POWER

Building a Better Grid—Infrastructure Upgrades Require Ingenuity, Innovation, and Investment

Darrell Proctor

The need for more reliability and resilience of power delivery, both in the U.S. and worldwide, has utilities and grid operators looking for solutions to the challenge of bolstering the electricity supply.

Electric grid infrastructure, both in the U.S. and other parts of the world, needs an upgrade. Increased power demand from energy-intensive industries such as data centers, the move toward greater electrification—particularly from the transportation sector—and higher demand from developed (and developing) nations means more electricity must be produced, and the distribution network must be able to handle increased loads. The U.S. Department of Energy (DOE) in April announced a program to streamline permitting and approval of large transmission and distribution (T&D) projects (Figure 1) in an effort to coordinate the work of at least nine agencies involved in permitting power lines. The plan sets deadlines that push for projects to be authorized within two years, eliminating regulatory bottlenecks. It also supports the integration of renewable energy resources, particularly solar and wind, to the power grid.

1. Electricity transmission and distribution (T&D) systems across the U.S., and also worldwide, need upgrades to handle increased loads and facilitate the integration of renewable energy resources. Courtesy: Salvatore Ventura / StockSnap[/caption] Officials in the Biden administration have joined utilities and other power producers in calling for more long-haul power lines, and for upgrades to existing transmission, to strengthen a grid that increasingly faces reliability and resiliency issues from extreme weather exacerbated by climate change. Energy Secretary Jennifer Granholm in April said the plan is

part of a “holistic, multi-faceted approach to grid improvements and to grid expansion. Together we’re getting more power to more people in more places with the urgency that Americans deserve.” The DOE has a goal to upgrade 100,000 miles of transmission lines in the next five years. The agency has said technologies such as high-performance conductors and dynamic line ratings (DLRs) are needed to enable existing lines to carry more power. The DOE through its Office of Energy Efficiency and Renewable Energy has said it intends to issue multiple funding opportunity announcements totaling more than $100 million for field demonstrations and for other research on ways to support grid planning and operations. “The bi est problems facing today’s T&D systems include aging infrastructure, capacity constraints and grid reliability, cybersecurity threats and vulnerabilities, regulatory and policy challenges, and the need for a skilled workforce. These challenges are amplified further by the electrification of transportation,” said Brendan Andrews, vice president of Sales, Energy & Renewables, for Bureau Veritas North America. “Addressing the challenges of aging infrastructure is critical and requires a combination of technological innovation, policy support, investment in infrastructure upgrades, and collaboration among stakeholders in the energy sector. By addressing these challenges effectively, T&D systems can become more resilient, efficient, and sustainable, supporting the transition to a clean energy future. This will also support overall grid reliability to reduce voltage fluctuations, brownouts, and blackouts.” Jørgen Festervoll, CEO of Norway-based Heimdall Power, which has its U.S. headquarters in Houston, Texas, said the problem of insufficient grid capacity is more than just a challenge for the U.S. “The growth is partly due to the unexpected explosion in the number of data centers, an abrupt resurgence in manufacturing, and millions of electric vehicles being plu ed in. Many utilities are already struggling to keep the lights on, especially during extreme weather, and say the strain on grids will only increase. Note that this is not only happening in the U.S., this is a universal trend,” said Festervoll.

