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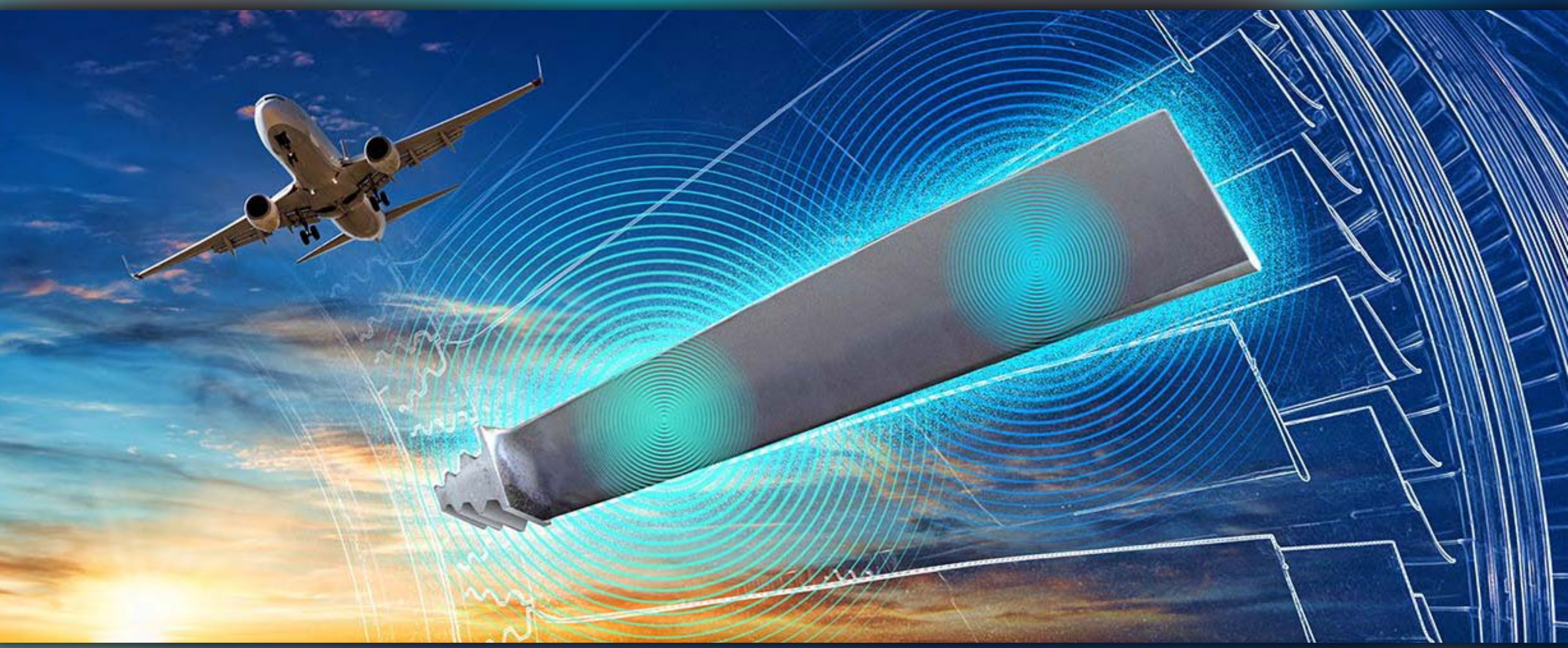
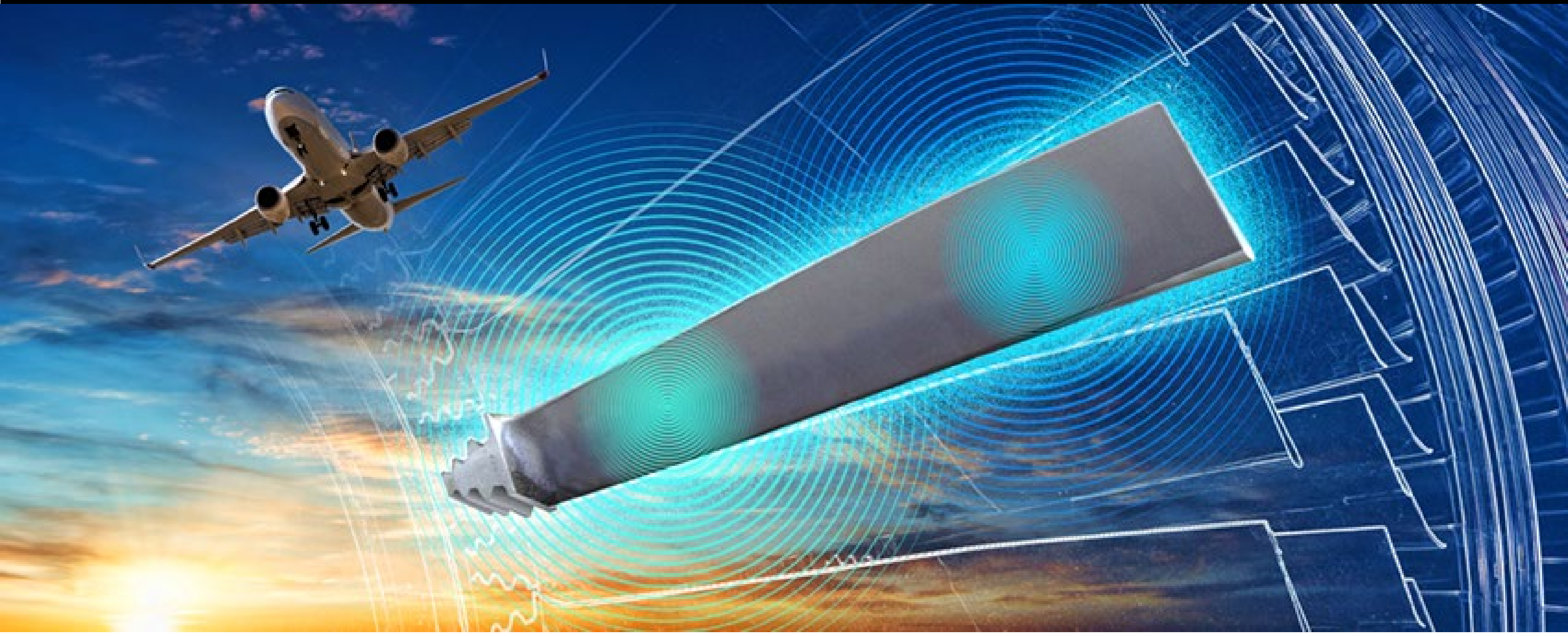
Gas Turbine Inspections Take Flight



