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OPERATIONS & MAINTENANCE Special Report

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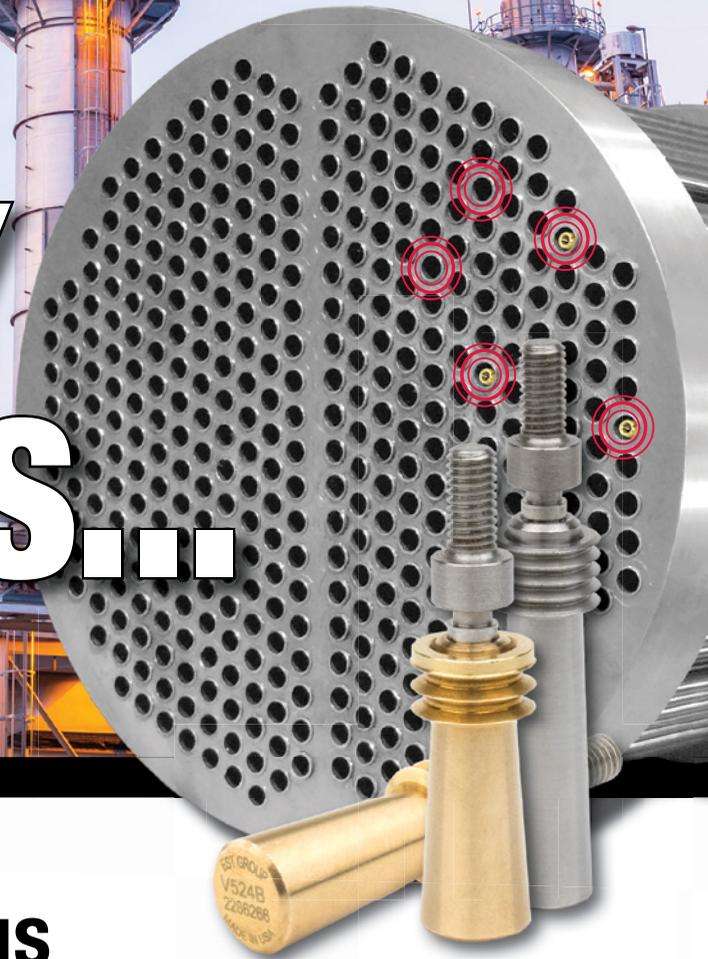
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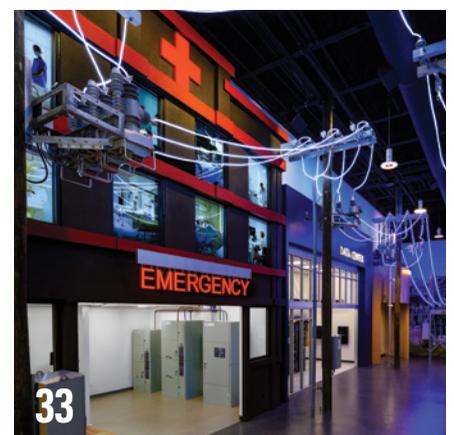
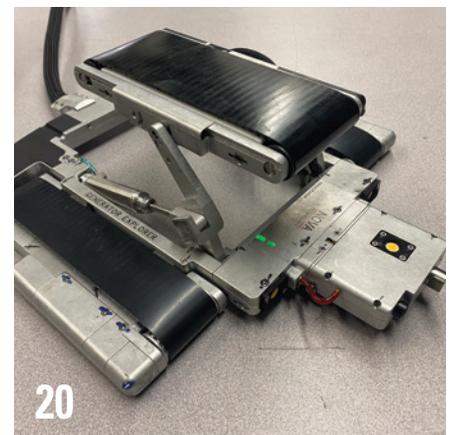
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ON THE COVER

In the power industry, sound operations and maintenance (O&M) practices are the critical backbone of reliability, preventing costly equipment failures and ensuring uninterrupted service. Proactive maintenance strategies not only extend asset life and minimize downtime, but also represent a strategic investment that can reduce operational expenses while enhancing plant performance and safety. *Source: Shutterstock*



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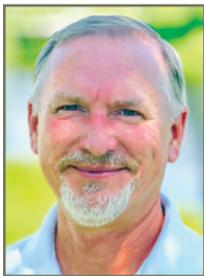
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PSEG Program Unlocks Neurodivergent Talent, Transforms Business and Lives

Aaron Larson

What does it mean to be neurodivergent? The term basically applies to people whose brains work in an atypical fashion. It was coined in the 1990s to counter stigma against people with autism, ADHD (attention-deficit/hyperactivity disorder), and learning differences such as dyslexia. Somewhat surprisingly, 19% of Americans in one recent survey said they personally identify as neurodivergent.

Neurodivergent individuals can bring unique strengths to the workplace. Some neurodivergent workers are able to focus deeply and pay great attention to detail—they can often maintain intense concentration on specific tasks and notice subtle patterns or errors that someone else might miss. Others are creative problem-solvers or have remarkable persistence and resilience, having navigated many challenges over the years, which may have forced them to develop strong determination. Many neurodivergent individuals also have deep expertise in their specific areas of interest, and they tend to be straightforward in their communication, which can help reduce misunderstandings and promote clearer workplace dialogue.

Unfortunately, neurodivergent individuals are often overlooked in the workplace and in the hiring process. As a result, neurodivergent individuals frequently experience higher rates of unemployment and underemployment compared to the general population. Furthermore, those that do make it into the workplace, sometimes feel unsupported by their employers.

PSEG's Neurodiversity Works Program

Public Service Enterprise Group Inc. (PSEG) is a diversified energy company with about 12,500 employees and headquarters in Newark, N.J. In 2021, when the business world was dealing with how to navigate labor shortages and COVID, PSEG developed its "Neurodiversity Works" program. The intention was to provide access to employment for

neurodivergent individuals and create a supportive working environment to help them succeed.

"In full transparency, we knew other companies were doing this, not necessarily in the industry, and it really seemed like something we wanted to get up and running at PSEG," Steven Fleischer, executive director, HR - DEI (Human Resources - Diversity, Equity, and Inclusion), Talent Acquisition & PSEG LI at PSEG, told *POWER*. "We recognized it was an opportunity and we were definitely missing out on an untapped part of the talent market."

PSEG hired its first employee through the Neurodiversity Works program in 2022. The company will soon begin recruiting to hire its sixth employee through the program. "We wanted to be thoughtful about how we did this, so we've been bringing in two people a year on average," Fleischer explained.

A Life-Changing Opportunity

One of the longest-tenured employees hired through the program is Voice of the Customer Group Senior Business Management Associate David Berlinsky. Berlinsky graduated from Rowan University with a Civil Engineering degree, but had great difficulty landing a job after finishing school.

Berlinsky learned of PSEG's program through one of his college advisors and agreed to conduct an online interview. "After being so down, after being rejected from so many things, I couldn't believe it when I heard that I was accepted," said Berlinsky.

Berlinsky is a member of PSEG's data analytics team. "I write the monthly reports for major departments such as customer care," he explained. "It tends to be getting the data from the partner company, organizing it through Excel to create graphs, then writing the analyzes to go with it." Berlinsky quickly realized he had a knack for the work. "The first report I worked on, it was organized in such a bad way, the first words out of my mouth were: 'No, I'm not doing it like this.' So, I restructured the whole Excel file," he said.

Since then, Berlinsky has made further improvements to many reports, and processes as well. "I've partially automated one of the reports that comes in quarterly, which I'm very proud of," Berlinsky professed. He redesigned other reports "because the neurodivergent and ADHD in me could not be quiet about it," he said. "I eventually got recognition for how the reports were set up," Berlinsky said. As a result, his template has been used to standardize many of PSEG's other reports.

In fact, Berlinsky has been so successful in his position that he was recently promoted and tasked with giving oral presentations to leaders within the organization covering the data and analysis he compiles. And the job has been life-changing for him. "This program was literally the reason I was able to get myself back up and actually be productive," Berlinsky said.

Challenges Lead to Growth and Self-Confidence

Rosalia Benanti, PSEG's Voice of the Customer manager, has supervised Berlinsky for about five months. She suggested that neurodivergent employees can be challenged to do more than they themselves might think is possible.

Berlinsky's immediate reaction to a request for something out of the ordinary is often negative. "The first words out of his mouth are: 'No, I can't do it.' But once he gets over that, he comes back with such profound work that it's just astonishing," Benanti said. "And with that, David has gained an enormous amount of confidence."

Success in the workplace comes from having an inclusive environment that allows all employees to leverage their individual strengths while providing appropriate support for challenges. PSEG's Neurodiversity Works program offers proof that breaking down barriers that often limit neurodiverse individuals from being considered for employment is worth the effort. ■

—**Aaron Larson** is *POWER's* executive editor.

The Evolving State of Power Plant O&M

As power plants confront aging infrastructure, surging demand, and the sweeping changes of rapid electrification, operations and maintenance (O&M) are being redefined to tackle unprecedented challenges and seize new opportunities.

Sonal Patel

In December 2025, the North American Electric Reliability Corporation (NERC), the region's designated electric reliability organization, issued a sobering assessment of the power sector's outlook for the next decade. More than half of North America may be at risk of electricity shortages, it warned. The scenario is exacerbated by the accelerated retirements of 78 GW of aging, fossil-fueled capacity—with an additional 37 GW announced but not yet confirmed—and sluggish progress on new resource additions. Compounding the challenge, power demand is projected to soar by 15% over the next decade, driven by rapid electrification, industrial growth, and the increasing energy needs of the data-driven economy.

In this context, the region's existing fleet will play an outsized role, underscoring a role for their sound operations and maintenance (O&M). However, NERC also flagged forced outages as a critical and growing concern for the power sector, noting that unplanned outages caused by equipment failures, insufficient maintenance, and resource shortfalls pose significant reliability risks, most prominently during extreme weather events. Without robust O&M practices, these issues could further undermine the grid's ability to meet rising demand, particularly as winter peaks begin to outpace summer peaks. That has exposed new vulnerabilities in resource adequacy planning, it said.

But as experts told *POWER*, the realm of O&M is itself rapidly evolving to address new complexities and expectations introduced by the rapid transformation. As IHI Power Solutions Director of Business Development Doug Machon notes, O&M emerged historically as a straightforward business function managed internally by utilities operating within regulated monopolies. The realm began a shift in the 1990s, as competition, introduced by electricity de-

regulation, ushered in third-party O&M services that offered basic maintenance, compliance support, and operational oversight. Today's landscape adds a growing involvement from private equity investors, a decline in long-term power purchase agreements, and the rise of diversified energy portfolios—including renewables, distributed energy resources (DERs), and hybrid configurations.

No longer limited to routine tasks, modern O&M necessitates "a higher level of expertise and innovation in plant operations," says Machon. The significant shift has catalyzed "the development of comprehensive O&M strategies designed to maximize efficiency, reliability, and profitability in an ever-changing energy landscape." Providers today are expected to integrate advanced technologies, foster flexible plant cultures, and navigate stringent regulatory landscapes, he notes. Essentially, O&M today functions both as a critical lever for optimizing performance and enabling grid reliability in an increasingly dynamic energy environment, but it must also simultaneously mitigate risks and seize opportunities, he says.

Tackling New O&M Challenges

According to Ricardo Guerrero, general manager for Global O&M at GE Vernova, O&M advancement varies by region. "It's different in every part of the world, but I would say the main factor that is affecting O&M services at this moment is the penetration of renewables," he says. Plunging costs for renewables have ushered in new operational demands for traditional thermal power plants, including combined cycle gas turbine (CCGT) power plants, which were historically designed as baseload workhorses. "Cycling is a big issue," Guerrero acknowledges. "Cycling is associated with how you are going to react, how you are going to accommodate your team, how you are going to accommodate your strategy, your planning—everything associated to

Best Practices for Maintenance in the Evolving Power World

While power plant maintenance is a cornerstone of reliable power generation, designing and maintaining an effective program will require careful consideration of modern challenges and strategies. Engineers at infrastructure solutions firm Gannett Fleming offer some pointers.

Understand Your Assets. Develop a detailed asset register to categorize and document critical assets, including electrical, mechanical, and civil infrastructure. Involve multidisciplinary experts to ensure a comprehensive understanding of maintenance needs.

Develop a Maintenance Strategy. Balance reactive, preventive, and predictive maintenance to address immediate needs while minimizing future risks. Document the rationale for each maintenance task based on regulatory requirements, manufacturer guidance, and risk analysis.

Leverage Technology. Invest in a computerized maintenance management system (CMMS) like Maximo or SAP CMMS to streamline scheduling, documentation, and data analysis, ensuring efficient resource allocation.

Stay Agile. Avoid static programs. Continuously assess and adapt maintenance strategies to reflect advancements in technology, changes in asset conditions, and best practices.

Prioritize Tasks. Prevent over-commitment by ranking maintenance activities based on risk to ensure critical tasks are executed effectively.

Address Challenges Holistically. Be wary of knee-jerk reactions to failures and aim for balanced solutions through root cause analysis and measured troubleshooting.

Foster Collaboration. Streamline decision-making by clearly defining roles while incorporating input from stakeholders to maintain agility in program updates.

Case No.	Technology Description	Net Nominal Capacity (kW)	Net Nominal Heat Rate (Btu/kWh)	Capital Cost (\$/kW)	Fixed O&M Cost (\$/kW-year)	Variable O&M Cost (\$/MWh)
1	USC coal without carbon capture — greenfield (1 x 735 MW gross)	650	8,638	4,103	61.6	6.4
2	USC coal 95% carbon capture (1 x 819 MW gross)	650	12,293	7,346	86.7	13.73
3	Aeroderivative CTs — simple cycle (4 x 54 MW gross)	211	9,447	1,606	9.56	5.7
4	CTs — simple cycle (1 x H-class)	419	9,142	836	6.87	1.24
5	CC 2x2x1 (2 x 1 H-class)	1,227	6,266	868	12.12	3.41
6	CC 1x1x1, single shaft (1 x 1 H-class SS)	627	6,226	921	15.51	3.33
7	CC 1x1x1, single shaft, with 95% carbon capture (1 x 1 H-class SS)	543	7,239	2,365	24.78	5.05
8	Biomass plant with 95% carbon capture (1 x BFB)	50	19,965	12,631	261.18	9.65
9	Advanced nuclear — brownfield (2 x AP1000)	2,156	10,608	7,861	156.2	2.52
10	Small modular reactor nuclear power plant (6 x 80 MW SMR)	480	10,046	8,936	121.99	3.19
11	Geothermal (Binary cycle)	50		3,963	150.6	0
12	Hydroelectric power plant (New stream reach development)	100		7,073	33.54	0
13	Onshore wind — large plant footprint: Great plains region (200 MW 2.8 MW WTG)	200		1,489	33.06	0
14	Onshore wind — repowering/retrofit (150 MW 1.5 – 1.62 MW WTG)	150		1,386	38.55	0
15	Fixed-bottom offshore wind: Monopile foundations (900 MW 15 MW WTG)	900		3,689	154	0
16	Solar PV with single-axis tracking (150 MWAC)	150		1,502	20.23	0
17	Solar PV with single-axis tracking and AC-coupled battery storage (150 MWAC solar 50 MW 200 MWh storage)	150		2,175	38.39	0
18	Solar PV with single-axis tracking and DC-coupled battery storage (150 MWAC solar 50 MW 200 MWh storage)	150		2,561	39.24	0
19	BESS (Lithium-ion, 150 MW 600 MWh)	150		1,744	40	0

Table 1. A December 2023 U.S. Energy Information Administration (EIA) cost and performance survey conducted by Sargent & Lundy summarizes costs for most technologies, including overnight capital cost information, fixed operating and maintenance (O&M) costs, and variable non-fuel O&M costs. Notes: USC = ultrasupercritical; CTs = combustion turbines; CC = combined cycle; SS = single shaft; BFB = bubbling fluidized bed; MWAC = megawatt alternating current; WTG = wind turbine generator; BESS = battery energy storage system. Source: EIA, Capital Cost and Performance Characteristic Estimates for Utility Scale Electric Power Generating Technologies, January 2025.

O&M services—to be really productive, take care of cost, and be efficient.”

Cost pressures amid inflation and market demand further compound these challenges. Power sector O&M costs typically fall into fixed costs and variable costs. Fixed costs cover consistent expenses like routine maintenance, staff salaries, and long-term equipment contracts, while variable costs fluctuate based on fuel prices, material needs, and unexpected repairs. Over the past five years, cost fluctuations have hinged emphatically on rising material costs for critical resources such as steel, copper, and silicon, with particular implications for aging thermal power plants that require frequent and costly repairs.

Renewable O&M costs, while generally lower than those of thermal power plants, have been steadily decreasing due to technological advances, economies of scale, and experience-driven efficiencies. However, they remain sensitive to material price volatility and

the growing demand for specialized maintenance services. Offshore wind, in particular, faces higher O&M costs compared to onshore wind, driven by logistical challenges, harsher environmental conditions, and the need for specialized vessels and remote monitoring systems. Meanwhile, as a recent cost and performance analysis from Sargent & Lundy suggests, costs for advanced technologies such as hydrogen retrofits and small modular reactors remain exorbitant (Table 1). Even as these technologies promise operational efficiencies and decarbonization benefits over time, high upfront investments and significant ongoing O&M expenses can pose serious feasibility challenges.

Enduring the Vast Realm of Policy and Regulatory Uncertainties

Still, the current power landscape is compelling more companies to adopt new technologies and approaches. A significant factor has been compliance

with the evolving patchwork of government mandates, including regulations and incentives increasingly focused on accelerated decarbonization. The U.S. Environmental Protection Agency's (EPA's) April 2025–finalized Carbon Pollution Standards mandate carbon capture and sequestration (CCS) for existing coal units and new baseload combustion turbines, adding to rules regulating nitrogen oxides, mercury, effluent, and coal ash. Regional decarbonization differences and overlapping state-level policies are, meanwhile, creating additional complexity, driving operators to adopt tailored strategies to meet diverse compliance requirements.

Beyond emissions, regulations now also emphasize grid stability and reliability, compelling conventional generators to provide ancillary services such as fast frequency response and inertia. The need for resilience has also generally spurred mandates that require plants to bolster infrastructure to withstand ex-



1. Completed in early 2025, the Leipzig Power Plant in Bavaria, Germany, is a cutting-edge gas turbine facility developed by Siemens Energy and German energy giant LEAG to bolster grid stability during renewable energy shortfalls. The plant, capable of ramping up remotely within 30 minutes to deliver 300 MW of power, is operated entirely from Siemens Energy's ISO-certified Remote O&M Support Center in Erlangen. Courtesy: Stefan Hobmaier/Siemens Energy

treme heat and cold events, floods, and droughts. Cybersecurity is another growing focus, with federal directives requiring power plants to implement stricter digital protections and incident reporting protocols.

"You must adapt to the market. If you don't react, if you don't change, if you don't adjust yourself to the new conditions, you're going to disappear," notes GE Vernova's Guerrero. GE Vernova's approach has been to prepare customers for these transitions, including tailored maintenance strategies. "We take into account the specific operational stresses caused by renewables integration, ensuring that even older assets comply with regulatory thresholds while optimizing performance," he explains.