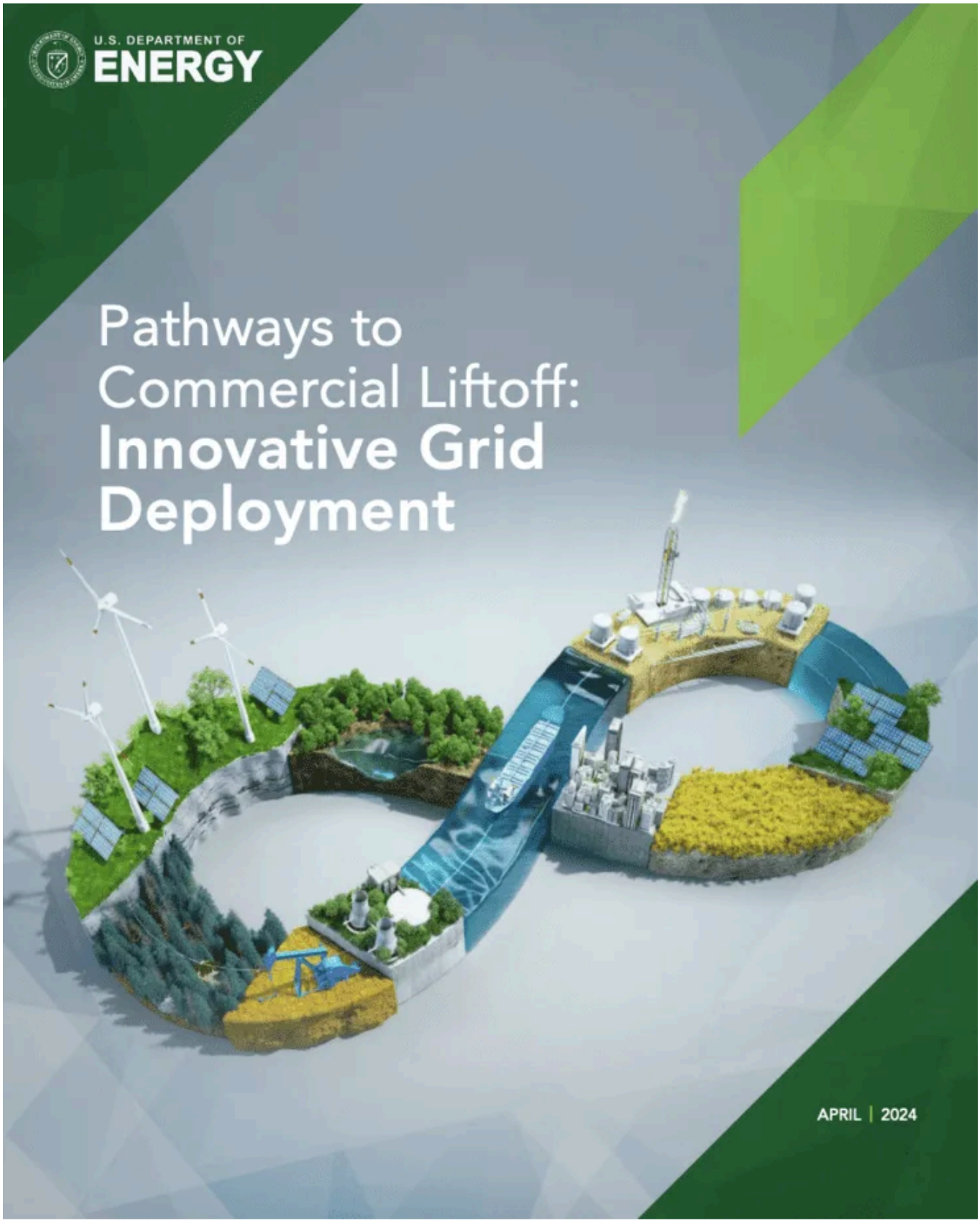
Dynamic line rating (DLR) enables utilities to unlock up to 40% additional capacity from existing infrastructure, allowing grid operators to rapidly increase energy throughput. Learn more about DLR technology in this article from the CEO of Iceland-based Laki Power.

“To provide one example, in the past four years, the Norwegian TSO [transmission system operator] received applications for new grid connections equal to all the capacity built in the past 100 years,” Festervoll said. “The lack of capacity is leading to massive curtailment and congestion costs all over the world, as well as grid connection queues.” Andrews added, “Regulatory changes are part of the problem and proposed solution. In some cases, these changes result in misinterpretation and industry confusion, which is why it’s important for policy support to be clear and easy to follow.” Andrews told *POWER*, “The most critical upgrades are needed to transmission lines, substations, transformers and switchgears, monitoring components, and energy storage capacity. Our aging infrastructure becomes more prone to failures, outages, and inefficiencies, which can result in reliability issues, increased maintenance costs, and potential safety hazards. Maintaining reliability is critical as our dependency on the grid becomes greater which requires replacement with newer, more durable materials or retrofitting with advanced technologies to enhance their performance and extend their lifespan.”

