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POWER SYSTEMS TECHNOLOGY

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TRANSFORMER TECHNOLOGY MAG

SUSTAINABLE POWER SYSTEM PLANNING AND ANALYSIS

Matt Schnugg: A Blueprint to Navigate the Modernization of the Energy Industry
Ron Harper: Collaboration Is Key to Maintaining a Strong North American Energy System
Tony McGrail: Think Twice?

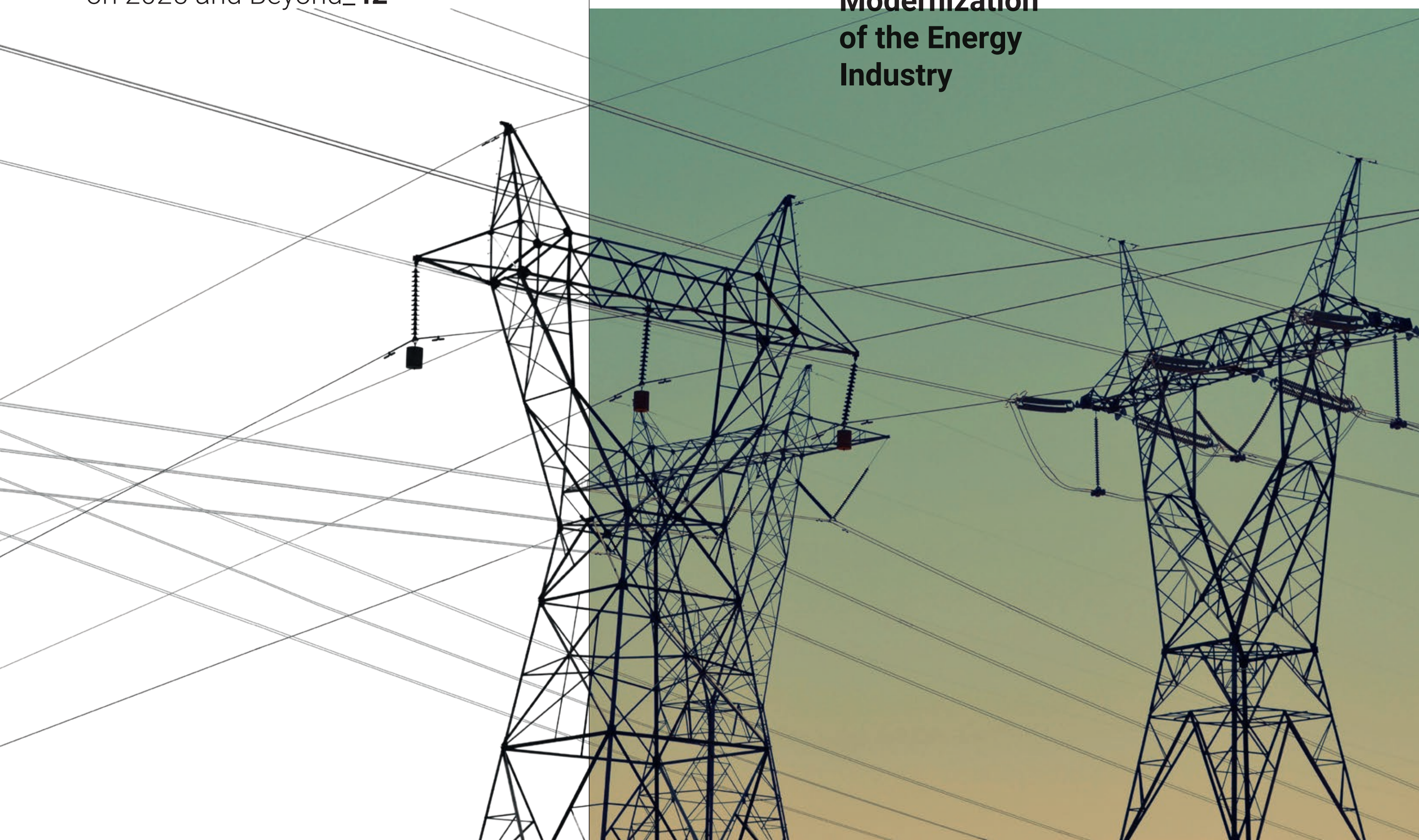
Index

Table of Contents_**04**
Editors & Impressum_**08**
From the Editor_**12**
A Blueprint to Navigate the Modernization of the Energy Industry_**16**
PTR Corner_**24**
3 Paths to Flexible Transformer Manufacturing_**28**
Think Twice?_**36**
CEO Forum: Insights from Leaders on 2025 and Beyond_**42**

Table of Contents

12
From the Editor:
Building the Grid of Tomorrow, Today

16
A Blueprint to Navigate the Modernization of the Energy Industry



24
PTR Corner:
The Expanding Role of AI in Power Systems

36
Think Twice?

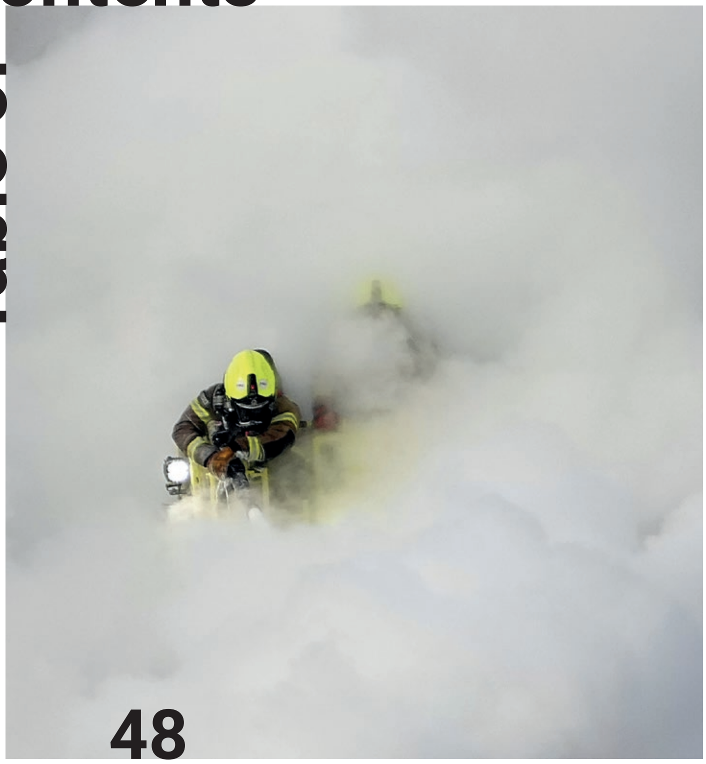
28
Micro Tool & Machine Ltd.:
3 Paths to Flexible Transformer Manufacturing

42
CEO Forum:
Insights from Leaders on 2025 and Beyond

Index

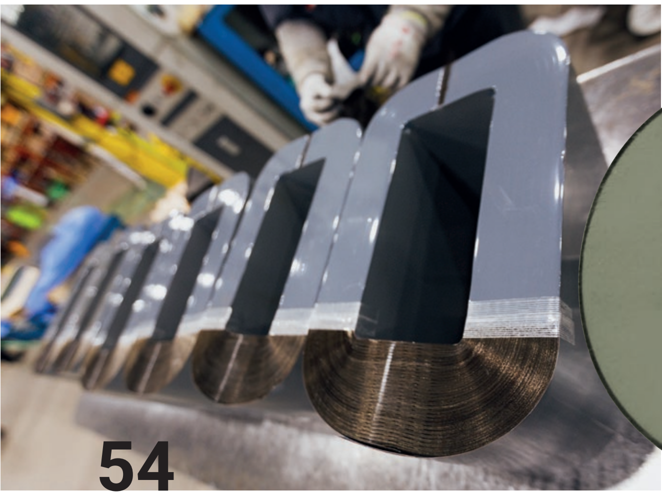
The Heathrow Transformer Explosion_**48**
RED Talks - Real. Experienced. Disruptive_**50**
Collaboration Is Key to a Strong Energy System_**54**
DISTRIBUTECH 2025_**60**
Practical Strategies for Undergrounding and Monitoring Cables_**64**
TechCon North America 2025_**70**
Coming in June/August_**76**

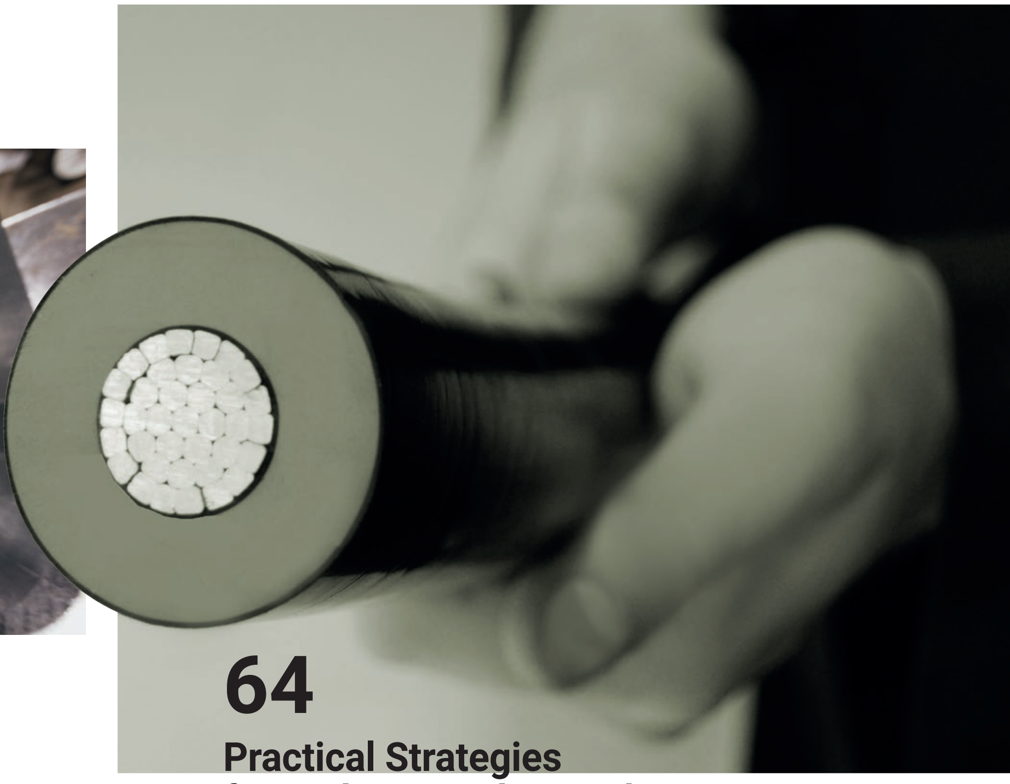
Table of Contents



48
The Heathrow Transformer Explosion: **A Preventable Disaster?**

50
RED Talks:
Real. Experienced. Disruptive.





54
Collaboration Is Key to Maintaining a Strong North American Energy System

64
Practical Strategies for Undergrounding and Monitoring Cables

60
DISTRIBUTECH 2025

70
TechCon:
North America 2025

Impressum

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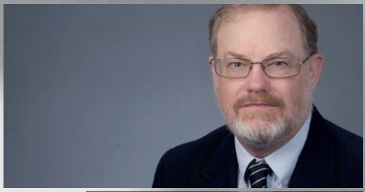

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Building the Grid of Tomorrow, Today

When we use the word sustainable as it relates to the power industry, several keys come to mind, keys that are not always understood or shared. For us, sustainability in the power industry is a multifaceted concept that encompasses the development and implementation of energy systems that are environmentally friendly, economically viable, and socially responsible.

At its core, sustainability in this context aims to reduce the environmental impact of energy production and consumption while ensuring that energy remains accessible and affordable for all. Often affordability forces decisions that are unsustainable but they need to go hand in hand. We are well aware that the **"electrification of everything"**, creating demand growth we have not seen in decades, involves a transition from traditional fossil fuels, which are major contributors to greenhouse gas emissions, to renewable energy sources such as wind, solar, and hydroelectric power.

US administration's love for carbon fuels, the power industry is too far along the path to sustainable and affordable to turn back now. Coal plants are not clean, expensive to operate and take a lot of people to operate. Given the current labor shortages, trying to go backwards will work against sustainability and affordability.