Siemens Energy, a global provider of power technology, solutions, and services, shares a similar outlook. "Our O&M service is designed to manage and maintain various types of technology infrastructure or equipment. This approach is especially beneficial in diverse and complex operational settings such as carbon capture, where multiple types of technology coexist," says Andrew Robson, Siemens Energy's technical expert for O&M Solutions.

"In the next decade, Siemens Energy will continue to offer expert O&M services to manage customer reliability risks, enhance efficiency, and centralize skills for consistent and reliable service supported by data-driven digital technologies," Robson adds. While the need to decarbonize conventional power generation affects all utilities and is not specific to O&M, the company's services "ensure that these technologies operate

reliably and efficiently, contributing directly to meeting decarbonization goals," he explains. Additionally, he underscores broader sustainability benefits, particularly through the use of a global network of remote operations and control centers. "Especially during COVID, it became clear that it is not always necessary to fly specialists around the world, but that a lot can be done remotely," he says (see sidebar "Best Practices for Maintenance in the Evolving Power World").

Solving the Workforce Puzzle

For now, experts agree the most urgent challenge facing the power sector is the shortage of skilled personnel. "O&M is all about people," says Guerrero. "People tend to believe that in the future, power plants will be operated completely by robots, but we are really far away from that." A key issue is that the workforce, traditionally the backbone of power plant operations, is aging, and with that comes the loss of decades of invaluable experience. "At the same time, we're finding it increasingly difficult to attract younger talent, who are often drawn to tech-savvy industries like software and artificial intelligence [AI] rather than traditional fields like ours. It's a problem we cannot afford to ignore because, without skilled workers, even the most advanced plants won't function," he says. To address these challenges, Guerrero explains that GE Vernova has developed structured knowledge-capture systems, including detailed playbooks created during contract mobilizations. "These are comprehensive guides that ensure when experienced team members retire



2. To bolster its supply chain and prepare for increasing demand for its heavy-duty gas turbines and upgrades globally, GE Vernova moved in November 2025 to acquire Woodward Inc.'s combustion parts business in Greenville, South Carolina. This image shows a 7HA.03 gas turbine at GE Vernova's own facility in Greenville, where it manufactures and tests gas turbines to provide global engineering support and other activities. Courtesy: GE Vernova

or move on, their expertise doesn't leave with them," he says.

At the same time, GE Vernova, driven by its "lean" business philosophy, has already begun transitioning from traditional reliability-based maintenance approaches to more proactive, data-driven design-making enabled by AI and analytics. Guerrero said the company has developed autonomous robot technology capable of conducting inspections and identifying issues that human workers may miss. Demonstrating these technologies carries operational benefits, but a key intent is to transform the perception of O&M, positioning it as innovative, future-focused, and dynamic—attributes that could be attractive to a younger workforce, he says.

Robson echoes Guerrero's concerns. "Even utilities with extensive experience in power plant operation and maintenance are now seeking our O&M expertise due to the skilled workforce shortage," he notes. Siemens Energy's approach has been to double down on technology. "Remote services are key to maintaining reliable operation and efficient maintenance," says Robson, citing Siemens Energy's 72-hour unmanned operation of the 300-MW Leipzig Power Plant in Germany (Figure 1). "Our remote monitoring centers handle routine monitoring and data analysis, freeing up experts for tasks that cannot yet be fully automated."

According to Emily Obenauer, global director of Product Marketing at SiteTracker—a software-as-a-service platform that provides end-to-end asset lifecycle management—emerging tools are also set to play a transformative role in streamlining O&M operations with tangible workforce benefits. "Tools like ours are also shown to increase the satisfaction and increase the effectiveness of those workers out in the field because we're getting so clear on what needs to be done and validating that that work has been done correctly the first time around," she said.

Shoring Up Supply Chains

While workforce challenges have long afflicted the sector, more recent global supply disruptions are posing new concerns, prompting companies to reassess the resilience of their O&M operations. Siemens Energy's Robson notes that, while temporary bottlenecks for parts and consumables remain a concern, "The shortage of people is, so to speak, the biggest bottleneck in the supply chain," he says.

He explains that most original equipment manufacturers (OEMs) proactively approach supply chain challenges to mitigate risks, leveraging global networks for flexibility. “We can access stock that was originally planned for other projects in the longer term. Additionally, close monitoring allows for the identification of required parts at an early stage as part of predictive maintenance,” he says.

GE Vernova’s strategy is similar, entailing a proactive, collaborative approach with its customers (Figure 2). The company closely monitors its customers’ equipment and provides advance warning of potential failures. In addition, Guerrero says it helps customers pre-position critical spare parts to minimize downtime in the event of an issue. For example, when GE Vernova identified that the generators at a 20-year-old power plant in Taiwan were nearing the end of their life, it advised the customer to purchase a spare stator and rotor in advance. Two years later, the rotor failed, but because the spare part was already on-site, GE Vernova was able to quickly replace the rotor, getting the customer back online in just seven days, he says.

The Rise of Third-Party O&M Services

In another important trend, given modern complexities and evolving risks in the power sector, many utilities and power companies are increasingly turning to value-driven partnerships, often through third-party O&M service contracts. These partnerships encompass project management, robust training programs, detailed plant assessments, and the adoption of tailored best practices to optimize operations. Many are designed to leverage economies of scale and advanced remote operations, providing utilities with cost efficiencies and enhanced reliability in managing diverse energy assets.

“For many plant owners, O&M is no longer a core focus,” Guerrero explains. “Their priority is on generating and selling energy, which opens the door for third-party providers like us to step in with specialized expertise. But it’s not just about taking over operations—it’s about adding value. By leveraging performance-based contracts and advanced technologies, we focus on aligning our services with plant owners’ goals for reliability, efficiency, and profitability.” Guerrero notes that performance-based contracts are increasingly becoming a defining feature of third-party O&M ser-



3. Operational since June 2023, the Kela PV Plant Phase 1, located in Sichuan Province, China, stands as one of the world’s largest hydro-solar hybrid power plants, combining 1 GW of solar capacity with the 3 GW Lianghekou Hydropower Plant. The site exemplifies advanced O&M practices in a challenging environment. Given that it is situated at an altitude of 4,600 meters, the plant endures extreme cold and high winds. Using a smart O&M platform with features like remote monitoring, automated fault detection, and real-time diagnostics, the plant minimizes manual intervention and ensures reliability. Courtesy: Huawei

vices because they play a pivotal role in aligning incentives with plant reliability, availability, and efficiency. The contracts ensure accountability by incorporating measurable metrics, such as performance guarantees, and often include penalties for underperformance as well as rewards for exceeding targets. “This model ensures that everyone is focused on the same goal: maximizing the plant’s performance,” he says.

Global renewable energy developer Invenery—a company known for its extensive portfolio of wind, solar, and storage projects—also highlighted the value proposition. The company says it approaches O&M services with an “owner’s mindset,” a philosophy that ensures top-tier maintenance practices and builds trust within their communities. “In addition to prioritizing safety, Invenery Services’ other O&M pillars deliver benefits to customers through innovation, flexibility, and cost savings,” it says.

O&M’s Future: Tech and Sustainability

According to experts, the future of O&M in the power sector will be shaped by two transformative forces: technological innovation and the global push for sustainability. Already, as power generation grows more complex, modern O&M practices are increasingly integrating cutting-edge technologies like predictive analytics, autonomous systems, and maintenance strategies. “The future of operations and maintenance will heavily depend on integrating AI with digital tools to analyze data in real-time. This allows us to predict is-

ues before they occur, saving costs and improving asset performance across the board,” says Guerrero.

Obenauer echoes this point. “We know that the future lies in digital transformation, and AI is a major focus. By applying AI to fieldwork and O&M processes, we’re already testing how to enhance efficiency and reliability while aligning with the workforce and industry needs.” AI-driven solutions also promise to unlock new opportunities in lifecycle management, she notes. “By centralizing asset data, companies can use AI to optimize resource allocation and focus on long-term asset health while navigating complex operational challenges.”

On the other hand, sustainability will support the general charge toward cleaner energy sources, such as accommodating new technologies and hybrid configurations (Figure 3). Companies are exploring how to integrate emerging solutions such as hydrogen retrofits, thermal energy storage, and batteries into power plants, all while keeping costs low, maintaining reliability, and minimizing environmental impact.

As Guerrero stresses, a key takeaway is that O&M will need to be flexible and responsive rather than rigid. “You can navigate the sea as a cruise ship, or you can be a motorbike on the beach moving quick, and that’s the idea, that’s what we are doing,” he explains. Ultimately, proactivity will be necessary for nimble adaptation to keep pace with the changing landscape, he says. ■

—**Sonal Patel** is a **POWER** senior editor.

Software, Hardware, Innovation All Needed to Upgrade the Power Grid

Enhancing the transmission and distribution of electricity is a priority to ensure a reliable and resilient power supply, as demand increases and grid challenges mount.

Darrell Proctor

Providing more electricity to meet growing global demand for power has put a spotlight not only on adding more generation to the grid, primarily through construction of new power plants, but on improvements to the grid itself. Enhancements to support power grid reliability include investments for a variety of technologies, such as battery energy storage systems (BESS), advanced transmission lines, smart grid infrastructure, and distributed generation. Upgrades also focus on improved grid monitoring and control systems that allow for better and faster response to fluctuations in demand and disruptions caused by weather, equipment, or other issues.

“Needed enhancements span across condition monitoring, advanced data analytics, fire mitigation, and improved system control mechanisms,” said John Russell, senior director, Solution Consulting at AspenTech, a provider of software and services for the process industries. “Reliability in these systems is crucial not only for preventing downtime but also for ensuring that power is consistently delivered to consumers with minimal disruptions. Specifically, key areas for enhancement include the implementation of condition-based maintenance, improved data collection with smart meters, AI [artificial intelligence]-powered asset management, and advanced control technologies for both transmission and generation systems. By integrating modern technologies, these systems can proactively address failures, optimize performance, and respond to real-time conditions.”

“Reliability is central to the modern power grid, especially as we integrate more renewables and electrify transportation and heating. Much work has been done in generation and distribution, driven by smarter hardware, predictive software, and data analytics,” said

Brandon Young, CEO at Payless Power, a Texas-based electricity group. “On the generation side, predictive maintenance technologies become game-changers. IoT [Internet of Things] sensors and AI are monitoring equipment like turbines and transformers in real time to pinpoint potential failures before they occur. That way, downtime is kept to a minimum, and power generation stays efficient.”

Utilities and grid operators are studying a variety of ways to improve the reliability of power generation and delivery, with data at the heart of much of the research.

“Reliability enhancements should be approached as a comprehensive, multi-pronged strategy that addresses design concerns and utilizes new and emerging technologies for improved data analytics,” said Michael Bennett, chief transformation officer at Powin, a battery energy storage company. “Up front, suppliers need to design and engineer components with reliability as a core principle. This includes using advanced materials, robust designs, and high-quality manufacturing processes.”

Bennett added, “Ensuring transmission, distribution, and generation assets are equipped with IoT sensors for real-time data collection, monitoring, and reporting capabilities has become a core focus over the past few years as well. These sensors provide operators with actionable insights into system performance and potential issues, allowing them to leverage both cloud and on-premise data to uncover complex insights, correlations, and predictions.”

Thomas L. Keefe, vice chair and U.S. Power, Utilities & Renewables Sector leader for Deloitte, said, “Increasing visibility and control through advanced grid technologies” is a major part of increasing grid reliability. “Sensors embedded throughout the network, including smart meters, automated control systems, and advanced monitoring tools, can provide real-time data on energy flow, equip-

ment health, and grid stability,” said Keefe. “Analyzing sensor data can allow operators to anticipate equipment failures before they happen, preventing outages, enhancing the utilization of existing resources, and ultimately increasing grid reliability.”

Efficiency a Key Part of Upgrades

Upgrades to transmission infrastructure (Figure 1) are just part of the work being done to improve power grids. The need for maintenance, particularly during a period of transition to digitization of energy systems, is evolving as well.

“There are several proactive maintenance solutions to improve grid reliability, such as implementing distributed intelligence [DI] systems for real-time monitoring and diagnostics,” said Matt Smith, who leads the global business and product strategy for the grid management business at Itron, a global group helping utilities develop innovative solutions for their operations. “Additionally, predictive analytics and edge intelligence can identify trouble spots below the substation, enabling utilities to automate fault isolation and repair processes, reducing the need for manual intervention, which leads to faster recovery times and



1. Power grids across the U.S. and throughout the world are in need of upgrades to handle increased loads. Those enhancements also are needed to help integrate more renewable energy resources into electricity transmission and distribution systems. Courtesy: Salvatore Ventura / StockSnap

improved grid stability. This integrated approach allows for a more efficient, resilient power grid, especially during times of increased demand or extreme weather events.”

Smith listed what he called “key enhancements” to improve the overall reliability of electricity transmission and distribution, including decentralizing grids.

“Traditional centralized grids are vulnerable to cascading failures during extreme weather events, like major hurricanes and heatwaves, which are becoming more prevalent. Switching to a decentralized model, which includes incorporating distributed generation resources [such as renewables] closer to demand points, improves resilience,” said Smith. The Itron executive also noted the importance of leveraging intelligent grid edge solutions. “Integrating distributed intelligence into utility systems enables grid sectionalization, allowing power to be rerouted automatically. This reduces outages by leveraging real-time data to detect anomalies more efficiently than manual inspections.”

The use of distributed generation is helping provide additional power apart from centralized power plants. Advanced metering infrastructure is helping monitor power usage in real-time, and supporting demand response programs. And then there are efforts to combat the problems associated with keeping the lights out during extreme weather events.

“At the top of the list for transmission and distribution is grid hardening and modernization,” said Young. “Utilities are replacing aging infrastructure with weather-resilient materials, and deploying smart grid technologies such as automated reclosers, which isolate faults and reroute power almost instantly, reducing outages. The growth in smaller energy sources, such as rooftop solar and batteries, has been supported by distributed energy resource management systems [DERMS] that aggregate them to provide stability to the grid in times of peaks or emergencies. Future technologies, like grid-forming inverters, will stabilize grids with high renewable penetration, controlling voltage and frequency independently and acting as virtual power plants.”

Itron’s Smith said, “EV [electric vehicle] charging stations are an increasingly valuable resource that can be quickly repurposed before and during grid failures to provide grid services and backup power, respectively. Additionally, EV bat-



2. Upgrades to the power delivery system in Morris County, New Jersey, got underway in December 2024. The construction is part of Jersey Central Power & Light’s New Jersey Reliability Improvement Project. Courtesy: First Energy / Jersey Central Power & Light

teries within vehicles, specifically within larger vehicles like buses, offer a robust source of energy storage. These batteries can be tapped during outages to enhance grid resilience and maintain power for critical operations, making them an essential component in modernizing grid infrastructure to cope with outages.”

Deloitte’s Keefe said that reinforcing physical infrastructure is another important step. “Strengthening, upgrading, and hardening key components, such as power lines, substations, and transformers, can not only help handle higher loads but also reduce transmission losses and improve resiliency and energy delivery efficiency,” said Keefe. “A few states have signed bills mandating that utilities consider grid-enhancing technologies as a shorter-term solution in their IRPs [integrated resource plans]. Replacing outdated transformers with high-efficiency models can cut energy consumption by up to 12%, further boosting grid efficiency.”

Keefe added, “Deploying grid-enhancing technologies and advanced conductors to add capacity and flexibility to the existing transmission system [improves] transmission reliability. These technologies offer a cost-effective way to expand capacity compared to rebuilding transmission lines. Upgrading to high-efficiency conductors can minimize transmission line losses by 10% to 20%.”

Keefe also noted how model predictive control (MPC) technology can support reliability. “MPC uses a mathematical model to predict future system behavior within a set timeframe. It is popular in power electronics for managing constraints, multiple inputs and outputs, and nonlinearities. Unlike other control methods, MPC explicitly considers system constraints and optimizes control actions over a prediction horizon. This results in better performance, lower energy consumption, and increased reliability in

power electronic applications. In renewable energy systems like photovoltaic [PV] and wind energy, MPC can optimize power extraction and facilitate maximum power point tracking [MPPT]. It also coordinates multiple energy sources, storage devices, and loads to ensure optimal performance and reliability.”

Grid Projects

Jersey Central Power & Light (JCP&L), a subsidiary of FirstEnergy Corp., in December began construction on infrastructure upgrades designed to enhance electric reliability for customers in three Morris County communities in New Jersey (Figure 2). The work, scheduled to be completed in October of this year, is part of JCP&L’s New Jersey Reliability Improvement Project, which is an element of the company’s rate review settlement approved by the New Jersey Board of Public Utilities in February 2024. Equipment enhancements will take place along more than five miles of power lines in Chester, Washington, and Roxbury townships.

Doug Mokoid, FirstEnergy’s president for New Jersey, in a statement said: “The upgrades we’re making under the New Jersey Reliability Improvement Project are part of our commitment to providing safe, reliable electric service for all our customers. These improvements, in particular, target areas where customers have experienced some of the most frequent outages in recent years.”

The New Jersey Reliability Improvement Project is a two-phase effort to enhance reliability for customers on high-priority lines selected based on historical outage data. The first phase, which includes at least \$95 million in upgrades, is set to be completed over the next three years, according to FirstEnergy. The second phase, which includes longer-duration projects, is expected to be completed by year-end 2028.

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Partner Insights

Take Back Control with Wind Turbine Retrofits

The rapid increase of global renewable energy generation has made existing wind farms an extremely desirable resource. While some organizations are acquiring a variety of wind turbines en masse, others are looking to more efficiently and effectively utilize existing wind assets. Decades-old turbines with outdated technologies are difficult to monitor and are even harder to control due to aging OEM system limitations.

Total turbine replacement can be expensive due to costly outages, supply chain shortages and changes in regulations since original turbines were installed. Rather than pricey replacements, power generation owners and operators can drive peak operational efficiency by retrofitting existing wind turbine controls.

Wind turbine retrofits allow for quicker turnaround, more efficient operation, and full ownership of each asset's data. When partnering with long-time power industry experts like Emerson, wind turbine retrofits deliver a quick return on investment (ROI) leaving legacy connectors in place while new plug-and-play control modules with modern logic are installed in the existing footprint.

Emerson's Ovation Green technologies and solutions enable quickly delivered retrofits for many legacy turbines across a farm, from a wide range of turbine manufacturers. Ovation Green pre-engineered solutions allow for most retrofits to be completed in just a day or two.

These wind turbine control retrofits can prolong lifespan while driving equipment performance and availability.

Despite original manufacturers limiting the amount of data accessible by asset end-users, Emerson's Ovation Green solutions and technologies offer full access to data and thorough control capabilities for end users. Operators gain access to logic features that deliver extended asset lifespans and 3%-5% more annual production, resulting in ROI within the first year.

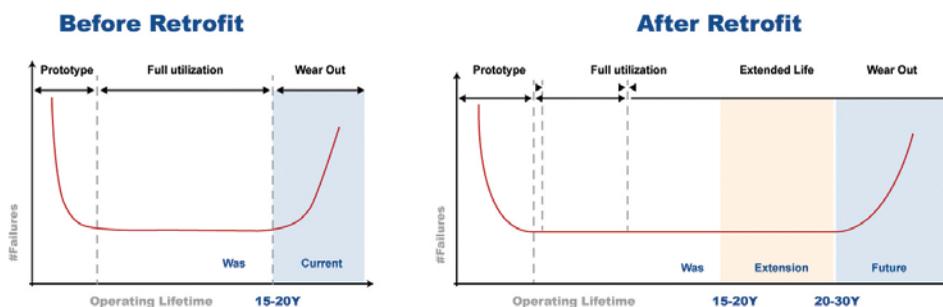
Emerson's seasoned wind power experts can help identify the best new control strategies to deliver fast ROI. Retrofitting half a dozen to a dozen turbines can quickly demonstrate the success necessary to scale a retrofit project across a wind farm or throughout an entire fleet.