Finding Funding

Investment from the DOE and other government agencies will help with grid upgrades and new construction, but outside funds almost certainly are needed to help finance projects. Utilities and grid operators are setting aside funds for upgrades; for example, National Grid plans to invest more than $4

billion to transform its energy delivery system across upstate New York through a project called Upstate Upgrade. The money will go toward dozens of projects, including new substations, and rebuilding more than 1,000 miles of transmission lines. National Grid plans to roll out these projects over the course of six years. The DOE in an April-released report (Figure 2) titled "Pathways to Commercial Liftoff: Advanced Grid Deployment" wrote that the U.S. could use advanced technologies on existing T&D systems to support as much as 100 GW of incremental peak demand when each technology is installed individually, a number that rises when that tech is installed in combinations. The DOE said that the use of technologies such as DLRs and virtual power plants (VPPs) could help defer $5 billion to $35 billion in T&D infrastructure costs over the next five years. [caption id="attachment_220343" align="aligncenter" width="333"]



2. This April 2024 report from the U.S. Department of Energy (DOE) detailed what the U.S. power grid needs to support increased electricity demand over the next few years. Source: DOE[/caption] “The responsibility for funding T&D upgrades is multifaceted and should be shared among grid operators, transmission operators, independent system operators, and the government,” said Jeremy Klingel, a senior partner in the Energy & Utilities group at Chicago, Illinois-headquartered West Monroe. “It’s crucial a cost-recovery mechanism is established to ensure that the financial burden does not fall disproportionately on the last project in the queue, as others will also benefit from the upgrades. “While utilities may pass some costs to customers, the rise of private infrastructure investment in T&D can provide capital and accelerate project completion. The financial burden should be distributed across the utility’s rate base, necessitating a shift in the utility model and alignment with state regulation for fair cost distribution,” said Klingel. “Private equity’s role in infrastructure investment is becoming increasingly significant, offering a more cost-effective and rapid path to interconnection, which ultimately benefits the end users. This approach ensures that the necessary financial burden is equitable and not frivolous, aligning with the greater good while spreading costs across the utility’s entire rate base.”

Read this POWER Interview with experts from New York University's Tandon School of Engineering, who talk about the challenges facing the grid and some of the actions that will be needed to upgrade and protect the delivery of electricity.

“Private investment in power grids can play a crucial role in financing infrastructure upgrades, supporting innovation, and driving the transition to a more sustainable and resilient energy system,” said Andrews. “Finding private money and investment is not an issue. However, the extent of private investment in power grids may vary depending on factors such as regulatory policies, market structures, and the availability of investment opportunities. Private enterprise investment will likely play an increasing role in power grids, but not to the extent of taking over the management of these assets.” Pascal Radue, executive vice president, Generation and Transmission, at Paris, France-based electrical infrastructure company Nexans, told *POWER*: “Responsibility for T&D upgrades is a complex issue conditioned by local and national requirements. As we grow the grid networks, it is important that upgrades are carefully considered to ensure that the solutions are sufficiently future-proofed while mitigating the cost impact for the end consumer.” Radue said it would be possible for a private investor to take over a grid’s operation. “Investor-owned utilities are already highly prevalent globally. There is no reason why a new private investor could not, subject to obtaining all necessary licenses, either take over or start a new utility company,” Radue said. “Typically, the operation of a grid will involve assets from multiple owners. In these cases, while the operation and maintenance of the assets are carried out by the utility owner, the system operation is managed by a discrete organization, which could be owned by a