In addition to the shift towards renewables, sustainability in the power industry also involves improving energy efficiency across the entire energy supply chain. This includes advancements in technology that allow for more efficient energy generation, transmission, and consumption. Smart grid technology enables better demand management and reduces energy waste by allowing for real-time monitoring and control of energy flows. At APC Media we believe that investing in energy storage solutions, such as batteries and pumped hydro storage can help to balance supply and demand, especially when dealing with the intermittent nature of renewable energy sources.

These renewable sources are not only abundant and inexhaustible but also produce little to no emissions during operation, making them a key component in reducing the carbon footprint of the power industry, leading to a more sustainable and cost-effective solution. Despite the current

The transition to a more sustainable power industry must be financially feasible, for utilities, regulators, industry and consumers, or prosumer which I call my son with his rooftop solar. We must create policies and incentives that encourage investments in renewable

Photo: Pexels

energy projects and the development of new technologies.

Governments and private sectors play a significant role in this by providing subsidies, tax breaks, and other financial mechanisms to support the growth of sustainable energy infrastructure. Our industry cannot be whipsawed between election cycles. There is more than enough room for renewables and carbon-based generation, simply because we cannot meet the new demand curve if we don't focus on the best financial, and readily available, solution.

> **Continuous advancements in technology are essential for overcoming the challenges associated with creating an affordable, sustainable and resilient grid, and collaboration between governments, research institutions, and private companies is vital to drive these innovations forward.**

At APC Media we are passionate about the impact that technology will have on sustainability in the power industry, closely linked to innovation and research. Continuous advancements in technology are essential for overcoming the challenges associated with creating an affordable, sustainable and resilient grid, and collaboration between governments, research institutions, and private companies is vital to drive these innovations forward.

Our industry is undergoing somewhat of a revival in how we are looked at by the next generations of engineers and trades workers. Why? Because not only is it a great, long term career choice at every level, it is also creating the future that the future generations deserve. Focusing on energy sustainability is a great way for them to know that what they do, every day, matters.

Alan M Ross
CRL, CMRP
Managing Editor
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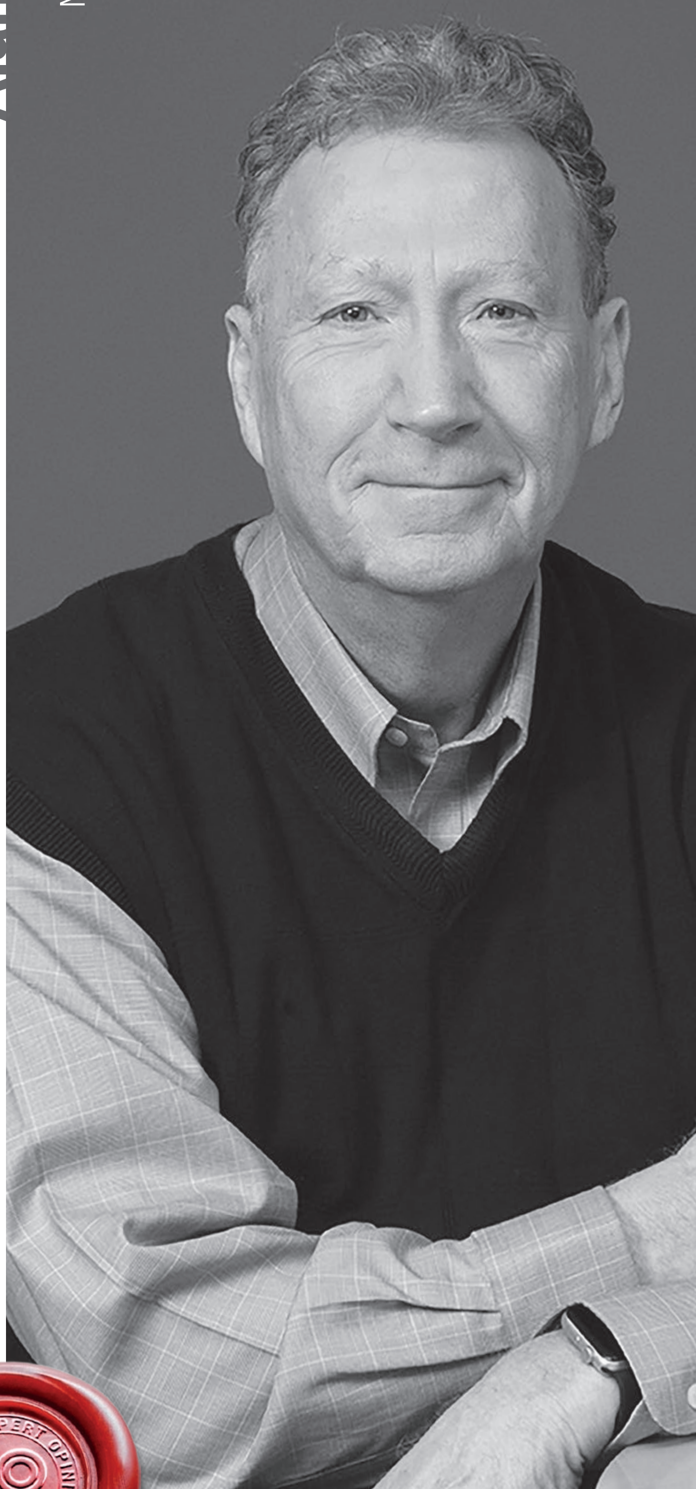
Technical Director

Alan has decades of experience in the power systems industry and is one of the greatest reliability experts out there.



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The Energy Industry stands at an inflection point. By learning from the modernization journeys of Software, Financial Services, and Healthcare, Utilities can thoughtfully accelerate their transition to open, resilient, and collaborative ecosystems.

A Blueprint to Navigate the Modernization of the Energy Industry

by **Matt Schnugg**

The utility sector within the energy industry is undergoing a significant transformation. As the energy landscape worldwide shifts towards a more complex operational environment and a potential tripling of electricity demands by the year 2050, utilities are forced to prepare for grid complexity due to distributed generation, changing weather patterns, and aging grid infrastructure, all while balancing cost-effectiveness and customer needs.

The convergence of these challenges necessitates a complete rethinking of how utilities plan, build, operate, and maintain their grids, while continuing to elevate end-customer experience. Much of this rethinking will require a new approach to the convergence of the customer's IT environment with its operational solutions (OT) within a utility's lines of business – enabling not only openness and resilience, but also intelligent operations powered by AI and automation.

Fortunately, there is precedent for this. In learning from IT modernization patterns of other industries, such as Financial Services, Healthcare, and in particular, Software, Utilities can confidently adapt with more interoperable solutions and have the flexibility to respond to evolving requirements of their grid's needs. Looking forward further in these modernization patterns, it becomes apparent that interoperability needs to be extended into the historically walled gardens of operational systems deployed in Utility control rooms.

While controls in mission critical systems such as the ADMS must remain carefully managed, this operational data can and should be made available to additional entities, i.e. other legacy software vendors, new start-ups, and even developers within the utility itself, to ensure that integrated planning and operations can be done in as efficient and flexible manner as possible. These data transactions can be managed through IT solutions colloquially referred to as "platforms" which provide standardized frameworks for integrating applications, enforcing security policies, and orchestrating complex workflows across diverse ecosystems. In doing so, platforms enable a more dynamic grid environment where operational (and other) data and workflows are no longer siloed, but instead become a shared resource for innovation, resilience, and improved decision-making.

This article explores a practical framework for how the energy sector can navigate this shift. Beginning with forces reshaping utility needs, it draws lessons from adjacent industries, examines how platform-based approaches are reshaping operational models, and outlines the organizational and technological actions needed to accelerate this modernization journey.

Photo: GettyImages

Matt Schnugg is the Chief Product Officer for Schneider Electric's Digital Grid business, where he oversees the Product Management, Product Marketing, and Software Commercialization functions for Schneider Electric's ADMS, DERMS, GIS, and asset, network, and performance management portfolio. Prior to Schneider Electric, Matt previously held leadership roles at Google, GE, and Microsoft, focusing on delivering transformational change across Engineering, Product Management, and Commercialization in both the Energy and Enterprise Technology domains. He holds an MBA from the University of Michigan Ross School of Business, where he was also a fellow at the Tauber Institute for Global Operations. Matt has also earned a Bachelor of Science in Business Administration from the University of Richmond.

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As the grid evolves further with increased load and higher adoption rates of distributed energy resources (DERs), traditional operational models and solutions will become less efficient due to the complexity of applications and data.

Utility Needs as Drivers of Evolution

Historically, utilities have managed the electric grid in separate segments (generation, transmission, distribution and retail), leading to disparate islands of investment planning and operational execution. These incongruities create scenarios of mismanagement wherein focus on localized constraints throttle more ambitious integrated planning and operations. As the grid evolves further with increased load and higher adoption rates of distributed energy resources (DERs), traditional operational models and solutions will become less efficient due to the complexity of applications and data. In the most recent report by Total Grid Orchestration Alliance, a utility-led collaborative forum, four key needs that are foundational for holistic grid management have been identified:

- **System-wide Coordination** implies ensuring that all segments of the electric grid (generation, transmission, and distribution) work together seamlessly. The goal is to balance supply and demand in real-time, which is crucial for maintaining grid stability and efficiency. By coordinating system-wide operations, utilities can respond more effectively to fluctuations in energy demand and supply, integrating renewable energy sources and distributed energy resources (DERs) more efficiently.

- **Holistic Situational Awareness** refers to the ability to monitor and understand the current state of the grid. This involves using advanced monitoring tools and data analytics to gather real-time information about grid conditions. Utilities can predict future conditions and potential issues by analyzing this data, allowing them to make informed decisions and take proactive measures to maintain grid stability and reliability.

- **Elevated Risk Management** is about identifying and mitigating potential issues before they impact the grid. This includes assessing risks related to equipment failures, cyber threats, natural disasters, and other factors that could disrupt grid operations. By implementing robust risk management strategies, utilities can enhance the resilience of the grid and ensure a reliable supply of electricity to customers.

- **Integrated Planning and Operations** bridge the gap between long-term planning and day-to-day operations. This capability ensures that investment decisions and operational strategies are aligned and optimized. By integrating planning and operations, utilities can make more strategic investments in infrastructure, technology, and resources, leading to a more efficient and reliable grid.

These new capabilities are essential for modernizing the electric grid and addressing the challenges posed by increased load, severity and frequency of major events, and the adoption of DERs. In addressing these challenges, utilities can create a more holistic and efficient approach to grid management, ultimately benefiting both the utility and its customers.

To implement this new approach, utilities will need to move from traditional, siloed operational models. Perhaps the best example of IT modernization is the first one, in Software itself; the evolution of this industry offers a compelling blueprint for how to make this leap successfully.

Other industries, such as financial services and healthcare, have also undergone similar transformations, offering additional insights on how to overcome structural, regulatory, and operational challenges. We will review these in the sections below.

Lessons from the Software Industry: A Model for Platform Transformation

Over the past 50 years, the software sector has evolved from coding basic commands onto a single machine, into integrated platforms and vibrant ecosystems – enabling greater interoperability, faster innovation cycles, and more resilient operations. As platforms matured, they also began to embed intelligence, with artificial intelligence and machine learning powering real-time insights, adaptive automation, and personalized assistance that spanned across systems.

Stage	Focus	Technology Environment	User Experience	Integration Approach	Utility Parallel
Machine-Level Programming	Solving isolated, specific tasks	Siloed; manual coding; no standards	Expert only; complex	Manual integration between systems	Legacy grid systems (DMS, SCADA) operating independently
Operating Systems	Enabling scalable, user-friendly environments	Standard interfaces; basic integration	Improved usability; difficult procurement & configuration	Integrated, but often limited to a single vendor	Movement towards integrated operations (GIS + ADMS + DERMS)
Ecosystems	Empowering dynamic collaboration and innovation	Open platforms & APIs; shared data models & security frameworks	Highly configurable experience; rapid innovation & 3rd party participation	Seamless interoperability across multiple vendors and services	Utility Platform ecosystems enabling modular apps and data sharing

Table 1: Evolution of Software Modernization and Its Relevance to Utility Transformation

It's helpful to look at this evolution in stages, to benchmark where many utilities are today and to understand what will likely be the form factor for the next stages of modernization for Energy. This modernization can be roughly broken down to three stages: Machine Level Programming in the 1960's and 1970's, Operating Systems in the 1980's through 2000's, and Ecosystems in the 2010's through today.