Modern turbine retrofit projects are a fast and easy way to drive more value from existing assets. Because ROI is typically delivered in less than a year, teams can quickly deliver operations that exceed expectation while increasing safety, visibility, and flexibility of operations fleet-wide.

Learn more at www.Emerson.com/Ovation-Green or contact PowerWater@Emerson.com



EMERSON™



Wind turbine control retrofits utilize modern software and technology to extend turbine lifespan and increase annual energy production quickly and economically.



3. Deployment of renewable energy across the U.S. has been slowed by issues with integrating wind, solar, and other clean energy resources to the power grid. Courtesy: Shutterstock

The upgrades include replacing existing infrastructure with thicker, stronger wires and poles that can carry more electricity and provide more resiliency in storms. The work also includes upgrading fuses, and installing additional devices and reclosers that allow power to be rerouted to adjacent lines when an outage occurs, minimizing the number of impacted customers.

Several projects are underway or planned to build new high-capacity transmission lines to facilitate power transfer across long distances, often to move renewable energy resources from remote, rural areas to the grid. Advanced conductor materials are being used to reduce transmission losses. Smart grid tech is being deployed for dynamic load management, and battery storage is being installed along the grid (often at substations) to help with grid flexibility and balancing.

The U.S. Department of Energy (DOE) last year awarded \$2.2 billion to eight electric transmission and microgrid projects across 18 states, with a goal of adding electricity delivery capacity and strengthening the grid against extreme weather. Jennifer Granholm, the Energy Secretary during the Biden administration, at the time said the money was part of a program to add 1,000 miles of transmission lines and 50,000 MW of electricity to the grid. Granholm at the time said, “and there’s much more to come,” although it’s not known how the Trump administration will approach funding for electricity transmission and distribution (T&D).

The DOE said \$700 million would go to the North Plains Connector project, a high-voltage direct-current power line that would create the first large-scale

grid connection between the Eastern and Western interconnections, the U.S. grid systems divided by the Rocky Mountains. Minnesota-based Allete Inc. and transmission builder Grid United are developing the project.

The Utah Office of Energy Development was awarded nearly \$250 million to install 250 miles of advanced conductor cables, increasing line capacity to support delivery of 500 MW of renewable energy (Figure 3) across six states.

Another grant, for \$30 million, was made to the New York Power Authority for its Clean Path New York project. That strategy is designed to deliver 1,300 MW of renewable energy from upstate and western New York to New York City, which the DOE said would help reduce reliance on coal- and natural gas-fired power generation.

Handling Increased Demand for Electricity

Technology innovations to improve power generation, transmission, and distribution have brought more complexity into power networks. That means utilities and grid operators are rethinking some of their earlier practices to adapt to a changing energy landscape.

Jon M. Williams, CEO of Viridi, a battery energy storage company, said, “The energy system is on the brink of a paradigm shift that will profoundly reshape energy transmission and distribution. After decades of relatively stable demand [no load growth], the grid must now manage an enormous demand increase resulting from industrial onshoring, the growth of data centers and AI, and, perhaps most significantly, the electrification of heat and transportation. Complexity has also been added

as distributed generation resources, like rooftop solar, complicate system management. These antiquated 19th-century grids are decentralizing, and the transition must be accommodated.”

Williams told *POWER*: “The solution to this challenge will not be to redesign and rebuild the grid of the 19th century. Instead, we must use new advances that prioritize safety, reliability, and enhancing system level efficiencies while focusing investments on technologies that provide layers of benefit. There is no greater technology to benefit power grids as we electrify everything than intelligently managed distributed energy storage. Distributed storage can enhance the value and operability of on-site generation. With advanced connectivity, it can be leveraged as a ‘virtual power plant [VPP]’ to better enable host facility loads for grid support through constraints and failures in real time.

“Behind-the-meter distributed energy storage has the potential to improve resiliency, support decarbonization, shave peaks, enhance value of behind-the-meter generating assets, enable utilities to pursue beneficial ‘non-wires’ alternatives, and avoid the massive costs that a replacement of the old grid would entail,” said Williams.

Utilities have developed programs to support a reliable power supply. The American Public Power Association (APPA) has a Reliable Public Power Provider, or RP3, program “that recognizes utilities that demonstrate high proficiency in reliability, safety, workforce development, and system improvement.” The group’s list includes utilities, both large and small, from across the U.S.

Said Young, “Real-world examples show the benefits: Florida Power & Light’s ‘Storm Secure’ program—undergrounding power lines and deployment of smart grid—has reduced outage durations after a hurricane like Irma. Similarly, Pacific Gas & Electric is now using AI to predict the risks of wildfires by analyzing weather, vegetation, and grid conditions in order to take action before disaster strikes.

“This brings, in short, today’s enhancements in reliability toward the goal of making the grid smarter and more resilient as AI and other power-hungry needs increase the demand for energy. Advanced software, durable hardware, and data-driven systems are revolutionizing how we manage and distribute electricity for future needs,” he said.

“The process of monitoring and setting up a system to proactively maintain assets to extend their lifecycle and prevent malfunctioning is also known as ‘asset lifecycle management (ALM),” said Terry Saunders, Worldwide Utilities and Industry leader at IBM. “As organizations continue to look for ways to conduct more efficient, cost-effective, and sustainable operations many are turning to ALM. For energy equipment specifically, ALM practices may include installing sensors and using cameras for immediate eyes on equipment to identify factors affecting performance, and using AI-infused software that recommends specific maintenance directed by the data. By approaching maintenance and operations management from a preventive, data-driven approach companies can ensure that their systems are performing optimally for longer, ultimately maximizing their return on investment.”

Tyler Lancaster, partner at Energize Capital, a group that invests in climate technology, including renewable energy, told *POWER*: “A big shift in the power sector has been moving away from cycle-based maintenance programs to data-driven, proactive maintenance programs. Some aspects can also be automated to drive further efficiency and reliability. This is true across every form of power infrastructure.

“For example, historically, utility poles were inspected on a cycle once every five to 10 years. Over time, utilities and their service providers have built up a large amount of data and information on common failure modes for utility poles,” said Lancaster. Increasingly, analytical models can be applied to estimate the probability of failure for each pole based on the type of wood, environmental factors like moisture, location, etc., and can tailor maintenance activities to inspect and repair higher risk poles sooner.

Lancaster said it’s difficult to standardize operations to improve reliability. “This is a key challenge for the power sector, as operations tend not to be ‘one-size-fits-all.’ Different grids, with different environmental factors and natural systems, with different power infrastructure configurations—generation mix, T&D system setup, consumption segmentation and load profile, etc.—require tailored operations to ensure reliability. Where operations can be standardized is through the use of modular and adaptable technologies which can be easily configured to the unique needs of a specific power plant or grid operator’s context.”

“Standardization can play an important role in power system reliability as it promotes consistency, predictability, and interoperability,” said Keefe. “It can help reduce human error, and improve communication and coordination—especially during emergencies, with faster response times, etc.”

Combating Failure

Working to eliminate grid failures, or at least mitigate their impacts, is a goal of those working with utilities and grid operators. That can involve gathering data, knowing how to interpret it, and also having systems in place to deal with issues as they arise.

“Reliability at the equipment or component level is driven by two key factors—probability of failure and impact of failure. Enhancements that address one or both these factors are key to improving reliability,” said Steve Morris, a managing director with FTI Consulting’s Construction, Projects & Assets practice. “Whether it’s a power plant or the grid, reducing the probability of failure comes down to maintaining the assets in good operating condition through preventive and condition-based maintenance. Reducing the impact of failure is reliant on having redundancy in the system so that the failure of a single asset or component doesn’t reduce plant or system performance.”

Morris said, “For a power plant or electric substation, this is typically achieved by having spare capacity that can be used if there is a failure. For example, instead of having one power transformer in a substation running at full capacity, you would have two running at 50% or less capacity. If one fails, you can switch the other with no impact on the system. For the transmission grid, in most cases, if a single transmission line fails, there is sufficient capacity to switch to another transmission line, which has spare capacity. For the distribution grid, redundancy is achieved by interconnecting circuits and having auto reclosers, which can automatically restore after a fault is cleared, and sectionalizers that can section off parts of the system to reduce the number of customers impacted by an outage.”

Sally Jacquemin, vice president and general manager, Power and Utilities at AspenTech, told *POWER*: “Redundancy plays a vital role in maintaining the reliability and stability of both power plants and power grids. As the energy landscape shifts toward greater integra-

tion of renewable sources like wind and solar, the variability of these resources increases the importance of backup systems. Redundant infrastructure, including reserve generation and microgrids, ensures that power continues to flow smoothly during both planned and unexpected disruptions, such as outages or system failures, minimizing the risk of blackouts.”

Jacquemin said, “Historically, utilities maintained excessive reserve generation to protect against worst-case scenarios, ensuring power availability in case of failure. Today, however, there is a balance between maintaining enough redundancy to prevent outages and avoiding overinvestment in reserve capacity. Modern systems focus on understanding the critical threshold of necessary redundancy, ensuring operational efficiency while still providing reliability in the face of unexpected events like sudden generation loss or extreme weather conditions.”

Jacquemin added, “Microgrids and localized redundancy solutions are increasingly important as they allow certain areas to maintain power even when the larger grid is disrupted. Powered by local generation sources like solar or batteries, microgrids can operate independently, providing resilience during storms or grid failures. The integration of renewable energy further highlights the need for redundancy, as renewables introduce variability that requires additional backup systems, such as storage or traditional generation, to ensure a reliable and stable power supply.”

“Redundancy is most important for the transmission system as North American Electric Reliability Corporation [NERC] requires that the transmission system must be able to handle the failure of a single component without causing a significant outage,” said Morris. “Therefore, transmission lines and substations are designed with redundancy. Redundancy is less important for power plants as typically a single unit of a power plant only produces a small portion of the power on the grid. In addition, power grids are required to have reserve capacity to be able to handle unit unavailability, maintenance, and higher than normal demand. The distribution system is similar to power plants in that most equipment serves a small number of customers, so a failure has little impact on the overall grid. Therefore, there is little redundancy in the system, other than in substations.”

Morris listed several ways to enhance reliability of power generation and the

transmission and distribution system. He noted that advanced distribution management systems can automatically detect faults, and also identify the impacts of anomalies. He also noted a distributed energy resource management system “monitors, optimizes, dispatches, and manages all types of distributed energy resources including black start for grid shutdowns. Dynamic line rating calculates real-time transmission capacity of a line to optimize capacity usage to reduce congestion.” Meanwhile, an “asset performance management system monitors real-time equipment condition to identify [any] need for maintenance or indicate increasing risk of failure.” Morris also noted what he called “non-intrusive inspection,” which can help operators “understand power plant equipment condition without taking it apart. [This] includes technologies such as ultrasonic, radiography, eddy current, magnetic particle, acoustic emission, dye penetrant, leak testing, vibration analysis, and thermography.”

Lancaster said there are programs that can be implemented to enable proactive replacement and/or restoration of older equipment—both software and hardware—in power plant and power grid systems. He referenced his earlier comments about power poles, and said, “Another example is for transformers. Transformers are a key piece of equipment for the electric transmission and distribution system. They convert high-voltage electricity down to the lower voltages, eventually to the 120V type that we commonly use in our homes and businesses.

“There are several methods that have emerged to predictively identify transformer failure through sensor technology and data science or machine learning techniques,” said Lancaster. “For example, sensors that measure the accumulation of dissolved gas particles in the oil contained within a transformer can prevent transformer failure before it causes broader damage to other power grid equipment nearby.”

Utilizing Digital Twins and Energy Storage

Ildi Telegrafi, a policy fellow at the Alliance for Innovation and Infrastructure, said digital twins—often used to study power generation equipment—can also be a vital part of understanding electric transmission and distribution.

“The clean energy transition is driv-

Cybersecurity and Grid Reliability

Shankar Somasundaram is CEO at Asimily, a risk management platform that secures Internet of Things (IoT) devices for healthcare, manufacturing, public sector, and other industries that depend on numerous connected devices. Somasundaram talked with *POWER* about how enhancements to support grid reliability also should address cybersecurity issues (Figure 4), especially with more digitization in power plants and along the transmission and distribution system.

“Cybersecurity has become an increasingly fundamental variable for power system reliability as utilities digitize operations and add more network-connected devices and equipment,” said Somasundaram. “As headlines in this industry continue to show, a more interconnected power infrastructure—particularly its operational technology [OT] systems that directly control physical equipment—means that cyber vulnerabilities can directly impact system reliability.

“In transmission and distribution systems, cybersecurity measures need to protect essential OT components like supervisory control and data acquisition [SCADA] systems, smart meters, and automated switches through authentication, encrypted communications, and continuous network monitoring,” said Somasundaram. “Power plants require additional protection for their digital control systems, including distributed control systems [DCS] and programmable logic controllers [PLCs]. This necessitates network segmentation, regular security patching, and strict access controls to prevent equipment damage or forced outages.”

Somasundaram told *POWER*, “Supply chain security and the human element are equally crucial for reliability. Utilities must verify the integrity of software updates and new internet-connected equipment while maintaining comprehensive training programs for personnel who operate and maintain OT systems. Building a culture of cybersecurity awareness cannot be glossed over.”



4. Global and U.S. energy infrastructure, particularly the power grid, has become a major target for both physical attacks and cyber threats. Grid operators and utilities are responsible for protecting their systems from risk, with the federal government and national laboratories supporting those efforts as part of their mission to protect national and economic security. Courtesy: Asimily

Somasundaram said as more automation enters maintenance programs, more vulnerabilities to cyberattacks are exposed. “From a cybersecurity perspective, every component in a power plant and the grid is potentially vulnerable if it has an access port. Historically, physical protection and maintenance have provided a strong defense. However, as network access and its many benefits are deployed more, this physical security is becoming less effective,” said Somasundaram. “Cybersecurity maintenance for power plants is like the price of democracy—it requires constant vigilance. This vigilance involves always detecting potential and current attacks. This requires processes backed by software that continually look for evidence of such weaknesses and attacks. When evidence is found, it’s important to act quickly to close security gaps or, in the worst-case scenario, terminate a successful attack.”

Somasundaram added, “Fortunately, much of this has been automated by the software industry. Implementing people and processes to leverage this technology effectively and act quickly, however, is not always in place. Ensuring this implementation is key to maintaining automated maintenance and reliability.”

ing the energy industry toward a new dynamic with vast renewable energy resources that can supply a high volume of energy over the year but with high intermittency,” said Telegrafi, who is also an analyst for New York-based utility Con Edison. Telegrafi said the need for bidi-

rectional power flow management, and the inclusion of energy storage onto the grid “to stabilize intermittency and flatten the peak,” means “the tools necessary to manage this continually changing dynamic are digital. Balancing an ever-increasing power dynamic that must sat-

isfy inconsistent load with intermittent generation supported by storage components requires the creating of a digital twin of the grid.” Of course, cybersecurity must also be considered whenever digital technology is added to a system (see sidebar).

Telegrafi said the digital twin “models the components individually and the systemic constraints binding operation via mathematical formulas. These mathematical formulas allow for optimization of the dynamic from the current dynamic to the future clean energy equilibrium that industry establishes. The digital twin can be manipulated freely to add or remove components into the digital emulation of the grid’s dynamics, enabling ‘what if’ scenarios for application toward strategically planning investment and policy.” Telegrafi said Optit S.r.l., an optimization and solutions group, has been working on these projects in the U.S.

Powin’s Bennett also noted the importance of digital twins to “enable continuous monitoring, simulation, and optimization of power plant or grid equipment, providing a real-time view of asset health.” Bennett said having “virtual replicas of physical assets” is just one of “several components of an effective, automated maintenance program to ensure the reliability of power plants and grid.” He cited condition-based maintenance, or CBM, which enables “transitioning from predefined maintenance schedules to dynamic, condition-based programs that rely on real-time monitoring and performance data. SCADA [supervisory control and data acquisition] systems and IoT devices provide the necessary data for this approach.”

Bennett said predictive maintenance also is important. “Using AI and machine learning algorithms to analyze historical and real-time data from sensors, enabling the prediction of failures before they occur ... [where] data sources can include environmental conditions, operating history, and current performance metrics,” he said. There is also automation, where “automating data correlation in the cloud allows predictive insights to be seamlessly integrated into control systems or maintenance scheduling tools. This reduces response time and ensures resources are allocated efficiently to address the highest-priority issues.” Inspections of power plant assets, and the power grid, using robotic systems and drones “can automate inspections of hard-to-reach areas, reducing the risk to personnel and minimizing



5. Twelve lithium-ion batteries, installed in a dedicated room, provide 500 kWh of usable power for resiliency backup and demand charge management for the Hauptman Woodward Medical Research Institute, located on the Buffalo Niagara Medical Campus. Courtesy: Viridi

downtime,” said Bennett.

FTI Consulting’s Morris said, “To enable proactive replacement/refurbishment of older equipment requires understanding several elements. First, there is a need to understand the condition of the asset and what the probability of failure of that asset is. Second, there is a need to understand the consequence of failure in terms of its impact. Third, the probability and consequence of failure need to be combined to understand the amount of risk. Once risk is known, it can then be assessed against the cost of replacement/refurbishment to determine the appropriate time for an intervention.” For example, a well-informed user can plan to replace equipment when the risk value exceeds the cost of replacement.

Morris continued, “In order to understand the condition of the asset, there is a need to invest in condition monitoring hardware, which varies based on the application. These are typically wired or wireless devices, which can be placed on equipment to collect different types of data. In addition to the hardware, there is a need for asset performance management software, which takes the data from the monitoring devices and performs analysis to identify the risk of failure. It does this by creating a digital twin of the asset and analyzing the data being provided by sensors and monitors to simulate the impact on the asset’s condition. This software typically can also determine the consequence of failure and calculate the risk value.”

Viridi’s Williams said the use of BESS can address several grid-related issues. “By charging batteries when energy is abundant and lower cost—in many parts of the U.S., this occurs during peak solar

production—and discharging when energy is at a higher price or when the grid is operating at a higher carbon intensity, distributed, behind-the-meter storage has the capacity to provide significant benefits to the host site,” said Williams. “These benefits include active management of on-site generation and cost reduction through peak shaving, while also supporting the grid by releasing energy when needed—all for the benefit of the battery owner. However, fulfilling these roles requires that the BESS be absolutely safe, and they must have advanced communications and controls capacity so they can be monitored and managed from anywhere and leverage real-time opportunities to provide forecasted return on investment.”

“A good example of the diverse benefits from distributed storage is the 600-kWh Viridi BESS installation [Figure 5] in occupied space at the Hauptman Woodward Medical Research Institute (HWI) in Buffalo, New York,” said Williams. “HWI had an undersized interconnection to support installation of a new cryogenic electron microscope. This need was satisfied by installation of the Viridi BESS, which charges in moments of lower power draw and discharges when the building is peaking to provide adequate power for this equipment whenever it is needed. However, when not used for this purpose, HWI uses the BESS in an automated fashion to peak shave, setting a kW ‘ceiling’ on operations that results in cost savings and reducing local grid strain. In this way, the BESS fulfills the promise of energy storage, which benefits both the host and the overall electric ecosystem.” ■

—Darrell Proctor is a senior editor for POWER.

