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Flexible Loads, Resilient Grids

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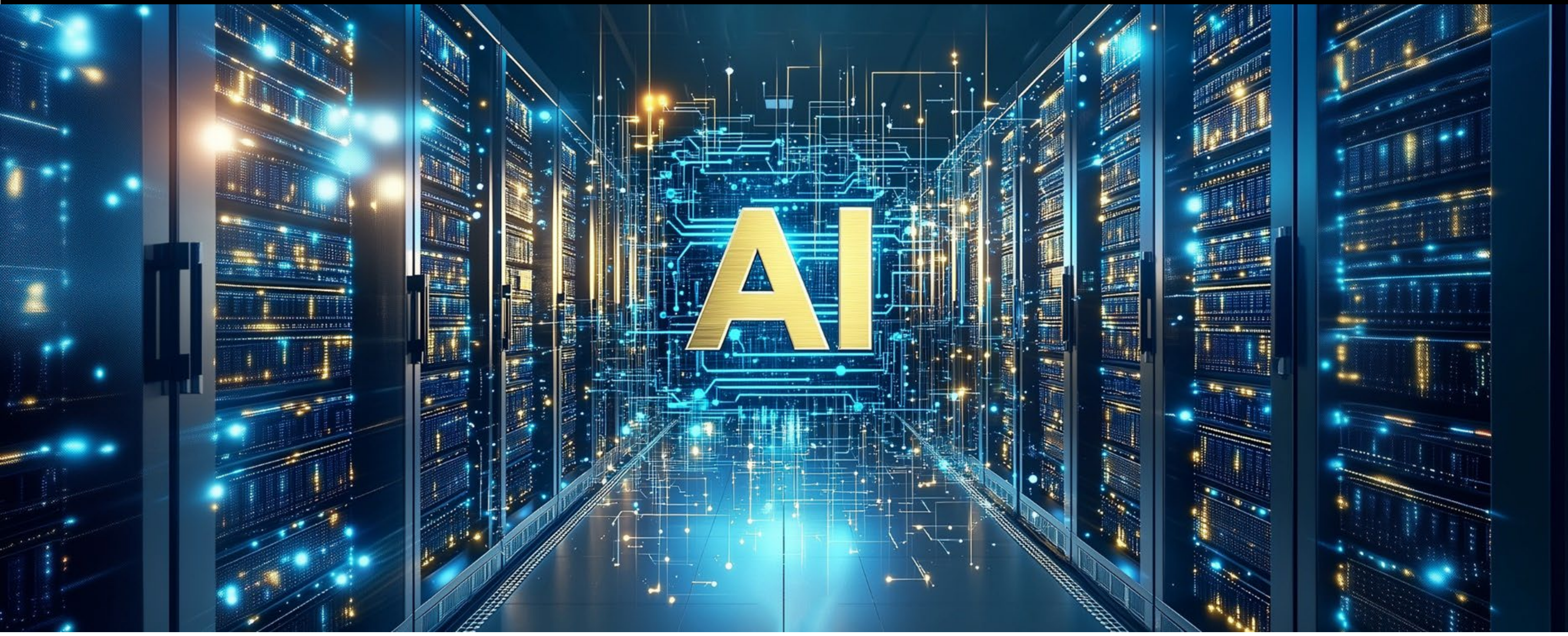

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Flexible Loads, Resilient Grids

EPRI's DCFlex initiative explores how large flexible loads can support grid reliability and AI-driven growth

By Chris Warren

Over his three-decade-plus career in the electric power industry, David Porter has seen just about everything. Before joining EPRI in 2009, Porter held a variety of positions in utility operations—from power marketing to transmission, distribution, energy efficiency, and customer programs for companies like Florida Power Corporation and Duke Power.

So, when an industry development catches Porter's attention, it's worth focusing on. These days, Porter is struck by the connection between grid reliability and the operation of large loads, especially data centers. "As someone who's been in and around that business for a long time, grid operations, reliability, and resilience have not been so tied to large point loads as it is now," said Porter, who is EPRI's Vice President for Electrification & Sustainable Energy Strategy.

The link between grid reliability and resilience and data centers can only be expected to strengthen. A study released last year by EPRI found that data centers could consume as much as nine percent of U.S. electricity generation by 2030, more than double the amount currently used. EPRI isn't alone in forecasting rapid data center load growth. According to an analysis conducted by the U.S. Department of Energy's (DOE) Lawrence Berkeley National Laboratory (LBNL), data center electricity consumption tripled between 2014 and 2024 and is expected to double or triple again by 2028.

A MISMATCH IN SPEED

The implications of data center load growth to support artificial intelligence (AI) applications and cloud computing are profound—both for the utility industry and society. "Every hour of every day, we really are interacting with the internet and with digital ecosystems in a way that relies on data center services. I like to think of data centers as the backbone of our modern economy," said Briana Kobor, Head of Energy Market Innovation at Google.

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For utilities, data center load growth poses opportunities and challenges. For one thing, meeting demand from data centers, manufacturing, electric transportation, and a growing population requires significant investment in the grid. The consulting firm Deloitte estimates utilities must spend about $1.4 trillion between 2025 and 2030—much of it on generation to serve new loads—and maintain similar levels of investment in the following decades.

While utilities are committed to serving new customers and loads, a significant challenge has emerged. "There's a timing mismatch between how quickly tech companies can build a new data center facility - at a scale much larger than what the utilities are used to dealing with historically - and the utilities' ability to provide that level of service in a similar time frame," Porter said. "There's a severe mismatch there today."

BRIDGING THE GAP

It's a mismatch that must be closed for companies like Google to develop new products and serve customers. "The scale and speed with which the tech industry operates is on a different time spectrum than the electricity ecosystem," Kobor said. "What we're faced with is a growing pain between where our tech companies need to be to serve our customers and to serve this demand, and what the electric industry is capable of doing."

But it's also a mismatch that is driving innovation and expanded collaboration between utilities and data center developers and owners keen to access the electricity they need as quickly as possible. One promising area of innovation is data center demand flexibility. In the past, Porter says, large loads could be curtailed or interrupted when the grid was stressed. But data centers and the digital services they provide can't just be turned off. Demand flexibility, by contrast, offers an opportunity for data centers to connect to the grid faster and operate in ways that simultaneously serve their customers and the grid. "Having the ability to have large, flexible loads to improve the overall operation of the grid is key," Porter said. "We believe that data centers can be that large, flexible point load. Not all the time, not for an entire year, but in times when the grid really needs some assistance to meet the loads. That's when it's really important."

LAUNCHING DCFLEX

EPRI launched the DCFlex initiative in 2024, a three-year effort to advance the understanding of data center demand flexibility and to begin testing how it can be improved in real-world conditions. DCFlex brings together hyperscalers like Google, Meta, Oracle, and Microsoft with technology companies like the chip maker NVIDIA, utilities, grid operators, data center developers, and equipment suppliers.

The initiative, which now has 49 participants, seeks innovative and collaborative strategies to empower AI growth while minimizing costs and enhancing grid reliability. While many of the companies participating in DCFlex are technology pioneers, the ability to transform data centers into dynamic AI and grid-supporting resources depends on both technological innovation and a shift in mindset around operations, business models, and regulations.

DCFlex is organized into four workstreams

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1 **Grid-informed flexible data center designs.** Not all data centers are alike. While a growing number of data centers are built with AI applications in mind, others provide cloud computing services. The varying purposes of data centers impacts their electricity demands and potential flexibility. "There are big differences in how they operate and what they can and can't do with compute load inside the data center," Porter said.