ALSO IN THIS ISSUE:

Table of Contents



Gas Turbine Inspections Take Flight

EPRI investigates how technology used to inspect jet engines can benefit utilities

By Chris Warren

A self-described "turbine guy," Clinton Lafferty knows the problems that can potentially occur if gas turbine blades in a power plant fail. "It can be catastrophic," said Lafferty, senior program manager for gas turbines at the Tennessee Valley Authority (TVA). In extraordinarily rare circumstances, blades can come loose and damage surrounding equipment and even injure plant personnel. "There is a lot on the line for keeping turbines running reliably for TVA and other utilities. If a turbine failure leads to an outage, it's not just the costs of replacing the parts. It can also be lost generation revenue, and in the worst cases, it can be a safety issue."

A big part of Lafferty's job is looking for ways to lower the costs and improve the speed and effectiveness of inspecting gas turbine blades that are in service or about to be installed. That's why Lafferty and his colleagues at TVA were eager to participate in an EPRI-led initiative to evaluate the effectiveness of a nondestructive evaluation (NDE) technology called process compensated resonance testing (PCRT) that is new to the utility sector.

PCRT was originally developed by researchers at the Los Alamos National Laboratory to analyze the effects of manufacturing variations on metal components. Albuquerque, New Mexico-based Vibrant Corporation, later commercialized the technology, successfully applying it to the inspection of jet aircraft engines. Like gas turbines in power plants, jet engines have turbine blades that operate in an environment of extreme temperature and pressure. The technology's approval by the Federal Aviation Administration and a Delta Airlines paper on its effectiveness caught the attention of EPRI researchers.

"Delta told the story of applying PCRT to an underperforming engine with an old design and a history of blade failure—and turning this engine into one of the most reliable units in the fleet," said Lem Hunter, president, and CEO of Vibrant. "EPRI called the author of the paper and said, we'd like to come and get an introduction to the technology and see it in action on the Delta floor. That led EPRI to get in touch with us."

For EPRI, the main question was whether PCRT could effectively inspect industrial gas turbine blades, which are much larger than jet engine blades. EPRI, Vibrant, and utilities like TVA have now tested more than 12,000 turbine blades using PCRT. The results so far have convinced gas turbine experts like TVA's Lafferty that PCRT has an important role in a gas turbine's inspection regimen, which includes other NDE technologies such as eddy current probes, X-rays, CT scans, and visual inspections by utility personnel.

"If we were to do a full series of NDE tests on a set of blades, it might take anywhere from a few days to several months, depending on which tests we were doing. PCRT takes between one and five minutes for us to identify potential problems in need of further inspection," said Lafferty. "We're now looking into how we can integrate PCRT into our inspection process."