Emerson Exec Discusses Grid Enhancements

There are many ways to enhance power grid and power plant reliability, including the implementation of advanced control strategies, proactive maintenance programs, and modern technologies for early detection of potential issues. Learn how utilities can leverage new software, automation, and predictive technologies to improve operational performance while managing aging infrastructure.

Darrell Proctor

Among those talking with *POWER* about reliability enhancements for the power grid was James Nyenhuis, plant performance consultant for Emerson. Nyenhuis provided *POWER* with insight about the work being done to support a reliable supply of electricity, from the power plant to the edge of the grid.

POWER: What are some enhancements that can be made to an electricity transmission and distribution system and/or a power plant (thermal or renewable) to improve its reliability?

Nyenhuis: Reliability has always been a key focus for the power generation industry, but what we see changing significantly in today's environment is a continued evolution of technologies, which provide efficient means to process more information closer to its source and provide earlier detection of evolving reliability risks [Figure 1]. One



1. Comprehensive asset performance management focuses on critical assets that require immediate attention to improve performance through increased production and decreased maintenance costs. Courtesy: Emerson

of the first enhancements that comes to mind, which can improve reliability of the power generating facility, is to ensure that operations teams are supported by a well-designed alarm and alert management process.

Many plants we engage with today are still burdened by underperforming alarm management systems that overload operations staffs and induce reliability risk by making it harder for operations teams to identify evolving issues. Significant impacts to reliability can be made with the right investment in optimizing the performance of the alarm system and providing clear identification to off-design process conditions to plant personnel.

Additionally, when off-design issues have occurred, we have seen advanced control strategies provide better coordinated responses due to their predictive control capabilities. These predictive capabilities allow the control actions to better steer through transient dynamic conditions and maintain stability, providing the plant an increased chance to stay online after these types of events.

Lastly, we are seeing technology enhancements at the "edge" that allow a better convergence of information from asset health, analytics, control, and performance to provide earlier detection of evolving issues from critical plant assets before they demand a real-time response from the automation system.

POWER: What are some of the maintenance programs that can be implemented to make a power plant and/or a power grid more reliable? How can this maintenance be automated?

Nyenhuis: Having a proactive maintenance strategy is the secret against declining operational performance and managing risks to reliability. More and more, power customers are expecting intelligence to be built by default into

the solutions they acquire. Ideally, we don't want a plant operator to have to notice that an alarm is intermittently coming in and going out to start a chain of events that leads to the identification of an under-performing cooling loop control, as an example. We want that control loop to be monitoring itself and raising its hand, telling somebody when it needs attention. That is how we need to be leveraging technology.

This same concept can be applied to the management of instrumentation, critical rotating equipment, control valves, etc. New technologies are allowing us to achieve these goals. Advancements in software [Figure 2] allow us to automatically communicate with assets and provide automated reporting and confirmation of expected operation. If the need arises, there's the ability to proactively notify the appropriate personnel via text or email of a potential problem that needs attention.

POWER: How important is redundancy as part of power plant/power grid operations?

Nyenhuis: The criticality of redundancy varies within different applications across the power generation playing field. Obviously, we will always ensure that safety is the top priority and deploy the right level of redundancy to maintain safe plant operations within industry best practices. Beyond safety considerations, there can be economic tradeoffs between the investment costs in additional levels of redundancy and the lost economic opportunity if the plant isn't available to produce power.

Generally, we are seeing a trend towards leveraging software applications to provide a more sophisticated risk analysis around the potential impacts of not having redundancy as it pertains to achieving the financial or operational



Early Detection, Reduce Cost, and Mitigate Risk

2. A proactive reliability management strategy is the secret against declining operational performance while improving process availability and lowering operating costs. Courtesy: Emerson

goals of a process. As an industry we have tended to design processes and equipment around static, fixed type assumptions, but we see this changing as the power generation world gets more sophisticated and dynamic. Technology allows us to more accurately model potential risks with historical data and design assumptions. These tools provide quantitative ways to balance the goals of process availability against the costs associated with various levels of redundancy.

POWER: How can operations be standardized to improve reliability?

Nyenhuis: One of the things that we are seeing is our customers leveraging additional levels of automation implementation within their existing technology to encapsulate operational expertise directly within the base level automation infrastructure before the existing expertise leaves the industry. This process forces customers to pull the right cross-functional team together, those who know the specific characteristics of the plant they operate and maintain. This leads to embedding the best practice operational procedures in sequence automation that can be leveraged over and over, driving consistency and repeatability. Tracking the appropriate metrics over time, such as startup times or fuel consumption, as well as operator interactions with the distributed control system, shows that operational consistency is enhanced and, over a longer time horizon, reductions in overall lost megawatt-hours have been achieved, directly improving reliability goals.

POWER: What are some of the specific components/equipment that can be used to enhance reliability?

Nyenhuis: We have found the best way to enhance reliability is to look back and wade through available data to understand, to the degree possible, what items show up as key negative contributors to a plant's overall reliability metrics.

Do particular trends show up? What types of events have led to the most lost production over the past number of years? Depending on the answers to these types of questions, different approaches may be called for.

Can a particular system or set of systems at a plant be identified as a key contributor? If so, aligning specific available technologies to manage the risk these systems pose may be warranted.

If human performance factors are a large contributor to lost generation, review of automation system performance and alarm management implementation may make sense. There is an abundance of useful technologies out in the market today: the challenge is aligning these technologies with stated risk mitigation objectives in as an efficient and cost-effective way as possible.

POWER: How can model predictive control be used to enhance reliability?

Nyenhuis: We have seen a significant increase in our customers deploying model predictive control in appropriate areas of the process such as steam temperature control, drum level control, load, and emissions control, as well as other critical process areas. The impact we are seeing to enhance reliability is model predictive control's ability to better manage critical off design situations.

When the control can be predictive in nature, we have seen it have a better ability to coordinate multiple control responses, ideally returning a process to a stable state after a critical upset, even if it is at a degraded output. For example, we have seen model predictive drum level controls better manage upsets to dynamic steam transition issues related to a combined cycle bypass system. When we have the predictive ability to steer the process through the upset, we increase the ability to avoid unit trips, which increases overall process reliability.

POWER: How can a program be implemented to enable proactive replace-

ment and/restoration of older equipment (both software and hardware) in power plant and power grid systems?

Nyenhuis: This effort connects to a question posed earlier and centers around what is known about the effective lifecycle stage of critical assets and systems coupled with an understanding of current symptoms that can be observed. We liken this to trying to understand whether an aging asset is like a fit 82-year-old with no indication of cholesterol issues, normal blood pressure, and a clean medical history, or is it an overweight 74-year-old with a history of medical issues such as hypertension, diabetes, and high cholesterol.

We have the ability, with technology today, to accurately track the "age" of critical assets and perform both periodic and continuous tests to monitor health symptoms and stress levels. Implementing these technologies and aggregating them into easy-to-understand outputs helps us understand where the "doctor" needs to focus.

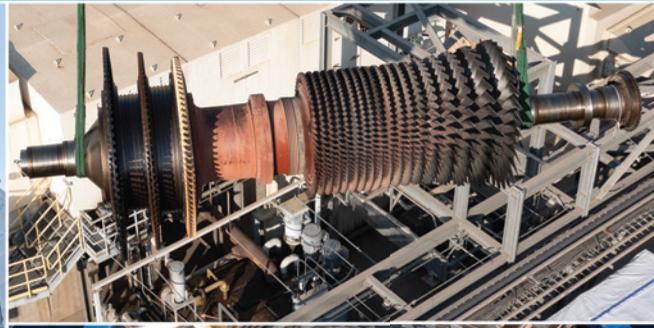
As previously discussed, reviewing historical data and what may be currently available to understand existing "symptoms" helps set the stage for where to initially focus efforts. We want to ensure there is a clear picture of asset criticality across the plant. Understanding a picture of historical impacts to unit reliability and ensuring this analysis lines up with asset criticality lens sets the stage for how to move forward.

Ideally, we want to deploy a proactive reliability management strategy that centers around actively monitoring the risk of aging assets while improving process availability and lowering operating costs. We especially want to identify any critical assets that require immediate attention. For ongoing monitoring, we want to leverage existing failure mode and effects analysis (FMEA), reliability strategies, work procedure development, and computerized maintenance management software (CMMS) integration to help focus initially on proper risk management of any identified high-criticality assets that may show signs of excessive age or poor health. These efforts allow us to target an asset management program and associated technologies that directly impact known reliability risks and lay a foundation that supports future expansion. ■

—Darrell Proctor is a senior editor for POWER.

Combined Cycle Overhaul

Hermiston Generating Plant



Read this case study at www.MDAturbin.com/CombinedCycle

MD&A recently completed an inspection and overhaul at Hermiston Generating Plant's 1 X 1 combined cycle power plant, which included gas turbine and steam turbine majors, an air cooled generator (7A6) stator & field rewind, and a hydrogen cooled generator (7FH2) robotic inspection and rewedged.

With a single point of contact, all MD&A divisions supported the common goal of returning the facility back online with long-term operations. MD&A is your full-service, OEM-alternative!



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MD&A: Your full-service, OEM-alternative

Mechanical Dynamics & Analysis (MD&A) provides power generators around the globe with a full-service, OEM-alternative for services, parts, and repairs for Gas Turbines, Steam Turbines and Generators.

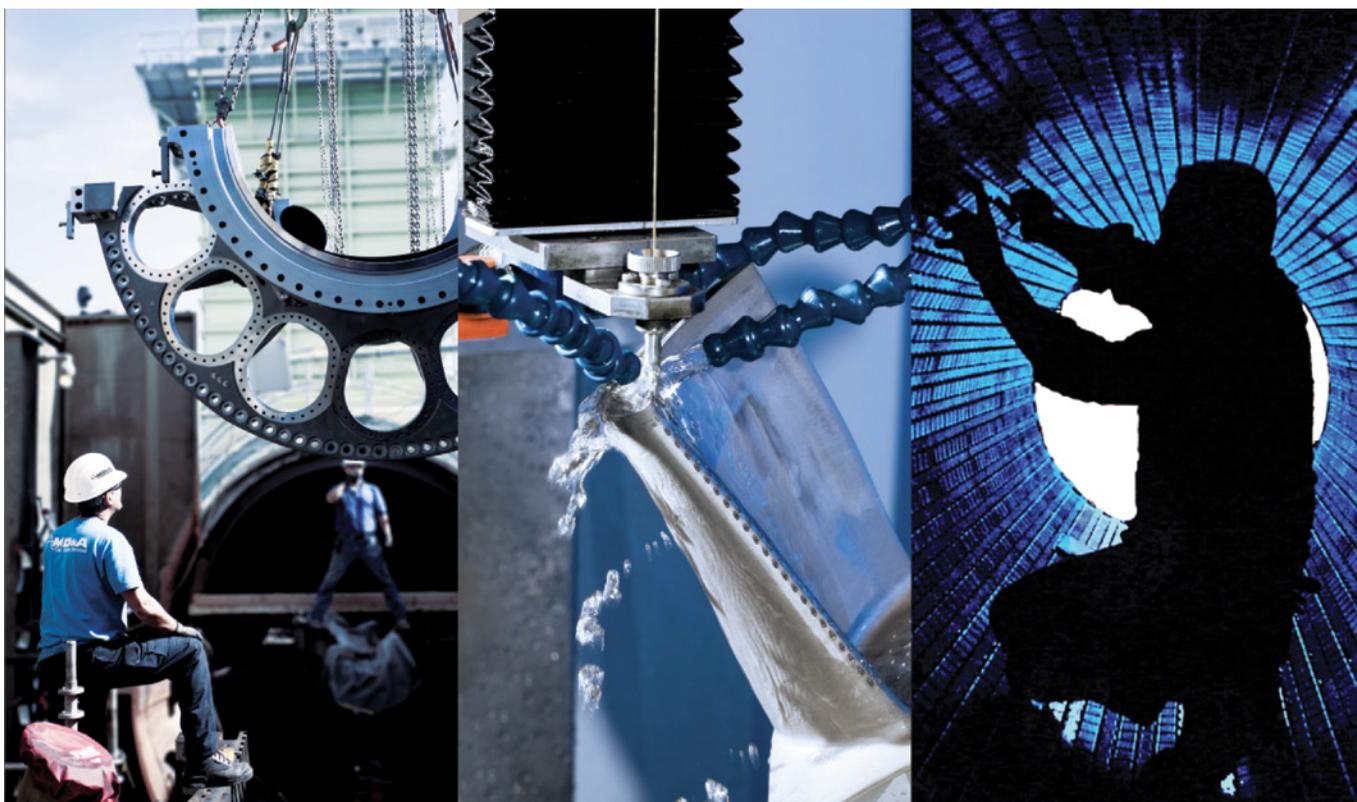
MD&A is easy to work with. We provide immediate access to expert help when you need it, where you need it. Around the corner or the globe, we ensure prompt, thorough communication and follow-through. For every repair job, large or small, the speed and effectiveness of our response team is matched only by the depth and breadth of our engineering expertise.

We extend the life of aging steam or gas turbine rotors and components, along with generator fields and stators. Our experts have knowledge of many different OEMs around the world. MD&A knows how to solve your turbine-generator's most complex problems and will get you back online quickly.

For over 40 years, our commitment to excellence has earned customer trust for all turbine-generator needs. We focus on delivering consistent quality and value with fast response, superior communications, and innovative solutions.

Find out today why so many power generators use MD&A to maximize operational effectiveness.

Visit www.mdaturbines.com



Turbine MRO Best Practices: Expert Guide to Maintenance, Repair, and Overhaul

Effective maintenance, repair, and overhaul (MRO) practices are vital for reliable turbine operation. Innovative technologies such as artificial intelligence and 3D scanning are transforming MRO processes. Proactive planning and using systematic problem-solving approaches can also help reduce downtime and ensure reliable performance.

Aaron Larson

Turbine MRO (maintenance, repair, and overhaul) operations refer to the comprehensive maintenance processes for both gas and steam turbines, and their associated generators, typically found in power generation plants and industrial applications. Implementing sound MRO practices is vital to maximizing turbine-generator reliability and performance while minimizing downtime.

The main components of turbine MRO include regular inspections and diagnostics to assess items such as blade wear and damage, bearing conditions, combustion system integrity, control system functionality, and alignment and vibration readings. Among major maintenance activities involved in the process are hot-gas-path inspections, rotor removal and refurbishment, blade replacement or repair, stationary component repair, bearing maintenance, control system updates, and component balancing. Modern MRO practices increasingly incorporate predictive maintenance using sensors and data analytics, digital twin technology for performance modeling, advanced non-destructive testing techniques, and automated inspection systems.

Managing a robust turbine MRO program involves significant planning. A strict maintenance schedule based on operating hours and starts must be adhered to, with good historical data being vital to success. The program not only requires reliable operating data, but also detailed documentation of all previous maintenance activities and inspection findings. Meanwhile, a comprehensive parts inventory management system is also important in the process.

“The most effective maintenance strategies for reducing turbine downtime are those that prioritize proactive planning, advanced diagnostics, and unit opera-

tional duty understanding,” Jay Eldridge, vice president of Sales and Marketing with Mechanical Dynamics & Analysis (MD&A), told *POWER*. “At MD&A, we’ve found that a combination of predictive maintenance, quality repairs, and comprehensive overhauls delivers the greatest results in minimizing downtime and ensuring consistent unit performance.”

Vibration Analysis: A Key Diagnostic Tool

When it comes to advanced diagnostics tools, few are more valuable than vibration analysis. At a high level, vibration analysis involves measuring the vibration levels and frequencies found in machinery, and using that information to gauge the health of components. In the past, vibration analysis has primarily been used to identify mechanical faults in rotating equipment and measure their severity, allowing repairs to be made in a planned and scheduled manner, thus reducing unplanned downtime. There’s definitely value in that, but in today’s world, online and wireless monitoring are making it possible to identify problems before they lead to faults, which allows engineers to be proactive rather than reactive.

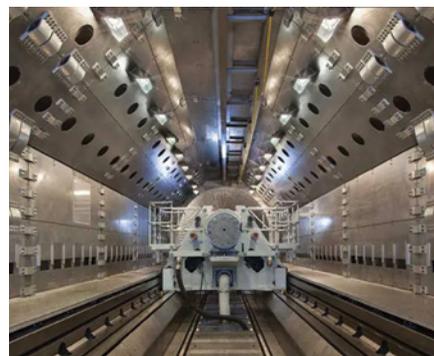
Many providers now incorporate artificial intelligence (AI) and machine learning (ML) into the process. Rather than waiting for a fault to be identified through a route-based methodology using a hand-held portable analyzer, permanently installed sensors can feed data to programs featuring AI and ML algorithms that continuously look for anomalies. The greatest value comes from identifying those times during operation when the equipment is operated outside its steady state parameters, such as during start-up or some other upset condition, and modifying procedures to minimize those hard-on-equipment periods.

MD&A uses vibration diagnostics as one of the tools to get a clear understanding of the state of equipment in power facilities. Its team of diagnostic/balance engineers can comprehensively analyze the mechanical condition of rotating equipment assets, and then offer the best and most cost-effective solutions for maintaining machine integrity.

Additionally, MD&A has a High-Speed Balance Facility in St. Louis, Missouri, which it uses to ensure vibrations are kept to a minimum in equipment it has repaired. The facility was designed with both vacuum capability and the ability to excite generator rotors at high speed, allowing the testing and balancing of both steam turbine and generator rotors (Figure 1). High-speed balancing has proven to be very effective in validating the repairs, ensuring effective operation when returned to service.

More Game-Changing Technologies

Beyond vibration analysis, MD&A said 3D scanning has revolutionized repair and parts replacement. “Using 3D scanning technology for reverse engineering, we can create precise digital models of



1. A generator rotor is shown here in Mechanical Dynamics & Analysis' (MD&A's) High-Speed Balance Facility in St. Louis, Missouri. Courtesy: MD&A

components, allowing for rapid reverse engineering and manufacturing of custom parts," Eldridge explained.

Other innovative inspection tools are also adding value. "Advanced imaging techniques, such as phased-array ultrasonic testing, X-ray inspection, and thermographic inspection, provide detailed insights into component integrity without the need for further disassembly. These methods allow MD&A to detect cracks, wear, and other issues with unparalleled accuracy, reducing inspection times and improving repair planning," he added.

Lastly, MD&A said advances in robotics have streamlined maintenance tasks in hard-to-reach areas. The company said its generator in-situ inspection robot can perform full generator inspections without removing the field. "These technological advances have allowed MD&A and the broader power industry to offer faster, more precise, and cost-effective solutions," Eldridge reported.

MD&A has used an innovative robotic generator inspection crawler supplied by East Hanover, New Jersey-based Nova Technology Inc. Called the GenEX (generator explorer), it is reportedly the lightest generator inspection crawler (Figure 2) and has the highest resolution available on the market today, according to Nova Technology. The crawler itself weighs less than 5 pounds and can enter generators with gaps as narrow as 0.9 inches (22.86 millimeters). It has dual full-HD (high-definition) color video cameras including one forward facing camera and one at a right angle that rotates and has variable focus. LED (light-emitting diode) lighting helps provide clear and crisp 5 megapixel annotatable still images of inspection areas, which can be displayed on a portable monitor or laptop computer.