For example, data centers supporting cloud computing products like Google Translate, Google Maps, and YouTube all have differing flexibility characteristics—characteristics that also differ from AI data centers. This workstream investigates, designs that enable flexible operations to support the grid when needed.

2 **Transformational utility programs.** A big challenge to leveraging the potential value of flexible data center operations is the lack of confidence many utilities have in the reliability of demand-side resources. "It's sometimes difficult for our utility partners to feel like they can rely on demand-side resources alongside supply-side resources," Kobor said. "This is the moment where we really need to find the models that get us past that logjam."

This DCFlex workstream seeks to bolster understanding and confidence in the flexibility characteristics of data center loads. But it's also focused on developing utility programs that encourage and fully leverage flexibility. This can happen through incentives and by utilizing beneficial market structures. Importantly, utilities also understand that incentives and programs must address equity and affordability concerns.

3 **Operational flexibility framework.** The third DCFlex workstream is focused on developing the tools and algorithms utilities need to confidently integrate flexibility into their interconnection, operations, and forecasting activities. This will include the creation of data center forecast maps and granular load forecasting methodologies.

As data center development scales, it will be especially important for utilities and data centers to adopt standardized communication protocols. "Data centers don't want to figure out how to communicate and take signals from all these different utilities in a different way," Porter said. "Part of what we're driving with DCFlex is to develop standard protocols that then can work with all large loads going forward. That gets to be much more seamless, and we can make flexibility for large point loads more accessible to more types of companies and better support the grid."

4 **Data center-informed energy supply.** Speed is paramount to data center development. Closing the gap between when a data center needs electricity and a utility's ability to provide it is at the heart of DCFlex. In some cases, that will mean devising interim solutions that allow data centers to begin operating while utilities expand their capacity to meet demand.

This workstream examines both front-of-meter and behind-the-meter solutions to meet the near-term electricity needs of data centers. "What can we do with bridge solutions to meet data center needs in a timely manner?" Porter said. "Particularly in places they may need to build for business purposes, but the transmission capacity may not be there, and it may not be there for quite some time. How do we bridge that gap so that those companies can get up and running and help grow the economy?"

REAL-WORLD LIVING LABORATORIES

DCFlex will include five to 10 large-scale demonstration sites to serve as living laboratories where innovative tools to improve operational flexibility, grid integration, and backup power can be tested.

The first three demonstrations have already been announced. Two of the projects—one in Lenoir, North Carolina, and another in Phoenix, Arizona—will explore how computational flexibility can help support the grid. The third project is in Paris, France, and will examine data center response to power quality issues to develop best practices that will support grid reliability and resilience.

These demonstrations—which are taking place in production facilities, not laboratories—will provide instructive lessons about data center flexibility. Google and Duke Energy will work together at the demonstration in Lenoir, North Carolina. Kobor says collaboration has already begun to develop

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operational and communication protocols that will give Duke Energy confidence that it can rely on data center flexibility as a grid resource.

"Can we reduce the load and, most importantly, can Google and others continue to get their products out the door in the way they need to when we enact those load reductions?" Porter said. "The second piece looks at the ability to flex those loads for varying periods, depending on what the utility programs in place might look like."

Similar to the Google site, the demonstration project in Phoenix, Arizona, will probe workload flexibility. In a preliminary field test at the Arizona site, Emerald AI successfully mapped which AI tasks can be slowed, paused, or relocated, allowing data centers to reduce power consumption during times of grid stress. This trial showed that an AI compute cluster could reduce its power consumption by 25% over a three-hour peak system event without compromising essential data center services.

The demonstration projects will also evaluate the ability of data centers to provide ancillary services to the grid and the possibility of using renewable fuels, like hydro-treated vegetable oil (HVO), instead of diesel, to run the backup generators at data center sites. Ultimately, the lessons from all the field tests will inform the framework EPRI is developing to guide the integration of flexibility into data center design and operation. The field testing could also speed data center grid connections by identifying and sharing the standards, frameworks, processes, and tools needed to overcome interconnection hurdles.

For his part, Porter is excited that EPRI is working with such a broad coalition of partners to advance AI in ways that benefit the grid and society. "The AI revolution is really our next industrial revolution, and it's really changing our daily lives. When you couple that with the clean energy transition that's underway in the utility industry, it's an intersection of great opportunity and challenge," Porter said. "I feel very fortunate that EPRI has a seat at the table with companies like Google, their peers, and others who are trying to drive change and build on the opportunities that are in front of us."

EPRI TECHNICAL EXPERT

David Porter

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Forecasting the Future: eRoadMAP Guides Localized Grid Planning for Transportation Electrification

By Chris Warren

Electric transportation is far from a new research topic at EPRI. Starting with the formation of the Electric Transportation Infrastructure Working Council in 1991, EPRI's wide-ranging and collaborative research efforts have included everything from demonstrations of electric vehicles (EVs) to economic and environmental impact studies to initiatives to advance charging and vehicle-to-grid technologies.

More recently, EPRI's engagement with auto and truck makers, fleet operators, utilities, regulators, and others in the broad EV ecosystem has evolved, driven largely by growing alignment across different stakeholder groups. For instance, last year, Atlas EV Hub reported that $312 billion was expected to be invested in domestic EV manufacturing, with $223 billion already allocated. Demand for EVs by drivers has also been strong, with EVs making up over 10 percent of new light-duty vehicle sales in 2024. In Colorado, California, Washington, and the District of Columbia, EV registrations account for more than 20 percent of all new vehicles sold—both California and Colorado are above 26 percent. EV sales are not limited to light-duty passenger vehicles. Large companies like Amazon, FedEx, and PepsiCo are also purchasing large numbers of light commercial, medium- and heavy-duty EVs.

A LACK OF GRANULAR DATA POSES PLANNING CHALLENGES

As improved economics and a growing selection of vehicles to choose from continue to drive sales, EPRI's research has increasingly focused on how to solve the challenges of integrating EV loads seamlessly onto the grid. "What are the barriers when we think about all these new EVs on the grid?" said Jamie Dunckley, an EPRI program manager focusing on electric transportation. "One of the greatest challenges utilities face is the uncertainty around where EV charging demand will arise. Understanding when, where, and how much EVs will charge is essential for effective grid infrastructure planning."

This presents a challenge because detailed data on where EVs are charging and how they're being driven has not been available. While information on EV purchases and registrations exists at the national, state, and county levels, it lacks the granularity

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needed for utilities to make informed grid infrastructure investments or to support fleet customers in identifying locations with adequate existing capacity. This lack of actionable data is far from ideal and creates inefficiencies for utilities, their customers, and vehicle manufacturers alike.

For example, consider a scenario where a large fleet customer plans to electrify many medium- and heavy-duty vehicles, or maybe has gone so far as to purchase them. Without advance notice, a utility would be caught off guard when a request for the 10 to 20 megawatts needed to charge the EVs arrives. "The utility may not be able to bring that power to a site for several years," Dunckley said. EV loads are fundamentally different from other large loads, such as building loads, which often include an extended permitting process, new construction, and long lead times. By contrast, large EV loads can materialize extremely fast. For example, a fleet operator may order a dozen Class 8 heavy-duty trucks that can be delivered in just a few months.

EROADMAP™ PROVIDES THE GRANULAR DATA UTILITY PLANNERS NEED

Granular, forward-looking, location-specific data can help overcome these challenges, especially for utilities seeking to serve large new customers. EPRI understood that to solve this challenge, a new approach was needed—one that was transparent, collaborative, and, most importantly, data-driven.

