeling the operations of various sensors along three feeders in the utility's service territory in the northwestern suburbs of New York City. These sensors monitor the status and production levels of DER and transmit that information to the DMS. This modeling study will help the team determine where sensors need to be added, assess the costs and benefits of metering distributed resources, and identify the minimum size commercial solar or wind facility for which metering should be required.

EPRI researchers also are evaluating computational techniques that can enable these sensors to accurately characterize the state of the system at key locations. One technique is *distribution state estimation*, which reconciles measurements with different accuracies while identifying and ignoring bad measurements.

LOCAL KNOWLEDGE

Once a DMS has access to measurements of distributed resources, it can be 'trained' to manage them. EPRI is working with National Grid in upstate New York to model this aspect of the NYSERDA project.

"We want to meet customers' increasing expectations for reliability along with state policy goals for the integration of clean, renewable, distributed energy sources," said Rob Sheridan, National Grid's director for grid modernization solutions. "We are deploying advanced distribution management systems and aggressively pursuing renewable distributed generation interconnections at the same time. This study will help us with these efforts."

The team is modeling the impacts of distributed generation on a key DMS application known as *automated restoration*. This application automatically responds to a distribution system fault by locating it, isolating it to the smallest possible area, and automatically restoring power for as many customers as possible.

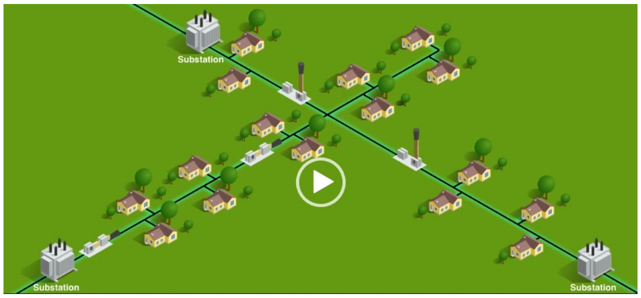
The control algorithms that manage automated restoration do not monitor distributed resources. When a fault occurs, these resources are required to disconnect from the grid for safety reasons. The algorithms are unaware of the resulting loss of production, which can potentially cause overloads, outages, or other undesirable outcomes.

"An automated restoration scheme can fail if it can't see the distributed energy resources," said Rogers.

When distributed resources challenge automated restoration operations, utilities may simply turn off the application and dispatch workers to address outages manually.

EPRI and National Grid are enhancing automated restoration algorithms so that the application knows where distributed energy resources are located and how much power they are producing. This can enable the algorithms to make the appropriate decisions to reroute power, maximize customer restoration, and minimize overloads or other adverse impacts.

"We would like to understand how the sensitivity of the automated restoration algorithms developed in this study can impact our reliability metrics," said Sheridan.



[Watch](#) an animation about research to enhance automated restoration.

THE BEST THE GRID CAN BE

Once the grid can monitor the operations of intermittent power generators, it can be optimized for efficiency. That means delivering electricity in the right voltage range.

EPRI is working with Central Hudson Gas & Electric on control system upgrades to enable stable power flow and enhance voltage control.

"Solar developers tend to gravitate toward lower cost rural land," said Heather Adams, director of electric distribution and standards at Central Hudson. "But those sites are often supplied by smaller wires many miles from a substation, making them more vulnerable to overloading and voltage levels that fall outside of allowable standard ranges. Those areas are ripe for additional tools to facilitate integration."

For example, when a solar power plant produces electricity, the local voltage increases. Making fixed changes to inverter settings to mitigate voltage increases may create other challenges for the grid, such as decreased power factor. As smart inverters are rolled out and adopted, they can mitigate voltage increases by changing their settings dynamically and autonomously. Sometimes, however, the voltage increase can be too great for the inverters to manage locally. EPRI and Central Hudson are developing enhanced DMS algorithms to coordinate local autonomous controls with controls at the substation or distribution control center.

"Central Hudson is interested in determining the appropriate balance of centralized and decentralized control of smart inverters and utility infrastructure," said Adams.

Rogers expects algorithm development and other DMS improvements to last about a year, after which EPRI and Central Hudson will demonstrate them in the field.

"Distributed energy resources are interconnecting at a rapid pace," said Deaver. "We intend to stay ahead of that curve."

KEY EPRI TECHNICAL EXPERTS

Brian Deaver, Jeff Smith, Lindsey Rogers

The Challenge of Setting Company Climate Goals

EPRI Informs Electric Power Industry on 'Climate Scenario Analyses' and Emissions Target Setting

By Brent Barker

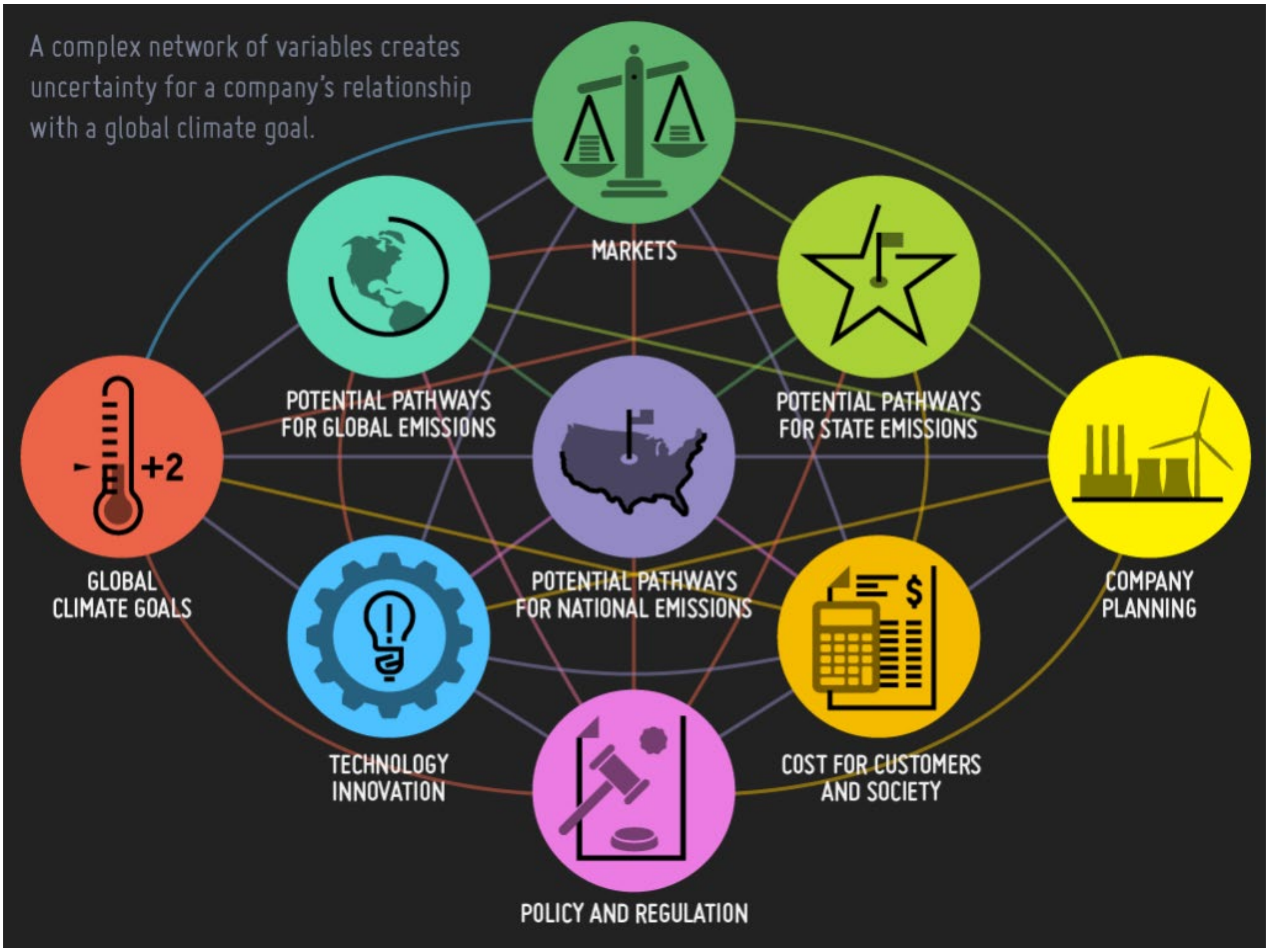
Rick Johnson, Entergy's director for environmental strategy and policy, has been involved in climate issues at the utility for more than 15 years. "In 2001, we were the first U.S. utility to set a voluntary greenhouse gas target," he said. "Our current target is to stabilize our CO_2 emissions at 20 percent below 2000 levels through 2020."