private investor." Jason Huang, CEO of California-based TS Conductor, which makes conductors for the power grid, said, "Privatization and/or public-private partnerships [P3s] are going to be part of a hot-button issue. But it's important to keep in mind that private sector investment vs. ownership vs. management of public infrastructure are three related but very different issues. We're talking about the capital to get new infrastructure built, who owns it once it's built, and who manages and operates it and keeps it in good working order. "There are plenty of examples of the private sector providing power and/or grid services—from single, large assets such as solar or wind farms or from many aggregated DERs [distributed energy resources] in VPPs, DR [demand response] programs, etc. But transmission infrastructure is inherently different, because it is a common, shared backbone. This emphasizes the privatization distinction between financing new infrastructure, managing that infrastructure, and who owns it. Could some transmission lines go the way of toll roads through fuller privatization? It's not outside the realm of possibility. But given how critical and central this infrastructure is, it's hard to imagine putting such important infrastructure into private hands." Huang added, though, that "there is still a role for the private sector to play here. I think there's no question that the private sector can and should play a role bolstering and accelerating government-led work. This is akin not only to toll roads, but also things like the work of NASA and SpaceX. That's where companies like TS come in, developing advanced conductors that grid operators and utilities can leverage. Overall, this conversation should be less about 'private companies taking over management' of infrastructure such as T&D, and more about how the government, utilities, and the private sector can work together toward shared ends."

Needed Technology

There's plenty of agreement that new transmission lines to deliver electricity are needed, and also that existing infrastructure needs upgrades. There's less alignment about where the majority of investment should be directed. "If we double or triple U.S. transmission grid capacity only through new-build lines, it is estimated that it will cost in the trillions of dollars. This could significantly impact the electricity price paid by ratepayers, especially those most sensitive to affordability. We can achieve the same capacity expansion end results for far less cost by instead upgrading existing rights-of-way through reconductoring projects where possible," said Huang. "Advanced conductors can tackle all of these challenges in one fell swoop. For example, TS technology offers up to three times the capacity of traditional wires and as much as a 50% decrease in line losses. All of this can be realized by reconductoring using the same structures in existing rights of way, no retrofits required. It's an instant line upgrade. Switching from traditional conductors to these advanced conductors is essentially like upgrading from copper-wire internet to fiber optic." Others who spoke with *POWER* agreed the use of advanced conductors is one solution—but just one among many. "The easy answer is upgrading the conductor lines to add more capacity. However, reconductoring or rebuilding transmission lines will take many years and have significant costs," said Eran Inbar, CEO of Prisma Photonics, which has headquarters in Texas and Israel. "Better line rating allows for a quick solution, optimizing the existing grid. With accurate data collected by an optical fiber sensing system, learning the wind patterns over long periods, it will be more accurate to make a data-driven decision on where something like reconductoring is needed instead of doing it in bulk, where it might not be needed." Inbar said, "We operate in regions where transmission grids are equipped with optical fibers, specifically the OPGW [optical ground wire]. These regions include North America, the EU [European Union], Scandinavia, and occasionally sophisticated grids in developing countries. Each territory and client has distinct priorities, whether it's resilience, addressing capacity shortages, or combating vandalism. "Our approach involves connecting an optical interrogator unit to standard single-mode optical fibers to develop highly sensitive

sensors for infrastructure monitoring. Leveraging our Hyper-Scan technology [Figure 3] represents a significant advancement over traditional methods, providing exceptionally accurate data for rapid issue identification and minimizing false alarms," said Inbar. "This capability allows us to effectively monitor power lines and pipelines over extensive distances, ensuring smooth and safe operations."

3. Prisma Photonics collaborated with the New York Power Authority (NYPA) to elevate T&D systems through the company's PrismaPower Hyper-Scan technology. The technology leverages distributed acoustic sensing; it facilitated real-time monitoring of a transmission line in the ru ed terrain of the Catskill Mountains over 24 months. Prisma Photonics empowered NYPA with insights into the health and functionality of its grid, enabling early detection of potential issues such as line icing and other anomalies. Courtesy: John Heaney / Prisma Photonics[/caption] "Low- and mid-voltage switchgear, transformers, and transmission infrastructure most critically need upgrades," said Klingel. "These components are essential for maintaining and improving the grid's capacity to meet growing demands. The investment growth rate for transmission, traditionally at 2% to 3%, must escalate to double digits to keep pace with the necessary advancements. These upgrades are vital for short-term improvements to support sustained progress over the coming decade." "Two of the largest problems facing the transmission and distribution system today are the aging infrastructure of the grid and the ability for that grid to keep up with ever-increasing demand," said Radue, whose company provides copper and fiber-optic cables, cabling systems, and advanced cable technologies for power and data transmission (Figure 4). "The electrical grid is 40 to 50 years old across the U.S. and the EU, and was designed to sustain the electrical load and system architecture of the 1960s and 70s. The current grid is struggling to keep up with the changing demands driven by the information age, electrification of vehicles and heating systems, and incorporating the changes in generation and storage. To increase the stability of the grid amid growing stress, we need to cater through the troughs and peaks, and ensure the grid does not collapse—which we can do by investing in transmission and storage solutions."