"We did not want to create a black box model," Dunckley said. "That wouldn't provide the transparency that utilities and others need to feel confident in using the data. The result is eRoadMAP, an online interactive map designed to estimate the power and energy needs for electrifying transportation at the local level—all the way down to a quarter square mile resolution—covering light-, medium-, and heavy-duty vehicles. What makes eRoadMAP unique is that it is informed by a comprehensive collection of data sets rather than a single source of information.

For example, vehicle registration may seem like an ideal data source for understanding where charging needs will emerge for EVs. After all, nationwide vehicle registration data is reasonably available and accessible. And while vehicle registration data can highlight broad trends for light-duty EVs, they are less useful in understanding where medium- and heavy-duty vehicles will charge. The reason is that commercial fleets frequently register their EVs at headquarters or states that offer favorable policies or lower costs, not where the vans, trucks, and buses operate.

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To overcome the inherent limitations of relying on a single data source, eRoadMAP combines a unique blend of proprietary and publicly available data, including:

- **Registration data** is valuable for light-duty EVs, delivering insights into sales and their general location.
- **Telematics data** from INRIX and Geotab combined provide critical behavioral data for approximately 25 percent of medium- and heavy-duty vehicles, delivering insights into travel patterns and dwell times without revealing personally identifiable information.
- **Cell phone data** from the company Replica provides travel model data based on cell phone usage—a very valuable indicator of the driving behaviors of vehicles in many different vehicle segments.
- **OEM data** from Daimler, Navistar, Volvo, and others provides insights about the companies' conventional ICE truck fleets, including where they travel and where they fuel. EPRI can use these travel patterns to make assumptions about what they would need if they were electrified.
- **Fleet data** from Amazon, Enterprise, and others provides vehicle behavior as well as their fleet electrification timelines.

PRACTICAL USES OF EROADMAP

The data within eRoadMAP is being continuously updated as EPRI collects more data, fleet electrification and charging infrastructure plans are announced, and as technology matures. Comprehensive, up-to-date, and localized information will provide utility planners with the information they need to make confident investments to accommodate new charging loads. Three primary eRoadMAP use cases are:

- **Local grid planning**: eRoadMAP enables utilities to identify and prioritize areas with high anticipated EV loads and to integrate these early load projections into multi-year capital and project planning processes. For example, Minnesota-based Great River Energy plans to use eRoadMAP to guide construction work plans and integrated resource planning efforts. It also sees the map as an important tool for efficiently sizing new equipment, like transformers. "If an engineer has to size a transformer today, eRoadMAP provides an additional input that might lead to installing a larger, more future-proof transformer that helps avoid costly replacements five or ten years down the line," said Rodney De Fouw, a member electrification specialist at Great River Energy, a generation and transmission utility serving 26 cooperatives.
- **Customer engagement**: eRoadMAP helps utility account representatives and fleet advisors identify and prioritize customer outreach, enabling strategic conversations about their electrification plans. It empowers utilities to take a proactive approach, rather than reacting after large commercial customers announce significant EV fleet deployments.
- **Stakeholder outreach**: By making critical data publicly accessible, eRoadMAP empowers regulators, state legislators, city planners, and government agencies to better understand the scope and location of future EV loads. This transparency builds common understanding and facilitates informed policy discussions, avoiding situations where utilities present data from "black box" models that are difficult for external stakeholders to scrutinize.

Great River Energy's use of eRoadMAP illustrates how utilities can adapt and enhance the tool to achieve their own unique objectives. Great River Energy is actively integrating eRoadMAP data into its grid planning processes, including transmission-level analysis. At the same time, its member-owner cooperatives plan to use it for distribution-level circuit analysis. De Fouw also notes that Great River Energy is augmenting eRoadMAP with internal data to improve load forecasting. Not only will eRoadMAP be utilized to identify potential areas that could see high levels of EV penetration, but also to understand where grid capacity is already available for EV charging.

Alabama Power has also used eRoadMAP to ensure that it is fully prepared for future EV charging load growth. The utility had already incorporated a two percent annual reserve margin into its distribution planning process to allow headroom for incremental new load additions. However, without tools to project future electric transportation demand,

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Alabama Power sought to validate whether that reserve margin would be sufficient.

"Our management wanted to see if our system is prepared for what's coming to make sure we are ready," said Philip Waters, who works in distribution planning for Alabama Power. "In our distribution planning department, we wanted to double-check that our substations and conductors were ready for any added load coming." Alabama Power especially wanted clarity about the potential impacts of EV charging on peak demand.

eRoadMAP enabled Alabama Power to apportion expected EV energy demands at the individual feeder and substation level. The utility was also able to estimate changes in peak demand by approximating the load curve impact on home EV charging. The ultimate result was that eRoadMAP validated the utility's existing approach to planning for EV-related load growth. The tool was especially helpful for understanding unmanaged charging of light-duty EVs. "This showed us that our planning process is in good shape and gave us data points we could take back to management to demonstrate there were no major red flags even at the most impacted feeders and substations," Waters said.

A BROADER ECOSYSTEM: EROADMAP AND EPRI'S EV INITIATIVES

eRoadMAP is not a standalone solution, but rather an essential component of EPRI's broader efforts to prepare the grid for transportation electrification. It is one of several first-of-its-kind products developed as part of the EVs2Scale2030™ initiative—a three-year program focused on putting in place new tools and streamlined processes that help utilities across the U.S. prepare the electric grid for growing EV adoption in ways that minimize impacts and maximize benefits.

Besides eRoadMAP™, EPRI's electric transportation EVs2Scale2030 initiative includes:

- **GridFAST**: This centralized online portal modernizes the way customers and utilities interact to encourage early and higher-quality electrification plans to be shared with utilities, allowing them to plan ahead for the aggregate impact of customer loads on their system. GridFAST streamlines the customer pre-service request intake process to simplify the process of working with 3,200 utilities nationwide, with the aim of accelerating customer interconnection timelines.
- **GridReady**: A state-specific assessment for each of the 50 states, GridReady outlines the impacts of transportation electrification across various facets, including the economic investment benefits to the state, providing state legislators and other policymakers with a high-level understanding of the local impacts and opportunities of transportation electrification.
- **Vetted Product List (VPL)**: A comprehensive database of available charging hardware and network systems, vetted against industry standards and practices, to support infrastructure programs offered by utilities, states, and others. To date, 700+ EVSE products and 50 networks from over 100 vendors are listed, providing these vendors with access to over $1.8 Bil in program funding incentives.

THE ROAD AHEAD: EVOLUTION OF EROADMAP

EPRI's commitment to eRoadMAP extends far beyond its current iteration. Recognizing that the industry needed this tool years ago, EPRI adopted an agile, iterative development process.

The next release, for instance, will incorporate school buses, a significant load that was previously not included. Future additions are planned for other vehicle sectors like transit buses, federal, state, and municipal fleets, and vehicles operating at ports and airports. The tool will also continue to integrate additional fleet and OEM data over time, ensuring its accuracy and relevance.

For his part, Great River Energy's Rodney De Fouw views eRoadMAP as a continuously evolving dataset that provides unparalleled foresight. "As long as EPRI continues to iterate on it, then it should be about the best crystal ball that I have," he said.