Lately, Entergy has received numerous requests for information on its climate initiatives. "Over the last two decades and especially over the last five years, we've seen a burgeoning interest by multiple stakeholders—investors, large customers, regulators, nongovernmental organizations, and even residential customers," said Johnson. "They want to know more about our environmental performance and how our business model will be impacted by a carbon-constrained economy."

Increasingly, stakeholders are requesting climate scenario analyses, which involve examining how potential climate policies may affect the company's decisions and business model. Many scenarios are focused on pathways to limit average global warming to below 2°C.

"When we started thinking about undertaking a 2°C scenario analysis, we wondered how our current process fits in," said Johnson. "Since around 2010, we have used a range of carbon price projections in our planning processes and investment decisions to frame our climate analysis and stress test our decisions. This evolution of best practices related to analysis of climate risks and opportunities has resulted in Entergy taking a broader view on the issue, while continuing to enhance our existing use of an internal price on carbon."

Entergy is not alone in its efforts to navigate complex climate issues. "Across the United States, utilities are receiving a growing number of requests from a diverse set of stakeholders to evaluate the risks posed by potential greenhouse gas emission targets and policies," said EPRI Technical Executive Steve Rose.



"This is part of a trend of increased climate policy activities at the state and local levels. We see some states increasing their commitment to address climate change. We see public utility commissions such as those in Minnesota and Colorado examining policies that may put a price on greenhouse gas emissions," said Rose. "There are proposals for some companies to set emission reduction targets along with requests for them to undertake climate scenario analyses to better understand the financial risks of managing assets in a carbon-constrained world."

Some proposals and requests come from utility shareholders. In 2017, there were 14 shareholder proposals to investor-owned utilities to undertake climate scenario analyses, report on stranded asset risk from climate policy, or set greenhouse gas emission targets.

Assessing how a company might be impacted by global scenarios, such as those focused on a 2°C temperature constraint, is extraordinarily complex. It involves understanding the relationship between a company today and global multi-century climate objectives. In 2017, EPRI launched a project to develop a technical foundation for informed discussion and decisions on climate scenario analyses and emissions target setting.

"There are valuable scientific resources available that can inform these efforts. For instance, understanding the relationship between future global temperatures and potential emissions pathways is central to both topics. There is a vast store of scientific knowledge that can help characterize relationships and uncertainties relevant to companies," said Rose. "We need to assess this knowledge and help bring it into discussions and decision making."

EPRI's project aims to evaluate scientific knowledge, identify key issues, provide insights to inform company options, and facilitate a collaborative industry forum for sharing ideas and experience. Diverse companies, many already deeply involved in efforts to reduce greenhouse gas emissions, are participating. Forums for discussion of climate scenarios also include nonutility stakeholders and technical experts.

"For a long time, power companies have performed scenario analyses to inform their strategic planning processes," said EPRI Senior Project Manager Morgan Scott. "But experience with climate-related scenario analysis is limited, and companies are seeking technical input on how best to approach it."

While the Intergovernmental Panel on Climate Change recognizes and evaluates more than 1,000 climate scenarios, "published methodologies to date have not considered this information," said Scott. "Companies need to better understand the state of knowledge for robust decision making and long-term planning."

"Everyone needs a better understanding of the methods and results and their strengths and weaknesses," said Rose. "We're characterizing what we know and don't know, as well as how to use that knowledge properly."

INSIGHTS TO DATE

As a first step, EPRI researchers are analyzing the technical literature on climate science, economics, and modeling. "We are evaluating current scientific understanding of the relationship between a company and a global climate goal, and we're identifying insights and issues companies and the public should be considering," said Rose.

The results, published in October, inform more detailed, quantitative analysis later this year. Recent insights include:

Abundant scientific resources. EPRI researchers are finding that the scientific literature offers substantial, useful information and data resources. "To date, utility discussions, recommendations, and proposed methodologies have focused on a very narrow body of information—often considering only one or two scenarios to inform company efforts," said Rose. "In fact, there are approximately 1,200 scenarios from more than 30 models from which to draw insights. A more comprehensive consideration of the state of knowledge can help companies to identify and characterize relationships, uncertainties, robust insights, and gaps in understanding. This is essential for assessing company risks and making good decisions."

Uncertain company role. Significant uncertainties define the relationship between a company and a global climate goal. "At the highest level, there is uncertainty in the relationship between a global temperature goal and global greenhouse gas emissions. From there, the uncertainty only increases as we move from global to country to local emissions with additional factors entering the story at each level," said Rose. There is uncertainty about future technology, markets, and policies, as well as about how the climate system will respond to greenhouse gas emissions. "Research also illustrates that the emissions pathways associated with limiting global warming to 2°C will be extremely demanding and may be unachievable, so companies don't know if and when global emissions will peak and start declining," said Rose.

While there are many uncertainties for companies to consider, they need not be an obstacle. The scientific literature can help identify robust insights. "In our study, we identify insights that hold regardless of the model and assumptions. These provide a strong foundation for decisions," said Rose. "Companies should embrace uncertainty in their analyses and build flexibility into their strategy."

Nonuniform emissions targets. Some stakeholders are encouraging companies to adopt a common greenhouse gas emissions reduction target. "Based on detailed results from emissions scenarios, it is unlikely that identical targets across companies will be cost-effective for society," said Rose. "Flexibility for companies to work together within and across sectors will be important to enable companies to achieve emissions reductions at a lower cost to society."

Potential electrification for decarbonization. Electricity from low-carbon electric power generation could help decarbonize the overall economy. "However, the level of electrification will depend on the design of policies and the availability of cost-effective, low-carbon technologies," said Rose. "Power companies need to consider the range of possibilities with respect to electrification."

Climate policy and company planning. Most power companies have planning processes that consider future demand, fuel markets, policies, and other variables. Potential climate policies could be another factor to consider. "Many companies already consider climate policies in their planning, particularly state renewable energy and emissions policies," said Scott.

DELVING INTO CLIMATE SCENARIO ANALYSIS

EPRI's research offers guidance to companies, drawing on the scientific literature. Among other things, EPRI's study includes steps on how a company might implement this guidance.

According to Entergy's Johnson, EPRI's project is helping his company better understand all the relevant issues and uncertainties as the company conducts a scenario analysis and considers setting its next set of emissions goals. Climate scenario analysis expands the range of considerations traditionally included in utility planning.

"This project is helping us to evaluate approaches to climate scenario analysis and to develop our own approach," said Johnson. "EPRI is evaluating analytical frameworks and methodologies, as well as company reports as they come out. The experts that EPRI brings to the table are helping us review the methodologies and frameworks with a critical eye."

Johnson points to the collaborative forum as a key benefit. "Hearing the perspectives of our peers at other utilities—as well as experts outside the utilities—brings great value to all of us. If we didn't have this project, we would each be thinking about this in a vacuum."

Entergy recently announced that the company is conducting a full 2°C scenario analysis and expects to publish it by March 2019. "This analysis will help us understand the impact a carbon constraint may have on our strategy and long-term planning," said Johnson.

A COMMON LANGUAGE FOR DISCUSSION

Another power company participating in EPRI's project, Public Service Company of New Mexico (PNM), is on an aggressive greenhouse gas emissions reduction trajectory. In 2017, PNM's integrated resource plan concluded that phasing out coal generation was the most cost-effective plan for PNM customers and resulted in a pathway to zero emissions from coal.

"Our integrated resource plan recommends shutting down our largest coal asset, San Juan Generating Station, by 2022 and completely exiting coal generation by 2031," said Maureen Gannon, PNM's executive director for environment, safety, and lands. "This will put us on track to reduce our greenhouse gas emissions by 60 percent by 2030. By 2040, we will have reduced our emissions by 87 percent from 2012 levels."

These plans are not final yet. "We still have to go through the regulatory process and gain approval from our Public Regulation Commission," said Gannon.

She added that EPRI's climate scenario analysis project "hit all the right buttons for us. This year, we had shareholder proposals related to climate issues, and we needed a better grasp of the subject in order to respond. As a small company, what do we do to help meet a global 2°C goal? And what does two degrees mean? The EPRI work gives us a solid basis to inform stakeholders that 2°C is a goal—not a scientific threshold."

Gannon says that EPRI's initial study has helped PNM become more familiar with the technical terms and issues related to climate modeling and scenario analysis. "For me, it's developing a much better understanding of the language. What is it going to take to perform a robust scenario analysis? The project is an opportunity to become better informed and create a common language for discussion with our many stakeholders, from investors and customers to regulators and nongovernmental organizations."

NEXT STEPS

Later in 2018, EPRI plans to conduct new analyses on research gaps and key issues identified in the initial study. EPRI and project participants will consider a variety of research opportunities to continue informing industry and public discussions.