Machine Level Programming

Initially, Machine-Level Programming involved literal 1's and 0's instructing single machines, purpose built to accomplish a specific task, with no system integration or scalability. This scenario is similar to the current grid environment: systems are siloed, built on legacy technology stacks, and require significant effort for simple integrations. Current grid software solutions have also been tailored to address specific, crucial elements of operation, but generally as standalone environments that require significant manual effort to integrate more broadly.

Operating Systems

The subsequent stage in software development, Operating Systems, was popularized by beginning to address scalable integration. Allowing users to operate in a single, standardized environment also introduced more structural security capabilities and common user-friendly interfaces. However, procurement remained complex; software had to fit hardware requirements and was difficult to acquire and deploy. So, while Operating Systems offered a foundation for a more robust IT environment, they did not fully realize the potential for seamless integration and scalability. An analog for Grid Management includes integrated systems such as ADMS, GIS, and Demand Response solutions, and potentially broader "system of systems" that manually integrate these technologies.

Ecosystems

To date, the most advanced stage in this example is the Ecosystem applicable to the software industry. This is best exemplified by the software capabilities enabling smartphones, where third-party applications enhance user experience within a secure, collaborative environment. These third-party applications allow each user to customize their device with applications that suit their unique needs, with applications utilizing shared data, accessed the data uniformly, and benefiting from a security guarantee governed by the Ecosystem provider. This environment thrives on partnership and collaboration; this Ecosystem approach is the best means of embracing the many different software solutions within the Utility's IT footprint.

This evolution illustrates a clear pattern: industries move from isolated, hard coded solutions to integrated platforms, and finally to open ecosystems that utilize embedded intelligence to accelerate innovation and resilience.

Utilities, facing similar pressures today, must likewise continue beyond siloed systems towards architectures that enable shared data and flexibility in vendor and application deployment. Further, they must have the freedom to seamlessly leverage the reliability of on-premises deployments, the minimized latency of workloads at the edge, and the massive scalability of the cloud.

As we have seen in Software, and increasingly in other critical industries, this shift is no longer optional – it is foundational to future success.

Over the past 50 years, the software sector has evolved from coding basic commands onto a single machine, into integrated platforms and vibrant ecosystems – enabling greater interoperability, faster innovation cycles, and more resilient operations.

Healthcare and Financial Services: Structuring Resilient Ecosystems

Beyond Software, industries like Healthcare and Financial Services demonstrate that even in highly regulated, risk-averse sectors, the shift toward integrated ecosystems has proven both possible and necessary.

The maturity of Ecosystems within Financial Services and Healthcare can be particularly instructive for design patterns that go beyond the existence of an Ecosystem alone. **These industries succeeded not just by modernizing systems, but by shaping ecosystems with different structural elements: strong governance models, mandatory interoperability, trust through compliance frameworks, embedded approaches to managing risk and resilience, and transforming their cultures to embrace this ecosystem approach.**

Each of these features holds critical lessons for how the Energy Industry must approach its own transition.

The modernization paths of Financial Services and Healthcare make one thing clear: successful ecosystems are not accidental – they are architected through deliberate choices about openness, trust, interoperability, and resilience. The challenge now lies in translating these proven ecosystem principles into solutions built specifically for the complex demands of the grid.

Marketplace	Industry	Size (Apps/Integrations)	Adoption (User/Customer Reach)
Epic Showroom	Healthcare	~400+ certified apps	250M+ patient records touch Epic systems
J.P. Morgan Payments Partner Network	Financial Services	~100+ integrations & APIs	J.P. Morgan processes ~$10T/day
Apple App Store	Consumer Tech	1.8M apps worldwide	1B+ iPhone users

Table 2: Popular Ecosystem enablers across Healthcare, Financial Services, and Consumer Tech industries

Ecosystem Principles for Building the Future of the Grid Today

To support a modern, resilient energy grid energy system, platforms must be designed with ecosystem principles at their core. These principles ensure that data, applications, internal stakeholders, and partners can interact seamlessly – ensuring scalability, flexibility, and operational excellence. The following capabilities are foundational to any future-ready grid platform:

Building Open and Interoperable Foundations: A modern grid platform must prioritize openness – using shared data models, standardized APIs, and interoperable true hybrid-cloud architecture to support AI-driven operations and allow utilities to make the most of their current IT/OT investments and partners to integrate flexibly without further lock-in.

Frictionless Availability of Platform Experiences with Native Product Interoperability: Product-level interoperability is the key to accelerated adoption and thoughtful chance management. As such, platform capabilities should be natively embedded into the software utilities already use – enabling them to govern workloads seamlessly without needing to procure and integrate standalone platforms.

Embedding Resilience and Risk Management at the Core: Through advanced cybersecurity, robust data protection, and adaptive response mechanisms, grid platforms must help operators confidently manage uncertainty, maintain uptime, and safeguard critical infrastructure – all while supporting continuous delivery

Enabling Ecosystem Collaboration Through Strategic Partnerships: Open platforms thrive through collaboration. Designing for third-party extensibility allows partners to co-create solutions, expand value propositions, and drive faster innovation across the grid landscape.

Simplifying the Growth of the Ecosystem: By employing modern "Infrastructure as a Code" technologies, platform-based grid systems can automate deployment processes that were once slow and manual. This allows for faster integration of new applications, easier updates to existing services, and more consistent operations – making the ecosystem both more efficient and more resilient.

Together, these five principles form a foundation for modern grid platform design, built around the core outcomes utilities need most: reliability to withstand complexity, flexibility to adapt to evolving demands, and simplicity to accelerate innovation. These are no longer aspirational features – they are baseline expectations for any future-ready energy ecosystem.

A Call to Action: What the Energy Industry Must Do Today

The blueprint is clear. Moving forward requires bold commitments to rethink operational solutions, forge ecosystems, and prioritize speed over tradition. The path ahead isn't about waiting for perfect conditions; it's about thoughtfully acting now, utilizing the tools, insights, and frameworks already available. Reassuringly, this blueprint is no longer speculative; industries like software, healthcare, and financial services have demonstrated remarkable transformation progress, especially where open, intelligent platforms have been thoughtfully empowered to navigate this substantial ambiguity.

To begin on their own journey, here is what Utility leaders can do to deliver the future of energy today:

1. **Embrace Platform Thinking**
   Utilities must think beyond isolated solutions, and begin building around open, interoperable, AI-enabled platforms designed to evolve with accelerating grid complexity.

2. **Build Ecosystem Partnerships Early**
   Future success will not be achieved in isolation; it will be a team sport. It demands collaboration across utilities, technology providers, innovators, and new entrants.

3. **Prioritize Data Portability and Interoperability**
   The resilience and adaptability of tomorrow's grid will depend on the seamless movement and governance of data across systems, applications, and stakeholders.

4. **Treat Flexibility, Innovation and Speed as Core Outcomes**
   Reliability remains foundational – but success in a rapidly shifting environment will require increased agility, faster innovation with thoughtful AI enablement, and significantly reduced time to implementation.

5. **Invest in Continuous Learning and Workforce Transformation**
   As technology platforms evolve, so must the people who operate, maintain, and innovate on them. The industry must invest in upskilling, cross-disciplinary training, and culture shifts that empower everyone to thrive in an open, ecosystem-driven future.

The opportunity to modernize is not a future hypothetical, it's a present imperative. The industry is now at an inflection point -- defined by exponential demand, unrelenting weather, and aging infrastructure – forcing Utilities to move from reactive mitigation to proactive innovation at scale.

Stakeholders who embrace the blueprint outlined in this paper – and the lessons learned from other industries - will not only shape a grid that is more resilient, flexible, and sustainable today, they will dictate the direction of tomorrow's energy landscape.

Structural Element	Philosophy	Description	Lessons for Utilities
Centralized Governance, Distributed Participation	Govern the core, unlock the ecosystem	In both industries, ecosystems evolved by establishing clear governance over core standards (e.g. data formats, security protocols), while enabling distributed innovation by third parties	Customers and Platform owners must tightly govern core operational and planning systems (ADMS, GIS, DERMS), but encourage broad participation for innovation to flourish
Data Portability and Interoperability as Non-Negotiables	No data stranded, no participant trapped	Financial Services & Healthcare succeeded by making data portability and interoperability mandatory – customers could with services without losing access to critical information	True ecosystems must treat data portability and interoperability as foundational, not optional features
Trust through Compliance and Certification	Trust accelerates ecosystem growth	Ecosystem growth in these industries was accelerated by introducing certification and compliance frameworks (e.g. HIPAA, PCI-DSS) that built trust among participants without stifling innovation	Strong compliance and certification mechanisms, such as NERC-CIP will be essential to build ecosystem trust without locking down flexibility
Embedding Risk Management into Ecosystem Design	Resilience and Security are native to the core	In Financial Services and Healthcare, risk management (e.g. fraud detection, cybersecurity, patient data protection) became a built-in, continuous function of the ecosystem – not an afterthought or external layer	Lesson for Utilities: Successful ecosystems must embed real-time monitoring, risk detection, and resilience into the Platform itself
Transforming Organizational Culture to Sustain Ecosystem Growth	Platforms enable ecosystems, people make them thrive	In these two industries, technology modernization was not enough. Successful ecosystems required cultural shifts: more cross-functional collaboration, greater openness to external partnerships, and new approaches to managing change	Recognize that ecosystem success depends on evolving not just systems, but mindsets and skills

Table 3: Key learnings from Financial Services and Healthcare Industries (transform the 5 structural elements above)

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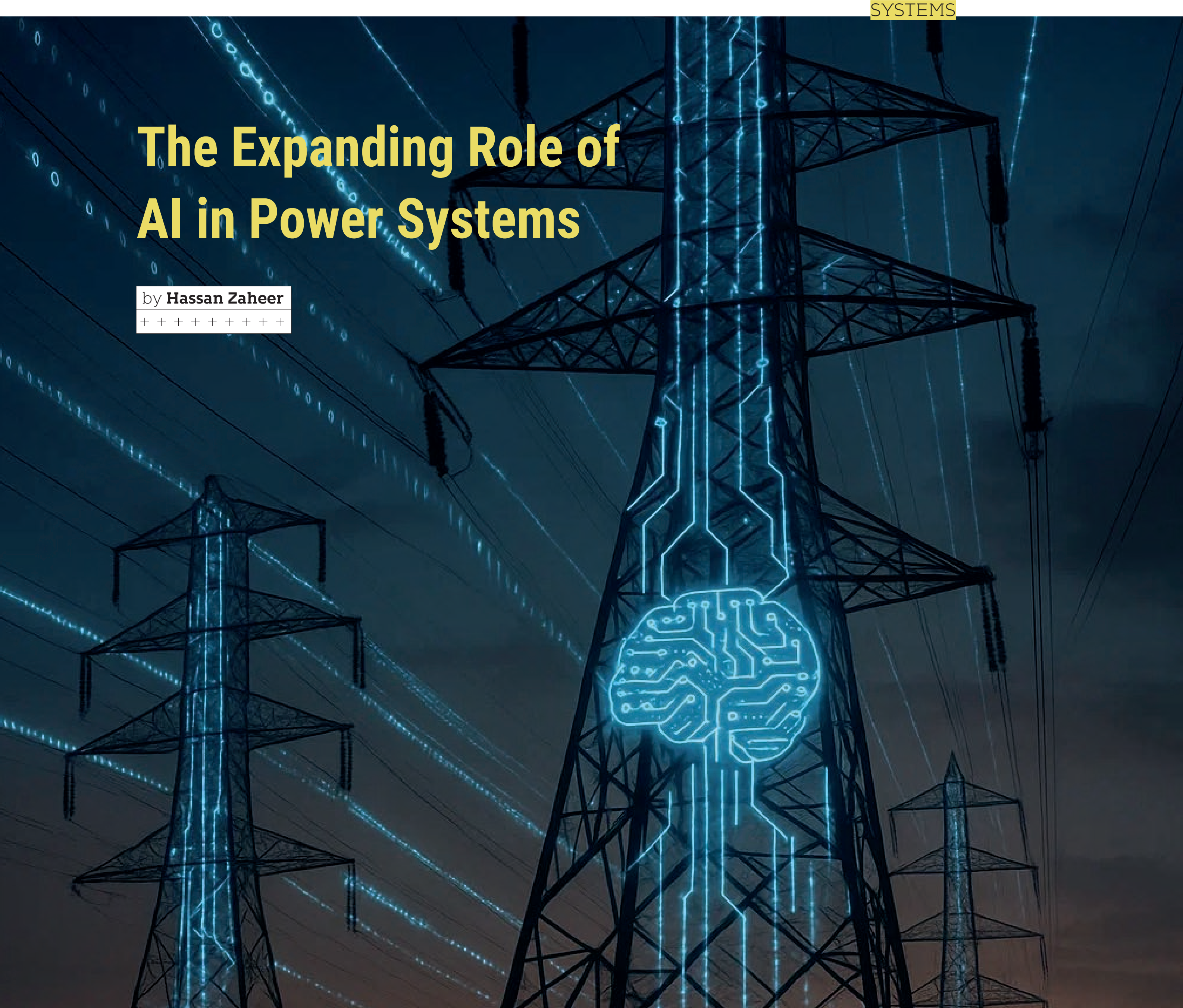

The Expanding Role of AI in Power Systems

by **Hassan Zaheer**

By automating routine tasks and delivering real-time intelligence, AI allows utilities to optimize capital and operational expenditures. It also strengthens grid resilience by enabling faster response to disruptions.