HOW PCRT WORKS

Consider that bells make different sounds depending on their shape and material. For example, a bell made of bronze sounds different than a bell of the exact dimensions made of aluminum because each material has a different elasticity. While a particular bell may make the same sound for years, it will emit a very different sound if it cracks. In other words, each bell has a sound signature—a set of sound waves with measurable frequencies—that can reveal a lot about its properties and health.

Like bells, turbine blade components resonate at different frequencies depending on their geometry, mass, materials, and defects. PCRT involves recording and analyzing the resonant frequencies of these components. If a frequency is far out of line with what is considered normal, that can indicate a problem.

Here's how PCRT works: A technician uses a piezoelectric transducer to feed energy into turbine blades, causing them to resonate at specific frequencies. With the use of algorithms and advanced pattern recognition software, these resonant frequencies are compared with a database of frequency data to identify potential abnormalities. Based on this analysis, turbine blades with standard resonant frequencies earn a passing grade, while those with irregular frequencies fail.

To enable this kind of analysis, EPRI has compiled a database of model-specific blade frequency characteristics of more than 12,000 turbine blades—a number that continues to grow as Vibrant, EPRI, and utility members test more turbine blades. When coupled with this database, PCRT can be used to assess a turbine blade's current health relative to what would be expected if it were aging normally.

"We are vibrating parts to identify common patterns of resonant frequencies when the parts are performing properly," said Hunter. "When there are disruptions to the patterns in those resonant frequencies, that can be due to material property changes and damage, such as fatigue."

"Vibrant owns the technology and the proprietary algorithms, and its work led to the development of ASTM standards for PCRT," said Nicholas Smith, a technical leader in EPRI's gas turbine turbomachinery design and maintenance group. "EPRI provides knowledge and understanding of gas turbine components and is working with Vibrant to do the testing and assemble this database."

EACH INSPECTION TECHNOLOGY HAS A ROLE

PCRT adds to the menu of tools utilities can use to assess turbine blades quickly and inexpensively. "This is a very inexpensive, rapid test, taking just one to five minutes per part. You can inspect all your components in a short amount of time and isolate and identify ones that may be suspect," said EPRI's Smith.

X-rays, CT scans, eddy currents, visual inspections by turbine experts, and other techniques each have strengths and limitations. For example, X-rays are extremely powerful in identifying structural defects but can expose workers to radiation, and excessive use can raise health concerns. In addition, X-ray inspections are expensive and require components to be shipped to and from an inspection site, which can take days. Perhaps no inspection is as effective as the close visual examination of a turbine blade by an expert. But that is not a scalable solution, given the high volume of inspections necessary and the attention to detail required to pinpoint problems. For example, a General Electric 7HA gas turbine has 300 blades that require inspection.

PCRT can complement these techniques. "There's almost never just one inspection that can be done on a part that gives you all of the information that you need," said Hunter. "If we really want the highest reliability for turbines, we want to employ all of the technologies at the right time, at the right place, and in the right way."