"Our project is designed to take a strategic pause in climate scenario and goal-setting discussions to develop the necessary technical knowledge and resources," said Scott. "People have been very receptive and appreciative of our objective approach and the insights coming out of it. In the end, grounding company decisions in robust science is in the best interest of society."

KEY EPRI TECHNICAL EXPERTS

Steve Rose, Morgan Scott

EPRI JOURNAL

Electrification 2018: Enthusiasm and Opportunity

By Steve Hoffman

At EPRI's Electrification 2018 conference, FirstEnergy staff baked cookies in their exhibit booth to demonstrate the benefits of an efficient electric convection oven manufactured in Cleveland. With an enticing aroma wafting through the conference hall, attendees could not resist, eating more than 3,000 chocolate chunk, peanut butter, red velvet chocolate chip, and macadamia nut cookies over the three-day expo. "People told us it was the best exhibit booth 'swag' ever!" said Randy Frame, FirstEnergy's director for emerging technologies programs. "And what better way to demonstrate the fast, clean, and uniform baking advantages that electric foodservice equipment has to offer for our customers."

Enthusiasm for the cookies mirrored the enthusiasm for the event—the first-ever international conference focused on efficient electrification. Many of the 1,830 attendees expressed excitement for electrification and the related opportunities for utilities, their customers, and society. "For decades, electrically-driven end-use equipment has consistently delivered comfort, convenience, and energy savings for our customers," said Steve Briggs, FirstEnergy advisor for retail innovation technologies. "This conference demonstrated that there are many new electric technologies that are cleaner and more cost-effective—providing even greater benefits for our customers."

There was a sense that the event was not just a conference, but the beginning of a new chapter for the electric power industry. "This is one of the most exciting times in any industry," said Paula Gold-Williams, president and CEO of CPS Energy. Expanding on this sentiment in his opening keynote, Edison International President and CEO Pedro Pizarro said, "This is the right time for us to come together and figure out how to respond to this crucial moment in the history of our industry, and of society in general."

Electrification 2018 packed a lot into four days. FirstEnergy's electric oven was just one of scores of electric technologies exhibited and discussed at the Long Beach Convention Center. Besides the plenary sessions and exhibit hall, the event included five pre-conference workshops, seven conference tracks, 42 breakout sessions, 225 speakers, 28 sponsors, and 32 additional supporting organizations. Participants discussed technologies, customer adoption, policy and regulatory considerations, grid modernization, environmental benefits, and more.

“The constituency of attendees was unique, exceptionally valuable, and not duplicated anywhere,” said Anda Ray, EPRI senior vice president, external relations and technical resources. “We had utilities, vendors, utility customers, regulators, academia, government, technology providers, associations, media, and more from around the world—all in one place.” Rob Chapman, vice president of EPRI’s Energy and Environment Sector, put it this way: “Electrification is a team sport. It will require utilities, regulators, and other industry stakeholders to collaborate and think differently about how to leverage a cleaner electric supply across all sectors of our economy.”

The exhibit hall at the Electrification 2018 conference. Photo courtesy of Edison International.

“As a complement to the presentations, the 115 exhibiters were very important,” explains EPRI’s Tom Reddoch, a 50-year veteran of the industry. “People need to see and touch things, and the exhibits provided that.” Transportation was a big part of this, including this electric vehicle presented by Pacific Gas & Electric.

Local Roots provided tours of an operational indoor vertical farm inside a tractor-trailer. The company builds modular indoor farms at retail distribution centers and offers its customers low upfront costs in exchange for a commitment to purchase pesticide/herbicide-free lettuce for an agreed-upon period.

The exhibit hall featured more than 30 startups that are part of the Incubatenergy Initiative.

Conference attendees enjoying cookies baked in an electric oven at FirstEnergy’s exhibit booth.

An electric bus exhibited by Lion Electric Company. Photo courtesy of Hoffman Power Consulting.

ELECTRIC TRANSPORTATION: MORE THAN CARS

Electric transportation is a rapidly growing industry worldwide. Reflecting on past false starts, General Motors Vice President of Global Strategy Michael Ableson said that he is often asked whether electric cars "are really going to happen this time." Ableson's answer for GM is an emphatic "yes." While a million electric cars will soon be on U.S. roads, the conference showed that electrifying transportation is about much more than cars.

"When an electric school bus pulls up, all you would hear are the squeals of the children inside," said Nate Baguio, vice president of sales at the Lion Electric Company, which exhibited a conventional electric school bus. Because the vehicle is so quiet, Lion has included in its design speakers under the front grill that play a song to alert children the bus is approaching. "At some schools, the best-behaved child on the bus gets to pick the song of the month," said Baguio. Drivers can set the bus to pre-cool in the summer and pre-heat in the winter, and children benefit from elimination of toxic diesel fumes.

According to a recent report from a group of environmental organizations, replacing the 480,000 primarily diesel school buses in the United States with electric models would reduce annual greenhouse gas emissions by 5.3 million tons. Electric school buses are in full operation in several states, including California, Massachusetts, and Minnesota.

BUILDINGS AS GRID ASSETS

Buildings offer significant electrification opportunities. Describing a roadmap for building decarbonization at the pre-conference workshop on Building Decarbonization and Electrification, Northeast Energy Efficiency Partnerships (NEEP) Executive Director Susan Coakley emphasized the need to treat buildings as grid assets. "In cold climates like the Northeast, under-insulated buildings can't hold their heat," she said. "We need to be aware of that and improve efficiency." Thermal improvements in the building envelope along with electric heat pumps and other grid-interactive appliances can help utilities manage dynamic building loads more effectively during extreme outdoor temperatures, Coakley added.

NEEP has developed a nine-step plan to accelerate long-term market transformation to efficient electrification in the northeastern United States. Key to this is linking climate stabilization goals with policies and programs that improve the energy performance of existing homes and buildings. The goal is to increase grid flexibility, while saving money, creating jobs, and increasing occupant health, safety, and comfort.

According to NEEP, one electric technology that can support building electrification is the cold-climate air-source heat pump, which can provide high-performance heating at ambient temperatures near or below 5°F along with highly efficient cooling.

Coakley asked attendees: "Would you buy a house—arguably the largest purchase you'll ever make—without knowing its energy performance?" The U.S. Department of Energy's Better Buildings initiative has a multi-state effort to provide more transparency through "home energy scores." According to Coakley, customer surveys have shown that such scores—whether high or low—can increase home sale prices and lease rates. "The transparency is valuable to home buyers and lessees," she said.

PROBLEM SOLVING FOR INDUSTRIAL CUSTOMERS

As a complimentary service to its industrial customers, Alabama Power's Technology Applications Center shares expertise related to various electric technologies, such as infrared heating, induction heating, and powder coating. "Specialists from our Technology Applications Center work closely with our industrial customers to assist in solving problems," said Cheryl McFarland, the utility's commercial and industrial sales and technical support manager, during a workshop on lean manufacturing through electrification. "We conduct process and product tests using efficient electric technologies as alternatives to other fuel types." She described case studies on solutions for weld defects, plaster drying, powder coating, veneer drying, and mop/broom handle production.

In one case study, a material coating company used a natural gas-fired convection oven to cure clear-coat paint in 20 minutes. Alabama Power specialists demonstrated that electric ultraviolet curing could complete the same job in about 7 seconds. By implementing the new system along with an electric infrared dryer, the company increased production, improved product quality, and increased energy efficiency.

THE CUSTOMER IS KING

Some utility customers don't adopt new technologies that offer clear benefits. Because widespread electrification relies on customer adoption, understanding customer behavior is essential. Dr. Jennifer Weeks, an associate at management consulting firm BEworks, shared an anecdote in which a utility mailed a flyer to its commercial customers offering incentives for efficiency upgrades with significant potential savings. Only 34% took advantage of the offer.

As part of an experiment to better understand this outcome, BEworks mailed one group of customers a postcard describing the upgrades (an "increased accessibility" approach), mailed a second group a formal letter (an "increased credibility" approach), and mailed a control group the original flyer. Relative to the flyer, the postcard had a 50% lower response, while the letter had an 81% higher response. These results indicate that utilities can improve customer participation in their programs using behavioral approaches.

WHAT'S NEXT FOR ELECTRIFICATION

In the Tuesday afternoon plenary session, Duke Energy Executive Vice President Doug Esamann announced that his company would host the next EPRI electrification conference in Charlotte, April 6–9, 2020.

"Our vision was to assemble every part of the industry and have a discussion about electrification," said EPRI CEO Mike Howard. "I think we achieved that. The next step is for us to work collaboratively to help realize the vision."

"The economy-wide benefits of using electricity to replace fossil fuel end-uses include increased energy efficiency, reduced carbon dioxide emissions, and improved air quality," said Chapman. "Tapping the opportunities that efficient electrification presents to society and consumers will require increased awareness of these benefits. EPRI looks forward to continuing work with all electric sector stakeholders to support this dialogue through fact-based research."