Artificial Intelligence (AI) is becoming deeply integrated into our lives. Ever since the inception of Large Language Models (LLMs) like ChatGPT, the impact of AI-driven data centers has been a key topic of discussion in our industry. Rightfully so, as according to IEA, the electricity demand from data centers is expected to double by 2030. For this editorial, however, I wanted to share insights from the flip side of this coin. Instead of looking at how our industry is helping address the electricity demand increase due to AI, I wanted to look at what AI is doing for our sector.

In recent years, the global power grid has faced unprecedented challenges. As electrification accelerates and renewable energy sources proliferate, traditional grid systems are under pressure to operate with greater flexibility, resilience, and intelligence. Compounded by aging infrastructure and growing demands for reliability, these pressures are prompting grid operators and utilities to rethink how they manage energy systems. AI, once a buzzword, is transforming our daily lives as individuals, and it is also emerging as a transformative force within the power sector. From generation to distribution and beyond, AI is reshaping the power grid's future.

As the power grids become increasingly complex, AI will not just support decisions, it will make them, in real time and with less and less human oversight.

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The Case for AI in Power Grids

The application of AI in power grids is being driven by three converging trends: the increasing deployment of digital infrastructure and monitoring systems, the exponential growth of data coming from these systems, and the declining cost of computational power. Utilities today have access to a wealth of operational data from smart meters, sensors, SCADA systems, and other Intelligent Electronic Devices (IEDs). AI algorithms can extract actionable insights from this data to support faster, more informed decisions.

Our sector's core challenges today, like managing demand volatility, integrating distributed energy resources (DERs), and enhancing system resilience, need solutions that go beyond traditional tools. AI provides utilities with predictive capabilities, enabling them to move from a reactive to a proactive grid management approach. Here are some examples of use cases, where AI is already being utilized, even at a pilot stage, to optimize power grids.

Key Use Cases Across the Grid

Power Generation

Leading generation companies (power producers) are deploying AI to monitor and optimize the performance of their renewable energy assets. For example, Enel Green Power has implemented AI-based systems to predict solar irradiance and wind availability, enhancing asset utilization and operational efficiency [1]. In thermal generation, GE Power has developed digital twin models powered by AI and machine learning to simulate and optimize operational efficiency of gas turbines and reduce unplanned downtime [2].

Transmission and Distribution

AI driven predictive maintenance is also helping utilities identify and address equipment failures before they occur. National Grid in the UK, for example, leverages AI to analyze transformer and cable health data, enabling risk-based asset management [3]. Several utilities, like Iberdrola, use AI powered drones and image recognition to detect faults on transmission lines, improving inspection accuracy, vegetation management and reducing manual fieldwork [4].

Beyond these examples, on the grid operations side, system operators like California ISO (CAISO) are using AI for load and renewable generation forecasting. By using quantile regression with historical load patterns, CAISO is able to calculate net load uncertainty [5]. In Germany, 50Hertz has committed to adopt AI to optimize generation, consumption and load forecasts for the grids and operating facilities to handle greater loads and make the grid more flexible [6].

Customer Experience and Interfaces

AI is also changing how utilities engage with their customers. EDF in the UK employs Machine Learning and smart meter analytics to detect irregular consumption, identifying financially vulnerable users and offering appropriate support, in addition to helping customers to improve energy [7]. Utilities have also developed AI-powered smart assistants (e.g. Rammas by Dubai Electricity & Water Authority) which is available 24/7 to address any customer queries and services like billing [8].

The Strategic Impact and Challenges

The strategic advantages of AI extend beyond operational efficiency. By automating routine tasks and delivering real-time intelligence, AI allows utilities to optimize capital and operational expenditures. It also strengthens grid resilience by enabling faster response to disruptions.

However, despite its promise, AI adoption in the power sector is not without its challenges at this time. Data silos, poor data quality, and lack of standardization remain major hurdles. Cybersecurity is another pressing concern, especially as AI systems become embedded in critical infrastructure. There is also a skills gap: implementing AI effectively requires interdisciplinary teams that blend domain knowledge with data science expertise. Finally, governance and regulatory frameworks must evolve to accommodate AI-driven decision-making in grid operations.

What's Next:
AI and the Future Grid

Our sector is undergoing a once-in-a-generation transformation. AI based solutions will inevitably be at the heart of this transformation. As the power grids become increasingly complex, AI will not just support decisions, it will make them, in real time and with less and less human oversight. Innovations like federated learning

will lower the barriers for utilities to share sensitive data, allowing them to train AI models collaboratively. Digital twins and AI-powered edge computing will bring intelligence closer to the assets and users they serve.

However, to unlock the full potential of AI, utilities must integrate AI into their strategic planning processes. This means moving beyond pilot projects and embedding AI in core operations, asset management, and customer engagement strategies.

For utilities, regulators, and technology providers alike, the imperative is clear: collaborate, innovate, and scale AI solutions that meet the evolving needs of the energy transition. The future grid is not just digital, it is intelligent.

The future grid is not just digital, it is intelligent.

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3 PATHS TO FLEXIBLE TRANSFORMER MANUFACTURING

An equipment strategy based on staged investment offers future-proof scalability when working with forward-thinking machine builders

Navigating changing markets and business goals is tough — especially without a roadmap for equipment investments. Keeping older, less efficient technology on the shop floor reduces your overall competitiveness.

That's why our team at Micro Tool & Machine Ltd. (MTM) developed a flexible deployment strategy for intelligent, automated machines. As a custom machine design firm focused on the transformer industry, MTM's staged-investment approach delivers upgradeable winding machines. So, our manufacturing customers across the globe can harness core machine functionality immediately while ensuring expandability in the future.

A strategy of **incremental upgrades** to winding equipment empowers transformer manufacturers to realign existing machines by integrating add-on technologies — from winding mandrels, wire flatteners and cold welders to laser welding. This applies to both new machines and retrofits. While this article focuses on winding lines, the strategy fits other production areas.

Let's examine three common upgrade paths for coil manufacturing equipment. Then we'll highlight a case study, along with some initial recommendations to get started.

Figure 1: Layout of a combined foil and wire winding machine – a versatile platform that can be incrementally upgraded.

Photo: Micro Tool & Machine

Upgrade Path 1: Portable Add-on Modules

Add-on systems offer a quick win to enhance coil winding capabilities, quality, and efficiency. MTM's portable or retrofittable modules often offer a low price point but yield significant performance improvements. Below are a few add-on options.

Wire Flattening Attachments

Wire flattening devices lightly compress round magnet wire (usually used for high-voltage coils) to create a more rectangular cross-section. This tool's benefits include tighter coil packing, lower core losses, reduced electrical stress, better short-circuit strength, and smaller, cheaper coils — often cutting total costs by 5–10 percentage. In a staged deployment, a manufacturer might install the flattener as volume or product requirements demand the improved performance.

Figure 2: Retrofit wire flattener installed on a coil winding machine to improve winding packing and performance.

Cold Welding Systems

Also known as pressure winding, a cold welding system creates joints faster and cleaner, with no cooling time and fewer quality issues. Cold welding joins two metal parts — copper-to-copper, copper-to-aluminum, or aluminum-to-aluminum — through high-pressure deformation without filler material or heat.

MTM can implement add-on cold welding equipment either through direct integration into the winding machine or as a portable unit, often resembling a small hydraulic press or clamp system mounted on a cart. This mobility is advantageous for factories with multiple winding bays.

Photo: Micro Tool & Machine

Figure 3: Portable cold-welding unit for transformer coil leads and terminals.

Bending Fixtures

Forming leads or bus bars typically entails making connections to other windings or external bushings. Traditionally, operators bend heavy copper leads or aluminum bars manually or with simple tools. Here, a portable bending fixture from MTM helps manufacturers achieve more consistent connector geometry and reduce manual labor.

As a staged investment, a company might start with manual bending and later introduce a semi-automatic bending tool as production ramps up. MTM's custom equipment portfolio often includes coil lead bending jigs or small hydraulic benders, increasing throughput and quality without needing a completely automated assembly line from day one.

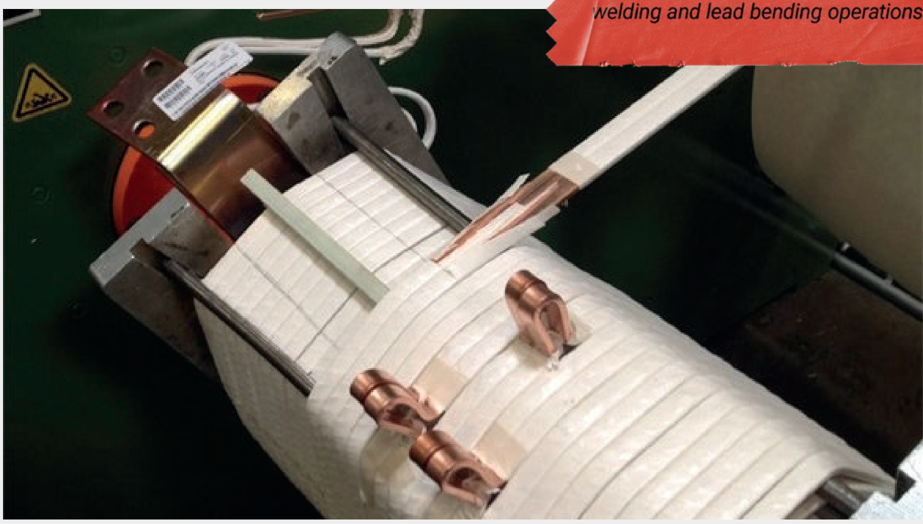


Figure 4: Integrated coil lead processing station combining cold welding and lead bending operations.

These modular, add-on upgrades in Upgrade Path 1 require a relatively low investment and set the stage for the next level of upgrades.

Upgrade Path 2: Multi-Coil Manufacturing Capabilities

As transformer demand grows, manufacturers must increase coil output without necessarily buying new winding machines. The second path is to upgrade existing MTM machines to wind multiple coils simultaneously or to deploy multi-coil configurations in the production line. We anticipate this need by designing base machines specifically to be expandable, or by offering additional modular multi-coil systems when required.

A common entry point is a combination winder that handles both LV foil and HV wire, initially set up for single-coil operation. This lowers complexity and cost. Once production ramps up, a machine upgrade can add more winding heads or parallel stations to enable simultaneous multi-coil winding.