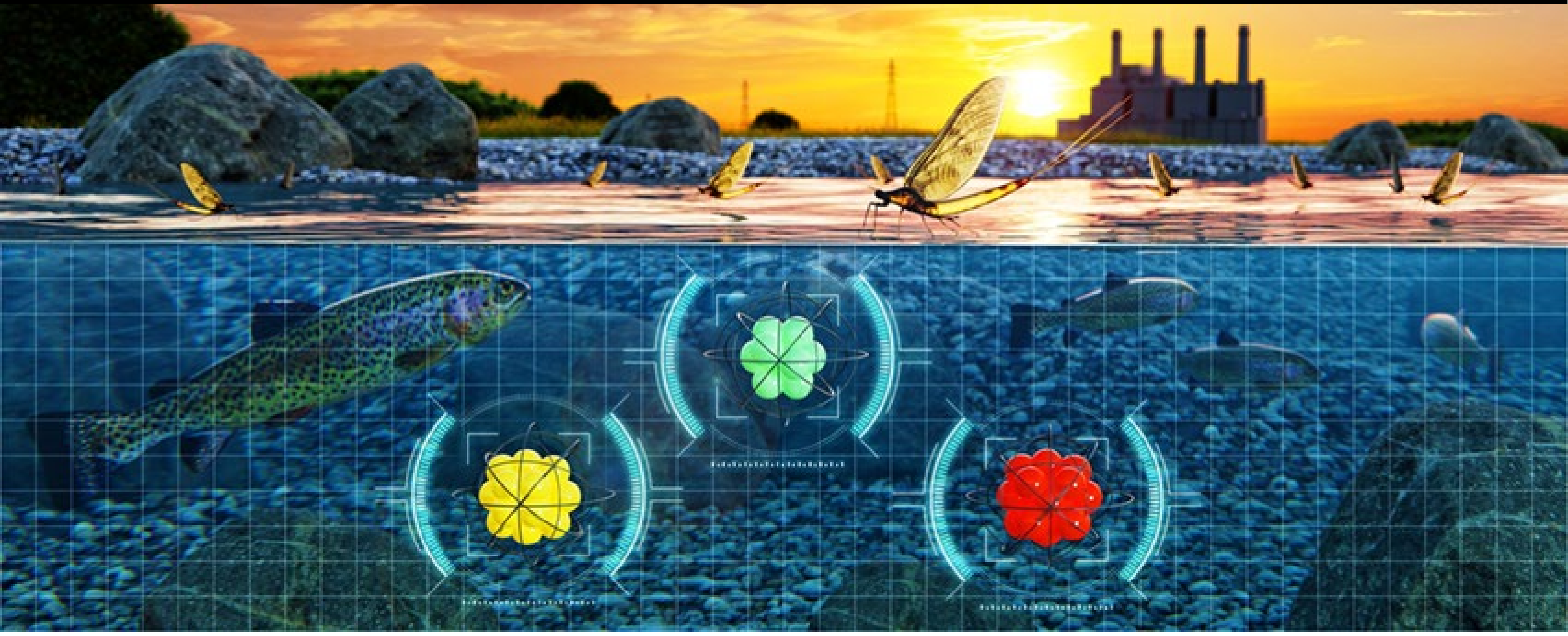
PCRT's role in inspections might be to diagnose issues that require additional inspection quickly. "If you are looking for a specific type of defect in a specific area of a component, like an indication of a crack, a fluorescent penetrant inspection is the way to go," said Smith. "That is the most detailed inspection for that type of defect. But what PCRT can do is perform an inspection of the whole component and point you towards potential problem areas where you could use additional inspection techniques."

The addition of PCRT to a utility's inspection toolbox can also provide more assurance about manufacturers' and maintenance companies' quality of components and services. "We're putting tools in the hands of the plant operators to help them determine whether they're getting the quality that they paid for," said Hunter.

For its part, EPRI will continue to expand the database of turbine blade characteristics and partner with utilities interested in PCRT. "Our goal is to bring the industrial gas turbine world up to the same speed as the aerospace world," said Smith. "We want to be able to inspect components on a pass-fail basis. We're confident this can help utilities perform inspections even more quickly and cheaply than ever before."

KEY EPRI TECHNICAL EXPERTS

Nicholas Smith



EPRI Models Inform a More Site-Specific Approach to Water Quality Protection

By Chris Warren

Two new EPRI models aim to enhance the effectiveness of water quality protection at power plants.

Wastewater produced by steam electric power plants can contain pollutants such as mercury, arsenic, and selenium. The U.S. Environmental Protection Agency (EPA) and state regulators both play a role in developing rules that limit discharge of these pollutants into bodies of water.

"To protect aquatic life and human health, the EPA develops water quality criteria, which define the maximum amount of a pollutant that can be present in water," said Jeff Thomas, a water quality expert at EPRI. "Then states take those criteria and turn them into standards that can be applied statewide. For example, a statewide standard could say that no body of water can have more than 12 parts per trillion of mercury."

States use these standards to grant power plant permits that define allowable levels of pollutant discharge into bodies of water. Utility compliance personnel typically sample and test wastewater discharges every quarter (or sometimes more frequently) to ensure permit limits are not exceeded. Permits generally are up for renewal every five years.

FROM CONDUCTIVITY TO THE MULTI-ION TOXICITY MODEL

The health of aquatic life like mayflies and fish can be negatively affected when the concentration of total dissolved solids in fresh water is high, particularly when salts separate into ions. The cooling of power plant turbines involves a recirculation process that concentrates salt ions through water evaporation. In addition, flue gas desulfurization systems that remove sulfur dioxide from combustion gases discharge wastewater with salt byproducts.

Recognizing the link between high ion concentrations and adverse impacts on aquatic life, regulators historically have considered establishing water quality criteria that include limits on conductivity levels. "The more salt and ions like potassium, calcium, magnesium, and chloride you have in the water, the higher the conductivity level is going to be," said Thomas. "There is a correlation between conductivity levels and the health of aquatic organisms."

However, the latest science indicates that the prevalence of seven specific ions—including calcium, sodium, and potassium—is more predictive of the potential harm to aquatic life than conductivity levels. This means that two water samples with the same conductivity levels could have very different toxicity levels, depending on the combination of ions present.

"The toxicity is dependent on which ions make up the conductivity level," said Thomas.