Environmental Benefits of Electrification

Electrification's environmental benefits flow from all customer sectors and many electric technologies. An air quality panel at the conference presented the results of several studies showing the importance of electrification in lowering local emissions and decarbonization. An energy-water nexus session presented various viewpoints on this set of complex interactions.

Edison International President and CEO Pedro Pizarro cited a long list of studies and reports that link electrification and decarbonization, including EPRI's National Electrification Assessment, Portland General Electric's vision for meeting Oregon's environmental goals, National Grid's 80×50 Pathway, the California Energy Commission's Decarbonization Strategy, and Edison's Clean Power and Electrification Pathway. "Everyone is starting to align," Pizarro observed.

Electrification 2018 Participants: Inspired and Enthusiastic

"Electrification is going to be important to us all, not only today but in the future. This is our opportunity, and being here means being part of the future."
Michael Kurzeja, Senior Manager, Exelon

"Clearly, our customers are thinking differently. Clearly, many of our regulators are thinking differently. We have to do the same thing."
Stan Connally, Executive Vice President of Operations, Southern Company

"We need to lean in, try things, iterate, and try again. We need to commit to the idea that if it's not for all, it's not for us."
Gil C. Quiniones, President and CEO, New York Power Authority

Cyber Security: From “The Grid Edge” to “The Grid on Edge”

EPRI is assessing how to best address the range of cyber security challenges across the electric power system. Our aim is to inform cohesive, enterprise-level strategies from utilities and others in the electricity sector.

Along with the ranks of cyber criminals and saboteurs, the power system’s threat landscape and attack vectors are expanding and shifting daily. Utilities see this most dramatically at the “grid edge,” with rapid growth in the numbers and kinds of connected sensors, controllable loads, electric vehicles, and distributed generation and energy storage.

Absent effective strategies and well-targeted R&D, this ever-shifting threat could put the grid “on edge”—a figure of speech meaning tense or apprehensive. Clearly there is an undercurrent of this everywhere cyber threats are perceived.

At EPRI, we focus both on the information technology (IT) and the grid’s operational technology. For operational technology, we need to address existing systems that predate cyber

Mike Howard, President and Chief Executive Officer, EPRI

protection and to mitigate risks associated with the projected long-term life of new devices coming into service.

Many of the grid’s existing operational digital assets are communicating with distributed energy resources already, but R&D must anticipate and address much greater automation and connectivity—including connections among electricity customers, utilities, and third parties in the Cloud. As networks become more complicated at the grid's edge, we must continually address cyber security vulnerabilities and risks at the device, system, and aggregator (third-party) levels.

To enhance cyber security R&D, EPRI will identify where relevant work is happening—whether in the national laboratories, manufacturers, or universities. Drawing on our deep expertise in cyber security and diverse aspects of the power system, we will transfer key insights and results of this work to the electric power industry, helping companies to apply them in their operational systems.

We are looking also at training. Those who are responsible for deploying and using digital and operational technology in power generation, delivery, and use generally are not cyber security experts. Training that targets this audience and focuses on utilities' unique operations is not readily available, and EPRI is proposing to fill this growing need.

For operational technology as elsewhere in the electricity sector, we characterize the adoption of cyber security metrics as "early stage." We see important opportunity to establish standard metrics to help quantify the effectiveness of a utility's cyber security program, justify investments, and support benchmarking.

Given all of the points above, here are four priorities we are discussing and pursuing:

1. **Security Standardization and Reference Communication Architectures for the Integration of Distributed Energy Resources**

   - Cyber security and risk analysis frameworks to support a complex, multi-party grid that involves large numbers of assets owned by customers and third parties
   - Develop commonly accepted communication and operational cyber security solutions for customer-, utility-, or third-party-owned assets/systems
   - Develop practices and solutions for the secure integration and continued operation of utility-, customer-, and third-party-owned devices

2. **Advanced Research in Supply Chain Vulnerabilities**

   - Develop near-term guidance on mitigating vulnerabilities of deployed technologies and service providers
   - Leverage EPRI's Technical Assessment Methodology to develop standardized procurement language and vendor specifications with greater transparency and consistency

3. **Security Metrics and Industry Benchmarking**

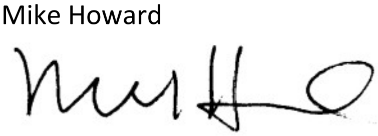
   - Common set of metrics for leaders to communicate security status to stakeholders
   - Measure the effectiveness of security controls and operations through performance metrics
   - Industry-level statistics on cyber security performance for benchmarking
   - Reliable historical data for establishing long-term strategic goals

4. **Identify Critical Research and Technologies, Transfer to Industry, and Apply to Operational Systems**

   - Develop a process to vet and disseminate emerging security solutions
   - Expedite technology development through deployment and demonstrations
   - Create advisory structure to prioritize cyber security research

Even as the scale and complexity of cyber threats can sometimes put us "on edge," EPRI believes it is most useful to offer a cyber security R&D portfolio that combines leadership, collaboration, expertise, and focus. We expect continual change and adaptation by the electricity sector and its stakeholders, and we expect that virtually everyone will have a contribution to make at the "cutting edge" of progress.

Mike Howard



President and Chief Executive Officer, EPRI

EPRI JOURNAL

How Electrification Can Benefit Low-Income Consumers

By Keith Dennis, Senior Director for Strategic Initiatives at the National Rural Electric Cooperative Association

By displacing direct combustion of fossil fuels, increased electrification of vehicles, space and water heating, and other end uses can significantly reduce greenhouse gas emissions. But what does this "beneficial electrification" mean for low- and mid-income consumers who cannot afford to pay more for energy?

For several decades, a major focus of energy policy has been to help low-income consumers reduce their utility bills through energy efficiency and conservation. Because these consumers use less energy than their higher income counterparts, it can be relatively difficult and expensive to provide them with significant savings through conservation. At the same time, low-income consumers spend a higher proportion of their income on energy, so any savings can greatly impact their quality of life.

Enter beneficial electrification, which opens new savings opportunities for consumers of all incomes through more efficient use of energy. With emerging realities such as excess renewable energy, low- and negatively priced wholesale electricity, and a growing need for flexible loads, utilities have more opportunities to provide savings to consumers by focusing on *when and how* they use energy rather than *how much*.

Keith Dennis

Increasingly, consumers can provide value to utilities by using electricity when it is best for the grid to help balance supply and demand. This value can be returned to consumers in several ways: traditional rate design (such as time-of-use rates), programs that help pay upfront costs of flexible loads (such as rebates on new or used electric vehicles or new water heaters), and pricing based on the value provided by customers' energy use. For example, if the benefits of a grid-interactive electric water heater with a 10-year life are $100 annually, a rebate of several hundred dollars could be available to the consumer. These savings are becoming easier to measure and reimburse with more communications technology and smart metering.

Consider electric vehicles. Utilities across the country are beginning to offer programs and incentives that make electric vehicles a more realistic option for mid- and low-income consumers. In addition to upfront incentives and low-interest financing, many utilities offer off-peak rates that enable dramatic savings for electric vehicle owners. For example, with “super” off-peak rates of 2.7 cents per kilowatt-hour from 10 pm to 5 am, customers of Piedmont Electric Cooperative in North Carolina pay $129 to charge an electric vehicle to drive 13,500 miles per year. Compare that with annual costs of nearly $1,200 to fuel a similar model with gasoline. Electric vehicle owners also avoid costs for oil changes, tune-ups, spark plug replacements, and emission tests.

Given current vehicle prices, it may seem like a stretch to think of electric vehicles as a savings opportunity for low- or mid-income consumers. But incentives can bring them within reach to more people. Members of New Hampshire Electric Cooperative who purchase the all-electric 2018 Nissan LEAF can receive a $5,000 rebate or a 0% annual percentage rate (APR) for 72 months, along with the $7,500 federal tax credit.

We need to update the cost tests that are used to demonstrate to regulators that such programs should be eligible for ratepayer, government, or other public benefit funds. These tests measure whether the amount of energy conserved is cost-effective relative to traditional generation options. They were not designed to determine the value of using electricity instead of fossil fuels during low demand or periods when renewable energy would otherwise be curtailed or negatively priced.

With the dramatic growth of renewable energy, many power industry stakeholders initially pondered the question, “What do we do when the wind isn’t blowing and the sun isn’t shining?” The more relevant question emerging is, “What do we do when the wind *is* blowing and the sun *is* shining and there is low demand?” The answer: Use that energy right away by putting it in a water heater, car, battery, or scooter while it is cheap.

These and similar questions make it imperative to unlock the value of beneficial electrification for consumers of all income levels.