In a dual- or triple-coil setup, the winder uses multiple wire payoffs and tension units to create identical coils side-by-side. Each mandrel rotation produces a preselected number of coils, significantly boosting throughput. A dual-coil setup nearly doubles output, while triple-coil winding can reduce per-coil time by up to 60%, depending on the coil design. Multi-coil machines can replace several single-coil units, improving productivity and saving floor space.

Since HV coils take far longer to wind than LV, multi-coil HV winders help eliminate idle time and better balance production flow. MTM has implemented production cell strategies around this: for instance, a dual-machine cell with a multi-coil HV winder and a flexible LV/HV machine working in tandem. This balances coil flow and reduces idle time, improving daily coil output by up to 20%.

Implementing multi-coil capability often involves adding hardware — extra winding heads, payoffs, etc. — and updating control software to manage multiple axes. The MTM team designs machines with these future upgrades in mind, so the transition can be made with minimal disruption. If expansion isn't feasible on the original machine, a new multi-coil unit can be added to the cell instead.

In MTM's scalable approach, Upgrade Path 2 helps transformer manufacturers expand output, shorten delivery times, and delay capital purchases while flexibly adding capacity later.

Figure 5: Example of a multi-coil winding machine setup, with three coils being wound in parallel on one platform, greatly increasing throughput.

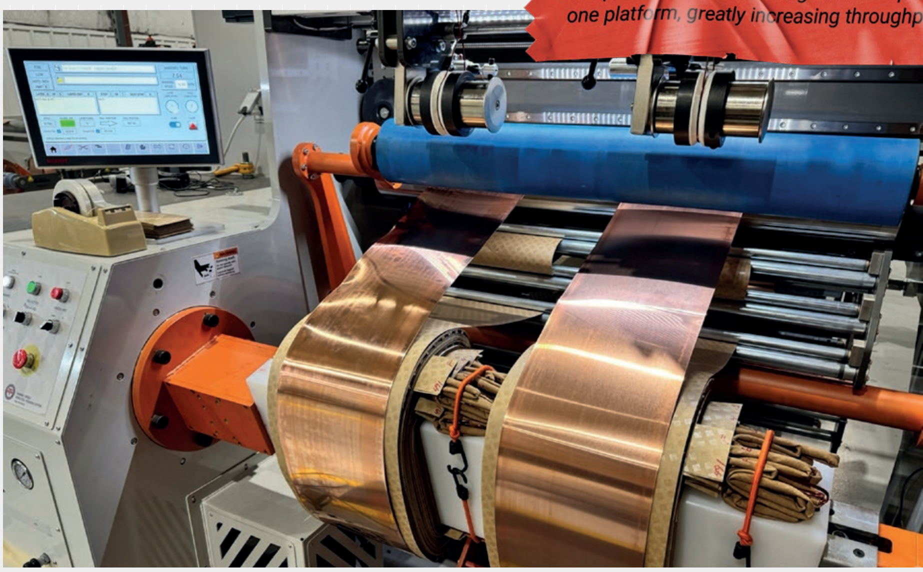


Photo: Micro Tool & Machine

Upgrade Path 3: Integrated Laser Welding for Internal Busbar Connections

The third upgrade path extends the machine's functionality into the precise joining of internal busbar connections within the transformer coil. By integrating laser welding technology, manufacturers can automate the fabrication of heavy conductor joints inside the coil structure.

In many modern distribution and medium-sized power transformers, the coils' internal connections are manually assembled. These crossovers, tap leads, or interlayer busbars handle high currents and mechanical stresses. Integrating laser welding capabilities for a seamless, automated flow from winding through completion.

Laser welding delivers precise, localized energy with minimal heat spread, ensuring strong, repeatable welds without damaging nearby insulation or conductor materials. Unlike traditional arc welding processes, laser welding allows for:

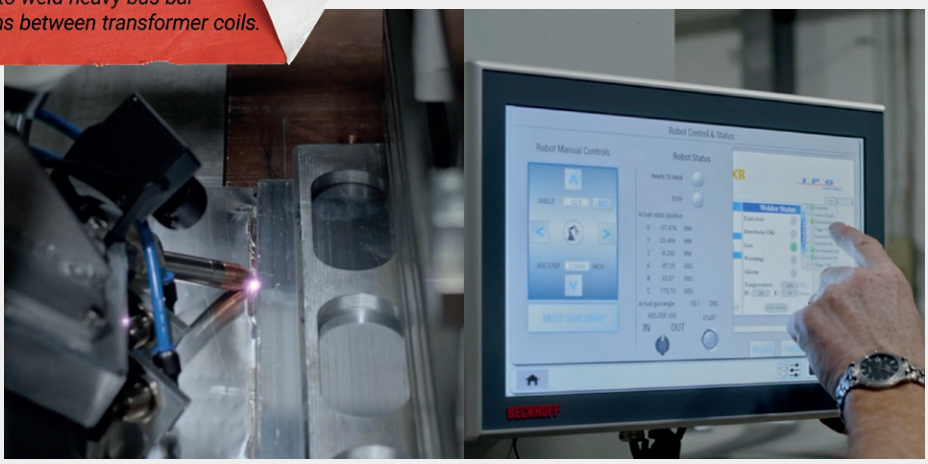
- Clean, reliable connections between conductors or foil stacks.
- Minimal distortion of delicate coil windings during joining.
- High repeatability and reduced manual labor.

While some laser welding capabilities should be specified prior to a machine purchase, standalone or modular laser welding stations can often be added later. The initial machine simply must include basic integration points, such as communication links and footprint, to ensure scalability as production volume or product complexity increases. Laser welding delivers repeatable joints, boosts efficiency by running in parallel with other tasks, and improves safety by moving welding into an enclosed, automated space.

Upgrade Path 3 often represents the culmination of the flexible deployment journey. At this stage, the manufacturer transitions from basic coil fabrication to a fully integrated coil manufacturing system that includes winding, lead preparation, and internal connection assembly — all managed within a coordinated production cell.

The key is to plan for flexibility early. The staged investment approach exemplifies the essence of a flexible machine deployment strategy: invest progressively, scale capabilities in line with demand, and maintain technical leadership in a rapidly evolving transformer market.

Figure 6: Robotic TIG welding station integrated into a coil production line, used here to weld heavy bus bar connections between transformer coils.



Case Study: Phased Upgrades in Practice

How do upgrade paths work in the real world? Consider AlphaTransformers, a mid-sized distribution transformer manufacturer that that is looking to partner with MTM on a flexible machine deployment strategy.

In year one, they modernized using a combined LV/HV winder from MTM with basic features — avoiding the need to buy multiple machines. This replaced two older winders and allowed operators to wind LV and HV coils back-to-back, reducing material handling and inventory.

Following a successful year, AlphaTransformers followed Upgrade Path 1: a wire flattener and portable cold welding unit. The flattener, easily mounted due to MTM's modular design, produced more compact HV coils with fewer layers, and improved surge withstand performance. The cold welder enabled copper-to-aluminum lead transitions in-process, eliminating brazing. This boosted production and quality with nearly zero internal joint failures in impulse testing.

By year three, growth in small kVA transformer demand created a bottleneck. To address it, AlphaTransformers upgraded went down Upgrade Path 2: adding a second winding head to create a dual-coil winder. With MTM's guidance, the upgrade was completed during a planned shutdown. This reduced HV coil winding time per unit by 45%. AlphaTransformers reconfigured its workflow into a mini production cell. The new machine handled HV coils and urgent LV jobs while a refurbished foil winder handled standard LV production, increasing throughput and utilization.

Encouraged by this progress, the company proceeded to Upgrade Path 3: a semi-automated TIG bus bar welding cell. Previously, manual brazing of bus bar connections caused delays. The new setup used a six-axis robot to weld preformed copper bus bars directly to coil leads. Operators loaded the bars, while the robot performed precise, repeatable welds. This optimized assembly time and format changes by updating programs rather than retraining welders.

Using a flexible machine deployment strategy, AlphaTransformers transformed in phases. Each upgrade built on the original machine's platform. By aligning investment with growth and giving staff time to adapt, the company boosted quality, output, and flexibility with minimal disruption.

Photo: Micro Tool & Machine

Getting Started with a Flexible Machine Deployment Strategy

A flexible deployment strategy scales investment with need, reducing risk and unlocking value in phases. So where should you start? Transformer manufacturers that want to align their capital outlay with future growth while staying on the cutting edge of production technology should consider these aspects:

- **Start with a Modular Platform:** Choose winding machines designed for future upgrades. MTM's combination HV/LV winders can be expanded later with add-ons, enabling smooth scaling over time.
- **Prioritize High-ROI Upgrades:** Early investments in compact coil tech can reduce costs and improve reliability. These low-cost, low-disruption retrofits offer quick quality and efficiency gains.
- **Scale with Demand:** Track coil hours and machine utilization to time capacity upgrades. When volume nears single-coil limits, consider multi-coil machines or cells to cut winding time per coil by up to 60% and eliminate process idle time.
- **Automate Strategically:** After output grows, target manual steps like lead welding for automation. TIG welding integration, for example, boosts consistency and reduces labor when justified by scale.

This staged equipment investment philosophy dovetails with continuous improvement philosophies: each upgrade stage brings a focused improvement, whether it's quality, speed, or automation. By partnering with equipment suppliers like MTM who embrace modular design and future-ready engineering, manufacturers can ensure that today's machine purchase offers a roadmap to meet tomorrow's production requirement.

Gord Atamanchuk is the President and CEO of Micro Tool & Machine Ltd. (MTM) in Winnipeg, Canada. He has over 17 years of experience in designing custom automation and machine tools for the electrical transformer manufacturing industry. Gord specializes in developing intelligent winding systems and has led MTM's initiatives in modular machine design and staged investment implementations for transformer OEMs worldwide.

Ready to get on the right path to upgrade or purchase machines using a flexible deployment strategy? Contact Gord Atamanchuk at gord@mtmmachines.ca for more information.

Think Twice?

by **Tony McGrail**

Tony McGrail is Doble Engineering Company's Solutions Director for Asset Management & Monitoring Technology, providing condition, criticality and risk analysis for utility companies. Previously Tony has spent over 10 years with National Grid in the UK and the US; he has been both a substation equipment specialist and subsequently substation asset manager, identifying risks and opportunities for investment in an aged infrastructure. Tony is a Fellow of the IET, a member of the IEEE, CIGRE, ASTM, ISO and the IAM, and is currently active on the Doble Client Committee on Asset and Maintenance Management and a contributor to SFRA, Condition Monitoring and Asset Management standards. His initial degree was in Physics, supplemented by an MS and a PhD in EE followed by an MBA.

> **It's a matter of time and probability: flip a coin for long enough and at some point you are almost certain to get ten heads in a row, but there's no guarantee as to when it will occur, and it could take a long time.**

This article looks at some examples of data analysis where making sure we have the relevant data has a significant impact on the analyses: whether it's a decision to enter an auto race, or to trust a stock market 'expert', or to assess and diagnose a critical asset, there will always be uncertainty and imprecision. Sometimes we need to look again and think twice.

Coin Trick

Derren Brown is a British illusionist who has hosted many TV specials which demonstrate his ability to apparently 'manipulate' the world around us in surprising ways.
A favorite is when, while being filmed from in front and from above, he says, "Ten heads in a row" and then proceeds to flip a coin ten times and gets ten successive 'heads', "as predicted" [1]. He's an illusionist, so, naturally, we look for the trick… but as far as we can tell there is none: it's a fair coin, we can see the flipping from two angles with no interference, and there's nothing to indicate the recording is being edited. So how does he do it?

If we only look at what's being shown, the 'data' in front of us, we may be missing a key element which enables us to reassess the data. That is certainly the case here: what are we not seeing? What information is missing? In this case it's the hours and hours spent flipping a coin where it did not result in ten heads in a row. This is a version of 'survivorship bias' where we start by looking at 'successful' efforts and overlook those that did not succeed [2].
It's a matter of time and probability:

Photo: Shutterstock

flip a coin for long enough and at some point you are almost certain to get ten heads in a row, but there's no guarantee as to when it will occur, and it could take a long time.

There's another video of the same 'trick' by a mathematician which goes a little deeper into probability theory [3]. But if all you see is the recording of the 'successful' trial, you may think there's some trick to it, some 'magic' or sleight of hand, when it's more a matter of stamina!