"Until now, in-situ inspection services have largely been the domain of the OEMs [original equipment manufacturers]," Richard Hatley, president of Nova Technology, told *POWER*. "We've enabled service providers to provide an offering that not only saves time but also can eliminate the tremendous expense of an unnecessary field pull. The GenEX provides accurate assessments in hours or days, not weeks."

The GenEX crawler can be used for stator wedge tightness assessment (Wedgetap) and electromagnetic core imperfection detection (EI-Cid) inspections, among others. The GenEX has proven to be incredibly valuable to users. It has found faults, shorts, material deterioration, and more, while cutting downtime



2. The GenEX crawler provides rapid assessment of generators without removing the rotor, meeting traditional inspection requirements at a fraction of the cost. Courtesy: Nova Technology

by avoiding costly field pulls. GenEX has greater maneuverability than a magnetic crawler and can get into spaces some other video inspection crawlers can't.

Hussien Sadek, past president and current member of The American Society for Nondestructive Testing (ASNT), and president and CEO at Technologies Consulting International, noted that eddy current array (ECA) examination can be an important inspection technology in power generation facilities. ECA rapidly scans large equipment components by using custom-designed array coils that generate C-scan images. These images assist visual inspection and determine the location, size, and orientation of defects in equipment including in turbine blades. Today, ECA technology employs advanced data analysis and software to record test results, minimizing an operator's analysis, and allowing future analysis by third-party interpretation, characterization, and generation of final reports.

"When eddy current array technology is incorporated into the overall predictive and preventive maintenance program at a facility, the inspection and the condition evaluation of major equipment is conducted rapidly with minimum downtime," Sadek told *POWER*.

Leaning on Experts

Yet, when routine inspections don't lead to easy answers and more complicated situations arise, consulting with experienced engineers who perform turbine MRO projects for a living can be important. That's because they often have a systematic, multi-disciplinary approach to diagnosing complex issues and/or may have come across a similar issue at another facility.

"At MD&A, we excel in tackling these challenges by leveraging cutting-edge technology and a methodical process to identify root causes and implement ef-

fective solutions," Eldridge said. "When routine inspections fail to reveal the source of a problem, we begin with a deep dive into the turbine's operating history, performance data, and maintenance records. Next, we deploy advanced diagnostic techniques tailored to the suspected issue."

Eldridge said MD&A's cross-functional team of engineers and technicians collaborates closely throughout the diagnostic process. "Their combined expertise in materials science, mechanical engineering, and turbine operations ensures a thorough evaluation of the problem from multiple angles," he said. "Once the root cause is identified, we work with the client to develop a targeted repair or mitigation plan. Whether it involves component replacement, precision machining, or an operational adjustment, we prioritize solutions that not only resolve the issue but also prevent recurrence. Comprehensive testing and validation ensure the turbine is returned to service with optimal reliability."

Aging Equipment

The increasing age of installed turbine fleets has fundamentally reshaped maintenance strategies, driving a shift from reactive repairs to proactive and predictive approaches. Older turbines present unique challenges, such as material fatigue, outdated designs, and limited availability of original equipment manufacturer (OEM) parts, leading to a requirement for innovative and tailored solutions.

"At MD&A, we've seen a lot in our 42 years and have become very familiar with the failure modes of older turbines and generators," said Eldridge. "This allows us to identify and address potential issues before they result in unplanned outages, reducing downtime and repair costs."

Eldridge noted that aging fleets often suffer from a lack of compatible replacement parts due to design obsolescence. "To address this, we utilize reverse engineering to manufacture custom components that match or exceed original specifications. This not only ensures compatibility, but also extends the operational life of aging equipment," he said. "In addition, we frequently recommend upgrade solutions, such as control system retrofits or upgraded valves or enhanced blades that enhance turbine efficiency and reliability."

Extending Component Lifetimes

Elevated temperatures take a big toll on gas turbine components, risking cracks,

corrosion, wall thickness, and material condition. Repair enhancements can extend a part's life by slowing its degradation and pushing out its usable service life. Operators can see significant savings by opting for lower-cost repaired spares rather than purchasing new parts.

For example, MD&A's Gas Turbine Parts Service Facility in San Antonio, Texas, evaluated two sets of 7FA second-stage blades to determine if they were capable to operate for a third service interval. The blades had operated through two service intervals and undergone one repair.

The team performed an X-ray inspection on the components in their as-received condition, which did not reveal any areas of concern, nor clogging on the cooling holes. A fluorescent penetrant inspection (FPI, Figure 3) was performed to look for significant cracking, paying close attention to the platform side face due to the substantial number of starts reported. The area around the shroud radius was also evaluated for cracks. The team found no major areas of concern during the preliminary FPI inspection but still performed a more thorough inspection once the metallic coating was chemically stripped.

The MD&A San Antonio facility deemed the condition of the internal coating as acceptable and in good condition to operate for one more service interval. The external coating protected the external surfaces and was recommended for removal to allow a good FPI inspection of the hot-gas-path surfaces.

Microhardness readings taken at several blade locations showed a significant drop in the base material hardness where parts had been exposed to higher temperatures. These areas also showed significant degradation to the gamma prime structure under inspection by a scanning electron microscope. Hardness values after heat treatment demonstrated that the GTD 111, a GE-developed nickel-based superalloy used in gas turbine blades due to its excellent high-temperature strength and corrosion resistance, responded well to the process and the overall blade hardness values were improved.

For heat treatment, MD&A experts use a vacuum heat treat furnace in which the heating and cooling of metals is controlled to alter their physical and mechanical properties. There is a pre-weld heat treatment, post-weld heat treatment, and a diffusion or aging heat treatment solution.

Samples were removed from the



3. A fluorescent penetrant inspection (FPI) uses black light technology to pinpoint any cracks. Courtesy: MD&A

blades for stress rupture testing. The as-received condition did not meet the minimum expected strength requirements for GTD 111. However, the samples tested after heat treatment exceeded the minimum requirements.

After the repair heat treatment, the rupture strength was improved. This demonstrates that the repair heat treatment was able to rejuvenate the parts sufficiently to operate for one more service interval.

In the end, MD&A experts evaluated each component in the as-received condition and in the post-repair heat-treated condition. Improvements in the alloy mechanical properties were evaluated to determine if the two sets were candidates for a lifetime extension repair. Once deemed that they were, the team employed repair practices to further extend the useable life of the components.

Overcoming Maintenance Challenges

MD&A told *POWER* that one of the most challenging types of turbine repairs it encounters involves addressing potentially catastrophic failures, such as cracked rotors or extensive blade damage caused by operational stresses or foreign object impacts. These types of repairs require not only technical expertise, but also precision and innovation to restore the turbine's integrity and efficiency. Eldridge said MD&A approaches these challenges with a structured and collaborative methodology that includes:

- **Thorough Assessment.** MD&A's process begins with detailed inspections using advanced non-destructive testing (NDT) techniques and 3D scanning technology. This allows the company's experts to understand the full scope of the damage and identify root causes.
- **Reverse Engineering Expertise.** For components where OEM parts are unavailable or outdated, MD&A leverages its in-house reverse engineering

capabilities to manufacture high-quality replacements that meet or exceed industry standards.

- **Custom Solutions.** MD&A said it recognizes that every repair is unique. Whether it involves intricate welding, specialized heat treatments, or alternatives to OEM design, the company tailors its solutions to address the specific challenges of each case.
- **Testing and Validation.** Once repairs are complete, MD&A rigorously tests the components to verify performance, including full-speed testing in its High-Speed Balance Facility, to ensure reliability and long-term success.

"Our goal is to not only restore functionality, but also to enhance reliability and efficiency, helping our customers minimize downtime and achieve peak performance," Eldridge said. "It's this commitment to innovation and precision that has earned MD&A its reputation as a trusted OEM-alternative in the power industry."

Secrets to Success

In the end, turbine owners and operators must balance the need for thorough inspection and maintenance with operational schedules. Success often requires a strategic approach that prioritizes efficiency, flexibility, and collaboration. Among the most important aspects that lead to a positive outcome are:

- **Planning and Scheduling.** Owners and operators must work closely with contractors to develop a customized maintenance plan that aligns with a unit's operational goals.
- **Communication.** Clear and constant communication among owners, operators, contractors, and suppliers is essential.
- **Project Execution.** Project managers must diligently manage all aspects of turbine MRO work in order to hit schedule and budget targets, and complete a successful outage.

"Ultimately, the key to reducing downtime lies in balancing proactive maintenance with experienced execution," said Eldridge. "By blending cutting-edge technology, engineering expertise, and a deep understanding of aging equipment, MD&A helps customers maximize the value of their turbine assets, keeping them reliable and efficient well beyond their original design lifespans." ■

—Aaron Larson is *POWER*'s executive editor.

O&M Innovation in the Power Sector: The Latest Tools Redefining Asset Optimization

As the power sector grapples with aging infrastructure, stricter sustainability mandates, and the rapid integration of renewables, innovation in operations and maintenance (O&M) has become critical to balancing cost, reliability, and environmental goals. Legacy power companies and new clean energy players alike are increasingly turning to digital solutions to streamline their O&M practices and unlock new levels of asset performance.

Sonal Patel

Just five years ago, grid operators managed a relatively limited number of centralized, one-way assets. Today, the power landscape is far more dynamic. Characterized by bidirectional flows, intermittent renewables, and an ever-growing fleet of distributed energy resources (DERs), the modern power ecosystem represents an intricate web of interconnected technologies, stakeholders, and systems that must be orchestrated in real-time. At the same time, business survival and growth in the sector are increasingly hinging on evolving demands that are forcing conventional power plants and grid operators to adopt more sophisticated, data-driven approaches to ensure reliability, flexibility, and cost competitiveness.

“Reliable, well-optimized operations and maintenance [O&M] practices are more critical now than ever before,” said Emily Obenauer, global director of Product Marketing at Sitetracker, a complete Asset Lifecycle Management platform provider serving the power, renewables, and digital infrastructure sectors. “The number of assets grid operators manage has grown significantly, and that’s without even factoring in bidirectional and mobile assets like vehicle-to-grid systems,” she explained. “Maximizing uptime for all these assets is absolutely essential to ensure peak performance and optimize returns.”

The shift has upended traditional approaches to O&M, forcing the power sector to rethink how it manages and maintains its assets. For utilities and independent power producers (IPPs), staying ahead of challenges has required adopting a proactive, data-driven approach. After years of implementing piecemeal

solutions to explore digitalization’s impact on asset performance, the sector is now firmly beginning to reap value from innovative approaches. While objectives vary, they are beginning to demonstrate gains in operational efficiency while tangibly extending equipment lifespans. Others work on a fundamental level to reduce costs and downtime, empower a more skilled workforce, strengthen cybersecurity, and provide the flexibility needed for rapid decarbonization and rising energy demand.

Key Considerations for Modern O&M Tools

According to Obenauer, the rapid transformation of the power sector has exposed the limitations of legacy systems. Paper-based work orders and fragmented software tools, for example, are proving increasingly inadequate to manage the growing complexity of O&M. “These or-

ganizations are managing incredibly complex and fragmented technology stacks across multiple platforms—pen and paper, emails, and everything in between,” she explained. “It’s becoming increasingly clear that these legacy approaches can’t keep up with the growing complexity of asset lifecycles.” At the heart of the new generation of O&M tools is a focus on data integration and workflow optimization. Rather than relying on siloed systems and manual processes, power companies are seeking solutions that can consolidate asset information, maintenance histories, work orders, and financial data into “a single pane of glass.”

“Centralizing workflows and data across the entire lifecycle is incredibly impactful,” Obenauer added. “It simplifies operations, reduces inefficiencies, and helps teams optimize resources.” Sitetracker, which launched over a decade ago, leveraged its early experience



1. One of Sitetracker’s many customers, Sweden-based energy technology innovator Flower, uses the platform to optimize the deployment and management of battery energy storage systems (BESS). Sitetracker’s deployment operations management software works to improve Flower’s efficiencies in engineering, procurement, and construction workflows to ensure data fidelity and seamless coordination across teams. This image shows the 42.5-MW Bredhälla BESS project, Sweden’s biggest operating battery park. Courtesy: Flower

working with customers' digital infrastructure to launch its SaaS platform. Today, the solution offers a comprehensive, end-to-end platform to manage the full asset lifecycle across multiple industries (Figure 1). "From early origination, planning, and development of projects and assets, to ongoing operations, maintenance, and eventual asset management through to end of life, we provide one centralized place to manage it all." She concluded, "This level of centralization drives efficiency, streamlines resources, and ensures optimal use of assets throughout their lifecycle."

Beyond simply aggregating data, these platforms are designed to streamline core O&M activities like preventative maintenance scheduling, reactive work order management, and field crew dispatching. Sitetracker's own tools, for example, provide job scheduling systems to improve field resource efficiency and coordination, mobile reporting tools for real-time updates from the field, and expense tracking, invoicing, and work order management.

By digitizing these workflows, asset owners and operators can realize significant gains in labor productivity, cost savings, and risk mitigation. But, as significantly, these solutions are also architected to integrate with other critical systems, from asset monitoring platforms to financial management tools. "It's critical to tie everything back to the financials," Obenauer said. "Whether you're an executive or a project manager, it's crucial to understand how each project or individual job impacts not just the financial return of an individual asset, but also the broader financial performance of the entire project or portfolio."

Customization and Scalability

As power companies grapple with an ever-evolving portfolio of generation, transmission, and distribution assets, the ability to customize and scale O&M solutions has become paramount, Obenauer said. While much of the core work in this space is highly repeatable, each utility or IPP has unique requirements based on asset types, operational priorities, and organizational structures, she noted. "There's always room for customization," Obenauer said. "As new assets come online—whether for new sites, projects, or programs—we work closely with our customers to ensure they're managed effectively. Our goal is to help asset owners and operators maintain long-term asset health while maximizing return on investment."

However, customization of any solution must extend beyond the initial deployment, taking into account that power companies continually adapt their O&M practices to new challenges, for example, to integrate the latest sensor technology, optimizing maintenance schedules for a new fleet of electric vehicle chargers, or adjusting field crew workflows to enhance safety, she added. At the same time, scalability is critical, given that power companies must manage an ever-growing number of distributed assets, she noted. The sector must seek out solutions that can seamlessly onboard new sites, projects, and work orders—without adding significant administrative overhead.

The Vast Landscape of Tools

For now, the power sector's existing tool kit varies widely.

Machine Learning and Predictive Maintenance. Machine learning (ML) algorithms have already begun transforming O&M by enabling predictive maintenance, mainly by helping to analyze vast amounts of sensor data to predict equipment failures before they occur. ENGIE Digital, for example, reported implementing predictive maintenance models using Amazon SageMaker, a cloud-based ML service, across its global power plant fleet. By monitoring nearly 10,000 pieces of equipment, the company says it has saved an estimated €800,000 annually. Separately, First Solar has leveraged predictive analytics for remote monitoring of its solar farms to address issues like dirt accumulation and shading proactively.

Digital Twins for Real-Time Monitoring. Digital twins, another transformative technology reshaping O&M, are virtual replicas of physical assets that could allow operators to monitor equipment in real time, test scenarios, and optimize performance without disrupting operations. In just one example, Duke Energy's Metrology Services team has since 2023 used laser scans to create precise 3D models of nuclear reactor units to enable virtual planning and safer, faster execution of maintenance tasks. A recent motor replacement project, which traditionally required a full shift, was completed in just 2.5 hours.

IoT and Sensor Technology. Sensors enabled by the Internet of Things (IoT) provide real-time data on equipment performance, environmental conditions, and energy consumption, empowering operators to make informed decisions quickly. Ørsted, in partnership with Vodafone and Microsoft, has integrated IoT



2. Southern California Edison's (SCE's) drone program is revolutionizing wildfire mitigation efforts, conducting 75% of aerial inspections in high-fire-risk areas while integrating artificial intelligence or faster, safer, and more precise infrastructure assessments. Courtesy: SCE

platforms into its offshore wind farms in Scotland. The system collects and analyzes data from 1,300 turbines, enabling predictive maintenance and reducing operational costs.

Drones. In India, Tata Power has used drones equipped with IoT sensors for geographic information system (GIS) mapping and asset inspection, reporting that the endeavor slashed mapping times from 10 days to just three. Another Indian company, Renew Power, has deployed drones with thermal imaging cameras to inspect solar panels and wind turbines. Heimdall Power in Norway has gone a step further by deploying autonomous drones to install IoT sensors on live power lines to enhance grid reliability without disrupting operations.

Drones are also becoming indispensable in hard-to-reach or hazardous environments. Southern California Edison, for example, uses drones equipped with artificial intelligence (AI)-powered image analysis to inspect high-risk areas across its 50,000-square-mile service territory (Figure 2). And in the UK, National Grid has piloted drones for inspecting transmission lines and substations, cutting inspection times and enhancing accuracy.

Augmented and Virtual Reality (AR/VR). Augmented and virtual reality technologies are reshaping how maintenance and training are conducted. Siemens Energy technicians now use AR glasses that overlay visual instructions onto machinery during repairs, enabling hands-free access to critical information. Similarly, France's EDF Energy has adopted VR training simulations for its nuclear plant operators to practice emergency procedures and complex maintenance tasks.

Robotics and Automation. Robotics and automation are taking O&M to new heights by enabling tasks that are dangerous or labor-intensive for human work-



3. A uniquely customized underwater drone, developed by the ORCA Hub in partnership with EDF, in 2022 conducted the first autonomous inspection of turbine foundations at the Blyth Offshore Wind Farm off the coast of Northumberland, UK. Courtesy: Heriot Watt University

ers. Sarcos Robotics has developed the Guardian S robot, which performs remote inspections in hazardous areas, reducing risks to personnel. Like several other utilities, National Grid has deployed Boston Dynamics' Spot robot to automate inspections at high-voltage converter stations, using thermal imaging sensors to detect potential issues. In another example, EDF Renewable Energy has tested autonomous underwater robotic vehicles (ROVs) for offshore wind farm inspections (Figure 3). The robots create detailed 3D models of underwater assets to allow for frequent and thorough monitoring without the need for divers.

Edge Computing. Edge computing is also poised to transform utility operations by enabling data processing and analysis closer to the source, significantly enhancing system responsiveness and reducing latency. For utilities, the technology promises to facilitate real-time monitoring of energy distribution, predictive maintenance, and grid management, all while minimizing reliance on centralized infrastructure.

Large Language Models (LLMs). While relatively new, LLMs—AI-powered tools designed for natural language processing—offer immense potential for advancing power sector O&M. These models excel at processing large volumes of text-based data, such as equipment manuals and regulatory documents, to streamline workflows. ComEd, for example, is exploring LLMs to improve outage management by categorizing messages, processing trouble reports, and extracting actionable details like locations and timestamps. LLMs are also being tested for summarizing dense technical manuals

and incident reports, providing faster access to critical information. Additionally, ComEd is investigating how LLMs can democratize data, enabling non-experts to query operational metrics in natural language with visualized results. However, LLMs require rigorous testing and human oversight to mitigate inaccuracies to ensure they complement, not replace, traditional engineering practices.