In addition to his role at the National Rural Electric Cooperative Association, Keith Dennis is on the advisory board of the Beneficial Electrification League, a new nonprofit organization focused on promoting market acceptance for beneficial electrification concepts, policies, practices, technologies, and business models.

In Development

Who's Responsible for Security in a "Multi-Party Grid"?

EPRI Develops Guidelines and Methods to Strengthen Cyber Security for Distributed Energy Resources

By Brent Barker

Growing deployment of rooftop solar, energy storage, microgrids, and other distributed energy resources (DER) poses unique cyber security challenges. Traditionally, utilities have tightly controlled cyber security of grid assets, but DER occupy a looser space on the periphery of the distribution system. They are connected to the grid, yet are often privately owned by third parties.

"Some entities own the devices, while others manage them. Still others provide private communication networks or communicate with devices using the Internet, which nobody owns," said EPRI Principal Technical Leader Candace Suh-Lee. "The big question is, where should the responsibility for security lie in this multi-party grid? We need a model that resolves this question within a few years, or we are going to face various scenarios that threaten grid security. For example, we may not know how to respond to an active cyber attack because we don't have a collaborative incident response plan. If a device owned by a third party makes a suspicious connection request, we may not know whom to contact. Or, we may not have a solution to a known security flaw since the responsibility for the fix is not specified in any contract."

"The grid is especially vulnerable in areas with a high penetration of solar photovoltaic (PV) as more third parties become involved in controlling energy resources and transmitting data to and from them," said EPRI Senior Program Manager Galen Rasche. "Further deployment of DER could slow or stall if we don't address cyber security adequately."

Growing rooftop solar poses cyber security challenges for the distribution grid.

To address these concerns, Suh-Lee is developing guidelines for secure communication architectures. These would serve as a reference architecture for utilities, aggregators, solar component manufacturers, and other companies involved in DER communications. According to Suh-Lee, these guidelines can inform industry standards from organizations such as the National Institute of Standards and Technology and the Institute of Electrical and Electronics Engineers (IEEE). Jurisdictions can address cyber security by establishing regulations that refer to these standards.

"It takes years to develop industry standards. Our goal is to develop the guidelines rapidly, make them available to the public by the end of 2018, and engage with standards bodies," said Suh-Lee. "We're working collaboratively with the SunSpec Alliance—comprising solar component manufacturers and integrators—to develop reasonable, practical guidelines for a secure network architecture."

"This process has involved extensive discussions to sort out differences of opinion. Utilities and third parties initially had different perspectives on the need for a secure network architecture," Suh-Lee continued.

"At first, many third parties saw limited benefit to the guidelines and were concerned about the cost implications. Eventually, they came to recognize the importance of understanding the cyber risks in order to protect their investments in solar power infrastructure. If the systems are hacked and not producing power, there could be quick and steep financial consequences," said Suh-Lee.

Suh-Lee also is developing a white paper that outlines a methodology to assess security risks in a multi-party grid—and that suggests for stakeholders' consideration a potential manner in which to enforce security responsibilities appropriately. Participants in a multi-party grid include:

- **Customers:** Owners of houses with rooftop solar are often customers of several service providers, including utilities, aggregators that manage DER, and private communications networks.
- **Utilities:** DER data flows back to the utility, which manages demand response and provides customers with grid power as well as backup power when DER go offline.
- **Aggregators:** These private companies manage numerous DER and controls on their networks, compete for new business among DER owners, and sign up customers for services. They can provide utilities with demand response services and operational data on DER.
- **Manufacturers:** Smart inverters can communicate with the grid and are connected to the manufacturers' proprietary networks, enabling data collection and periodic software updates. Cyber security must be designed and built into inverters and other smart devices in the factory—not on a rooftop after they are installed.
- **Standards and certification bodies:** Standards organizations certify various functions and attributes of smart devices. Ideally, manufacturers build cyber security into their devices and then standards bodies certify these features. To make this process routine, manufacturers will need to implement cyber security features in parallel with efforts to develop their devices' functional requirements.
- **Industry trade groups:** Industry groups can serve an important role in facilitating DER cyber security. The SunSpec Alliance, comprising more than 100 solar and storage companies, is pursuing information standards to enable interoperability among grid assets and DER.

The forthcoming white paper will describe an idea for a "cooperative security model." This provides a way for a regulator, utility, or other entity to manage and track cyber security tasks among many different interconnected devices and systems owned or managed by multiple parties. Tasks of concern include secure communications, security patch updates, threat detection, and incident response.

As part of a project to support high solar PV penetration, the California Energy Commission is considering the use of a new communications protocol with smart inverters and has commissioned an EPRI "red team" to probe its vulnerabilities. The protocol, known as *IEEE 2030.5*, is intended to connect DER with grid operations.

"Our job as a red team will be to hack into smart inverters," said Suh-Lee. "We are working with highly skilled, reputable hackers who are very familiar with grid operations."

According to Suh-Lee, the central question guiding EPRI research in all these areas is, "How radically will cyber security change communications on the grid?"

KEY EPRI TECHNICAL EXPERTS

Candace Suh-Lee, Galen Rasche

Smarter on Low-Level Radioactive Waste

EPRI Informs Environmentally Sound Management and Disposal, Enables Millions in Savings

By Chris Warren

The bulk of the radioactive waste generated by nuclear power plants is classified as low-level waste. In fact, the World Nuclear Association reports that just about 3% of power plant radioactive waste is considered high-level waste (primarily used nuclear fuel).

The U.S. Nuclear Regulatory Commission (NRC) divides low-level waste into three classes—A, B, and C—based on the concentration and nature of the radionuclides.

Class A, with the lowest concentration, comprises materials such as contaminated personal protective equipment, used ion exchange resins from non–reactor coolant systems, and contaminated soil. Given the low radioactivity, relatively low-cost disposal options are available.

Class B and C wastes typically comprise filters and ion exchange resins used to capture and remove radionuclides from the reactor coolant system. With disposal requirements more stringent than those of Class A, disposal costs are higher. EPRI estimates that it can be up to 10 times more expensive to dispose of Class B or C waste than Class A waste. It is important to classify waste properly and minimize waste generation, particularly Class B and C waste.

Since 2005, EPRI's Radiation Safety Program has developed guidance and technical solutions to assist utilities with environmentally sound, cost-effective approaches for low-level waste management and disposal. EPRI research has focused on techniques to minimize generation of Class B and C waste and to process wastes to maximize Class A waste volume.

LESS WASTE PRODUCED, LESS TO DISPOSE OF

As low-level waste disposal facilities faced closures in the mid-2000s, EPRI began investigating ways to help plants produce less Class B and C waste. "Most U.S. plant operators were losing access to disposal facilities that accept Class B and C waste," said EPRI Radiation Safety Program Manager Phung Tran. "Our research helped them implement practices to minimize generation of this waste, reducing waste storage and disposal costs."

One strategy involved filter replacement. Traditionally, filters have been replaced on a prescribed schedule, serving for 18 to 24 months and often accumulating enough radionuclides for classification as Class B or C waste.

EPRI documented approaches for monitoring filters to determine when radionuclides approach levels requiring Class B or C disposal—then replacing the filters before radionuclides reach that level.

RESEARCH-DRIVEN CHANGES TO WASTE CLASSIFICATION

Since the 1980s, the methodology for classifying low-level nuclear waste has been dictated by the NRC's Branch Technical Position on Concentrating Averaging and Encapsulation, or BTP.

The BTP's most recent revision in 2015 was informed by EPRI research. "We took into account the latest information on health effects, waste volumes, and disposal site designs to better understand how waste may impact the public many years from now," said Tran. "This informed a new approach to the concentration averaging methods used to classify waste."

As in previous versions, the revised BTP does not permit plant operators to mix non-radioactive materials with radioactive waste for the purpose of changing the waste classification. However, operators have more latitude to mix similar radioactive materials containing different levels of activity. The resulting mixture is classified by its concentration of activity.

"The updated rules provide more flexibility in how plant operators average the radionuclide concentrations in their waste," said Tran. "If plants can produce a certain amount of higher activity resin waste and have enough lower activity resin waste, they may be able to blend them to yield Class A waste for the entire volume. The final waste volume is less hazardous to workers and the public and less costly to dispose of."

Following the BTP revision, EPRI organized a group of nuclear power plant operators, industry experts, disposal site operators, and state and federal regulators to develop guidance for its implementation.

As a result of the regulatory changes and EPRI's guidance on waste reduction and concentration averaging, utilities have made changes leading to large savings. By applying EPRI's guidance, Pacific Gas and Electric's Diablo Canyon Power plant reduced Class B and C waste generation by more than 50%, with annual savings of $400,000–$500,000. Exelon expects to save about $5 million in its 23-reactor fleet in five states. For plants implementing these techniques to reduce Class B and C waste, annual savings can reach about $300,000.