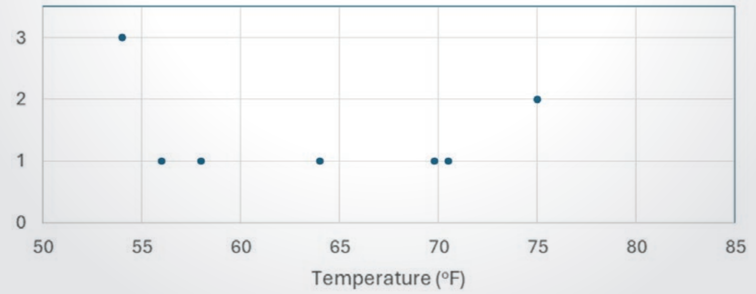
Carter Racing

There's an interesting case presented by British Mathematician Hannah Fry involving auto racing [4]. It was dreamed up many years ago by a couple of business professors and used in risk management classes: a summary is in Box 1. What would you do: race or withdraw?

Box 1: Carter Racing Intro

John Carter has an hour to decide whether to compete tomorrow in the most important auto race of the season: success may mean sponsorship and a stable team future. But in 7 of the past 24 races the engine has blown out, and if that happens again it will put sponsorship at risk, not to mention the driver's life. But withdrawing means the team will end the season in debt and will miss out on a chance of 'glory'. And as Burns's First Law of Racing Says: "Nobody ever won a race sitting in the pits."

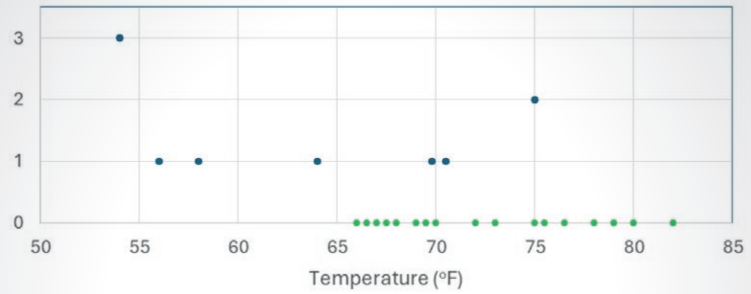
The team's mechanic thinks the engine's head gasket breaks in cooler weather and puts together a chart showing how many cracks were found in the gasket after each of the 7 unsuccessful races, and how they relate to ambient temperature, as shown below. Is there a link between failure and temperature? The ambient tomorrow is forecast to be about 40°F.



So, what do you think? Should they race or withdraw?

Box 2: Carter Racing: Decisions

How does our analysis change if we add into the chart those races which were successful? They have no cracks in the gasket and are shown in green in the chart below.



The additional data makes it very clear that there has never been a successful race completion below 65°F. So, with the additional data: now what would you decide? Race or withdraw?

We can, in fact, add an extra bit of spin to the analysis by noting that the charts actually have nothing to do with auto racing: the Box 1 chart is basically the data used to decide to launch the Challenger Space Shuttle, in 1986. The data was hand tabulated and faxed from the manufacturer to an emergency NASA meeting: given only the failures, most experts were not convinced there was a link between temperature and gasket failure. But nobody asked for the missing data, as per the Box 2 chart, related to successful launches, and the 'go ahead' was given, with disastrous and fatal consequences.

Ten years later Edward Tufte used this example as 'the wrong way' to display quantitative data, noting that the right chart would tell you what you need to know at a glance [5].

The case has been put to hundreds of people over the years, and most people choose to race, based on the data they have in the chart.
Very few ask for more data, and even fewer specify what that data should be – see Box 2.

Stock Buying Cows

As another example (and you're probably getting the idea now) we could look at the Norwegian documentary which looked at performance of different stock market investors: two industry 'experts', two 'influencers', an astrologer, and some cows [6].
How did the cows pick stocks?
By having their field marked into a grid with available stocks individually written on the grass in each grid cell, and wherever the cows 'relieved' themselves would be in their portfolio. At the end of a three-month period, with portfolios reviewed at the beginning of each month, the stock index had gone up by 5%.
The astrologer's portfolio rose by 4%, the industry experts by 7.28% and the cows by 7.26%.

It is often the case in generating health indices that we end up with the index being reduced to a set of categories and unless we look at the raw data which was used to put an asset into a specific category, we may be misleading ourselves.

But the influencers, who admitted to knowing nothing about the stocks and picked them 'on intuition' made 10 percentage.

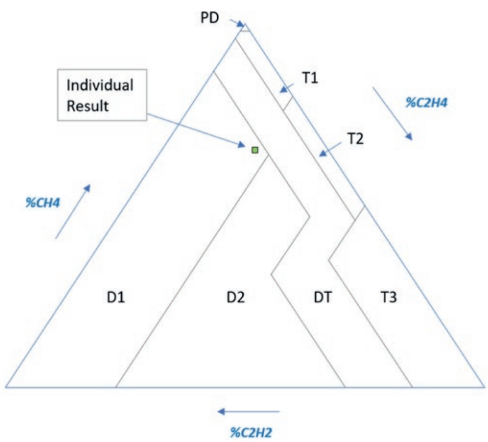
Admittedly it was only a 3-month experiment so there may have been a lot of luck involved, but the TV crew announced that they had also 'managed' a portfolio, and it had gone up 24%! Question is: how did they manage to get such high returns? The 'answer' is at the end of this article.

Dissolved Gas Analysis Accuracy

A common and popular tool for use in diagnosis of DGA results is the Duval Triangle [7] which plots three key dissolved gas concentrations as a single point on a triangular chart. The individual gas levels are summed and the percentage each one contributes to the total provides the value between 0 and 100% on each axis, as shown in an example in Figure 1. Each area of the chart is labeled with an individual diagnosis, as per the table to the right.

It would be easy to assume that the boundaries between areas are 'sharp' when, in fact, those boundaries are themselves based on historic DGA values with their own inaccuracies.

We may conclude from the point plotted in Figure 1 that we definitely have a D1, discharge of low energy. However, DGA comes with some inaccuracy, and a reasonable laboratory measurement is expected to be within 15% of the 'true' value. If the oil has exactly what we've measured in a sample, then we have just one 'successful' data point, but there are many more possible sets of values for the actual dissolved gases which could also yield the single result we got. On the left in Figure 2 the cloud of green points represents possible 'true' values of the DGA levels for the three gases which could yield the measurement we have made with



Label	Diagnosis
PD	Partial Discharges
D1	Discharges of Low Energy
D2	Discharges of High Energy
DT	Mixture of Thermal and Electrical Faults
T1	Thermal Faults of temperature < 300°C
T2	Thermal Faults of temperature 300°C < T2 > 700°C
T3	Thermal Faults of temperature > 700°C

Figure 1: Plotting a Single DGA result on a Duval Triangle

Photo: Shutterstock

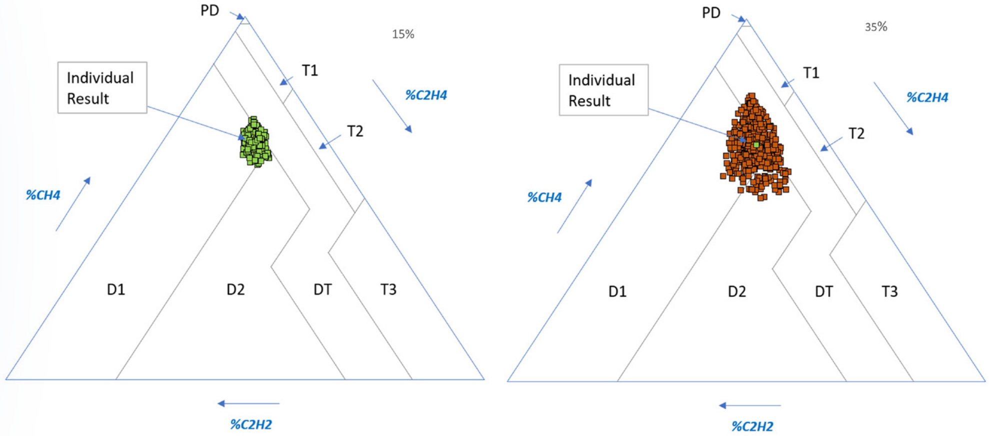


Figure 2: Plotting Possible True DGA Values at 15% and 35% accuracy on a Duval Triangle

an accuracy of 15%, these are the 'missing data' and most are in D1. But to the right in Figure 2 the cloud of dark red points all represents possible 'true' values with an accuracy of 35%, which is what online DGA systems may have in practice [8].

The result of the monitor inaccuracy is that more possible values for the actual DGA in the oil, the red dots in Figure 2, lie outside of the D1 diagnostic area than inside. Without knowing the accuracy of the laboratory or the monitor used we may have a very poor diagnostic result and an inappropriate prognosis.

Similar diagnostic inaccuracy can be found in other test/assessment measurements, such as power factor, winding resistance and so on, where the imprecision may have significant impact on interpretation and diagnosis.

Health Index Boundaries

When we make a measurement of some value, in whatever measurement unit we are interested in, our measurement technique and measurement system will provide sources of both systematic and random errors. The result of our measurement is thus only an 'estimate' of the true value. Numerous measurements of the same value will provide a 'distribution' around the actual value, often in the form of a Normal (a.k.a. Gaussian) distribution, symmetrical about a 'true' value. The spread of the distribution is characterized by the standard deviation, the confidence interval and the error [9].

In Figure 3, a measurement of 25 'units' (whether feet or degrees or picofarads or whatever…) is characterized by an error of +/-10% with a confidence interval of 90%, and a resulting standard deviation of 1.52 units. The vertical axis indicates the probability, on a scale of 0-1.0 (representing 0-100%), that the result is at a particular x-axis value.

20-40 range is 99.95%. A video on the pitfalls of thinking in categories, by Prof. Sapolsky of Stanford University, USA, is worth watching – it's a very human thing to assume that everything within a category is similar to everything else within that category, and everything in one category is very different to anything in another category [10].

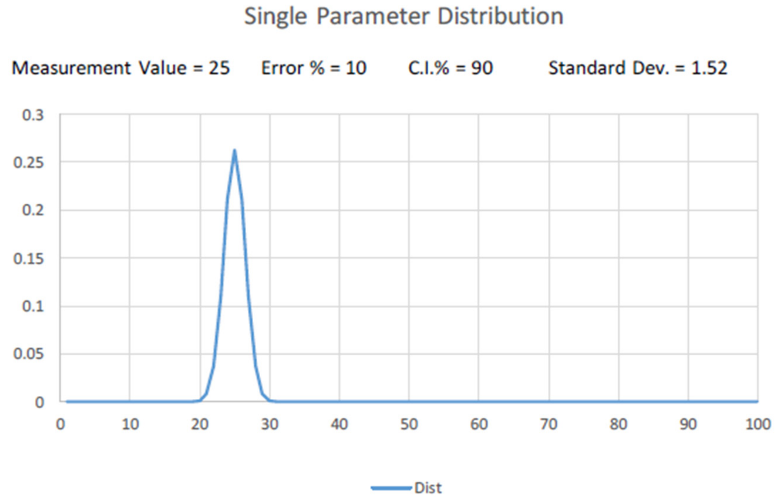


Figure 3: Parameter Measurement with Normal Distribution Around a True Value

The data in Figure 3 shows that there is uncertainty built into our measurements. Any system which attempts to encode the data into a scale – say 1-5 for condition with 1 is 'good' and 5 is 'bad', will be subject to the precision of the original measurement. As an example, Table 1 shows category, or coding, boundaries which may be applied to the measurement in Figure 3.

Overlaying the categories on to the data gives an indication of where the true value might lie, as shown in Figure 4. Note that in this case the likelihood that the true value is in the

Category/Code	Lower Limit	Upper Limit
1	0	20
2	20	40
3	40	60
4	60	80
5	80	100

Table 1: Category or Coding Limits for a 0-100 Measurement

If we now make a new set of measurements which happen to lie on or near a boundary, as shown in Figure 5, we can see that the likelihood of being in a particular category is 65.59% and 34.41% of being in an adjacent category. We have a lot less certainty in deciding the 'true' category.