4. The Nexans factory in Halden, Norway, is manufacturing equipment for high-voltage direct-current projects for offshore wind farms. Courtesy: Nexans[/caption] Radue continued: “There is always more that can be done in terms of digitalization, such as sensors and control systems, to provide detailed, real-time information about the performance of the grid. This information can then be used to enhance the operation of the system, for example, by supporting dynamic ratings of lines. Sensors exist to let us know what really happens. If we have sensors, we can utilize the true operating limits of the system, rather than theoretical limits, which have huge safety margins and conservative assumptions of the outcome.” Artificial intelligence (AI) and machine learning (ML) also are impacting grid operations, and offer their own upgrades for electricity T&D. Said Andrews: “Utilities should integrate smart meters, advanced conductors, long-duration energy storage, sensor and monitoring devices, cybersecurity solutions, and STATCOM [static synchronous compensator] technology. These technologies can improve efficiency, reliability, and resilience while also supporting the transition to a more sustainable energy future.”

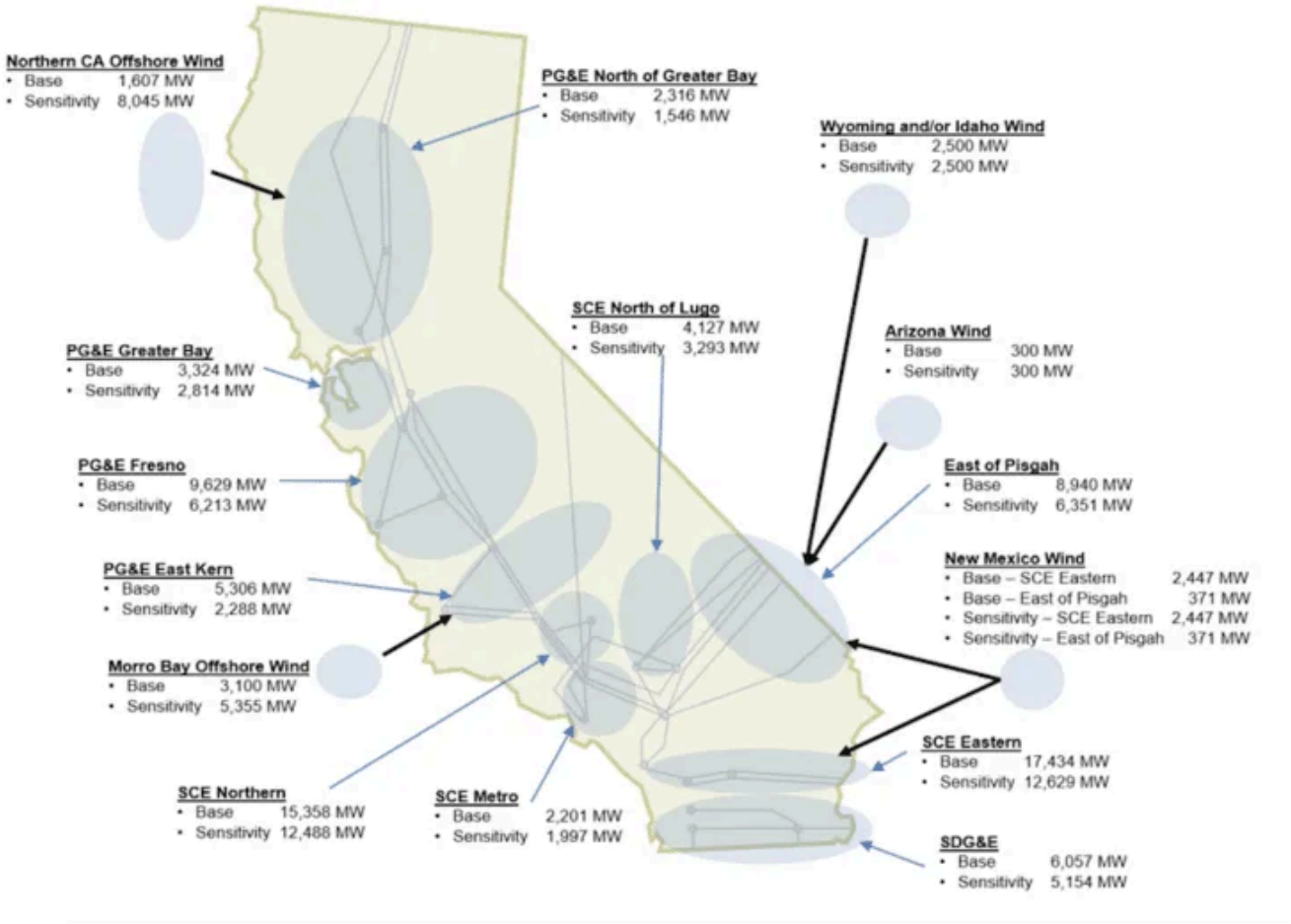
Communications Infrastructure

There is widespread agreement that real-time, uninterrupted communications are vital for the reliable operation of power grids. It’s communication that enables proper network management, automation, and protection, and supports the continuous supply of electricity to customers. That task is more difficult in today’s environment because older infrastructure is co-existing with new devices and next-generation equipment. And this equipment, both legacy and new, needs protection from cybersecurity and physical threats. “Today’s transmission and distribution networks are facing both demand- and supply-side challenges. On the demand side, rapid electrification is increasingly straining an already aging grid that was never built to withstand modern energy demands,” said Sean Moser, senior vice president of Digital Product Management for GE Vernova’s Grid Software business. “On the supply side, the rise of distributed and renewable energy sources, which are variable and intermittent by nature, has introduced an element of uncertainty. Gone are the days when supply and demand were static or predictable—and this fundamentally changes the way the grid is operated. “While transmission and distribution networks could be managed independently of one another in the past, the changes in distribution are now