KEY EPRI TECHNICAL EXPERTS

Phung Tran, Lisa Edwards

A New Waste Category?

Most waste produced during nuclear plant decommissioning and site remediation is lightly contaminated soil and building rubble. Given the very low concentration of radionuclides and similarly low risk to the public, the International Atomic Energy Agency established a separate waste category: very low-level waste.

Because of the lower risk, disposal facility requirements for this waste are less stringent and less costly than requirements for facilities managing higher activity waste. Engineering measures in place at hazardous, non-radioactive waste disposal facilities are considered sufficiently robust for the safe disposal of very low-level waste. While the United States does not have a very low-level waste classification, some states have processes that enable disposal of this kind of waste in hazardous, non-radioactive waste facilities.

EPRI research has shown that nuclear power plants and the public could benefit from reduced disposal costs if a new very low-level waste category allowed disposal of these materials at a non-radioactive waste disposal facility (such as an industrial or hazardous waste facility).

"The NRC is evaluating whether to begin a rulemaking process to develop a category for waste with extremely low levels of radioactivity," said EPRI Senior Project Manager Lisa Edwards.

EPRI has evaluated how other countries approach this category, providing potential options for how it might be defined in the United States, should the NRC decide to move forward with rulemaking.

"Our research does not suggest that the U.S. should or should not do this," said Edwards. "Rather, it provides technical information about the concept, shows how other countries approach it, and presents options for creating a category."

In Development

New Insights on the Stability of Steam Generator Tubes

By Tom Shiel

EPRI laboratory research has yielded insights on a vibration mechanism that can cause costly damage in nuclear plant steam generators. The results may lead to new guidance for steam generator design to help avoid these vibrations.

Tubes in nuclear plant steam generators prevent radioactive liquid in the primary coolant loop from mixing with nonradioactive liquid in the secondary coolant loop. Tube leakage can result in loss of primary coolant, expensive plant outages, and shutdowns.

Tube bundles are subjected to cross-flow of a steam-water mixture, making them susceptible to vibration. In-plane fluid elastic instability, a type of severe vibration demonstrated in laboratories, was observed for the first time in an operating steam generator in 2012 at San Onofre Nuclear Generating Station in California. Unit 3 experienced a small coolant leak, and subsequent tube inspections identified damage caused by in-plane fluid elastic instability. The damage was a factor in Southern California Edison's decision to permanently shut down San Onofre in 2013.

In-plane fluid elastic instability was observed for the first time in an operating steam generator in 2012 at San Onofre Nuclear Generating Station in California. Photo courtesy of Southern California Edison.

To identify configurations that can cause in-plane fluid elastic instability, EPRI and Canadian Nuclear Laboratories subjected tube bundles to air flow. While air behaves somewhat differently from the steam-water mixture in a steam generator, it enables easier control and adjustment of variables in a laboratory.

“In these tests, our objective was to determine which parameters might influence the onset of in-plane fluid elastic instability,” said EPRI Program Manager Helen Cothron. “Air flow tests enable us to vary important parameters, and they are relatively inexpensive compared to steam-water tests.”

Researchers examined the interaction between the tubes’ U-bend area and the flat bar supports that stabilize the tubes. They focused on variables such as the number of tubes subjected to air flow, the number of supports, and the gap between the tubes and supports. Key findings:

- In-plane fluid elastic instability occurred in a cluster of tubes when the supports failed to stop tube motion in the air flow’s direction.
- As the flow velocity increased, the onset of in-plane fluid elastic instability was observed.
- Instability rarely occurred where the gaps between tubes and supports were small.
- As the flow velocity was reduced incrementally, tubes consistently stabilized at the same velocity.
- Out-of-plane fluid elastic instability often preceded in-plane fluid elastic instability.

“These results helped the project team develop a test rig for a second round of laboratory tests using a refrigerant instead of air,” said Cothron. “A liquid-vapor refrigerant mixture can simulate steam-water flow in a steam generator more precisely than air.”

Researchers conducted the refrigerant flow tests earlier this year and are evaluating the results now.

“Steam generator manufacturers were involved in the refrigerant tests,” said Cothron. “They provided input on the development of the test rig, and we will share the results with them.”

The results may be used to develop new guidance for the design of new steam generators that can help prevent in-plane fluid elastic instability during operations.

KEY EPRI TECHNICAL EXPERTS

Helen Cothron, Sean Kil

Live Wire

EPRI Investigates Promising Technologies and Approaches to Detect Dangerous Downed Power Lines

By Chris Warren

Live downed power lines (conductors) on utility distribution grids present a public safety challenge for utilities. They may not arc, sputter, or give off any other indications that they are live. This increases the possibility that someone would touch the wire, causing serious injury or death.

For decades, the electric power industry has investigated ways to improve the detection and prevention of downed conductors. Recent research has put more effective, scalable detection methods within reach.

As part of a three-year project begun in 2016, EPRI is examining approaches to high impedance fault detection. A low impedance fault can occur when a fallen tree limb forces two wires together in the air and there's little fault impedance to limit the flow of current between the two wires. Protective equipment such as a fuse or circuit breaker senses the high current and trips to end the fault.

In contrast, a high impedance fault limits the flow of current. "If a conductor breaks and falls on the ground, then it's a high impedance fault because the wire has poor electrical contact with the soil. Little current flows, so it won't blow a fuse or trip a circuit breaker," said EPRI Senior Technical Executive Tom Short, who leads research on high impedance faults. "The conductor can sit on the ground live for a long time and threaten public safety without the utility knowing it."

Today, there is no widely used method for detecting downed power lines. Most utilities publicize a phone number that customers can call when they see a downed power line, but this does not fully address the problem.

Watch an animation about a "meter pinging" approach under investigation to detect downed wires.

Following a literature review of research on high impedance fault detection, Short and his colleagues conducted tests at EPRI's research facility in Lenox, Massachusetts on newly available arc detection technologies. "When a live conductor on the ground is arcing and sputtering, arc detection technology looks for changes in the flow of current," said Short. "The tests showed that off-the-shelf technology could detect some downed conductors but not others."

For example, when live wires were placed on asphalt—which provides significant insulation—there was no current flow or arcing, and the faults were undetectable. "On a patch of freshly laid grass and sod, there was a better electrical connection that caused arcing, so the technologies were able to detect the faults," said Short. "While not a comprehensive solution, this approach offers an improvement over what is done now."

EPRI is investigating a potentially more effective detection approach that involves the use of a utility's advanced metering infrastructure and outage management system (OMS).

When advanced meters lose power during an outage, they send alerts to the OMS. Based on the meters' locations, the OMS may determine that a blown fuse caused the outage. It can pinpoint the fuse's location, directing repair crews to replace it.

Advanced metering can be used to detect cases in which outages are caused by a broken, downed conductor rather than a blown fuse. Distribution grid operators can send messages (known as pinging) to meters just downstream from the fuse located by the OMS.

"If the fuse really is out, the meter won't respond," said Short. "If the meter responds, that means that the fuse didn't blow, and the problem is somewhere else. Operators can continue pinging meters further down the feeder until one doesn't respond. That indicates that the problem is between two meters and could be a downed conductor. That is where you send the crews."

In the project's final year, EPRI will continue to investigate methods for detecting downed conductors. Researchers plan to test the pinging approach with several utilities.

"We will work with at least six utilities to implement an automated detection system and evaluate how it works in practice," said Short.

KEY EPRI TECHNICAL EXPERTS

Tom Short

Innovation

A Deep Dive into Wind Turbine Performance

EPRI Uses Data Analytics to Increase Wind Power Production

By Chris Warren

With 536 gigawatts of global capacity as of 2017, wind power is a mainstream power source. Yet as operators focus on reducing wind energy's levelized cost of electricity, they face a significant barrier: The metrics typically used to assess wind farm performance don't provide a clear picture of energy production and the potential for improvement. There is a potential solution: Readily available turbine data can be analyzed to reveal underperformance, guide maintenance, and reduce operational costs.

"Operators use metrics that tell them how often the turbines are running, which is usually between 95% and 98% of the time," said EPRI Senior Project Manager Brandon Fitchett, who is leading research to improve measurements of wind farm performance. "The industry is very good at assessing how often wind assets are running but does not know precisely how *well* they are running."

The most widely accepted method for assessing efficiency involves measuring the wind speed that hits a turbine along with its corresponding power output. "This standard test, established by the International Electrotechnical Commission (IEC), uses wind speed sensors to correlate wind speed and power output," said Fitchett. "The IEC test typically uses calibrated instrumentation mounted on a hub-height meteorological tower or other calibrated wind measurement equipment located upwind from the turbine," said Fitchett. "This is not cost-effective nor physically possible to maintain in front of every turbine for the life of a project."