The result of the inherent error in our measurement, as shown in Figure 5, is that we have an imprecision built into subsequent diagnoses and in anything which uses the result in calculations. What may be missing from the data we use is an estimate of the imprecision and thus the likelihood of being in a particular category.

It is often the case in generating health indices that we end up with the index being reduced to a set of categories and unless we look at the raw data which was used to put an asset into a specific category, we may be misleading ourselves.

This is especially true with risk matrices, where the health index is often used as a proxy for a probability of failure: we need to see the raw data with its imprecision, the 'audit trail' from that data to a diagnosis and thence to a probability of failure range which can be justified in terms of timescale: say 'the probability of failure in the next 12 months is between 0.5% and 1.2% with 90% confidence [11]. In fact, it would be more sensible to start with the data trail and then develop a health index based on the resulting probability ranges and their urgency. This does, of course, require that our health index addresses a well stated 'question' in a clear and auditable manner, and it may be that we need

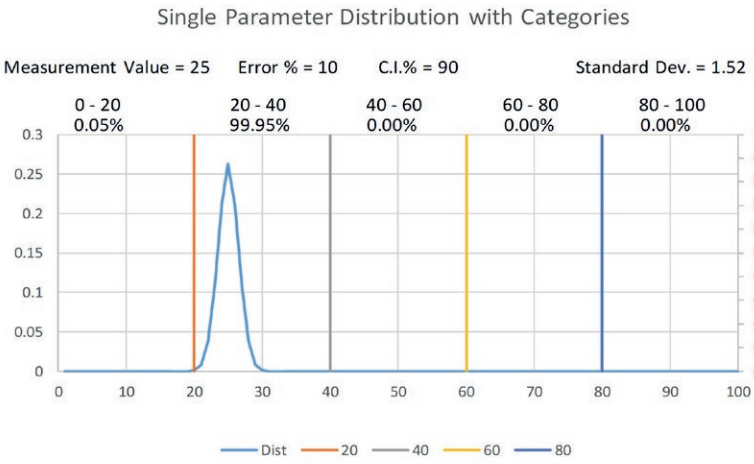


Figure 4: Parameter Measurement with Normal Distribution and Category Codes

Photo: Shutterstock

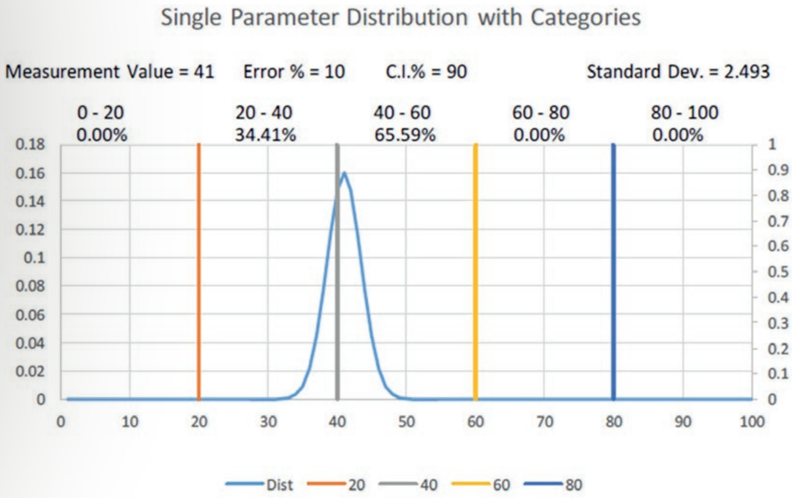


Figure 5: Parameter Measurement near a Category Boundary

multiple indices to address multiple questions.

Discussion

"What's missing?" is a useful question to ask and helps remind us to look for more than just the data we may have available and avoid 'survivorship bias'. It may be that we can never have a complete set of data, but at least we should be aware of that, and do what we can to counter the shortfall.

For the coin flip and the stock picking TV crew, we see survivorship bias in action: adding the unsuccessful efforts shows a very different story in each case. For the stock picking, there's a famous quote form Burton Malkiel: "A blindfolded monkey throwing darts at a newspaper's financial pages could select a portfolio that would do just as well as one carefully selected by experts [12]."

For the 'Carter Racing' we have a couple of different effects, first being that we start with the failure data, rather than successful data, but the result is similar – knowledge of what's missing can be crucial. The second effect is when it is revealed that the initial data was used to justify the space shuttle launch: the consequence of making the wrong decision becomes a lot greater and usually has a lot more influence on the decision-making process; it becomes a lot more about the risk involved and not just the 'go/no-go' decision.

...by reducing a lot of data, including data about the precision of that data, to a single value or category we may make things easier to understand but lose the information about the precision and its consequences for categorization.

Duval's triangle is a useful diagnostic tool, but interpretation of an individual result, or even a series of results, requires an understanding of how the chart works and what the implications of imprecision are.

Similarly, an asset health index can be a great tool for communicating technical information in a condensed form to less technically adept colleagues, often for asset ranking or prioritization purposes. The problem is that by reducing a lot of data, including data about the precision of that data, to a single value or category we may make things easier to understand but lose the information about the precision and its consequences for categorization.

As a colleague once asked: "I can see a few power transformers in the 'Category 4' box, which means do something within 12-24 months, but which one do I do first?" To answer that, we need to look at the individual units and their individual data and their individual urgencies: someone has to know what's going on.

Stock buying cows: how did the TV crew do so well? It's the 'missing data' scenario again: unlike the other participants, where each 'team' had just one portfolio, the TV crew secretly set up 20 different portfolios, and one of them did very well, and that was the one they shared to show their 'success'. The other portfolios didn't 'survive' and if we don't ask for the 'silent evidence' of history's losers we may well deceive ourselves [2].

Acknowledgment: thanks to Rick Aguilar for his comments and feedback.

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A Look Ahead: Insights from Leaders

Martin Robinson
The founder & CEO at IRISS Inc.

IRISS
ENGINEERED RELIABILITY

Jon Bucciarelli
President at SDMyers

SDMyers ACTS 4:12

on 2025 & Beyond

Angelo Rizzo
President & CEO at Systems With Intelligence

Alan Ross
Managing Editor & Technical Director at APC Media

This is part 2 of the CEO Forum Editor's Report, after interview with Angelo, Martin and Jon, focusing on what is ahead for us as an industry? The full CEO Forum is available for viewing through our community hub at www.powersystems.technology/ceoforum.

The power industry stands at a pivotal crossroads, grappling with the weight of legacy infrastructure, accelerating technological disruption, and an urgent need for workforce adaptation. Interviews with key executives—Jon Bucciarelli of SD Myers, Angelo Rizzo of Systems with Intelligence, and Martin Robinson of IRISS—reveal an industry that is simultaneously burdened by outdated norms and buoyed by a new era of digital potential. The present may be challenging, but the vision for the future is defined by intelligence, resilience, and a reimagined relationship between people, data, and machines.

A Sector Under Pressure

The interviews make clear that the current state of the power industry is reactive, under-resourced, and grappling with the persistent challenges of aging infrastructure. As Jon Bucciarelli from SD Myers puts it, "A large part of our business, about 50%, is reactive... Those cost the customers a lot more." Despite efforts to move toward more proactive models, many utilities and industrial operators continue to rely on time-based maintenance—fixing problems only when they surface, rather than anticipating and preventing them.

> One of the industry's paradoxes is that utilities and asset managers are surrounded by massive volumes of data, yet often struggle to make sense of it.

Photo: Shutterstock

This model, according to all three executives, is no longer sustainable. With the rise of extreme weather events, from hurricanes to wildfires, as well as increasing loads on aging systems, utilities are under increasing pressure to evolve. "We try really hard to be proactive and not reactive," Bucciarelli emphasizes. His company is focusing more on “fleet reliability,” which means establishing comprehensive electrical maintenance programs that enable customers to manage risk before failures occur.

Bridging the Data Gap

One of the industry’s paradoxes is that utilities and asset managers are surrounded by massive volumes of data, yet often struggle to make sense of it. “What used to frustrate me is utilities have a lot of data and they do nothing with it or they don’t take any action,” explains Angelo Rizzo, whose company Systems with Intelligence is built on exactly this premise.

His team’s strategic focus is to use intelligent systems that transform passive data into actionable insights—moving from traditional, scheduled maintenance into condition-based models.

Rizzo emphasizes the importance of visibility: “We are giving the utility that visibility on the reliability and where they’re at with their assets.” Using thermal and visual sensors, his company enables early detection of problems without requiring manual inspection—something he refers to as “Touchless monitoring.” This doesn’t just save labor; it gives operators precious time and foresight, shifting the entire model of asset management from reaction to prevention.

Innovation with a Purpose

At IRISS, innovation is not just about adopting the latest tech for its own sake, but about building systems that are deeply integrated, intuitive, and trusted by the people who use them. Martin Robinson describes how his company has evolved its original business—inspection windows—into a broader ecosystem of intelligent diagnostics and AI-powered platforms. “You bolt a window in and it’s got sensors, software—it’s a smart inspection system,” he explains. But what stands out in Robinson’s approach is the commitment to designing solutions that operators will actually use.

A key development at IRISS is the E-Centry system, a Gen AI-powered data management solution. Unlike traditional CRM or SCADA systems, E-Centry is designed to interface with any data source—from equipment sensors to enterprise resource platforms—and deliver actionable, conversational insights. “It will tell you what you need to know about any part of your business, not just the maintenance aspects,” Robinson notes. This system is intended to serve not only engineers but also CEOs, offering clarity in decision-making at every level.

However, Robinson also acknowledges a fundamental barrier to adoption: trust. “The biggest problem is trust,” he says, describing the skepticism operators often feel toward new systems—especially when there's a fear of job displacement. His approach is to engage these “troops” directly, ensuring that the systems serve as tools that empower rather than replace. “I have never found a program that can fix anything,” he adds. “People have to fix it. This is a tool to make your job far more eventful, far safer, and far more beneficial to the operations.”

The Human Element

While technology is a central theme throughout these conversations, there is a strong recognition that human expertise, training, and collaboration are indispensable. Jon Bucciarelli speaks at length about the importance of workforce development in addressing current labor shortages. “We use the word TED—Training, Education, and Development,” he says. He emphasizes that utilities must either build their own expertise internally or partner with companies like SD Myers to access it. In an industry increasingly starved for skilled labor, this kind of investment is not optional—it is essential. This need is echoed by Robinson, who points out that a significant percentage of failures in the power sector come down to human error. Whether it’s improper switching sequences or missed warning signs, the cost of mistakes can be enormous. “Sometimes because of those mistakes, in the electrical industry… people die,” he says gravely. His company uses technology to minimize these risks by walking operators through precision maintenance procedures and capturing “tribal knowledge” before it exits the workforce.

Designing for Resilience

All three leaders agree: the future of the power industry lies in building resilient systems. That means systems that can adapt to volatile weather, shifting demand, and the increasingly digital nature of grid management. “Reliability, resilience—it’s all about design,” Robinson says. At Systems with Intelligence, Rizzo talks

Photo: Pexels

> The future of the power industry lies in building resilient systems. That means systems that can adapt to volatile weather, shifting demand, and the increasingly digital nature of grid management.

about building a "resilient system" for their clients by providing infrastructure visibility that anticipates and avoids catastrophe. For SD Myers, resilience is about moving customers from “being fixed by others after the fact” to self-sufficiency through preparation and education.

The shift to resilience also aligns with global trends in automation and AI. As Robinson notes, traditional IoT and machine learning programs are already being eclipsed by Gen AI tools that make data actionable without overwhelming operators. “They said something like 87 to 92% of current IoT programs are failing to meet their mission directive,” he recalls from a recent industry event. The reason? Too much data, not enough guidance. Gen AI’s ability to interpret, filter, and communicate data in human language offers a new path forward.

The Heathrow Transformer Explosion: Mitigating Future Risks

How new fleet monitoring solutions can help get in front of potential transformer failures.

On March 20, 2025, at 23:23 GMT, a catastrophic fire erupted at the North Hyde electrical substation in Hayes, north of Heathrow Airport. The high-voltage transformer explosion severed power to Europe's busiest airport and over 63,000 homes, disrupted more than 1,350 flights, and caused economic losses estimated at £60-120 million (~$70-150 million US) in just one day. The airport was closed for 18 hours, with approximately 150 people evacuated from properties surrounding the substation.