EPRI TECHNICAL EXPERT

Jamie Dunckley

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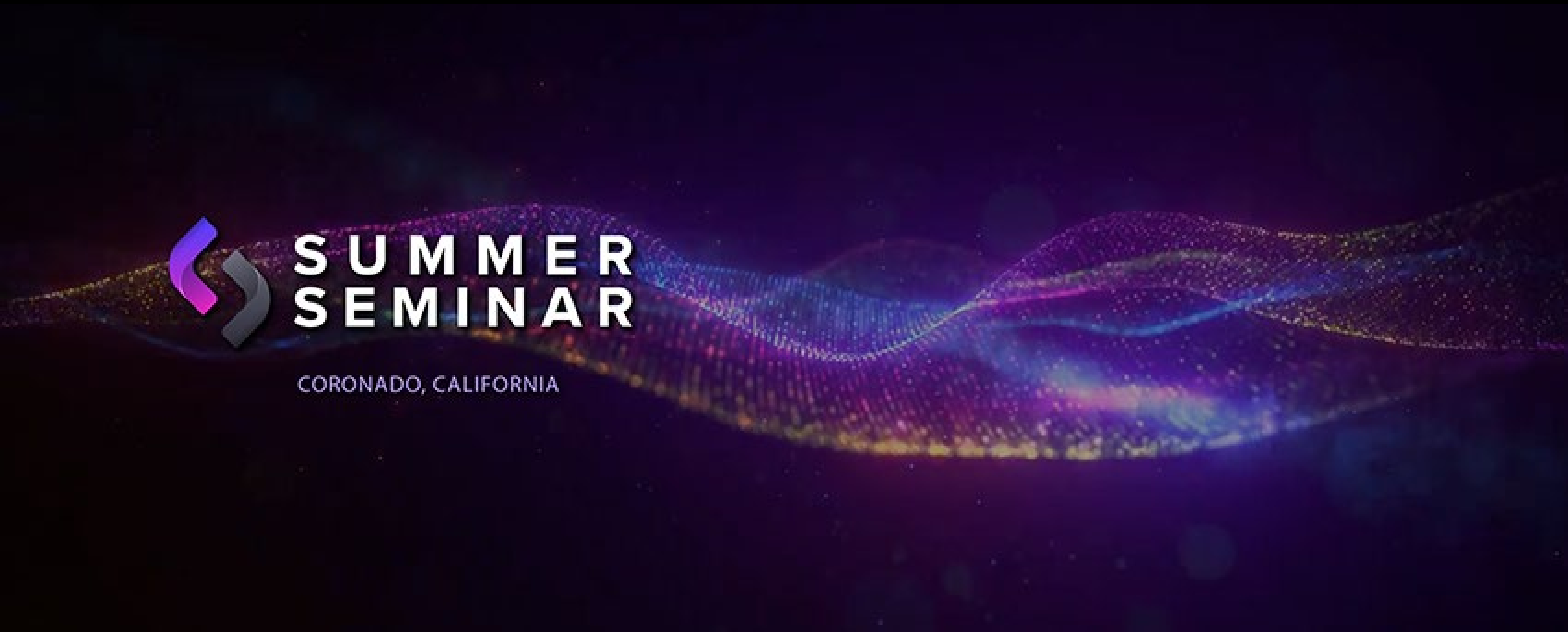

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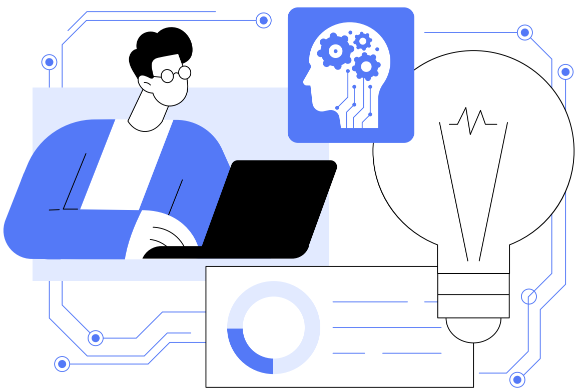
When Knowledge Demands Power

EPRI's Summer Seminar tackles the historic challenges and opportunities of AI and the Future Energy Landscape

By Chris Warren

Few, if any, people realized it at the time, but the future course of the electric power industry was a topic at a technical conference held in Long Beach, California, at the end of 2017. The *Neural Information Processing Systems* (NIPS) conference was the venue for eight Google researchers to discuss their paper, "Attention Is All You Need."

What could a vaguely named paper discussed at a highly technical conference possibly have to do with the future of utilities and electricity? The short answer: a lot. The paper outlined the next step beyond the Google founders' original idea to index every word on the World Wide Web and create an online yellow book. "What that paper said is you really can't just look at every word. You have to look at how every word is used in a sentence," said Arshad Mansoor, president and CEO of EPRI, at the kickoff to this year's EPRI Summer Seminar, held in Coronado, California, on August 11 and 12. "What's the context? How does that word relate to the paragraph, how does that word relate to the page, how does that word relate to the whole book?"



Put more simply, the paper described how large language models (LLMs) work. These models are a key subset of artificial intelligence (AI), trained on massive amounts of text to generate and interpret natural language. Today, the connection between AI and electricity is no mystery. "It all takes compute time. In the U.S., we are hearing 50-gigawatt, 100-gigawatt numbers thrown around. I was in the UK, and they say they have 60 gigawatts in the queue," Mansoor said. "Knowledge is power. Now, power is creating knowledge, but that power has a different meaning. It's electricity. It's energy."

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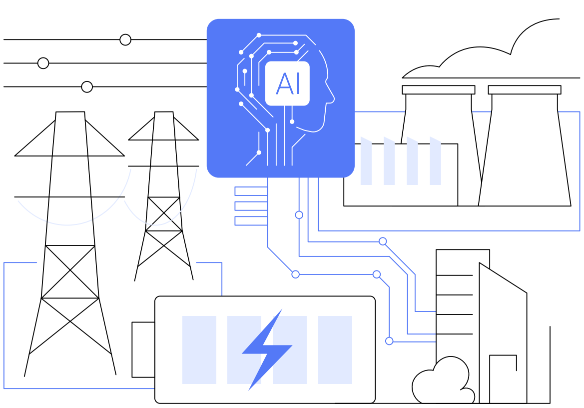
Forecasts abound about the hefty power demands of data centers needed to train large language models, enable AI applications, and run cloud computing operations. For example, EPRI recently teamed up with the research institute Epoch AI to investigate the power needed to train large-scale AI models. Their findings: the power demands for training models have more than doubled over the past decade, and by 2030, it could take more than four gigawatts to train leading models—the equivalent of the power demand of millions of U.S. homes.

AI'S RISING POWER DEMANDS TRANSFORM ENERGY PLANNING

These are big numbers with short timelines. But utilities can take some solace in knowing this is not the first time the industry has had to meet skyrocketing demand for electricity. "This is what Con Edison's transmission and distribution substation build looked like over the last 70 years," Mansoor told the Summer Seminar audience. "100 gigawatts seems like a lot. But we have done it."

How the industry meets rapid load growth today and over the next few years will obviously differ from the past and will include AI-driven power solutions. One reason is that continuous advances in the specialized computer chips inside data centers will require ever more power. "The chips are changing every three to five years. A rack [of chips] that used to be 30 kilowatts is now going to 1.2 megawatts," Mansoor said. "If you designed your distribution substation for 400 megawatts, did you think you might need 600 after five years? That's the type of different thinking we will need to do."



AI AND ONSHORING DRIVE ELECTRIC SECTOR POWER GROWTH

This year's Summer Seminar fostered the fresh thinking and innovation utilities needed to surmount the pressing challenges posed by AI-driven load growth and seize the many opportunities it presents. Since the 1970s, EPRI's annual Summer Seminar has provided an opportunity for company executives, policymakers, and leaders from academia, NGOs, government, and industry to meet and discuss pressing issues facing the sector. Summer Seminar is a critical part of EPRI's role as an industry convener, helping to foster collaboration and knowledge sharing about near-term actions and to set a longer-term research and development (R&D) agenda.