Typically, such measurements are taken on a small subset of a wind farm's turbines during the first year of operation, and they don't account for equipment degradation and performance shortfalls over time.

EPRI is examining analytical techniques with potential to monitor performance of wind farms more comprehensively and accurately.

Operational expenses account for more than a quarter of onshore wind's levelized cost of electricity. Better measurements and data analytics can reduce these expenses while boosting turbine production and revenue. A 1% annual production increase at a typical wind farm with 100 two-megawatt turbines can boost revenue by $250,000–$500,000. Based on EPRI's performance analytics research, most wind farms likely have an opportunity to increase production.

Collaborating with power companies such as Duke Energy, DTE Energy, and Southern Company, EPRI is examining and implementing innovative analytical techniques with potential to monitor performance more comprehensively and accurately. At several wind farms across the United States, EPRI researchers are testing these methods using up to three years of supervisory control and data acquisition (SCADA) data from hundreds of wind turbines.

"We're using the owners' databases to collect about 100 readily available, historical data streams from each wind turbine, including the speed and direction of wind, the pitch of turbine blades, the rotation speed of rotors and generators, and power output," said Fitchett.

After the turbine data go through a quality assurance process, researchers use them to analyze power production over time. Results for each unit are compared with those of nearby turbines as well as with generation estimates provided by turbine manufacturers. By analyzing months of data in this way, EPRI pinpointed turbines that were underperforming, investigated the causes, and recommended corrective actions to increase power production.

"The analyses revealed that the biggest opportunities to improve performance involved correcting equipment calibration, such as blade pitch and alignment with the wind," said Fitchett.

EPRI confirmed Duke Energy's suspicion that extended shutdowns as a result of high winds had negatively impacted production at some of its wind farms. "We knew it impacted us but didn't realize to what extent," said Dustin Wambeke, director of performance services at Duke Energy Renewables. "EPRI was able to capture that for us precisely. We can now correct the problems ourselves or inquire more intelligently with the manufacturer."

Seeing the value in better performance assessment, Duke Energy recently hired new wind power staff with expertise in analytics. "We want to maximize the value of our data and enable our performance engineers to identify and fix problems using more sophisticated analytical techniques," said Wambeke.

EPRI is sharing its findings with participating utilities, enabling them to monitor and mitigate turbine underperformance.

"We're handing over results that companies can use immediately, and we're providing them with techniques that they can use on their entire fleets for years," said Fitchett—adding that the results of this project could inform a new standard for measuring wind turbine performance.

EPRI plans to provide utility members with best practices and methods for turbine performance monitoring, along with documentation of common underperformance problems and corrective actions. EPRI is developing new methods that enable operators to use monthly (rather than annual) data to identify turbine underperformance promptly.

Wind turbine performance monitoring is part of a broader body of EPRI collaborative research aimed at reducing wind power costs and improving performance and reliability.

KEY EPRI TECHNICAL EXPERTS

Brandon Fitchett, Rajasekhar Pulikollu

Technology At Work

A Twist in Hydropower Monitoring

Torsional Vibration Sensors Enable Operators to 'Feel Around' for Trouble

By Mary Beckman

In 1991, mechanical engineer Eddie Duncan was the lead startup test engineer for Duke Energy's new Bad Creek Hydroelectric Station near Salem, South Carolina. His mission was to prepare the 1,065-megawatt plant for safe, reliable service.

Today, Duncan still works for Bad Creek but has a new, additional assignment—to increase its power output. This comes at a time when Bad Creek and other Duke Energy power plants serve a growing customer base and operate alongside intermittent renewable energy sources.

"It is exciting to be able to be there for the initial startup and then have the opportunity to be part of the team doing upgrades 30 years later," said Duncan, now Duke Energy's director of regional services for regulated renewables.

The upgrades include more than a power boost. Recent changes in hydropower operations are driving new maintenance needs and approaches. Plant staffs are smaller. Many plants are remotely operated, and traveling maintenance crews make rounds regularly. Plants increasingly operate in flexible modes, which include starting and stopping units and operating at lower power levels. Manufacturers are designing plant equipment to be lighter and more efficient.

With this new direction for hydropower, EPRI researchers are working with utilities such as Duke Energy to improve sensor applications and monitoring systems to help catch minor problems before they become major ones.

One potential problem that's difficult to monitor in hydropower turbines is torsional vibration, which occurs when objects twist.

"Torsional vibration is difficult to detect with standard vibration monitoring equipment, and most torsional vibration monitoring systems are expensive," said Clay Boyd, who monitors the condition of hydropower plants for Duke Energy. "Some utilities have had catastrophic failures due to a torsional vibration problem, but they are fairly rare."

"We've seen multiple cases of shaft failure or shaft coupling hardware failure in the hydropower industry," said EPRI Senior Project Manager Megan Nesbitt. "These failures may have been caused or compounded by torsional vibration."

Several years ago, EPRI engaged New Hampshire–based Suprock Technologies to collaborate with EPRI to develop and commercialize the Turbine Dynamics Monitoring System, a collection of sensors that continuously monitor turbines in nuclear and fossil power plants for torsional vibration, torsional strain, axial strain, and axial vibration.

Unlike other torsional vibration sensors, this monitoring system uses radio frequency transmitters for power and data transmission, so operators don't have to stop the turbine to replace batteries or download data. The readout is a set of vibrational frequencies that can be analyzed to identify problems with components.

EPRI is collaborating with Bad Creek, a pumped hydro storage facility, to adapt this system for use with turbines and other components in hydro plants.

To account for the slower rotational speed of hydro turbines relative to steam turbines, the team added an extra antenna to the monitoring system and deployed it on Bad Creek's turbine shaft and rotor in

2017. For about a year, a technician collected data from the sensors regularly. To collect supporting data, researchers tested auxiliary sensors on other plant components such as the gates.

According to Duke Energy's Duncan, the utility plans to upgrade the facility from 350 to 420 megawatts by altering the design of the turbine runner. Data from the monitoring system will enable engineers to compare the old and new turbines.

"By using the sensors, we've identified frequencies of concern that indicate torsional vibration," said Duncan. "We can use this information to pinpoint problems with the new turbine design."

The monitoring system also revealed the plant's normal vibrational frequencies so that operators will know when it malfunctions. For example, the team found that each of the facility's two operational modes—generating electricity and pumping water into the upper reservoir—produced different frequency signatures.

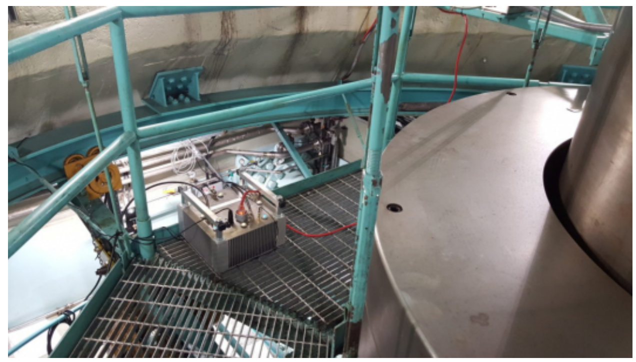
Another observation gleaned from the system's readouts: Seasonal changes in lake level and water temperature affected the water's path and the rotor dynamics.

"Hydro plants are akin to living systems," said Chris Suprock, principal investigator of Suprock Technologies. "Understanding their regular behavior can help you avoid misdiagnoses."

EPRI is developing software to enable operators to collect and analyze vibrational data automatically and in real time. This will help run plants with smaller staffs.

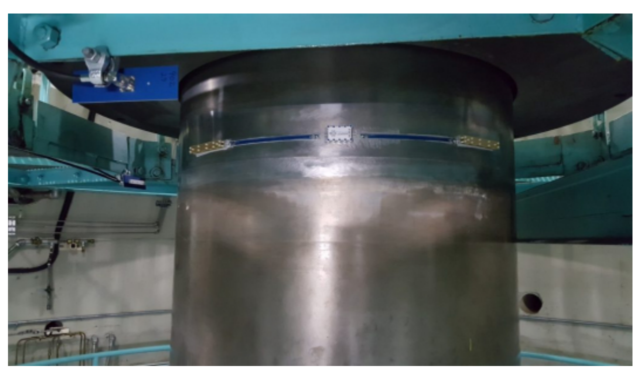
"Innovative application of sensors can inform hydropower owners and operators on the health, operation, and efficiency of their plants," said Nesbitt. "This can provide insights previously not available and result in increased reliability as the use of hydropower plants changes."

Bad Creek Hydroelectric Station. Photo courtesy of Duke Energy.



Stationary components of the monitoring system placed in the turbine room of Bad Creek Hydroelectric Station.

Readout from the monitoring system's interface at Bad Creek Hydroelectric Station.