Barriers to Adoption

While the benefits of innovative O&M tools are clear, their implementation is not without challenges. The most cited involves operational integration. Many utilities struggle with integrating data from disparate systems and standardizing it across their operations, often against legacy infrastructure. Costs are also a major concern, particularly as cost competition grows more complex amid rapid shifts in the power space. Another much-cited deterrent is that companies must demonstrate value, including long-term savings. Resistance to change within organizations can also hinder the adoption of O&M tools. Other issues concern cybersecurity and regulatory complexity, specifically related to environmental compliance and grid reliability standards. Supply chain issues and workforce adaptation also factor in heavily. While recent global events have highlighted vulnerabilities in supply chains for critical components, securing skilled talent to implement and maintain tools can be cumbersome.

To alleviate these concerns, companies are increasingly tailoring their approaches to meet the unique challenges of the power sector. Many have homed in on flexible, interoperable platforms—

like Sitetracker's—that seamlessly integrate with legacy infrastructure, reducing the burden of operational integration. To address cost concerns, providers are emphasizing the long-term savings that advanced O&M tools can deliver through preventative maintenance, optimized workflows, and reduced downtime. Finally, user-friendly interfaces and robust training programs are helping to overcome internal resistance by empowering employees to adapt to new technologies with ease and focusing on workforce development, including upskilling programs.

Investing in the Future of O&M

Looking over the long-term, Obenauer predicts that companies will sink their investments more prominently in "systems that are helping to consolidate their view of the world." The future of O&M will rest on "tools to help them do work better and smarter and faster," she said.

A key focus for future investment will likely rest on advanced analytics and AI. "This is going to be a huge piece moving forward," she said. The tools hold two important capabilities. First, they can help power companies maximize the uptime and efficiency of their assets, reducing costly outages and maintenance expenses. Second, they can enhance the productivity and safety of field crews by automating repetitive tasks and providing data-driven insights to guide their work, she noted. Sitetracker is "being incredibly intentional about how we're investing in AI to help enhance the workflows our customers are already managing within our platform. Ultimately, we believe that traditional methods used to plan, build, operate, and maintain critical infrastructure can't keep pace with modern demands. But, Sitetracker can. And when enhanced with AI and machine learning, the possibilities are endless," she said.

Andrew Robson, technical expert of O&M Solutions at Siemens Energy, agreed. "Artificial intelligence is, of course, on the rise at O&M, and we have not even begun to exploit its true potential," he said. "One notable aspect is our use of AI and various machine learning techniques to review extensive maintenance and historical data at a power plant." However, while these technologies will provide "valuable recommendations," the human factor is non-negotiable "to ensure the accuracy and appropriateness of the AI-generated conclusions and confirm the final decisions," he said. ■

—**Sonal Patel** is a POWER senior editor.

Maintaining critical infrastructure is a race against downtime, complexity, resources, and costs. It's not easy.

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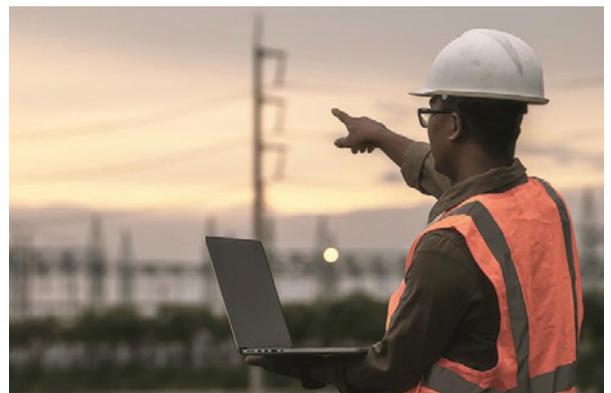
Sitracker enables strategic oversight of operations with tools for asset tracking, contract and document management, inventory control, and real-time reporting.

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To learn more visit: <http://sitracker.com>

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Cut Downtime and Costs with Predictive Maintenance (PdM): Here's How

Predictive maintenance (PdM) is transforming power plant operations by leveraging artificial intelligence (AI), data analytics, and automation to prevent costly equipment failures. Learn about real-world applications, challenges in adoption, and the significant cost savings achieved through advanced monitoring and proactive maintenance strategies.

Aaron Larson

In an era where power outages can ripple through communities and industries, causing significant economic impact and disrupting essential services, the reliability of power generation equipment has never been more crucial. Yet, across the fleet of aging power plants worldwide, maintenance teams are caught in a delicate balance between preventing catastrophic failures and avoiding unnecessary downtime for inspections and repairs. This is where predictive maintenance (PdM) is revolutionizing the industry's approach to equipment health.

Gone are the days when power plant operators relied solely on scheduled maintenance intervals and reactive repairs. Today's PdM technologies harness the power of sensors, data analytics, and artificial intelligence (AI) to detect potential failures weeks or even months before they occur. For an industry where unplanned turbine downtime can cost hundreds of thousands of dollars in lost generation production, this shift from reactive to predictive maintenance isn't just an operational improvement—it's a competitive necessity.

Consider this, at any given moment, a typical combined cycle power plant (Figure 1) has thousands of critical components operating under extreme temperatures and pressures. Each bearing, blade, and valve tells its own story through vibration patterns, temperature fluctuations, and performance metrics. By listening to these mechanical whispers and interpreting them through advanced analytics, maintenance teams can now predict and prevent failures with unprecedented accuracy.

Combining the Right Tool with the Right Expertise

Orangeville, Utah-based Taber International is an engineering and automation consulting group that offers fully customized solutions in smart automation, optimization, data visualization, and process control. It works with existing hardware and systems, and also deploys new systems from the ground up, providing end-to-end software platforms.

The company was founded in 2006, and initially focused on combustion optimization and intelligent sootblowing applications for coal-fired electric utility generators. Over the years, it expanded its scope to include ancillary systems in thermal power plants and diversified into other industries including chemicals, manufacturing, water and wastewater, oil and gas, and others.

Taber has deployed applications within the Griffin AI Toolkit, a no-code interface and companion rapid prototyping run-time engine, which provides an excellent platform for improving maintenance practices. With these tools and Taber's help, many power plants have replaced time-interval or "gut-feel" based maintenance approaches with condition-based solutions.

"Taber's expertise in the power industry combined with the capabilities of the Griffin AI Toolkit provide insight into a wide range of conditions," Jake Tuttle, CEO of Taber International, told *POWER*. "We've had success in recognizing condenser and heat exchanger fouling throughout the fouling process, keying into subtle performance degradation during the early stages of formation, allowing for minor corrective actions to be taken at much lower cost."

In other cases, Tuttle said the compa-



1. A modern combined cycle power plant has literally thousands of sensors installed to monitor temperatures, pressures, flows, levels, vibrations, water quality, and more. Data from these sensors is vitally important to predictive maintenance programs. Source: Envato

ny has been able to recognize the immediate onset of tube leaks in steam power plants, before acoustic monitoring or other systems detected it. One such example occurred in a fossil power plant while load ramping. During one ramp from minimum to maximum load, the system recognized a change in operating state once the unit reached full load. No other systems reported any change. Eight hours later the tube had a massive failure and caused the unit to come offline immediately. Other examples include bearing fatigue in motors, sensor calibration and measurement errors, fan performance deterioration, oil and lubricant leaks, equipment filter pluggage, general performance degradation, mechanical stress failures, and more.

Challenges to Implementation

Yet, as game-changing as Taber's technology is, it can be difficult to get a team of power plant managers, engineers, operators, and technicians to move beyond past practices. "The big-

gest customer challenges—or more accurately, perceived challenges—are usually their own available resources and trust,” said Tuttle. “Most customers feel they don’t have the personnel and the time to support development of a predictive maintenance program. There’s an assumption it takes multiple people multiple months or even years to get a good, reliable program in place. Customers become daunted when they realize just how much equipment and the scale of maintenance efforts they have at a site. On the trust side, it’s hard to break tradition and rely on a new system to perform on ‘your’ system, no matter how well it’s worked elsewhere.”

Among the other obstacles customers sometimes bring up is the fear of false alarms. “Many existing programs have experienced the situation where an alarm is always coming up that isn’t real or isn’t a concern, and the alarm just gets shelved or personnel become desensitized,” Tuttle explained. “Nobody wants to add to the list of alarms, especially if that’s going to add to the desensitization problem. It’s critical to avoid alarms being activated just because a threshold is crossed, but that alarms be verified by the behavior of the current conditions of the process, which is something we take major steps to achieve through customization and specific element-by-element deployment of the PdM program.”

Tuttle said Taber’s hybridized approach combined with its personnel’s experience only requires the site to retrieve some operating data (1 day), answer some questions about the different system processes they want to focus on (2 to 3 hours), and be available to answer some follow-up questions. Taber builds out the PdM program within its platform, then there’s a validation period where the system provides notifications and insight while the site continues its existing program. The site can monitor and compare the findings of both approaches for as long as it takes for the site to be satisfied that it’s seeing favorable results. And then the switchover can be finalized.

“We also very often work on an incremental scale, meaning we start with a small portion of the process or a few pieces of equipment. Building the PdM program out on this reduced scale only takes a few weeks total to be functional, then we move on to the next piece. Typically, the reduced scale feels more manageable to the site, and as these

perform well, trust is developed in the system and the remaining steps move even faster,” Tuttle said.

Consistency Is Essential

At the heart of any successful PdM program lies a fundamental truth—the quality of your insights can never exceed the quality of your input data. Even the most sophisticated AI algorithms are fundamentally limited by the data they process. This is why establishing rigorous data quality standards and validation processes isn’t just a technical detail, it’s the foundation upon which all reliable PdM capabilities are built.

“As far as data quality, the key is that the data is consistently represented. Even if it’s noisy data, if it’s a consistent amount of noise, and it reflects and follows the process reliably, it can be integrated within the system,” said Tuttle.

“Similar to our approaches in automation and controls, we utilize a hybridized approach to system development, combining real-world process knowledge and systems experience with machine learning and AI, dramatically reducing the bulk data needs upfront. Doing this, with just a month or two of process data representing a ‘healthy’ component, we can begin reliably informing predictive and condition-based maintenance programs,” added Tuttle.

Implementations Vary

How a system is deployed often changes based on the scale of installation. Sites that want only a local deployment at a specific plant site inside a firewall can avoid some of the cybersecurity concerns that others face when wanting corporate-wide visibility.

For standalone plant sites, the sys-

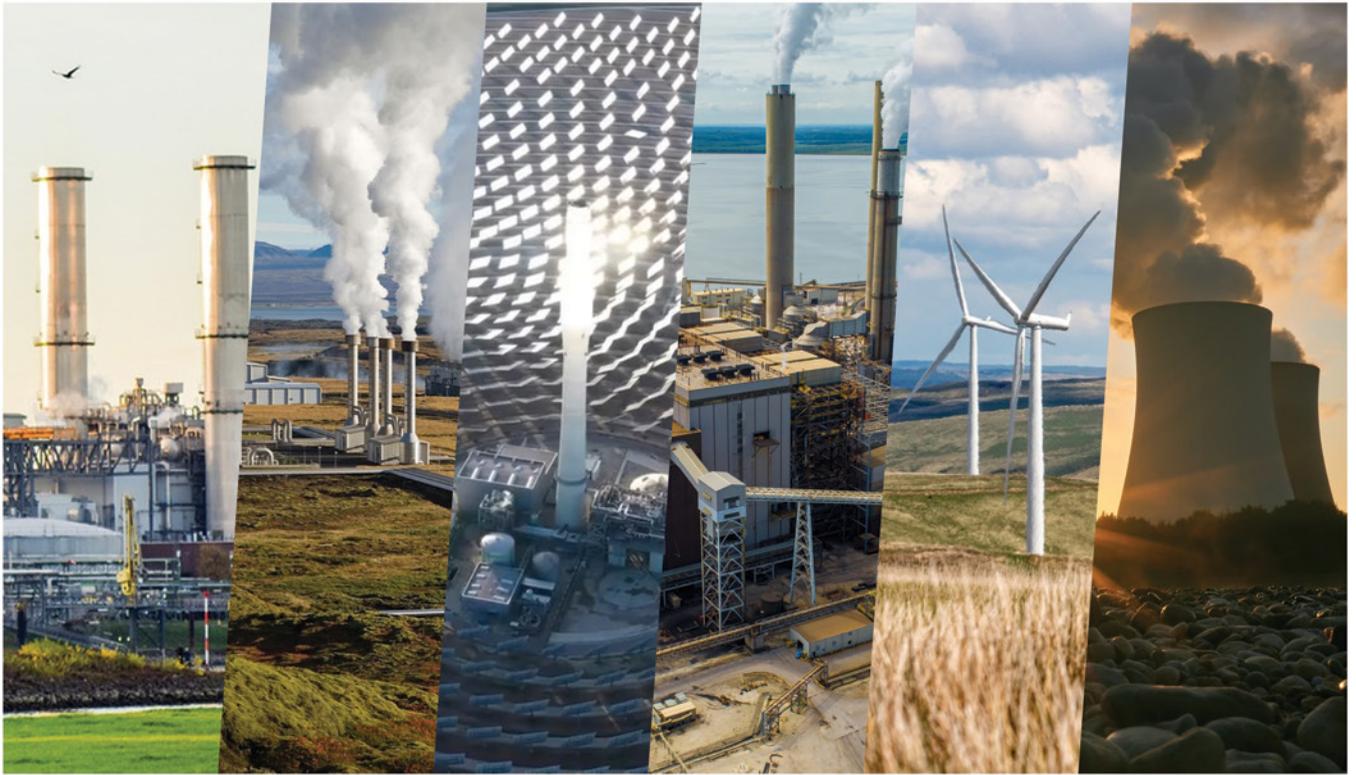
tem is considered a “local, on-prem installation.” Installed in this arrangement, the system retrieves real-time process data from the plant’s distributed control system (DCS) using industry-standard communication protocols: either OPC (Open Platform Communications), which enables secure data exchange between industrial equipment from different manufacturers, or Modbus, one of the oldest and most widely used industrial protocols for connecting electronic devices. The system can then communicate notifications back to the DCS, displaying them either on a new monitoring graphic or in the form of alarms.

“Here the only absolutely required site changes are to support data communication setup,” explained Tuttle. “It’s great to have additional sensors and greater resolution, but we can commonly do quite a bit with existing signals. We also commonly build our own HMI [human-machine interface] available only within the same network level for more in-depth information display.”

For corporate-wide visibility, Taber prefers to avoid the direct DCS link, and rather, communicates with a historian system such as PI or something similar. “This way the established process data pathway for historical system information retrieval is used and no other pathway is needed that involves that critical system,” said Tuttle. “At this level, more information access across the organization is obviously supported, and a suite of HMIs and displays are generated for various levels of the organization to interact with. Sometimes this requires a few additional data points be added to the existing DCS-to-historian path, but that’s generally the extent of changes required.”



2. If a PdM program can prevent a turbine from being taken offline for repairs during peak season, it can literally save tens, if not hundreds, of thousands of dollars for a power company. Yet, quantifying events that didn’t happen is difficult. Source: Envato



TABER INTERNATIONAL

A graphic of a circuit board with various components and lines extending from it, positioned below the company name.

TOTAL PLANT INNOVATION

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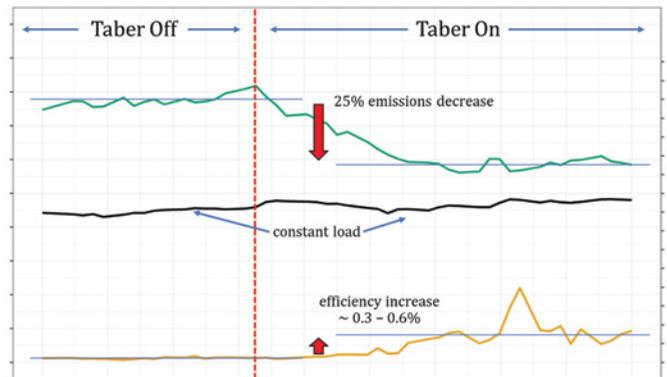
Data-Driven Innovation and System Transformation Achieves Real Improvements

Power systems worldwide are evolving rapidly, with generators and networks stretching to meet new demands in a variable environment. Using only conventional methods like manual or basic control, simple analysis tools, and traditional practices can make achieving optimal performance feel unattainable. Taber International brings this goal and many other process improvements back within reach using artificial intelligence (AI) and machine learning (ML) to enhance control and analysis, empowering systems and personnel to perform at peak capacity and efficiency.

By combining advanced data-driven methodologies with decades of expertise and knowledge together with knowledge-capture from a site's expert personnel, Taber delivers fully customized solutions tailored to each system's unique characteristics and goals. These applications are specially designed to fuse and address all of a site's goals and constraints to meet operational and corporate objectives continuously and effectively.

Key Services Offered by Taber International:

- **Combustion & Power Systems Optimization:** Taber uses AI-driven hybrid-system closed-loop optimization for power generation processes like combustion, temperature control and attemperation, sootblowing, scrubber and lime management, chemical additives, and other areas enhancing efficiency and productivity.
- **System Monitoring & Analytics:** A customized analysis platforms monitors anything from individual processes to entire fleets, identifying events, seizing opportunities, and providing actionable insights for better decision-making across the system.
- **Process & Workflow Automation:** Taber automates routine and mundane tasks like regular reporting and reviews, reducing errors, improving efficiency, and allowing personnel to focus on critical work.



Example of Taber closed-loop control off-on test for emissions reduction

- **Electronic Logging & Dashboarding:** Taber develops web-based logbooks and input forms designed for easy use and rapid adoption. Customizable panels can be incorporated together with dynamic behavior, enabling automated reporting and notification. Data recorded using the system remains safely stored and easily accessible for more effective logbook keeping and communication.

Taber International remains dedicated to supporting all forms of power generation and infrastructure by delivering the right tool for the job (simple or complex) and the domain expertise necessary for system innovation and resource optimization.

To learn more, visit www.taber-intl.com or contact info@taber-intl.com.



Tracking Performance

Quantifying the value of a PdM program presents a unique paradox, that is, its success is measured by the absence of events, specifically, equipment failures that never happened. While traditional maintenance metrics can count repairs made or man-hours worked, PdM's true value lies in invisible victories—the bearing that didn't fail during peak demand, the transformer that didn't overheat during summer, or the turbine that didn't require emergency maintenance (Figure 2). This makes building a business case simultaneously essential and difficult, but not impossible. Key performance indicators (KPIs) offer a good place to start.

"The most important KPIs for our deployments are event identification and confirmed events," explained Tuttle. "If or when an event occurs, did the PdM program identify it? And for each identified event, did the subsequent or recommended maintenance effort confirm it was accurately identified? The goal is, of course, that all events are accurately identified."

In the end, this is really just confirmation that the system is reliable and effective. From there, when all the supporting information is provided, tracking cost and manpower savings is what provides users the confirmation that they've made a good choice in deploying the system. However, Tuttle agreed that it's always difficult to characterize "what didn't happen," so this can take some time to accurately develop.

"If ever a customer receives a recommendation or an event is identified, but the customer doesn't act on it for whatever reason and eventually a failure takes place, the potential cost savings had the event been acted upon is much more readily and precisely determined, and this is tracked," Tuttle said. "Maintenance costs for an organization can be reduced 20% to 30%, basically shaving off the big maintenance costs due to failure, and stretching the preventative maintenance windows to lower the average. Equipment reliability increases, and unplanned downtime can be dramatically reduced, as much as 75%," he added.