Given the sprawling and rapidly changing nature of AI and the critical nexus between the AI and electric power industries, this year's Summer Seminar discussions were necessarily wide-ranging. For example, after Mansoor's opening remarks, he also moderated a conversation between the CEOs of Constellation, Nebraska Public Power District, and PPL Corporation. The session, "From Insight to Impact: Setting the Stage for Action," provided a C-suite perspective on opportunities utilities have to fully harness AI to create a more resilient and cost-effective AI-enabled energy system.

Valuable AI tools can support electricity companies in a range of scenarios, including predictive maintenance, real-time monitoring, and optimized dispatch. The CEOs also offered their views about how EPRI's global network can drive the innovation crucial to meet soaring demand from AI-enabled infrastructure. They also outlined tangible steps EPRI, its members, and industry stakeholders can take to quickly deliver scalable and affordable solutions. After the panel discussion, Gil Quiniones, the president and CEO of Commonwealth Edison (ComEd), offered a company-specific perspective about how ComEd is planning, investing, and innovating to meet demand from not only AI but also electrification and a resurgence of industrial activity.

This was a theme Mansoor emphasized to the audience. While data centers and AI grab daily headlines, a series of recent announcements underscores a trend in onshoring that will also drive

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load growth. Just a few days before Summer Seminar began, for instance, Apple announced an additional $100 billion commitment to domestic manufacturing, bringing its total planned investment to $600 billion over the next four years. One day after the Summer Seminar, GE Appliances announced a five-year, $3 billion-plus investment in U.S. operations, including plants in Kentucky, South Carolina, Georgia, Alabama, and Tennessee.

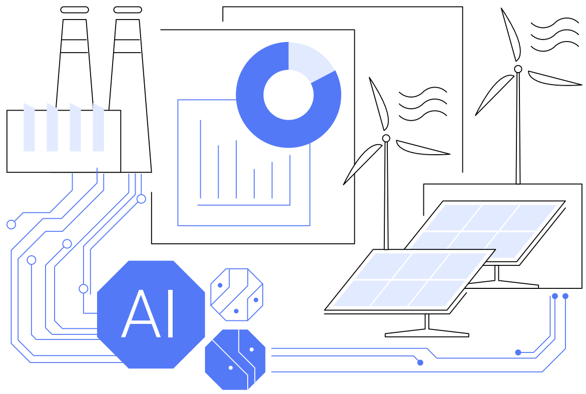
"There are 50 gigawatts of power that is not considered in most of our IRPs (integrated resource plans) in the U.S. that will come from reindustrialization," Mansoor said. "Globally, other countries are also seeing this. So, data centers are huge, but they're not alone."

INNOVATION AND FLEXIBILITY ARE THE NEW IMPERATIVES

Speed and innovation were also prevalent themes in Summer Seminar panels. Though the electricity industry has indeed met soaring demand before, load growth is driven by data centers, reindustrialization, and electrification, and it is on a much quicker timeline. Moving quickly depends on robust supply chains. The session, "Navigating Bottlenecks: Solutions for Data Center and Power System Supply Chains," dug into the effects of growing global supply chain pressures. CEOs from Omaha Public Power District, Vistra, GE Vernova, and Quanta Services addressed bottlenecks and resilience strategies, pointing to the need for innovation and forward-looking procurement.

Innovation must infuse everything utilities and their partners do to meet surging demand. Pacific Gas & Electric (PG&E) CEO Patti Pope led a session titled "Meeting the Moment: Planning for the Current Wave of Load Growth," which underscored the industry-wide innovation imperative from grid modernization to transmission expansion to public-private partnerships.

One area that connects innovation and the need to move quickly is grid flexibility. Simply put, maximizing the existing grid helps contain costs for electricity customers while also providing time for the critical capacity additions needed to meet growing demand. The session, "From Concept to Reality: Demonstrating Data Center Flexibility in Production Environments," shared lessons from



EPRI's DCFlex initiative, which is exploring how data centers can function as flexible grid resources. Already, results from DCFlex show potential for computational flexibility, ancillary services, and the use of renewable fuels in backup generation.

"We have to build smart—and fast. The need for speed in every country means asking what you can do in the next 12 to 18 months," Mansoor said. "Much of that will come from unlocking headroom in the existing grid, through flexibility and load curtailment," he said.

AI IS PART OF THE POWER SOLUTION

Understandably, utilities, data center developers, hyperscalers, and others are all focused on how to meet AI-driven demand. However, AI itself can also be a tool to help meet data center demand. In the session, "Empowering Power: Time for AI to Return the Favor," Jeremy Renshaw, EPRI's executive director of AI and Quantum, explored how AI can be a tool for utilities to unlock new levels of system performance.

It's a theme Mansoor also emphasized. "If you look at what the one holy grail that AI can really help, it's the orchestration of flexibility," he said. "We can get flexibility from markets, EV charging, batteries, and demand response." Where EPRI can play a role, he said, is in standardizing how devices communicate.

Summer Seminar concluded with the session, "From Insight to Impact: Bringing it All Together," a plenary featuring Mansoor alongside leaders from Southern Company, the Nuclear Energy Institute (NEI), and the New York Power Authority (NYPA). The discussion underscored how accelerating innovation, convening global collaboration, and

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balancing investment priorities are all essential to managing AI-driven load growth while keeping electricity reliable and affordable.

If a single research paper could reshape how machines understand language, the worthwhile outcome of the Summer Seminar is to spark meaningful research, collaboration, and—most importantly—action to accelerate progress in meeting the growing demand for electricity. These conversations will continue and evolve, all moving towards the same goal. "We have to be ready to power this demand," Mansoor said.

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Two Decades of Global Bridge-Building: A Conversation with Neil Wilmshurst

By Chuck Ross

STORY IN BRIEF

Neil Wilmshurst, EPRI's chief nuclear strategy officer and managing director of EPRI Gulf, is retiring effective September 30, after 22 years at the organization. In those years, he's been instrumental in expanding EPRI's presence internationally, especially in the aftermath of Japan's Fukushima disaster, when he led EPRI's efforts to help Tokyo Electric Power Company (TEPCO) stabilize its nuclear power industry. Since then, he's worked to further existing global stakeholder relationships and establish new ones, particularly in the Gulf region. In a farewell interview with EPRI Journal, he looks back on his entry into the nuclear industry and his more than two decades at EPRI.

EPRI JOURNAL: YOU'VE BEEN INVOLVED IN THE NUCLEAR POWER INDUSTRY NOW FOR DECADES. WHAT INITIALLY BROUGHT YOU TO THE INDUSTRY?

Wilmshurst: I grew up in the UK. And when I was at school, about the age of 16 or 17, we had a school trip to the Calder Hall nuclear power station, which was the first commercial nuclear power station in the world. It all started there. Something clicked. When I left school, I joined the Royal Navy. I did a three-year engineering degree, and then went to sea and ended up navigating a destroyer off the coast of Beirut. I remember sitting on the bridge late one night, talking to the captain. He said, What do you want to do? I said, at that point, I wanted to be a nuclear submarine engineer. Six months later, I became an engineer in the Navy, and there you go. Nuclear training, off we went.

EJ: WHAT BROUGHT YOU TO EPRI?