Drawing on this science, EPRI and the environmental services company HDR, Inc. have developed the multi-ion toxicity (MIT) model, a tool that can predict ion toxicity to aquatic life more accurately than traditional conductivity measures. In addition to measuring the conductivity of their quarterly water samples, utility compliance personnel can analyze their ion composition and feed that information into the MIT model, which predicts the impacts on various aquatic species. The model can enable regulators to develop site-specific water permit limits based on the unique chemistry of wastewater discharges and the water bodies that the discharges enter.

"Site-specific criteria allow regulators to move away from a uniform, statewide measure of conductivity," said Thomas. "This process creates discharge permit limits that are more tailored to local conditions rather than applying a one-size-fits-all approach."

The model's beta version currently is available for testing by utilities that funded its development, and EPRI will incorporate their feedback. EPRI is also collaborating with the EPA to strengthen the model. If the EPA accepts it as a tool for utility use, it could improve the accuracy of water quality permits, enhance environmental protection, and allow utilities to direct limited resources to other important environmental issues.

"The potential benefits of this new approach for utilities, customers, and the environment are enormous. If utilities can't meet a conductivity limit, they may have to install wastewater treatment technologies or transport wastewater for discharge in a different body of water—both of which could cost hundreds of thousands or millions of dollars," said Thomas. "A site-specific permit limit based on ion composition rather than conductivity levels could result in additional protection of aquatic organisms. In other cases, it could loosen permit limits that don't provide any additional environmental protection, allowing companies to focus their resources on genuine environmental risks."

THE BIOTIC LIGAND EPISODIC EXPOSURE MODEL

EPA water quality criteria—and associated state permits for allowable power plant discharges of contaminants—are based on tests in which aquatic organisms are continuously exposed to a particular contaminant for a defined period, such as 24 hours or 96 hours. But in many cases, power plants do not discharge contaminants into bodies of water for extended periods of time. For example, power plants discharge water accumulated during rainstorms, which can often contain zinc and copper.

"During or after a storm, the plant may flush the majority of the contaminants out in an hour," said Thomas.

EPRI partnered with the consulting company Windward Environmental and University of Florida researchers to better understand the risks of episodic copper and zinc exposure to the fathead minnow and a certain type of water flea. They consistently found that shorter exposure times led to lower mortality rates. "The results of this research suggest that water quality permits based on an assumption of long-term, continuous exposure to pollutants will overestimate the toxicity to aquatic life," said Thomas.

The findings prompted the question, could water quality standards and permits be made more effective by accounting for the intermittent nature of discharges? To answer this question, EPRI developed the biotic ligand episodic exposure model, which is expected to be available this year for testing by utilities.

To assess exposure of aquatic organisms to zinc and copper, users input into the model information on a discharge's zinc, copper, and dissolved ion concentrations as well as its organic content, pH, and temperature. Another key input is the amount of time the organisms are exposed to each of the measured parameters. The output of the model is the likelihood of toxicity of a given discharge to various aquatic organisms. In the short term, this model offers value in characterizing the potential toxicity of stormwater and other intermittent discharges. In the long term, if the model is adopted by the EPA and state regulators, it could be used to determine site-specific permit limits.

"This model can enable utilities to conduct site-specific analyses that take into account the actual exposure of aquatic life to zinc and copper," said Thomas. "It can inform permit limits based on a more accurate understanding of the impacts of pollutants while minimizing the use of assumptions about how long aquatic life is exposed."

KEY EPRI TECHNICAL EXPERT

Jeff Thomas

The Right Education for Utility Workers of the Future

By Chris Warren

Nanpeng Yu has had a unique career trajectory. Before becoming an associate professor in the Department of Electrical and Computer Engineering at the University of California, Riverside (UC Riverside), he spent nearly four years at Southern California Edison (SCE). While at SCE, Yu worked as a senior power system planner and managed the integration of more than a gigawatt of demand response resources into California's wholesale electricity market. Yu's professional experience helped him understand the challenges utilities face in recruiting and hiring workers with the skills needed to operate an increasingly distributed, clean, and digital power system.

"Utility hiring managers tell me that they are struggling to find people who have the skills to use new tools for analyzing the big data sets that utilities are collecting from smart meters, asset management systems, and SCADA systems," said Professor Yu.

New technologies and digital tools are reshaping the day-to-day responsibilities of utility workers. For example, utility workers record data on handheld tablets rather than paper and clipboards and use data analytics to plan investments in future grid infrastructure. "One of the fundamental components that makes the electric system dependable is the protective relay," said Tom Reddoch, a principal technical executive at EPRI. "Historically, protective relays were electromechanical devices and later solid-state units. Now they are digital, and new skills are needed to deploy and manage them."