impacting transmission, and to ensure availability, reliability, and resiliency, the networks must be interoperable," said Moser. "In other words, they must be able to 'talk' to each other in a way they haven't before. The challenge is exacerbated by the fact that there is not enough visibility into the grid to ensure the right control and automation is in place to keep it running uninterrupted. Lack of visibility results in lack of granularity and speed of control, which in turn results in significant impact when events happen." Scott Caruso is president of Gridmetrics, a company that "monitors and tracks the status of the distribution portion of the power grid by utilizing existing broadband infrastructure to glean first-of-its-kind data and insights that drive grid resiliency." Caruso told *POWER*, "The grid is undergoing a tremendous change led by three megatrends that converge on the distribution grid." Caruso said those three issues are decarbonization, particularly the transition to renewable energy resources; electrification, specifically of transportation, which could double peak load; and climate. Caruso said resilience challenges are compounded by more severe and frequent weather events, as storms become more prevalent and stronger. "The overarching problem is that instrumenting and managing a dynamic distribution grid requires secure, reliable, and abundant communications, but at a scale 10 times that of transmission," or roughly 6 million miles, said Caruso. "The grid of tomorrow needs to be viewed holistically. What happens in distribution now impacts transmission, particularly with IBRs [inverter-based resources] such as microgrids, data centers with battery backup, rooftop solar, and soon-to-be bi-directional EV chargers. IBRs are not motors that slowly ramp up or down, rather they are instant on and instant off. An immediate need is to provide high-fidelity, time-synchronized visibility of the distribution grid behaviors to transmission." Caruso said one technology solution could be Gridmetrics' Power Event Notification System (PENS). "Gridmetrics leverages the existing co-incident broadband networks in the distribution grid to supply a continuous, constant and consistent view of the distribution grid. Gridmetrics' PENS solution opens the door to utilizing the available broadband infrastructure to provide high-fidelity, time-synchronized grid visibility."

T&D Projects

Several jurisdictions have released plans for T&D upgrades in their territories. The California Independent System Operator (CAISO) unveiled a $6.1 billion transmission plan (Figure 5) that includes 26 proposed projects. CAISO said the plan is based on projections that California needs to add more than 85 GW of generation capacity by 2035 to meet greenhouse gas reduction goals and load growth, including increased electrification from the transportation and building industries.