Monitoring components deployed on the turbine shaft at Bad Creek Hydroelectric Station.

'We Listen, We Look, We Smell'

For decades, humans have served as essential 'sensors' for monitoring hydropower plants.

When opening the gates and flipping the switches for the first time in a new or refurbished hydro facility, the operators position people around the plant so that the startup goes smoothly.

"We'll probably have two people up top, two people near the generator, two people in the turbines, some people down below, all paying close attention for anything unusual," said EPRI Senior Program Manager Megan Nesbitt. "We listen, we look, we smell."

Unusual sounds, sights, smells, and sensations will tell them if something unexpected has happened in the plant's systems, directing technicians to inspect. An oily acrid smell might indicate a malfunctioning pump that needs to be replaced. A bearing might run a little hot—though an operator might know that this particular component always runs a little hot and that it's nothing to worry about.

"Some operators will even say, 'I was on the headcover today, and it seemed to be vibrating a little more than usual,'" said Nesbitt. "That sounds a little subjective, but these people know their plants."

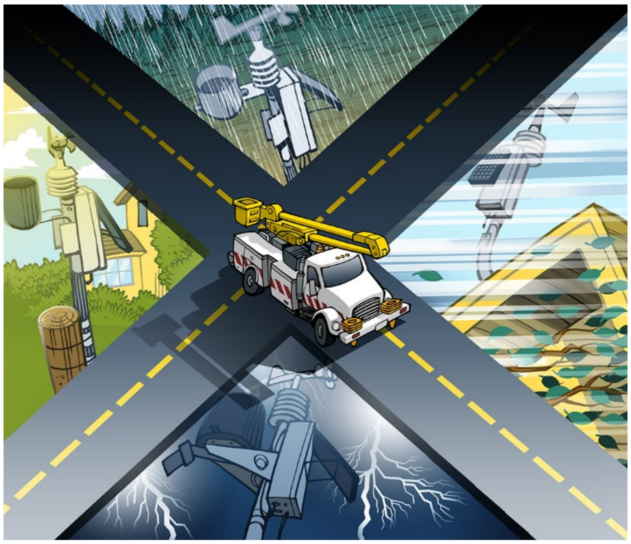
KEY EPRI TECHNICAL EXPERTS

Megan Nesbitt

R&D Quick Hits

A Utility 'Crystal Ball' for Weather

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



EPRI, Ameren Missouri, and Saint Louis University demonstrated that carefully designed mesonets coupled with customized models can provide utilities with weather forecasts superior to traditional sources alone.

Forecasts from those sources, such as the National Weather Service, The Weather Channel, and AccuWeather, do not provide local detail necessary to guide crew positioning ahead of severe weather. Regionally configured mesonets can potentially provide more precise data to weather- and damage-forecasting models, enabling better utility response.

Using Saint Louis University's QuantumWeather® algorithm, researchers determined the optimal placement of more than 100 weather stations for a mesonet in Ameren Missouri's service territory, with 1.2 million electric customers. Over the past several years, weather data from the mesonet enabled a 40% reduction in average forecasting error relative to the National Weather Service. More than 700 storm simulations validated this improvement. Other findings:

- Forecasts derived from properly configured weather sensors are more precise with respect to storm intensity and location.
- Areas with the greatest population density and load generally require more sensors than rural areas.

Recently, researchers used the algorithm to [propose optimal mesonet configurations] in portions of the service territory of American Electric Power. The utility desired 24-hour notice for conditions producing more outages than can be handled by their regular crews. This research pointed to the importance of considering a region's weather history and topography along with a utility's unique response needs.

Key EPRI Technical Experts

Doug Dorr

A weather station deployed in the service territory of Ameren Missouri. Photo courtesy of Ameren Missouri.

EPRI JOURNAL

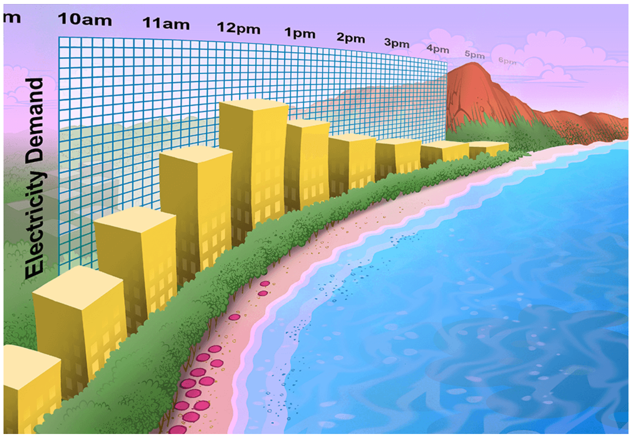
R&D Quick Hits

Demand Response, Waikiki Style

At three large hotels on Hawaii's Waikiki Beach, researchers have demonstrated that a new, "fast" type of demand response can yield significant load reductions without sacrificing customers' comfort. The project was a collaboration among EPRI, Hawaiian Electric Company, and the U.S. Department of Energy's Lawrence Berkeley National Laboratory.

Demand response can offer a cost-effective option to balance intermittent generation from widespread deployment of rooftop solar in Hawaii. During traditional demand response, utility customers reduce energy use for 3–6 hours during peak load periods, with advance notice ranging from 12 hours to 2 days or more. With fast demand response, buildings are asked to reduce load for an hour, with as little as 10 minutes of advance notice. Because of the shorter demand response periods and flexibility to implement them over a much longer window (7 am–8 pm), this approach offers potential for deeper load reductions.

Researchers implemented new control technologies for in-room thermostats and ice and soda machines at the hotels, which have peak loads ranging from 500 kilowatts to 3 megawatts. The tests showed that 10–15% of total building load could be shed during fast demand response, with a total load reduction of up to 1 megawatt. The primary reduction came from the chillers; other reductions included heat pump water heaters and swimming pool heating.



The buildings' latent capacity enabled them to pass through a 1-hour cooling load reduction without substantial loss in comfort, as verified by customer surveys. This outcome is significant for the hospitality sector, which has historically been reluctant to participate in demand response because of concerns that it might sacrifice customer satisfaction.

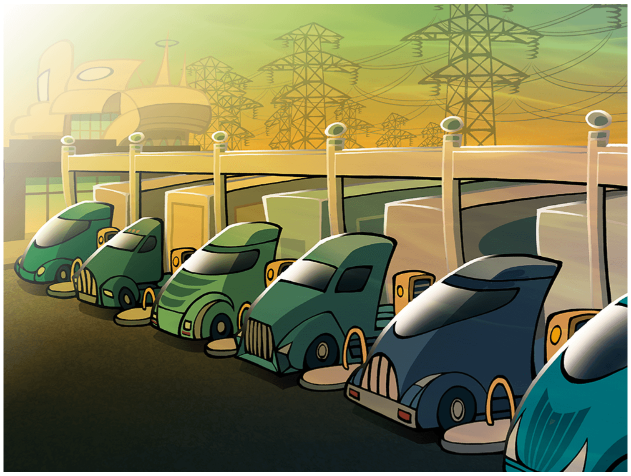
EPRI's new Advanced Buildings program is conducting various research projects examining how buildings can serve as a grid resource.

KEY EPRI TECHNICAL EXPERTS

Ram Narayanamurthy

R&D Quick Hits

It's Time to Prepare the Grid for the Long Haul



With electric long-haul trucks on the way, utilities need to prepare for higher power charging and related grid impacts, according to an EPRI Quick Insights paper.

With falling battery prices, more truck manufacturers are considering production of short- and long-haul electric trucks. Daimler's trucking division is deploying and testing two medium-range electric trucks. Tesla announced plans to manufacture trucks with 300-mile and 500-mile ranges, beginning next year. While the price of the 500-mile model ($180,000) is $60,000 more than a diesel-fueled semi truck, Tesla claims that its truck will save about $250,000 over the first million miles relative to a diesel. Dozens of companies have placed advance orders.

To be viable, electric semis require widely deployed high-power fast chargers, with significant implications for the electric grid. The 500-mile Tesla model will require 1.6 megawatt chargers to provide 80% of capacity in 30 minutes, which in turn will require truck stops to add these chargers. Consider this: If the world's largest truck stop in Walcott, Iowa, deployed 35 such chargers, it would add a connected load of 63 megawatts.

"This amount of power may be available in an optimally located truck stop, but it may require expensive upgrades in others," the report says.

The Charging Interface Initiative (CharIN), a charging standards group, is working on a charging connector that can handle up to 1.6 megawatts.

EPRI is evaluating the four largest fast charging plazas in the United States, examining how to plan for and deploy high-power fast charging plazas for all sizes of electric vehicles—and assessing the potential impacts on distribution and transmission grids.

KEY EPRI TECHNICAL EXPERTS

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