Wilmshurst: What happened was that peace broke out, and the Berlin Wall came down. European powers reduced their defense spending. I decided at

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that point that it was time to change paths. I joined British Energy at Sizewell B, a nuclear power plant that was under construction in the UK in 1993. I went on to run the maintenance department. In 1998, British Energy and what was then PECO Energy in the US formed a partnership to buy nuclear power stations in this country, and that operation was known as Amergen. We looked at a number of plants, including Three Mile Island. We closed the deal at TMI, and I was asked to stay as the British Energy guy on the ground. Along the way, I became the lead for the vessel-head replacement project at TMI. At a conference in Florida, I met some people who convinced me that a move to EPRI would be a wonderful thing. In September 2003, I started at EPRI.

EJ: WHAT WERE SOME OF THE FIRST EPRI PROJECTS YOU MANAGED?

Wilmshurst: I joined as a project manager, and within six months, I was a program manager, managing what is now the plant engineering program. Two years later, I became the senior program manager for equipment reliability for the nuclear sector.

At that point, the nuclear sector VP sent me to South Africa to sell membership to Eskom. That was the start, really, of a drive to expand EPRI internationally. I found my groove at EPRI, which was building relationships globally.

EJ: WHAT ARE THE DUTIES OF THE CHIEF NUCLEAR OFFICER ROLE AS YOU'VE LIVED IT?

Wilmshurst: It was EPRI's job to climb to the top of the hill, look over the rise, see what was coming, and be ready for it. That was the value proposition we (EPRI nuclear staff and its Chief Nuclear Officer or CNO) were providing to the industry CNOs. We were making sure that, as best we could, we saw what was coming towards them and made sure we had all the pieces in place to address it. They haven't got the time to look into the future of technical needs. They expect us to be doing that.

I've got several good examples. First, for nuclear plants, the typical benchmark was that they run for 40 years, which was a financial decision, nothing else. But it needed technical work to get into 60 years. EPRI did the technical work to extend the lifespan to 60 years. Then we asked the question, why not 80 years? And that turned into what's now known as EPRI's Long-Term Operations program. Look how valuable that is now. Almost every nuclear plant in the US is going to extend its life to 80 years.

Finally, about eight years ago, there was an issue in the pressurized water reactor fleet of bolts breaking inside the reactor vessel. We had gotten our arms around that and had done all the analysis on inspection, so we were ready for that.

EJ: SO, HOW DID THAT EVENT CHANGE HOW YOU SAW YOUR JOB?

Wilmshurst: I remember getting phone calls from various people who were saying Fukushima would result in EPRI's funding going down. They thought that the nuclear industry would be decimated and that Japan would back away. At that point, I made two promises to myself: we're going to do everything we can to support TEPCO, and we're also going to do everything we can to ensure that we sustain EPRI's nuclear funding.

And it was more than Fukushima. The Japanese prime minister told the Hamaoka plant to shut down after the Fukushima event. We happened to be there the day after Unit 5 at Hamaoka shut down, and it had a huge seawater ingress. We were able to mobilize EPRI people to help them literally that day. We earned a reputation for being there and following through on commitments we made.

EJ: AS THE TEPCO OFFICIALS WORKED TO CONTAIN EVERYTHING, WHAT WERE THE MOST SIGNIFICANT RISKS THEY FACED?

Wilmshurst: The business case for bringing the plants back revolved around how long they were going to continue to operate. Working with the Japanese companies, EPRI managed to develop a strategy that said the aging clock for the plants stopped when they were shut down at the Fukushima event. So, those ten years of shutdown, you add that life to the end of the plant. It basically preserved the business case for bringing the plants back.

So, that's the technical thing we did to help them. But the real lesson was that we weren't known in Japan before Fukushima. Fukushima got us into the conversation. And into the global dialogue.

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We started building relationships with global organizations, such as the International Atomic Energy Agency (IAEA), the Organization for Economic Cooperation and Development (OECD), and the World Association of Nuclear Operators (WANO). Then we started meeting the players in all the global nuclear companies—building those relationships, going from a conversation over coffee to a trusting relationship where people start joining EPRI. And then the technical people show the value, and the whole thing grows.

Every culture is different. EPRI nuclear membership grew from being pretty much US-only to representing more than eighty percent of the world's reactors.

EJ: WHY IS CONNECTING GLOBALLY IMPORTANT FOR OVERALL NUCLEAR DEVELOPMENT?

Wilmshurst: Well, nuclear is unique in that nuclear companies collaborate very well together. In EPRI's technical scope, we had the answers to many of the questions that these companies were trying to address. We focused on making sure we had the right scope. And then it became compelling to say, we've got the answers you need, come join us.

EJ: DO YOU THINK THERE WAS SOME KIND OF SECRET SAUCE THAT YOUR TEAM BROUGHT TO THIS EFFORT?

Wilmshurst: A long-term reputation for knowing what the industry needs and doing it in the right time frame. And the US nuclear fleet is really important to that success. The US nuclear fleet is the oldest fleet in the world, so it tends to see things before the rest of the world. That gave us an angle as well, and we could actually interpret that for the rest of the world.

EJ: IT SOUNDS LIKE THE GULF IS BECOMING A BIGGER AREA OF ATTENTION. WHY IS THAT?

Wilmshurst: The United Arab Emirates (UAE) started thinking about how to reduce its carbon footprint. So, the UAE got ahead of the curve and built four nuclear power plants at Barakah. So that's how I first got involved in the Gulf, using the same approach of building relationships.

As these countries start building out infrastructure, there's an incredible opportunity to learn from them. You think about integrating solar or building nuclear plants in different environments. You can learn a considerable amount from these operations, and they can learn a lot from other countries because they're trying to catch up very quickly. EPRI is perfectly positioned to help accelerate that learning. It's two ways. They need us, we need them.

EJ: WHAT ARE YOU MOST PROUD OF WITH YOUR WORK AT EPRI? IS THERE A LEGACY YOU HOPE TO PASS ON?

Wilmshurst: Obviously, the Fukushima work. Another thing I'm really proud of is the Global Forum for Nuclear Innovation, working with the IAEA, OECD Nuclear Energy Agency, and the UK's National Nuclear Laboratory. It brings people around the world together to understand how to break through the barriers to innovation in nuclear. The other ones are training and workforce development, pushing to increase EPRI's footprint and impact in training. As I walk out the door, it's starting to bear fruit. Because everything is about transferring information to people. Training people to be more effective at their jobs is essential.

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REFLECTIONS FROM COLLEAGUES

Rosa Yang
EPRI Fellow

As Neil retires, I find myself reflecting on the privilege of having worked closely with him for over a decade. During this time, his strategic vision and unwavering support were instrumental in expanding EPRI's international engagement—especially in Asia.

Neil took a special interest and support in building relationships with our Chinese, Japanese, and Korean colleagues. His commitment to peer-to-peer engagement and his willingness to travel opened doors that might otherwise have remained closed. I truly believe that without his leadership and strong support, our Asian membership would not be what it is today.

What I've always appreciated most is Neil's respect for different cultures. He approached international collaboration with humility and care and encouraged staff to do the same—to lead by listening and learning in cultures outside their own.

Neil's legacy is one of global connection, thoughtful leadership, and respect. I'm grateful for the years we worked together and proud of what we have accomplished together. He leaves behind a stronger, more international EPRI—and a lasting impact on the global energy community.

Michael W. Howard
CEO Emeritus, EPRI

There are many memories, but one I will never forget is Neil calling me early in the morning on March 11, 2011, to let me know about the Fukushima accident and that Rosa was already on her way to support TEPCO. The unyielding assistance that Neil and his team provided exemplified the unique value EPRI brings to the nuclear utility sector and, more broadly, to society, which depends on reliable electricity.