For his part, Yu is working on training more students at UC Riverside to develop the data science and power engineering skills upon which utilities increasingly rely. But Yu and other academics know that traditional undergraduate curricula need a comprehensive upgrade to adequately prepare students for tomorrow's utility jobs.

"Cyber security is almost nonexistent in the current university power curriculum, but you don't have to convince anybody at utilities about its importance," said Chen-Ching Liu, a professor in the Department of Electrical and Computer Engineering at Virginia Tech University and a global expert in cyber security for power systems. "In some important areas like cyber security, curricula are five to 10 years behind what is happening in the utility industry."

IDENTIFYING SKILLS UTILITIES NEED

Liu and Yu, along with colleagues from five of the top electric power and information science universities in the United States, recently took part in a U.S. Department of Energy (DOE)-funded and EPRI-led initiative called the Grid-Ready Energy Analytics Training with Data (GREAT with Data) initiative. GREAT with Data aims to train and educate the utility industry's future workforce to plan and manage the grid with transformative digital technologies effectively.

"GREAT with Data addresses the convergence of operational technology and information technology," said Reddoch. "It focuses on the skills associated with collecting, communicating, storing, analyzing, and securing data and how to effectively use these skills in utility operations."

As part of GREAT with Data, EPRI and its academic partners identified three increasingly fundamental areas to the safe, reliable delivery of electricity: data analytics, information, and communications technology; cyber security; and integration of distributed energy resources (DER).

Drawing on feedback from EPRI, utility hiring managers, and subject matter experts, professors from the five partner universities identified the skills students should acquire in each of these three areas by the time they graduate. The professors then examined 84 courses from 19 universities to determine which skills were not addressed. The analysis pointed to significant gaps in all three areas.

For example, the evaluation of data analytics curricula revealed numerous courses on machine learning and other data science topics, but most of the courses were for graduate students, not undergraduates. General data science courses for undergraduates exist but do not cover how the knowledge can be applied to power systems, leaving students to seek additional training to connect the dots.

"Most hires in the utility industry are undergraduates, not graduate students, who often go to work for consultants or get their PhDs," said Reddoch.

As one example of a gap found in DER integration, courses contained inadequate instruction on how energy storage and flexible loads can be used to mitigate grid impacts of intermittent renewable energy. The study also revealed that there is minimal instruction about how communication technologies (such as 5G), cloud and edge computing, and artificial intelligence can be used to improve power system reliability, security, and resiliency.

The analysis of curriculum gaps is part of EPRI's GridEd workforce development initiative, which brings together utilities, universities, government, and other power industry stakeholders to help students and utility workers acquire the skills needed in a rapidly changing industry. In 2020, with the support of the DOE, the initiative assembled course materials from 21 undergraduate- and graduate-level courses covering many of the topics identified in the curriculum gaps analysis. These materials, available on EPRI|U's website, can be used by universities to adjust their curricula or by utilities to train their workforce. In addition, EPRI and the academics involved in the gap analysis are developing sample curriculum modules that universities can use to update their courses.

UTILITIES HAVE A ROLE IN CHANGING CURRICULA

Getting universities to update their curricula is no simple matter. Virginia Tech's Liu says that providing sample course modules can be helpful, though each school makes its own decisions about new curricula. "EPRI or DOE cannot direct a university to teach these courses," he said. "Each school's curriculum is driven by a unique set of local needs and considerations, including the skills that employers need in the workers that they hire. So there cannot be one solution for all."

Most schools have industry advisory boards that provide input to university deans and department heads about the curriculum. Making changes to undergraduate courses also involves securing Accreditation Board for Engineering and Technology certification.

Utility engagement with universities can be beneficial, given that the job prospects for students influences decisions about curriculum changes. “If universities have active engagement from utilities and see a clear pathway for their students to obtain power industry jobs once they graduate, they may be more likely to change the curricula and invest in new professors to build more power industry-related skills,” said Reddoch.

Some utilities have deepened their relationships with universities by funding professorships, such as Liu’s position as the American Electric Power Professor of Electrical and Computer Engineering at Virginia Tech. Duke Energy has engaged with the University of North Carolina-Charlotte, Clemson University, and North Carolina State University by establishing the Center for Advanced Power Engineering Research, which develops and demonstrates grid modernization technologies while enhancing student education. Southern Company is investing $50 million to support improved training and scholarships for students at 21 historically black colleges and universities.