Taking the analysis a step further involves estimating a return on investment (ROI). "Many factors go into ROI on these PdM programs, things like scale of deployment, nature and age of the process, current maintenance program, and others. When the system is deployed at a site as the first real effort to establishing a good maintenance program, often times this is a place that's been experi-

encing several supporting equipment failures in a year, and the ROI lands in the neighborhood of one year for a large site, maybe two years for a smaller site simply due to scale," Tuttle supposed. "However, if that site is 30- or 40-plus-years old, we've seen instances that several long-developing problems are immediately identified, and the system has effectively paid for itself out-of-the-gate in identifying these and avoiding a looming major failure."

For a site that is very active with a PdM program, the benefits come from reducing disposables cost and labor time (Figure 3). "This takes longer to add up and may be several years," Tuttle presumed. "That said, if that same site is preparing for an overhaul or major outage and would typically spend a great deal on preventative maintenance, again, our system can provide confidence in forgoing some of the more costly efforts that aren't necessary, and again, this can result in rapid ROI."

Real-World Losses

To get an idea of how much money can potentially be lost through inaction, Tuttle gave an example without mentioning names. "The closest example is from a site where we were consistently indicating air heater performance issues," he said. "Unfortunately, because the site was nearing end-of-life, for several years no maintenance was performed to address this, being considered by some levels of the organization to be an unwarranted cost. The unit was forced to derate at full load by an ever-increasing amount, at its worst, by more than 5% consistently."

Ultimately, conditions changed and the maintenance was performed. "The air heater's condition was atrocious, just as the system had indicated for those several years," explained Tuttle. "Simply in direct lost generation, millions of dollars went unrealized. When this is coupled with greater fan power consumption, reduced heat transfer performance, and other efficiency and process effects, it is very likely that not performing this maintenance cost tens of millions of dollars."

Innovation Continues

Tuttle said one of the best things about Taber's process and deployment platform, the Griffin AI Toolkit, is its inherent open system design. "This tool and our approach are, by design, fluid and adaptable to evolving industry demands and technology availability. We make a



3. Part of the value of a successful PdM program comes from eliminating unnecessary time-based inspections, which frees up workers time to do those jobs that are truly important. Source: Envato

point to almost immediately integrate technological advancements as soon as they're demonstrated as more reliable than simple theory, and to be familiar with and comfortable as a team with the industry and changing demands. So be assured that as advancements in approaches are available, they'll be a component within our program, and that as the industry evolves, we'll be there to support it," he said.

Getting started with a usable PdM program is not an intensive effort. Even if a facility simply wants to "test the waters" and consider a single piece of equipment, that's a good first step to evaluate the approach and performance of such a system and gain the experience that is often necessary to proceed further with system and scope expansions. "We all know how much maintenance costs, and since maintenance is a sure thing, any steps that can be taken to reduce those costs by simply adjusting procedures—effectively, no hardware or major system changes—are beneficial across the board," Tuttle argued.

"At the end of the day, for us it's about supporting our customers through fully customized systems. Whether this is through a simple single component system, or an enterprise-wide platform and program that integrates real-time data signals, personnel logging interfaces, maintenance and workorder system communication, and automated reporting and tuning. At whatever level a solution is needed, we have the capability and tools to turn it into reality," he concluded. ■

—Aaron Larson is *POWER's* executive editor.

Building Better Ways to Keep the Lights On

Utilities and power grid operators walk a fine line when it comes to providing reliable and resilient power while also protecting valuable assets in the electricity transmission and distribution system.

Darrell Proctor

Power outages are disruptive, and in some instances life-threatening. More frequent outages, often caused by extreme weather events, mean utilities and power grid operators are looking for better ways to detect outages, restore electric service more quickly, and even prevent blackouts altogether.

It can be a daunting task. The ever-growing global list of major outages has grown in just the past few weeks and months. Thousands of electricity customers were left without power as winter storms moved across much of the U.S. in January. Millions were left in the dark on New Year's Eve across Puerto Rico due to blackouts there, as the island continues to struggle with upgrading its electricity transmission infrastructure after numerous storms, beginning with Hurricane Maria in 2017.

A major storm left more than 600,000 without power in Washington state in November. Cuba, with a population of about 10 million, sustained a nationwide power outage in October due to the unexpected shutdown of a major power plant—adding to a series of blackouts that have plagued the island in recent months. Ecuador has sustained several power outages in the past year, with the country's leaders calling the situation an "unprecedented energy crisis."

Utilities and power grid operators are looking at infrastructure upgrades, along with technology such as outage management systems (OMS), to help mitigate the impact of blackouts.

"Our daily lives depend more than ever on reliable electricity service to our homes and businesses: computers, smartphones, and networking equipment for home-based work, electric vehicle [EV] chargers for transportation, etc.," said Tom Eyford, global industry specialist at Oracle Energy and Water. "At the same time, electric grids are operating much closer to their limits than ever before as utilities strive to



1. Eaton Experience Centers in Houston, Texas, and Pittsburgh, Pennsylvania, provide hands-on training in real world application environments, advancing industry education on the technologies vital to power reliability, safety, and security. Courtesy: Eaton

keep electricity affordable while seeing a resurgence in system load growth due to the expanding consumer energy technology as well as larger, centralized loads such as cloud-based computing and artificial intelligence (AI).

"Given the shrinking operating margins, modern grid control capabilities such as advanced distribution management systems [ADMS] are needed to predict where problems are likely to occur on the network, and to recommend and execute pre-emptive actions to mitigate them before they happen," said Eyford. "All of this requires a steady diet of real-time data from grid devices, sensors, smart meters, weather stations, and more."

"Real-time insights into grid conditions are critical for reducing outages caused by extreme weather or managing peaks in electricity demand," said Jasmin Giroux-Maltais, product manager—feeder automation at Eaton, a company with training centers (Figure 1) that provide hands-on experience across the electricity sector. "We at Eaton are working closely with utilities to identify the event signatures needed to better detect disturbances early and enable rapid response through automated grid services. This capability helps utilities minimize the impact of potential outages by identifying and addressing issues before

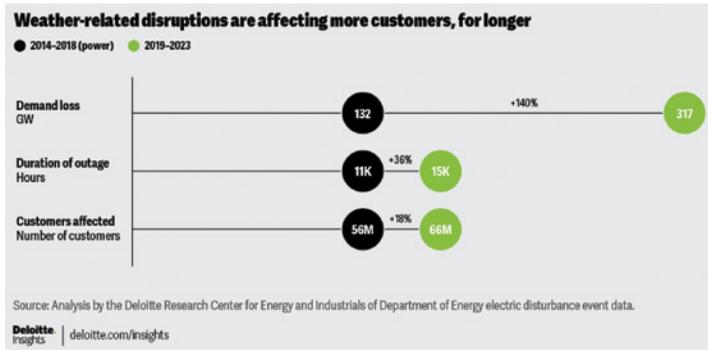
they escalate, ensuring the reliability and resilience of the electric grid under the most demanding conditions."

Thomas L. Keefe, vice chair, and U.S. Power, Utilities & Renewables Sector leader for Deloitte, said having real-time information available "is very important because the impact of electric disturbances due to weather events [Figure 2] has significantly increased over the past few years, and they mostly hit the distribution grid, where 90% of outages originate. Demand losses have more than doubled between 2014 and 2018, and over the past five years, the disruption of 317 gigawatts of electricity impacted 66 million customers for longer durations [Figure 3]."

"Real-time information is absolutely crucial for modern grid management, particularly when dealing with extreme weather events or demand surges. The key is having systems that can process and analyze millions of data points simultaneously, enabling operators to identify potential issues before they escalate into outages," said Nate Walkingshaw, CEO and founder of Torus, a company building energy storage and management products. "Our approach integrates multiple data streams to pinpoint outage locations and impact assessment. Our real-time monitoring gives us incredible visibility and insights into the distributed energy resources [DER] across the network. This compre-



2. With severe weather occurring more often across the U.S. and the world due to the effects of climate change, finding ways to harden power grids and transmission and distribution infrastructure has taken on new urgency. Courtesy: StockCake



3. Research by Deloitte based on data from the U.S. Department of Energy shows how power disruptions are occurring more often, and lasting longer, in recent years. Courtesy: Deloitte

hensive view allows us to track system performance at both macro and micro levels. We've developed sophisticated algorithms that can rapidly assess outage scope and impact, enabling more efficient resource allocation and faster response times."

Outage Management Systems

Several companies have designed OMS packages, offering a wide range of services. At the core of a modern OMS is a detailed network model of the distribution system. A utility's geographic information system, or GIS, is often at the heart of this network model, finding outage locations and also areas where a failure may be imminent. Those include locating equipment issues along the grid that could lead to a blackout.

An OMS also can help organize power restoration efforts, and manage resources (such as the number of workers needed), based upon the size of an outage and its likely duration. An OMS also can improve safety performance and ensure regulatory compliance. A highly integrated system can leverage distribution automation that supports fully automated fault location, isolation, and service restoration (FLISR), which will minimize the impact of an outage. It can provide higher visibility into localized outages, and allows for better planning and restoration of larger network outages.

Safety is improved through increased situational awareness and real-time connectivity between the control room, the field crew, and SCADA (supervisory control and data acquisition), which helps utilities better monitor the network and crew activity for potential safety hazards. The OMS also can provide a record of performance, including during major weather events, and an electronic audit trail helps ensure compliance with regulatory reporting requirements such as

system and customer average interruption and duration indices.

"Oracle offers an outage management system used in many utility control rooms around the world, but because outage management has been and remains such a critical process for both utilities and facilities, there are many mature options in the market to choose from," said Eyford. "GE Vernova, Hitachi, Hexagon, AspenTech, Schneider, Survalent, Minsait, Trimble, and ETAP are some of the more common platforms, but there are many others as well. In addition, industrial automation systems and microgrid controllers from providers like Schneider Electric, Siemens, Eaton, and GE can act in much the same fashion for the local devices and networks that they supervise, and in many cases, they can provide additional visibility and flexibility to the utility's central outage management capabilities."

An OMS also supports the improvement of distribution reliability by providing historical data that can be studied to find common causes, failures, and damages leading to blackouts. Improvement programs can be prioritized with an understanding of the most common modes of failure. Hitachi Energy said its Network Manager OMS is part of the group's ADMS. It said the system features a "highly integrated system leveraging distribution automation that supports fully automated fault location, isolation, and restoration, minimizing the impact of an outage." The company said its system "provides higher visibility into localized outages, and allows for better planning and restoration of larger network outages."

Survalent offers its SurvalentONE OMS, which it calls "a comprehensive outage management solution that empowers utilities to reduce the scale and duration of outages through efficient

tracking and management. The solution provides predictive outage analysis that helps operators determine the probable fault location so that field crew can quickly commence restoration activities."

The company said the SurvalentONE OMS "enables transparency between the control room and field crew, as well as processes for rapid damage assessment, to ensure the right crews and equipment are dispatched at the onset of restoration. SurvalentONE OMS integrates seamlessly with SurvalentONE SCADA and DMS applications to ensure that all applications share the same data. For example, FLISR events are automatically captured in the OMS. This ensures that all operators, dispatchers, customer service reps, and executive team members are equally informed about the status of outages and restoration activities, and all integrated applications are leveraging comprehensive, accurate data about the system. The solution's enhanced customer communications capabilities include automated text messaging and social media update capabilities to provide customers with up-to-date outage information, including the estimated time of restoration and safety information."

MCG Energy Solutions said its outage management software "provides features and functionality to manage outage systems tickets across the entire lifecycle, including execution and coordination activities with field operators and [grid operators]." The company said its Versify OMS software and operator logbook software, known as OpLog, "utilize a unique workflow enabled architecture that may be configured to manage complex processes associated with outage management, control room operations [Figure 4], [and] switching within generation, transmission, and distribution businesses."



4. Automated solutions are part of outage management systems, with features and functionality that would enable systems and assets to be controlled from a central location. Control rooms are becoming more sophisticated through the use of software and digital technologies. Courtesy: StockCake

Grid Automation Software

The executives who spoke with *POWER* said grid automation software is critical for utilities and grid operators in support of improved electricity transmission delivery. The software enables connections and protections, and when integrated with smart grid tech such as voltage regulators, capacitors, reclosers, switchgear, sensors, and more can help improve transmission system reliability and often reduce operating costs.

“Grid automation software automates the fault isolation and restoration process, reducing the need for large field crews to manually handle these tasks. Restoration times are calculated more accurately through real-time data insights, and the utility can deploy crews into the field more strategically by first assessing the severity and scope of the outage,” said Giroux-Maltais. “To put it simply, automated systems improve efficiency by centralizing operations, allowing the utility to deploy the right number of field workers to the right place the first time to minimize service disruption for its members.”

Walkingshaw told *POWER* that software upgrades “provide three critical advantages for outage management. First, they enable comprehensive real-time monitoring across hybrid systems, processing millions of data points to detect subtle pattern changes that might indicate impending issues. Second, they facilitate intelligent load management through advanced predictive analytics, particularly valuable when managing complex systems combining traditional power sources with newer technologies like flywheel energy storage systems, in our case. Third, they enhance cybersecurity protocols, which has become increasingly crucial as power infrastructure becomes more interconnected. Our experience has shown the value of owning our software stack, giving us total control of the modern software systems that are essential for maintaining grid stability while responding to unplanned events.”

Giroux-Maltais said Eaton is “working with utilities across North America to improve outage detection, management, and response through distribution automation software such as our Feeder Automation Manager—Reliability Module, which is part of our Brightlayer Utilities suite. This solution intelligently detects grid disturbances, isolates faults, and automatically reconfigures the grid to restore service to unaffected areas. The software integrates fault location, isola-

tion, and service restoration capabilities, enabling the utility to minimize the duration and impact of outages across its distribution network.” Giroux-Maltais added, “It is important to flag that FLISR capabilities differ from an outage management system. The latter handles customer communication and crew management during an outage, whereas FLISR capabilities are aimed directly at grid automation functionality.”

Keefe detailed how this technology supports utilities and grid operators as they work to make the electricity delivery system more reliable and resilient.

“Advanced sensing protection and controls build on the foundational advanced metering infrastructure and advanced distribution management systems, which enable maximization of use cases from complementary technologies such as fault location, isolation, and service restoration,” said Keefe. “DER and microgrid integration and utilization can develop as ADMS modules or interconnected systems. Bidirectional charging, grid-forming inverters, and smart grid chips communicating real-time data further enable integration. Finally, utilities are starting to deploy AI for resilience. Use cases include pre-outage and outage prediction and monitoring, and enhanced real-time grid operations.”

Giroux-Maltais said, “By applying distribution automation software solutions and advancing metering devices, utilities are significantly reducing outage frequency and duration, while helping to reduce truck rolls and time for utility crews. That’s because these types of upgrades can automate fault detection, isolation and service restoration, reducing the need for manual investigation and intervention. They also integrate seamlessly with existing legacy systems, allowing utilities to modernize operations without replacing current infrastructure.”

The Eaton executive provided a real-world example. “Carroll Electric Membership Corporation (EMC) in western Georgia utilizes 250 intelligent electronic devices across its distribution network and our Feeder Automation Manager—Reliability Module to automatically isolate damaged sections and restore power to as many people as possible. Since the start of initial deployments in 2014, this distribution automation program has helped the utility continually reduce its System Average Interruption Duration Index [SAIDI] year-over-year.”

Giroux-Maltais said, “In 2022 alone, Carroll EMC calculated that Eaton’s

[module] reduced outage time by about 75 minutes. The utility anticipates a 41% reduction in outage duration, including 34% reduction from the three-phase deployment and an additional 7% reduction from the single-phase project as Carroll EMC continues to expand deployment of our FLISR technology.”

Advanced Digital Technologies

Keefe said project resiliency targets often revolve around shorter outage duration and faster restoration. “Unlocking the potential of DER to better manage power outages requires advanced digital technologies to enable active management, and could deliver cost savings to utilities and customers. While controls to manage DER in real time require significant utility investment, DER management includes least-cost mechanisms such as time-of-use rates and demand response for programmable thermostats that have been operating for decades with simple controls,” Keefe said.

Keefe added, “Studies commissioned by the states of California and New York show that managed electrification could lower the cost of distribution upgrades needed through 2035 by more than \$30 billion in each of these states. That’s because building efficiency measures and smart devices to manage energy usage and smooth EV charging could reduce capital spending on new substations, transformers, feeders, and other distribution equipment.”

Keefe referenced a Department of Energy program designed to reward companies working on grid upgrades. “Grid Resilience and Innovation Partnership [GRIP] awards provide a window into the needed technical capabilities and software upgrades that can help power plant operators and grid managers better manage power outages. The first round of GRIP provided funding to 24 investor-owned utilities [IOUs]. All but two of the awarded projects cover distribution.”

Keefe said, “The projects range from infrastructure replacement and hardening to AI deployments. The figure below [Figure 5] shows all IOUs awarded GRIP grid resilience and smart grid grants, with projects categorized according to a distribution investment prioritization pyramid, where each level builds on the preceding one. Basic distribution automation projects among IOU awardees involve sectionalization, or dividing feeders into sections so that utilities can isolate a fault on one feeder to a small area while restoring power to adjoin-

Historic federal investments in grid resilience are propelling DER distribution projects

Legend: AI (green), DER and microgrid integration and utilization (blue), Advanced sensing, protection and controls (orange), Basic distribution automation (purple), Infrastructure replacement and hardening (red)

Investor-owned utility (location)	Cost (US\$M) Federal cost share █ Total	Technology	Resilience target
AEP (AR, IN, KY, LA, MI, OH, OK, TN, TX, VA, WV)	28 █ 55	DERMS module ADMS; FLISR; Volt/voltampere reactive optimization (VVO)	Improve grid reliability 5%
Ameren (MO)	47 █ 101	Automated and digitized grid controls for real-time monitoring Advanced restoration technology	Faster restoration and fewer outages
CMP (ME)	20 █ 61	Advanced grid restoration; Sequential reclosing; SCADA	Minimize blackouts
ComEd (IL)	50 █ 116	Intelligent control framework for advanced communications and data analysis to automate and optimize DER; EV charging; Grid-interactive efficient buildings and intelligent sensors	VPP; local system restoration via renewables
Consumers Energy (MI)	100 █ 200	Advanced sensors Automated loops sectionalization Reclosing; Lateral fusing; Circuit tie; Pole hardening	67-minute SAIDI improvement
Dominion Energy (VA, NC)	24 █ 67	Intelligent grid devices for real-time grid visualization and management Grid-forming inverter and BESS	500 fewer outages/year
DTE (MI)	23 █ 46	Renewable adaptive networked microgrid responsive in real time; grid sensing Fault location and communications devices, and reclosers	Reduce outages 50-80% and duration 15-30%
Duquesne (PA)	20 █ 40	Advanced machine learning Smart grid chip technology with real-time data Remote communications and controls	Prevent faults causing wildfires and outages
Empire District (AR, KS, MO, OK)	48 █ 95	Comprehensive sectionalization; Install and integrate vacuum reclosers, upgrade poles, stations and telecommunications for automatic system restoration	Improve reliability 23%
Entergy (LA)	55 █ 110	Microgrid with battery system Hardening distribution lines	Avoid 45M customer minute interruptions
FPL (FL)	30 █ 67	Fault locators, manhole monitors for real-time visibility, transformer life extension and underground infrastructure maintenance; Advanced asset-health telemetry and predictive failure analysis	Reduction in outage frequency and duration
HECO (HI)	95 █ 191	Situational awareness tech Hardening customer circuitry; Control circuits and critical poles; Lateral undergrounding; Hazard tree removal	Fewer outages, restoration times and wildfire risk
Liberty (CA)	12 █ 26	Smart meters, network, and software for distributed intelligence	Lower wildfire risk and outages
National Grid (NY, MA)	50 █ 139	Network-adaptive DER connect; FLISR-DER integration; Substation-edge computing; Streamline interoperability of smart tech for real-time monitoring and control Autonomous controls and improved sectionalization	Upgrade system resilience
OG&E (OK)	50 █ 102	Smart grid platform	Lower climate impacts and risk
PacificCorp (CA, OR, UT)	100 █ 206	Adaptive protection and control microprocessor relays with remote communication Covered conductors, fire-resistant poles; Non-expulsion fuses	50% fewer outages; eliminate ignition risk and flood outages
PacificCorp (CA, ID, UT, WA, WY)	50 █ 138	AI cameras for wildfire detection; Advanced weather-forecasting models Distribution fault anticipation devices and advanced relays with wildfire protection enabling real-time analysis	Reduce avg. outage by 5 min; prevent faults; better wildfire risk metrics
PECO (PA)	100 █ 257	Battery backup power Underground monitor/control Low-voltage conductors	50% increase in line ratings; islanding
PGE (OR)	50 █ 108	AI models to predict pre-outage conditions Smart grid chips for grid-edge computing to integrate DER; Real-time data and modeling	Outage prediction; DER use
PPL (PA)	50 █ 99	AI to monitor outages, forecast and real-time operations Automated grid for DER integration; Two-way power flow	Lower outage duration; fault prevention
Rhode Island Energy (RI)	50 █ 285	Fiber-optic communications of granular data to ADMS and AEMS Centralized asset hub data and GIS with digital twin of grid	30% better reliability Restoration time lowered
Xcel (CO, MN, NM, TX, WI)	100 █ 242	EV bus-to-building and charging backhaul; Microgrids Non-expulsion fuses; Fire-resistant poles; Circuit undergrounding Hazard tree clearing	Reduce frequency and duration of outages

Source: Analysis by the Deloitte Research Center for Energy and Industrials of Department of Energy's Grid Resilience and Innovation Partnerships grants.