That conviction was reinforced about six months later, when Neil and I visited Tokyo to meet with TEPCO's CEO and tour the Fukushima site. I vividly recall the CEO expressing his deep appreciation for EPRI's support, even noting that without it, the accident would have been much worse.

Neil's dedication and leadership within the global nuclear industry have been extraordinary. His efforts not only strengthened EPRI's reputation but also underscored the essential role EPRI plays in delivering value to utilities worldwide.

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Neil and I have worked together for over 20 years. He has incredible energy and enthusiasm for the nuclear industry!

Thinking back on our many adventures, in the U.S. and across the world ... never a dull moment. He was always keen for another adventure and another glass of red wine!

We worked on equipment reliability when I was on EPRI's advisory committee, and later became the chair. The buried piping initiative went from a conversation over a glass of wine to an industry initiative with the full support of NSIAC!

And we worked tirelessly when I was the NPC Chair. I never saw him frustrated or downtrodden. No matter the issue or concern, he had a contact who could help. He truly has a worldwide contact list for all things nuclear!

Neil, the industry is indebted to you and all you've done to position us to thrive!

Thank you!

"EPRI's hired a Brit to run their nuclear program."

"Really? Why did they do that? Who is it? Do we know him?"

"No, never run into him. Some guy named Willhorst."

Thus was my first introduction to Neil, a quick conversation with an industry colleague. The heads of EPRI's nuclear activities were always quite technically competent, but weren't always easy to get along with. I was interested in meeting this "Brit" to see if he would be someone with whom I could work. As it turned out, EPRI had made the best hiring decision in its history, bringing aboard a happy warrior in the complex and challenging nuclear utility environment.

Whatever might have been his job description, Neil turned the position into something new. It became "Neil Doing Neil Stuff." He became an indispensable international resource, advising, facilitating, and engaging in a tireless and compelling manner, making things happen that would not have happened otherwise. What I will always remember about Neil during his long, impactful tenure at EPRI is that I don't think I've met anyone who got as much joy from his job as did Neil. And I don't think I enjoyed working with anyone as much as I enjoyed collaborating with Neil WILMSHURST.

Congratulations, Neil – and thanks!

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Bernard Salha
Électricité de France

Neil is a key member of the nuclear community. EDF has collaborated with EPRI for over 30 years, primarily focusing on the nuclear sector as we continue to be the leading nuclear operator worldwide, with 56 reactors in France and 9 in the UK. Neil has been a vital component of this enduring partnership.

Recently, Neil assisted us in launching our Long-Term Operation program, aimed at extending the operation of existing units beyond 60 years. He brought invaluable U.S. experience with the Second License Renewal process, which was pivotal in engaging the French Safety Nuclear Authority in this endeavor.

A global traveler with his primary office in an airplane, Neil has emerged as one of these key global authorities in the worldwide nuclear community who contribute significantly to making the nuclear industry a cornerstone for safe, cost-effective, and decarbonized electricity generation.

Neil, please accept EDF's warmest thanks!

Fiona Rayment
OBE FREng FRSE

I have had the pleasure of knowing and working with Neil for too many years to remember, but I remember vividly one conversation that really made a difference, and it was all over a lovely dinner on a beautiful evening in Paris!

Neil and I had been participating in a senior meeting at OECD NEA on the importance of innovating in nuclear. Following this, we decided to have dinner, where we continued this discussion. We both knew the importance of driving more innovation into nuclear, and we both felt we needed to create much more visibility in this area. Neil said to me why don't we have a Global Forum for Nuclear Innovation? Well, that's exactly what we're bringing together: key challenges for our sector with the right people to enable dialogue and solutions for resolution. I'm very proud to have been part of that discussion and to know Neil—A real innovator and a fantastic person to have dinner and fun with!

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EPRI JOURNAL

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Lessons From the Iberian Peninsula Blackout

By Chris Warren

There was little indication that a blackout would soon cascade across the Iberian Peninsula when dawn broke this past April 28th. In both Lisbon, Portugal, and Madrid, Spain, springtime temperatures were expected to top out in the low 20s Celsius (70s in Fahrenheit), with ample sunshine and none of the extreme weather typically associated with blackouts.

Yet at exactly 12:33 p.m., approximately 55 million people across Spain, Portugal, and a small portion of France lost power, grounding airplanes, halting public transport, and triggering the deployment of tens of thousands of police officers across Spain to prevent possible looting and disorder. News of the blackout quickly grabbed global headlines, in large part because widespread power outages are exceedingly rare in Europe. The last significant outage to hit Spain was in 2006, when 10 million customers across Europe were impacted, including in Madrid and Barcelona.

The blackout also sparked immediate speculation about its cause. Some observers initially raised the possibility that a cyber-attack had brought the grid down, which Spain's grid operator, Red Electrica, quickly ruled out as a cause. Critics of wind and solar power were also quick to blame renewables for the sudden loss of power, claiming, among other things, that an overabundance of solar resulted in a supply and demand imbalance that triggered the blackout.

Clearly, it is important to understand what caused the blackout on the Iberian Peninsula and to use that knowledge to both identify measures to prevent future outages and pinpoint gaps in understanding that must be addressed by rigorous research. "What are the lessons that we should learn from this?" said Daniel Brooks, senior vice president, energy delivery and customer solutions at EPRI. "Where are the gaps in the existing understanding and capabilities, as we have systems that continue to evolve and emerge into much more dynamic systems that are highly inverter-based? How should we work together to make sure that we have the capabilities to operate these systems to the reliability and resilience that we must have for the electric sector as we go forward?"

These are not questions that can be answered quickly in the immediate aftermath of a blackout. In fact, significant data collection and analysis are

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necessary to understand the causes of an outage of this scale properly.

Sean McGuinness, an EPRI senior technical executive based in Dublin, Ireland, who specializes in blackout investigations and grid protection, says thousands of measurements from across Spain and Portugal were necessary to begin a thorough analysis. "There are log files that need to be collected. All of them need to be time synchronized and verified against each other," McGuinness said. "You really do need a comprehensive country-wide set of measurements to verify you know exactly how it started, exactly what happened next, and exactly the cause and effect."

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A CLEARER PICTURE EMERGES

In June, Red Electrica released a report detailing its findings about the causes of the blackout and the grid operator's recommended actions to avoid future outages. Investigations and research into the causes and best next steps will undoubtedly continue. Still, this report and other publicly available data help move beyond speculation to a more concrete understanding of the factors that resulted in the outage.

Iberia was in what system planners refer to as "shoulder season," a temperate time of year when electricity demand is moderate and grids are typically less stressed. It's also a season when operators perform planned maintenance. On April 27, multiple 400-kilovolt transmission lines were out of service in Spain, and studies conducted the day before identified 10 synchronous generators that would be needed to support voltage control during daylight hours. When one of those units declared itself unavailable that evening, it wasn't replaced.

As April 28 began, morning loads ramped steadily to 25 gigawatts in Spain and 8 gigawatts in Portugal. With clear skies, solar PV generation surged to over 20 gigawatts by midday. Some hydro was pumping in preparation for evening peaks, and nuclear generation was stable. Wind output was relatively low. Overall, the grid appeared to be in a relatively benign state.

But early on the morning of the 28th, small oscillations began to emerge. Oscillations are fluctuations in power and voltage that occur when different parts of the grid briefly fall out of sync, often caused by generation and consumption imbalances across regions. By 10:30 a.m., one oscillation caused a noticeable four-kilovolt swing on a major 400-kilovolt line. These oscillations are not inherently dangerous—European operators deal with them routinely—but the fact that they kept recurring was a troubling sign. Around 11:00 a.m., they returned with increased magnitude and duration, lasting several minutes at a time and requiring operators to intervene and stabilize the system.