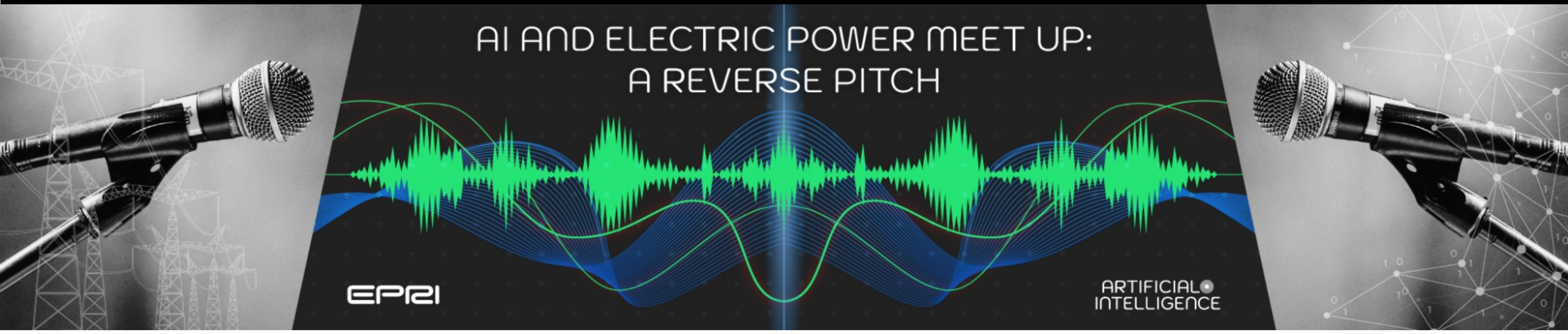
Utilities engaged with EPRI’s GridEd initiative can nominate universities to become affiliates, enabling the universities to receive the curriculum resources developed through the initiative.

Continuing to cultivate these relationships will be essential to develop the workforce of the future. “At the end of the day, utilities need workers with the skills to support the resilience and reliability of a rapidly changing grid, and universities want their students to find jobs and start successful careers,” said Reddoch. “The best way to accomplish that is through relationships between utilities and local universities.”

KEY EPRI TECHNICAL EXPERTS

Tom Reddoch

EPRI JOURNAL



Pitch Perfect

EPRI's reverse pitch event is part of a larger effort to tap the power of AI to benefit the grid and society

By Chris Warren

Successful Silicon Valley entrepreneurs have a knack for pitching their business ideas. A lot of ingredients go into a good pitch. Having an impactful product or service that solves a big problem is fundamental. But successful pitches inevitably require entrepreneurs make educated guesses that the solutions their businesses have labored to develop uniquely address a challenge their audience wants to solve.

That traditional paradigm for matching business solutions with business challenges was completely upended at EPRI's recent Reverse Pitch event for AI and electric power companies.

"When you have solutions that are chasing problems, you often get the situation of trying to force a square peg in a round hole," said Jeremy Renshaw, an EPRI senior program manager who leads the AI.EPRI Initiative, which seeks to promote collaboration among utilities, leading artificial intelligence (AI) companies, and academic researchers. "We wanted to bring the problem to the solution. So we had utilities bring forward data challenges and present them to AI companies and researchers instead. Then the AI community responded with solutions they have or could develop to address these—and potentially other—challenges."

The event brought together utilities like Duke Energy, RTE, TVA, PG&E, PPL, Ameren, and Southern Company, universities such as Stanford and MIT, national laboratories such as Lawrence Berkeley National Laboratory and the National Renewable Energy Laboratory (NREL), as well as AI companies like Intel, Google, and C3 AI. Over 100 organizations participated in the event, where AI experts responded to utility reverse pitches about decarbonization, asset management, digital twins, cybersecurity, grid resiliency, and outage optimization.

For example, Kevin Thompson, a manager for Asset Information and Intelligence for Duke Energy, says he was eager to participate in the event to learn more about how AI and machine learning can help improve the maintenance and replacement of grid assets. "We see huge potential for AI to move us from time-based to condition-based maintenance and replacement so we can reduce failures," said Thompson.

FACILITATING COLLABORATION TO ACCELERATE AI ADOPTION

The reverse pitch event was one of many gatherings EPRI organized to increase collaboration between the two industries and was co-hosted by Stanford University's Bits & Watts Initiative—the university's effort to accelerate technology innovation to benefit the 21st century grid.

Earlier in 2021, EPRI, Stanford, and NREL hosted the event *This is AI: Introductory Training Course and Expert Panel on AI for Electric Power Experts,* which featured presentations by Google, NREL, and

Stanford. Another was the virtual roundtable *Convening AI and Electric Power*, which included participants from AI companies like Microsoft and RWI Synthetics, utilities such as Ameren and CPS Energy, and NREL. EPRI hosted its first *AI and Electric Power Summit* in September, which focused on how AI can accelerate innovation for a clean energy future.

In addition to these events, EPRI researchers are identifying applications for AI in the power industry and educating utilities about a range of AI topics, including technical topics like natural language processing and image processing as well as issues around use cases, data sharing, and data governance.