5. The California Independent System Operator (CAISO) recently unveiled a $6.1 billion transmission plan that looks at the grid operator's transmission zones. Courtesy: CAISO[/caption] The Midcontinent Independent System Operator (MISO), the regional transmission grid operator in the Midwest, in March announced its Tranche 2 portfolio, with an estimated cost of $17 billion to $23 billion. The project includes plans for several 765-kV transmission corridors across parts of Minnesota, Iowa, Wisconsin, Illinois, Indiana, Michigan, North Dakota, and Missouri. MISO said that many of the new lines would connect to projects being built as part of the $10.4 billion Tranche 1 project, which MISO approved last year. The grid operator has said it expects to build a third group of projects, focused on MISO's southern territory; a fourth project will look at connecting lines running north and south across its service area. ISO New England in a March update said it expects to invest $1.3 billion to improve power reliability across its system through 2027. The grid operator said four upgrades were recently placed into service, and three new projects were added. The March 2024 update to its ISO New England Regional System Plan Project List noted 27 active projects as of March, including 15 projects under construction, 11 planned projects, and one proposed project. Most of the projects are in Massachusetts and Maine. Con Edison in New York recently said it completed a $200 million construction project. It included two 138-kV underground feeders running 4.6 miles across Staten Island, from a substation in Travis, a residential neighborhood on the west side, to a substation on Dongan Hills Avenue on the east side. The substation serves several Staten Island neighborhoods. Pacific Gas and Electric (PG&E) recently filed with the California Public Utilities Commission for approval of a transmission lease program with the nonprofit Citizens Energy Corp. Officials said as much as $1 billion could be invested through the program, which would allow PG&E to accelerate work on its electric system to improve safety, reliability, capacity, and infrastructure health, the groups said. It also would enable new interconnections for clean energy projects. Citizens Energy said it has committed to contributing much of its profits from the program to clean energy programs in low-income and disadvantaged communities across PG&E's service area. Heimdall Power and Great River Energy, a power cooperative serving the Midwest, in March announced

what the companies called the largest DLR project in the U.S. to date. Great River Energy will increase the transmission capacity of existing infrastructure through the installation of Heimdall Power's Neurons —known colloquially as "magic balls"—across its grid. The companies said the project will exceed previous U.S. DLR projects, which have involved about 40 sensors. Meanwhile, in the UK, National Grid ESO—which operates the electricity system in the UK—has said an "electrical spine" should be built from the east coast of Scotland to the city of Liverpool, which sits on the Atlantic Ocean. The grid operator said the project would cost about £58 billion ($74 billion) and would help bring 86 GW of offshore wind to the grid by 2035. UK media also reported there would be so-called electrical "bootstraps" built along the UK's eastern coast to move electricity from Scotland's wind farms to areas of demand such as London.