Deloitte insights | deloitte.com/insights

5. This chart identifies projects designed to upgrade the power grid that are receiving federal funding. Courtesy: Deloitte

ing areas from a second feeder. More advanced applications the technology enables include creating dynamic DER microgrids to minimize the impact of outages. Other basic distribution automation projects include fault locators and reclosers to detect and interrupt faults, and supervisory control and data acquisition systems to remotely monitor and control the grid."

Roy Fadida, co-founder and Chief Product Officer of enSights, a group that monitors solar energy systems, said, "Software can forecast upcoming outages based on electrical parameters collection and by performing anomaly detection to realize that the current load on the grid might cause outage." Fadida, like the other executives who spoke with *POWER*, said having real-time information—particularly about renewable energy's availability for the grid—is critical.

"By collecting and analyzing data from a wide array of geographically dispersed

PV [solar photovoltaic] systems, a renewable management platform can predict potential power fluctuations before they evolve into serious issues. For instance, if the data and the forecasting analysis based on this data indicates a pattern of unexpected output drops across multiple PV sites, the system can anticipate impending grid imbalances or load swings."

Fadida continued: "Equipped with this foreknowledge, the platform can send timely alerts to the utility's OMS. These early warnings allow utilities to take proactive measures, such as adjusting dispatch schedules, coordinating energy storage resources, or initiating demand response programs, to stabilize the grid and prevent widespread outages. In essence, integrating PV and storage management insights into OMS operations ensures more effective and preemptive outage mitigation.

"Moreover, storage systems can also provide critical black-start capabili-

ties, enabling portions of the grid to be restarted after a system-wide outage. This makes it easier and faster to bring renewable-powered microgrids and isolated systems back online, improving overall restoration times," said Fadida. He said his company's "ecosystem collects data from multiple clean energy sites and calculates nearby behavior to detect anomalies. The goal is to identify if a specific issue [such as an outage] is related to a specific PV site or the larger area. In addition to simply detecting outages, by aggregating distributed storage systems, our ecosystem can help prevent or compensate for various grid events, such as outages."

Smart Meters, SCADA, and Mobile Data

The use of smart meters (Figure 6) by many utilities supports advanced automatic meter reading (AMR) systems, which can provide outage detection and restoration capability. These systems can serve as "virtual calls," indicating customers who are without power without the need for those customers to alert the utility. Such systems may be integrated with SCADA systems, which can automatically report the operation of monitored circuit breakers, along with other intelligent devices such as SCADA reclosers.

A mobile data system also can be integrated with an OMS. This integration enables outage predictions to automatically be sent to crews in the field; the crews also can update the OMS with information such as estimated restoration times without requiring radio communication with the control center. Crews also can transmit work reports about what actions were taken during an outage restoration.

"Improving visibility, situational awareness, and flexibility is critical for managing the modern electric system, especially with the rapid adoption of customer-owned distributed energy resources such as electric vehicles, solar arrays, and local energy storage," said Eyford. "Although the industry buzz is generally around virtual power plants and flexible interconnections, these technologies can create both operational risks [‘hidden’ load that must be picked up by the grid due to the local generation previously serving it remaining temporarily offline] and safety risks [many more potential generation sources to be aware of and secure]. At the same time, they offer the potential to restore portions of the network that may be isolated from the grid due to damage and may even be

able to pre-emptively do so to avoid an outage altogether.”

Eyford noted, though, that “Sensors and communications are now standard on most modern grid equipment, but traditional utility systems were designed well before these technologies were envisioned. Software upgrades are needed to model, monitor, and manage them effectively.”

Eyford told *POWER*: “There is a great deal of data available to help determine outage locations, both from utility systems as well as from external sources. For larger outages, the utility’s SCADA system and other telemetered devices will immediately inform grid operators that a problem has occurred, but for outages affecting a smaller area, technologies such as advanced metering infrastructure can provide near-real-time notifications that customers have experienced a power outage.

“Where utilities haven’t yet deployed AMI [advanced metering infrastructure], or in cases where communications to those meters is not fully reliable, they are still largely dependent on affected customers reporting their outage themselves, typically by calling the utility’s outage reporting hotline or submitting their information via the utility’s website or smartphone app. They may also receive information directly from 911 dispatchers or emergency service personnel, especially if public safety concerns are present such as a car-hit pole or a downed power line. As artificial intelligence and large-language models such as ChatGPT become more widely available, utilities are increasingly looking to AI to analyze social media data to help identify affected customers and safety issues as well as non-customer locations such as streetlights and traffic signals.”

Matt Smith, who leads the global business and product strategy for the grid



6. Smart meters are being used by more utilities as a way to gather data, with a goal to improve power delivery and efficiency—along with automating collection of outage information. Courtesy: PxHere

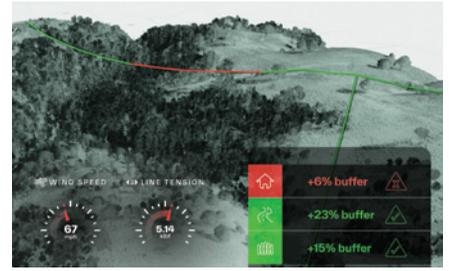
management business at Itron, a global group helping utilities develop innovative solutions for their operations, told *POWER*: “A structured DI [distributed intelligence] system continuously monitors the performance of both hardware and software, enhancing grid reliability by identifying potential weaknesses or components under strain due to increased demand or environmental factors. By leveraging predictive analytics, utilities can anticipate when equipment is likely to fail and schedule timely updates or replacements before failures occur, preventing costly downtime and ensuring grid reliability. The approach not only maintains system stability but also supports long-term resilience as the grid evolves.”

Smith said model predictive control, or MPC, “can impact grid reliability by predicting energy demand and leveraging the use of EV energy storage to prevent potential overloads. Additionally, by integrating advanced weather forecasts, MPC can also prepare the grid for incoming extreme weather events. MPC can also isolate potential faults and reroute power before disasters strike, thus minimizing outages and maintaining grid stability. This combination of demand prediction and weather integration preparation helps ensure that the grid remains resilient during high-stress periods.”

Terry Saunders, Worldwide Utilities and Industry leader at IBM, said: “Model predictive control can optimize asset health and predict failures while extending the useful life of assets through a strategy that prioritizes repairs and replacements. Conditional-based predictive maintenance based on health insights from operational data and analytics helps you put your asset data to work. One example of this could be software that helps you understand the status of critical equipment and assets with insights from data and analytics to help make smarter decisions.”

Saunders noted, “Utilities rely on inspections to understand current asset condition and need for maintenance. Many assets are geographically dispersed throughout the service territory making physical inspections time-consuming and expensive. With aging critical assets, more frequent inspections are warranted ... however, there are fewer people available to conduct these inspections with ongoing retirements and a transitioning workforce.”

Saunders said IBM’s Maximo Application Suite, or MAS, “helps support condition monitoring to trigger warnings or



7. Mapping technology that enables data collection from transmission assets is important to help utilities and grid operators take steps to mitigate or avoid power disruptions. Courtesy: Neura

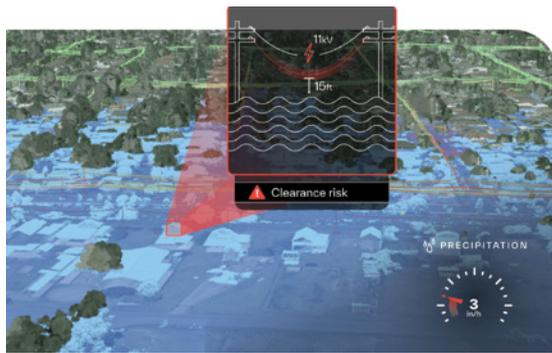
immediate actions. Capabilities such as Monitor, Health, and Predict provide an enterprise view of asset health, helping organizations identify anomalies and justified maintenance,” which can help prevent outages and enhance power reliability.

Resource Management During Outages

Torus is building technology that Walkingshaw said takes “a multi-layered approach to resource management during outages. Our hybrid energy storage systems, combining flywheel technology with traditional batteries, provide us unique flexibility in responding to outages of varying sizes and durations. For shorter-duration events, our Nova Spin flywheel system can respond within milliseconds to maintain frequency stability, while our chemical battery systems handle longer-duration support needs. Our resource allocation is driven by real-time data analytics that help optimize deployment of both technological and human resources based on the specific characteristics of each event.”

Walkingshaw said his company has developed “an integrated approach to outage management that combines real-time monitoring with predictive analytics. Our outage management system, built in-house, excels at managing distributed energy resources and hybrid storage solutions. This approach has proven especially valuable in coordinating nearly 1 GWh of facility-managed power across 60-plus projects in 2024 alone, while responding to more than 120 unplanned demand response events. The system’s architecture emphasizes cybersecurity and integration with existing SCADA infrastructure, enabling rapid response to potential outages before they cascade through the network.”

Utility executives for years have said customers want a better understanding of how long their power will be out, along



8. Technology that can help utilities and grid operators determine flood risk to their infrastructure is another way to enable proactive measures that can mitigate the impacts of disruptions to an area's power supply. Courtesy: Neara

with more details about why service has been disrupted. Walkingshaw noted the importance of more accurate forecasting.

“Our restoration time estimates integrate multiple data sources and predictive modeling to provide accurate projections. The calculations factor in real-time system status, historical performance metrics from comparable events, current operating conditions, geographic distribution of affected areas, and available resource capacity,” he said. “For field crew management, we employ an adaptive dispatch system that optimizes deployment by prioritizing critical infrastructure, coordinating between automated and manual interventions, and adjusting resource allocation as events unfold. This approach enables efficient coverage across our infrastructure while maintaining appropriate emergency response capabilities. We continuously refine our estimates based on real-time feedback from field operations and system diagnostics, ensuring our restoration projections remain accurate as conditions change.”

Meeting Future Challenges

Rob Brook, senior vice president Americas at Neara, a group that works with utilities worldwide on simulations of severe weather events to support grid hardening, said, “We’re asking the power grid to do more in the next 10 years than we have in the last 50. This demand is driven by a number of factors, like an increase in severe and unpredictable weather, multiple accessible technology devices in the hands of every consumer, and power-hungry data centers.

“To meet this unprecedented energy demand and better manage power outages, migration to AI-assisted software platforms can help grid managers identify outage and safety risks such as equipment failures and maintenance

blindspots,” said Brook. “Upgrading to AI-enhanced software helps utilities surface bottlenecks in their network that they can’t easily see otherwise, and can offer tailored recommendations to reduce the likelihood of outages and shorten their duration. For example, by simulating various weather-related conditions, Neara’s technology highlights where specific upgrades, like increasing pole height or changing the conductor type, would result in the network’s ability to support fast-growing loads. Today, every business and consumer rely on electricity and they expect clear communication and maintenance from their providers during outages—up-to-date software helps every stakeholder do just that.”

Said Brook, “While real-time information is essential to fuel effective in-the-moment decision-making, the ability to anticipate potential outages and their impact before an actual grid-threatening event also plays a critical role in accelerating recovery times and minimizing impact. Accurate 3D mapping across network environments [Figure 7], including manmade assets like poles, lines, and stakes, as well as natural elements like vegetation and ground topography, is extremely important for establishing the ground truth that can help utilities proactively plan to reduce outages and respond more effectively by monitoring real-time conditions in extreme weather.”

Brook said Neara’s technology “enables utilities to simulate weather like storms, wildfires, floods [Figure 8], and winds to see how these events will impact the grid, and provide AI-enhanced improvement recommendations accordingly. Neara helps utilities take a more proactive approach to resiliency, reducing time-spent on processes from structure loading assessment to new network design and vegetation management

from years to hours. Risk mitigation is the ultimate goal, and new AI-assisted software programs empower utilities to better understand the vulnerabilities within their networks so they can identify exactly where their networks need attention and the best ways to get ahead of potential issues.”

Neara’s modeling technology takes into account a range of data sources, including LiDAR (light detection and ranging), GIS (geographic information system), imagery, pole libraries, etc., that help paint the most accurate possible picture of utilities’ entire networks, including all assets and surrounding things like vegetation, roads, buildings, and more. “A common delay in power restoration is the reality of poor data quality. Utilities must understand the relative strengths and weaknesses of different data sources, then employ the right mix of these sources to maximize visibility and de-risk networks. Without accurate data, utilities are unable to easily identify the cause of an outage, such as a pole failure, and critically, the precise location of that pole failure,” Brook said.

“By modeling customers’ networks with multiple data sources, we help them automatically correct errors in GIS, which means that they can pinpoint the cause of an outage and the exact location of the offending equipment failure or vegetation encroachment, save time across routine field operations, particularly in instances where a pole marked for maintenance might be 600 yards from where the map indicates, and most importantly, in emergency situations when on borrowed time, they know exactly where to send field teams, and when it’s safe to do so,” he explained.

Giroux-Maltais also noted the importance of gathering data and automating processes. “Grid automation software automates the fault isolation and restoration process, reducing the need for large field crews to manually handle these tasks. Restoration times are calculated more accurately through real-time data insights, and the utility can deploy crews into the field more strategically by first assessing the severity and scope of the outage,” he said. “To put it simply, automated systems improve efficiency by centralizing operations, allowing the utility to deploy the right number of field workers to the right place the first time to minimize service disruption for its members.” ■

—Darrell Proctor is a senior editor for *POWER*.

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Creating a Successful Utility Workforce Succession Plan

Caitlin Humrickhouse

Succession planning is a priority in the utility industry as an aging workforce, changing technologies, and turnover reshape the sector. The utility sector faces unique challenges, striving for seamless transfers of institutional knowledge while recruiting young talent and preparing the next generation of leaders to navigate complexities and emerging trends.

Identifying High-Priority Positions

When it comes to developing a strong succession plan, it is a priority to focus on the roles that are vital to operations and continuity. Conduct an organizational scan by gathering and analyzing data by department or division to pinpoint critical roles. This scan should also identify which roles will be open due to projected retirements and which positions have high turnover rates.

After conducting the organizational scan, the team should analyze any additional factors that may impact succession planning. Think of roles that may have impacts on regulatory compliance and safety, or may require specialized skills.

The last step combines everything that has been learned throughout the process by creating a list of critical positions. When creating this list, start off slow by only including about 10% of the company's total positions. From here, the organization can slowly build up its succession plan.

Developing Core Competencies

A competency is a pattern of behavior associated with effective performance that helps an organization achieve desired results. Competency modeling acts as a framework to define what good performance looks like across different roles. Competency modeling is critical as it ensures that employees are evaluated and developed against the right standards for their roles.

Competencies are separate from but equally important to education, certifications, or specialized technical knowledge required to perform a job task. For example, financial acumen may be a competency for any senior leader in the organization. Depending on the organization, you will identify your role levels. For example, the levels we often use in the utility industry are individual contributor, first line supervisor, middle manager, and strategic leader. From here, competencies should be incorporated into hiring, performance evaluations, and development plans.

Talent Identification

The basis of workforce succession planning is developing a pool of talent within the organization to draw from when leadership change takes place. To begin identifying internal talent, conduct a scan to create a pool of potential succession candidates. In the internal candidate assessment, start with a larger pool of candidates and narrow it down to only a few after re-

viewing their skills and competencies.

Once you begin narrowing the field, it is time for the "9-box assessment." This visual chart combines past performance reviews, certifications, and special skills for each employee. The 9-box assessment looks at two key factors: performance and potential. At each end of the assessment, employees are scored on a scale of low, medium, and high performance, as well as low, medium, and high potential.

It is possible that a utility company works through the 9-box assessment and finds that the existing workforce does not possess the required competencies or certifications to fill the needed roles, which is common in the utility industry as many positions require multiple certifications. In this case, external recruitment becomes part of the workforce succession plan.

Coaching, Development, and Knowledge Transfer

Training and development programs are also a key part of a succession plan so current employees are provided with the resources and opportunities to grow into future roles. By the end of the talent identification process, core competency gaps will be identified, which can guide where training and development dollars should be used.

Succession planning is not about "cherry-picking" the next in line to fill a position. Rather, it is an opportunity to strategically assess the current skills, knowledge, and competencies in your organization, and determine how you can better prepare the workforce—both internal and external to your organization—to fill critical vacancies when they arise.

Institutionalizing knowledge so that it can be transferred to the next generation is a core feature of succession planning and makes a world of difference during transition periods. Documenting policies and procedures is an important component of knowledge transfer, but it can also be hard to juggle during busy workdays. Organizational leadership must prioritize the investment of time and resources, but there are several paths to ensure documentation is created including dedicating employee time to the effort using special project teams or positions, using consultants to do the heavy lifting, and leveraging artificial intelligence (AI)-powered software tools.

Implementing Your Succession Plan

The final step is implementing your succession plan. This can vary by organization, but building a succession planning task force, setting timelines and goals, developing action plans, and engaging employees throughout the process will ensure successful implementation. The time is now to begin succession plan development for your organization to guarantee operational excellence, organizational continuity, and a culture where employees can grow their careers. ■

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