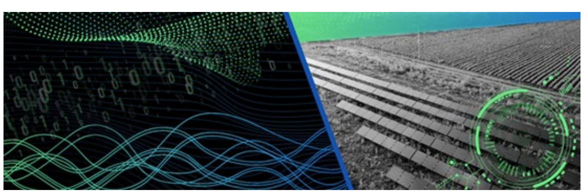
Such collaboration and education are critical for empowering utilities to tap AI's potential value. "The utility sector is very risk-averse. A lot of utilities have applied AI to some areas, but they have not yet realized the full value," said Liang Min, the managing director of Stanford's Bits & Watts Initiative. "We are trying to form a consortium of academia, national labs, utilities, and AI companies to de-risk the adoption of AI technology and accelerate research, development, and deployment of AI."

Grand Challenges to Focus Collaboration

At the AI and Electric Power Summit, EPRI and its collaborators in the AI and utility industries unveiled and discussed a series of grand challenges—specific areas where AI can make a meaningful impact on utility operations and objectives.

Grid-Interactive Smart Communities: As more homes and commercial buildings connect to the power grid, AI can be used to improve communications, energy efficiency, load shifting, and emissions reductions among a vast array of distributed energy resources to support decarbonization.

Energy System Resiliency: AI could help predict weather, electricity demand, and plant and grid conditions. This would allow the power system to continuously optimize in ways that minimize the unplanned outages of assets. AI could also intelligently control energy flows to minimize or eliminate future extreme weather impacts and reduce unplanned outage durations.



Environmental Impacts: AI can help maximize the grid's use of renewable energy, reduce wildfire risk, improve vegetation management, minimize wetland impacts, and help protect endangered species.

Intelligent and Autonomous Power Plants: Resource flexibility is becoming increasingly important as cleaner, distributed energy resources are added to the grid. AI can automate power plant startups and improve maintenance so that central station resources connected to the grid can work together efficiently.

AI-Enhanced Cybersecurity: AI can be used to monitor the power system's information technology (IT) and operational technology (OT) components and systems to identify suspicious activity and respond to potential cyberattacks faster than humans can and help to support human cyber experts.

COLLABORATION TO UNLOCK THE POTENTIAL OF AI

While the grand challenges are distinct and require unique solutions to address properly, they all share something important. They are critical to the success of the future power system and represent significant enough challenges that no single utility or organization can solve alone. Collaboration across industries and companies is a necessity.

One of the presenters at the reverse pitch event was Steve Orrin, who leads Intel's technology engagement with the government. Orrin discussed AI's potential to identify cyber attacks on the grid more quickly and also serve as a tool to improve grid resilience. "Good AI can understand normal and abnormal grid behaviors," he said. "It can also prevent outages because the anomalies it detects could be related to a fault that can be addressed with maintenance."

Orrin emphasized that for utilities to derive value from AI, they need large, high-quality data sets along with rules that protect that data. "The hard part is not developing AI models; it's getting the right data to drive the models," he said. "The number one barrier to improving cybersecurity is getting access to data from IT and OT."

According to Orrin, before utilities can apply and reap the benefits of AI, large datasets need to be collected, curated, protected, labeled, and shared. It's those large data sets—which may be impossible for any single utility or organization to collect—that allow AI models to be built and to improve continuously. EPRI has assembled ten datasets, called the EPRI10, spanning topics from maintenance to operations to power quality and even satellite imagery that utilities can use to build AI models.

While utilities are constrained by strict regulations related to customer data, Orrin says that there are precedents that utilities can follow. "This requires governance. You don't just publish IT and OT data. You need to anonymize the data and compile it to create models," he said. "We've seen how to do this in financial services and in government."

Duke Energy's Kevin Thompson says that he is particularly interested in EPRI's efforts to advance power industry-wide data sharing and collect high-value datasets that can accelerate the industry's use of AI. "We want all utilities to share their data so that they can leverage AI and machine learning," said Thompson. "By ourselves, we don't have enough data. We need other utilities to join us in this effort and to structure their information in the same way. If I call something an apple and you call it an orange, we can't work together."

Duke Energy already uses AI to identify transformers at risk of failure and in need of additional testing and maintenance. The utility is examining the use of AI to inform decisions about replacing a wider range of aging grid equipment. "Many utilities are in the same place as us. A lot of grid infrastructure was built over 50 years ago and can't be replaced all at once," said Thompson. "AI and machine learning can tell us the risk of equipment failure, which can be more effective than the historical approach of replacing equipment based simply on how long it has been operating."

KEY EPRI TECHNICAL EXPERT

Jeremy Renshaw

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