Grid Modernization Projects

Tantalus Systems has announced two grid modernization initiatives across three states. The Canadian tech company will deploy its technology for Bolivar Energy Authority (BEA) on the Tennessee and Massachusetts distribution grids, and will test its tech in a separate Connecticut pilot program. BEA, which serves parts of Tennessee and Massachusetts, in the first initiative will use Tantalus Systems' Grid Modernization Platform (TGMP). The utility will use Tantalus' TRUSense Fiber Gateway to harness the capabilities of BEA's advanced fiber network deployed in partnership with Irby Utilities, which supplies equipment to the electric utility sector. The TGMP also will replace an existing advanced metering infrastructure (AMI) solution in support of BEA's grid modernization initiative. The new system will include TRUSync, a grid data management solution that automates the integration of data across devices, systems, and vendors. The TRUSense Gateway is a multi-purpose socket-based device that accelerates the modernization of the distribution grid for utilities. It delivers interoperable integration of behind-the-meter DERs onto the distribution system while capturing and analyzing granular power quality data to enhance grid resiliency. "We are thrilled Bolivar Energy Authority is joining our user community alongside the growing number of Tennessee Valley Authority [TVA] local distribution companies," said Tantalus President and CEO Peter Londa. "We continue to witness an increasing number of utilities that are harnessing the power of data to accelerate their grid modernization efforts. TGMP and the TRUSense Gateway are purpose-built not only to help with near-term needs, like enhanced resiliency and advanced applications, but also to provide a flexible and expandable platform to support long-term requirements, such as those outlined as part of TVA's Regional Grid Transformation initiative." The second program will feature United Illuminating, a subsidiary of Avangrid operating in Connecticut, deploying a pilot program that includes Tantalus' TRUSense Gateway and TRUSync solution. The pilot is part of the first round of the Innovative Energy Solutions (IES) Program designed and led by the Connecticut Public Utilities Regulatory Authority and will be deployed across a distribution circuit in Bridgeport, Connecticut. The first cycle of the IES Program is centered on demand-side flexibility to shift or reduce electricity demand or consumption from a device's normal electricity profile, supporting advanced forecasting, providing automation, incorporating strategies to manage peak demand, and integrating thermal storage. The project will center around Tantalus' TRUSense Gateway, GE Appliances' electric water heater, and Savant's smart circuit breaker companion modules and smart thermostats that will be deployed behind the meter of homes on dedicated feeders and circuits within the distribution grid. The University of Connecticut's Eversource Energy Center will provide grid visibility analytics that leverage data from the deployment, while the Colorado-based National Renewable Energy Laboratory will seek to optimize the use of DERs.

Areas of Focus

Claudia Cosoreanu, Grid Automation CTO and Production, Automation, and Control Product Line Leader for Grid Solutions at GE Vernova, and her counterpoint Moser said there are three key areas of focus when it comes to equipment upgrades for the grid. “A large portion of the transmission and distribution networks need upgrading. We have aging infrastructure that’s 40, 50, even 60 years old,” said Cosoreanu. “But the reality is that we can’t replace everything all at once. That would be too costly, and the current supply chain wouldn’t be able to support it.” Cosoreanu and Moser said the first focus area should be software. “Whether that’s upgrading your current Advanced Distribution Management System or investing in an end-to-end software portfolio for grid orchestration like GridOS, digital technology allows us to visualize the networks better than we can today. Through a combination of monitoring and modeling, software can also accurately predict when and where the most critical physical upgrades will be needed.” Moser said the second area is “automation and control infrastructure at the substation level and wide-area networks,” which “need a significant revamp to latest technologies to enable the integration of renewables generation and maintain grid stability and reliability in the conditions of high variability of generation and load.” Cosoreanu said transformers are critical for upgrades. “Transformers are probably at the top of that list [of important equipment], which is why we’re seeing increased demand and supply shortages. In fact, a recent DOE study estimates that transformer demand in the U.S. could triple by 2050—and utilities needing to add or replace them are currently facing high prices and long wait times. And then, of course, when you put a new transformer onto the network, all the equipment that goes around it needs to be upgraded, too. “To realize the automation and control required for grid autonomy, there is a need to digitize the entire network by installing as many sensors as possible—at the edge, in the substation, and along the lines. These sensors need to be connected via a fast, deterministic, and reliable communication infrastructure to computing technology that can run sophisticated automation algorithms and AI/ML technology to maintain reliability and resilience of the grid when disruptions occur,” said Cosoreanu. “There is a layer of cybersecurity technology that needs to be added across the network to ensure that system safety and security is not impacted while we realize the grid of the future.” Said Klingel: “The conversation around T&D infrastructure must evolve to include alternative resources like battery energy storage. These assets are not only crucial for peak demand reduction and grid resilience but also represent a shift toward more sustainable energy solutions. We must establish a valuation framework and operating model for these resources to ensure they are integrated effectively into the energy market. This will require collaboration among asset owners, operators, and utilities to build trust and operational reliability.” That collaboration has been difficult to realize, as making changes across a vast T&D network, especially in the U.S., has proven costly and time-consuming. Said Caruso, “The U.S. has a non-nationalized power infrastructure. The existing dynamics make it a challenge to roll out a ubiquitous solution to the benefit of all parties—government, transmission, distribution, and ratepayers.” *—**Darrell Proctor** is a senior associate editor for POWER.*