"Oscillations are not uncommon, and usually the system can handle them," McGuinness said. "But by late morning, they weren't going away. That was unusual."

To mitigate under-voltage concerns during these oscillations, operators began switching out shunt reactors. Shunt reactors act like sponges, soaking up reactive power to keep voltages stable. But those actions had a side effect: increasing system voltage. With solar output already high and transmission lines lightly loaded, the additional capacitive VARs raised voltages further, setting the stage for what was to come.

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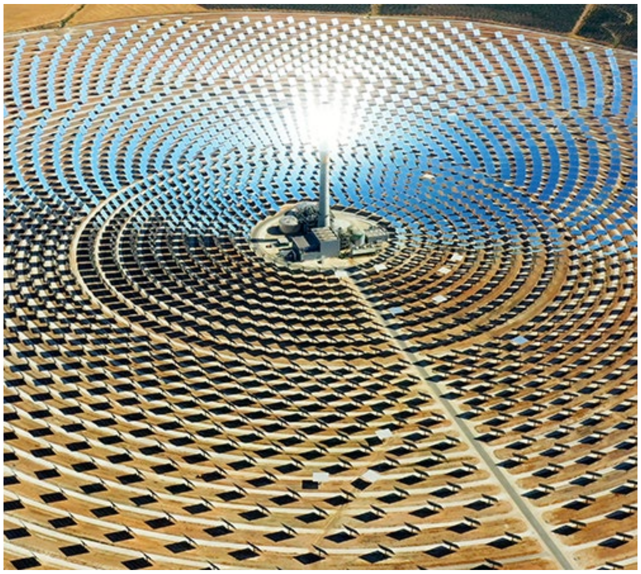
A QUICK-MOVING COLLAPSE

Just after 12:30 p.m., a power plant in southern Spain tripped offline. Usually, such an event is absorbed by the grid's reserves without any problems. But shortly afterward, a second generating unit disconnected. Within seconds, a third event occurred, involving one or more large plants. This final loss pushed the system past its limit.

"There were sufficient reserves to handle two gigawatts of generation loss," said McGuinness. "But once the third plant tripped, the system had no remaining flexibility."

The cascading effects were nearly instantaneous. Voltage began to spike, and frequency declined as more generation shut down. The interconnection between France and Spain, already relatively weak, was automatically severed to protect the broader European grid. Spain and Portugal were islanded, and a blackout engulfed the entire Iberian Peninsula.

What made this event so startling wasn't just its scale, but its speed. According to McGuinness, blackouts typically unfold over tens of seconds or even minutes. This one unfolded in as little as five seconds. "The system went from stable to blackout faster than anyone expected. That's created a lot of questions."



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A MORE COMPLEX GRID

Many questions have focused on the role of inverter-based resources (IBRs)—including solar PV and battery systems—which now supply an increasingly large share of electricity in Spain and Portugal. Unlike traditional synchronous generators, like gas and coal plants, which rely on large rotating masses, IBRs are governed by power electronics, which inject power based on programmed logic.

"This isn't about blaming renewables," said Eamonn Lannoye, managing director of EPRI Europe. "But how they connect to and behave on the grid is different. And those differences matter, especially when the system is under stress."

One key issue was how voltage was managed on the grid. Many of Spain's wind and solar plants were set up to operate in a fixed way that didn't allow them to adjust voltage when the system was under stress. A new rule that would let them help stabilize voltage was planned for later in 2025, but it hadn't been put into action yet when the blackout happened.

That inability to adjust voltage likely contributed to the severity of the event. Without the ability for IBRs to help regulate voltage, each plant that tripped meant not only a loss of megawatts but also of reactive power. This created a feedback loop: voltage rose, causing more plants to disconnect, which in turn caused voltage to rise further.

DISTRIBUTION GRID IMPACTS

When voltage levels suddenly jumped, those changes quickly rippled down into local power lines and neighborhoods. In some areas, the sharp swings caused rooftop solar panels and other distributed energy resources (DERs) to shut off to protect themselves automatically. As a result, electricity that had been supplied locally by these systems suddenly had to come from the main grid instead, adding even more strain to an already unstable system.

"Fast voltage swings on the transmission system don't stay there," said McGuinness. "They're reflected in the distribution grid. And if the distribution grid was already elevated, even small changes can push devices out of their protection limits."

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At the same time, some of the usual tools used to stabilize the grid weren't available or couldn't respond fast enough. Pumped storage hydro plants—which act like big batteries—were already running or couldn't be brought online quickly. Some natural gas plants that could have helped were offline and needed over an hour to start up, which was too slow to make a difference. Meanwhile, possible load-shedding may have made things worse by lowering the amount of electricity flowing through power lines, which can cause voltage to rise even further in certain situations.

LESSONS LEARNED AND THE ROAD AHEAD

Despite the unprecedented speed and scale of the blackout, system operators restored power quickly. Portugal's grid was fully energized within 12 hours. Spain's was back up and running in under 23 hours.

While it was encouraging that power was restored so quickly, the blackout still revealed serious challenges in how the grid was operated. For example, some of the steps taken by system operators—like turning specific power lines and voltage control equipment on or off, and following standard safety procedures—followed standard protocol. However, when combined, those actions left the system too fragile, with not enough cushion to handle unexpected problems.

"From a procedural standpoint, operators did what they were trained to do," McGuinness said. "But the system was so close to its edge that any additional disturbance pushed it into collapse."

Several lessons from the Iberian blackout are already informing industry discussions and research. Chief among them is the need for improved voltage control, both in real time and across planning and operational timeframes. That means reconsidering how static and dynamic reactive power resources are balanced and ensuring more inverter-based systems can respond to the system's voltage needs.

The outage also highlights the importance of protection coordination across the entire system. Developments such as the first generator tripping while voltages were still within normal range suggest a need to review and refine protection settings and protocols, especially for rooftop solar and other behind-the-meter systems.

Lannoye also emphasizes that grid resilience isn't just about adding hardware. "We need to look at the full lifecycle—from planning to commissioning to operations—and find the procedural and regulatory gaps," he said. "Sometimes it's a matter of how assets are used, not just whether they exist."

Grid codes and market designs may also need to evolve. For example, Spain is transitioning from 60-minute to 15-minute market intervals. Under certain price conditions, some solar plants curtailed output to avoid negative pricing, taking both watts and VARs offline. Those kinds of natural responses to market signals can have real-time consequences on physical grid stability.

PLANNING FOR COMPLEXITY

What makes the Iberian blackout such an important inflection point is that it occurred under seemingly normal conditions. There was no storm, no cyberattack, no extreme demand. It was a blue-sky day. And yet, a series of small factors aligned to create a continent-scale blackout in under 30 seconds.

"This wasn't a high-stress day," said McGuinness. "That's exactly why it's so important to understand. If it can happen then, it can happen anytime."

As EPRI and other research organizations continue their analysis, the focus is shifting toward building new tools, simulations, and best practices for operating grids in a world of fast dynamics, decentralized resources, and highly automated systems.

Some of those efforts are already underway. Others will emerge as more is understood. However, one thing is certain: the lessons from April 28 will shape how modern power systems are designed, operated, and regulated in the years ahead.

EPRI TECHNICAL EXPERT

Eamonn Lannoye and Sean McGuiness

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About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, and affordable access to electricity across the globe. Together...shaping the future of energy.

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