Could new cost-effective monitoring systems prevent this disaster?

About 60% of transformer failures are caused by internal faults that can develop over periods of days to months. These internal faults can be caused by external power events, overheating from excessive power loads or electrical arcing due to system aging, manufacturing defects, moisture ingress, etc. When these issues occur the transformer oil used for insulation and cooling breaks down, generating gases that collectively signal the presence and severity of internal issues. Lack of awareness to these early warning indicators (and corrective action) can lead to catastrophic failures. Unfortunately, the cost of traditional continuous monitor systems to measure these gases are expensive and thus only large, expensive, highly critical transformers incorporate continuous monitoring - leaving most transformer unmonitored or receiving periodic manual measurement every 1 to 4 years, which can miss these faults. To address this gap the electrical power industry has begun to adopt cost effective single gas (hydrogen) transformer monitors that act as an early warning system for liquid-filled transformer operating health.

Hydrogen is the first gas released during a transformer abnormality, and monitoring hydrogen production in a transformer is a reliable indicator of evolving issues. It is produced 3-10x faster than other gases during thermal and electrical events. Its low oil solubility causes rapid migration through the insulating fluids, making it the ideal early warning indicator. Many transformer operators are now implementing single gas transformer monitors as part of their fleet management initiative to extend transformer operational lifespans through conditioned based maintenance.

The Heathrow incident, while still under investigation at this writing, highlights the risks of operating transformers at or beyond their limits to meet demand, the worldwide aging condition of transformers and the global shortage of new electrical transformers that currently stretches to two years.

"Many transformer operators are now implementing single gas transformer monitors as part of their fleet management initiative to extend transformer operational lifespans through conditioned based maintenance.

Photo: London Fire Brigade via AP

While we don’t know the precise cause of this transformer failure, we do know that many progressive power utilities and transformer operators have begun to rely upon single gas monitoring, a cost-effective technology that brings the visibility needed to avoid catastrophic failures of all transformers.

The Anatomy of a Disaster

Investigation into the root cause of the failure is underway, but likely causes reported by the UK press point to several potential contributing factors:

1. **Demand growth:** Substations often operate above capacity. North Hyde was reported at 106.2% of its rated load.

2. **Aging infrastructure:** The transformer was very old, and its insulation had likely deteriorated over time.

3. **Insulation breakdown:** A major insulation failure likely caused arcing, which ignited 6,600 (US) gallons of insulating oil.

"Based on what we have read, the transformer may have experienced progressive deterioration before catastrophic failure, and in this case continuous monitoring would have detected the buildup of hydrogen and alerted operators to the impending failure”, Dave Meyers, CEO of H2Scan shared.

Conclusion: A Call to Action

The Heathrow transformer explosion stands as a stark reminder of the potential advantage of incorporating innovation in critical infrastructure monitoring. As utilities face increasing pressure to maintain aging infrastructure while supporting decarbonization initiatives, online condition monitoring represents not just a safety enhancement but an economic imperative.

While we don’t know the precise cause of this transformer failure, we do know that many progressive power utilities and transformer operators have begun to rely upon single gas monitoring, a cost-effective technology that brings the visibility needed to avoid catastrophic failures of all transformers.

Author:
Dave Meyers
CEO and President
H2scan Corporation

Dave Meyers joined H2Scan in February 2022, to lead the business on its next stage of growth by leading the expansion of its product portfolio, sales team and operational infrastructure. He brings deep H2scan experience from five years on the board and previous collaboration during his time at Altran, a global engineering services firm. Meyers joined the board in 2017 after leading an investment as Altran’s VP of Corporate Development for North America. He later served as General Manager of Altran’s Innovative Product Development business, overseeing engineering services across energy, industrial, aerospace, and life sciences sectors. His team supported the development of H2scan’s Gen 5 sensor and Automated Sensor Manufacturing (ASM) system to enhance efficiency and scale. Before Altran, Meyers held executive, technical leadership and business roles in startups and major firms across semiconductors, life sciences, defense, and aerospace, gaining strong expertise in MEMS and high-performance sensor technologies. He holds a B.S. in Mechanical Engineering from the University of Delaware, where he is a distinguished alumnus.

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Collaboration is Key to Maintaining a Strong North American Energy System

by **Ron Harper**

Trade barriers threaten critical electrical steel supply chains

North American consumption of electrical energy is expected to grow by more than 50% in the next 25 years, driven by the clean energy transformation, the rise of electric transportation, and the rapid expansion of AI and data center infrastructure. This unprecedented demand highlights the urgency of modernizing and expanding our electrical grid. At the same time, 70% of the North American grid's core infrastructure is reaching its end of life and in need of replacement.

Critical minerals of the future, such as cobalt and nickel, have received a lot of attention, but an equally vital material deserves urgent focus: **grain oriented electrical steel (GOES)**. GOES is the magnetic backbone of transformers and power generation equipment, enabling grid reliability and energy efficiency. Yet, it is increasingly constrained by rising demand, limited domestic production and insufficient investments in new global capacity.

Any trade disruption or barriers (like tariffs) create additional vulnerabilities and obstacles to growth in supply. These factors, combined with the expected growth in electrical demand, are having tangible tightening impacts. It's a formula for massive demand growth and potential scarcity of resources. To meet these challenges, industry players—from materials to manufacturing—must collaborate to ensure long-term growth, supply chain resilience, and the ability to scale production.

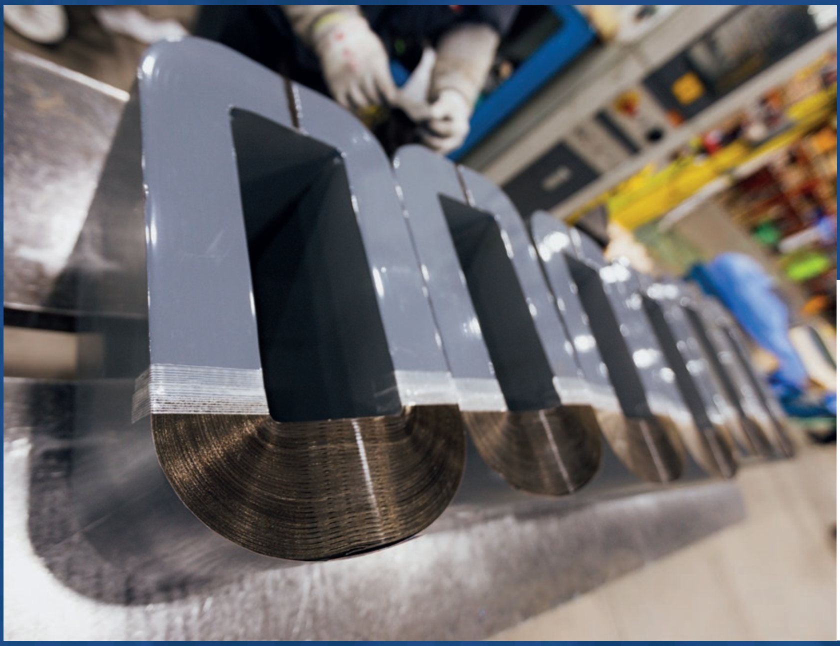
Collaboration within the industry and active engagement from government officials would enable the level of growth needed. Protectionism and tariffs add significant strain and cost, and they inhibit the open flow of critical materials and components from partners around the world. At a time when we need to be accelerating investments in the supply chains and capacity to build critical electrical equipment like transformers, tariff disruption is creating punishing added cost and disruption.

While global supply chains have supported North America's energy needs for decades, today's grid transformation calls for a more resilient, multi-partner ecosystem — one that builds local capacity while strengthening ties with trusted partners in Japan, Europe, and beyond.

Ron Harper is the President & CEO of JFE Shoji Power Canada (JSC), a Burlington-based company that is an integral part of the North American supply chain for electrical steel components for power generation equipment, motors, power and distribution transformers, and specialized magnetic equipment. Ron has worked in manufacturing for over 40 years, mostly in senior leadership positions in marketing, engineering, operations and general management. He has been with JSC since 1995 and has held the role of President & CEO since 2008. Ron has served on several industry and community boards for the past fifteen years. He is a current member of the Transformer Manufacturing Association of America and has previously served on the Association for Manufacturing Excellence Executive Committee (including as Chairman) and the Centre for Skills Development and Training in Canada. Ron regularly advises on government policies and initiatives with Next Generation Manufacturing and Canadian Manufacturers & Exporters, along with sustainability and clean electrical energy policies. Ron is also a leading member of the strategic initiative for People Centric Leadership. This movement is intended to educate leaders to engage and lead teams in a manner to maximize job satisfaction and fulfillment, while creating significant value in business.

The inputs necessary for high-performing electrical grid components

Two materials will shape the backbone of the future electrical grid: **grain oriented electrical steel (GOES)** and **Amorphous Metal (AM)**. Each offers distinct advantages, and together they form a complementary path forward.



Amorphous Transformer Cores

Photo: JFE Shoji Power Canada

GOES is a key material for distribution transformers and is essential for medium- and high-voltage transformers that power transmission infrastructure. Modern transformers demand high-performance materials that can support tighter winding, higher energy density, and reduced losses. Its magnetic properties enable highly efficient energy flow, and its role is irreplaceable in large-scale power systems.

AM, with its ultra-low core losses, is ideal for highly efficient distribution transformers, especially in urban and residential areas where load variability is high. Canadian utilities have led the way in AM adoption, demonstrating successful integration over the past decade.

While global supply chains have supported North America's energy needs for decades, today's grid transformation calls for a more resilient, multi-partner ecosystem.

Technical trends driving demand for GOES and AM

The technical evolution of transformer cores using these key materials are driving growing expectations around efficiency, reliability, and sustainability. Utilities across North America are raising standards to improve energy efficiency. The U.S. Department of Energy (DOE) has introduced new regulations which prioritize high efficiency GOES grades, and these are set to take effect by 2029. These changes require power transformer manufacturers to use thinner steel (0.23 and 0.20mm) and pursue lower core loss (down to 0.65 W/kg).

GOES grades have evolved from conventional levels to advanced Hi-B and laser scribed versions that offer superior magnetic properties and reduced energy loss.

Leading global producers have invested heavily in recent years on the hard journey to make these unique materials more electrically efficient. High performance grades of GOES will be crucial as utilities look to cut operating costs and reduce carbon emissions across their networks.

As a result, GOES producers are now focused on creating steels with uniform grain orientation and thinner gauges, notably as low as 0.20mm thickness, and these thinner steels are becoming the standard for power transformers. Thinner material reduces eddy current losses, helping utilities meet stricter DOE efficiency regulations. Steel mills are also investing in R&D to refine laser technologies that control grain boundaries, enabling even higher performance.

AM has a disordered atomic structure that enables even lower core losses. Canadian utilities have demonstrated successful integration across urban and rural networks over the last decade. Today, more than 50% of new distribution transformers in Canada use amorphous metal as its core material.

A U.S.-based company, Metglas, is planning to double its capacity as it responds to growing demand, and as OEMs convert designs to support new DOE efficiency standards by 2029. AM is projected to make up as much as 30 per cent of the market for distribution transformers in the U.S. within the next five years. However, tariffs and the ongoing market uncertainty and lack of commitment is potentially delaying investments.

Electrical steel shortages and the impact on transformer manufacturing

The transformer supply chain is under strain. Lead times for power transformers have increased in some cases to beyond five years, as utilities scramble to secure production slots and de-risk supply chains. Risky supply chains inhibit growth and expansion investments from transformer OEMs.

Applying Noise Reducing Epoxy on a Power Transformer Core

This is a complicated challenge: there is a need to fulfill the growing demand for electrical equipment, while also providing the incentives to local businesses and manufacturers of electrical transformers.

North America's electrical grid modernization depends on a resilient and diversified supply of GOES, much of which is currently sourced through trusted international partners. It is critical to foster open, predictable markets that encourage local investment while deepening strategic collaboration with global producers who share a commitment to innovation, sustainability, and grid reliability. A balanced strategy that expands both GOES and AM capacity—leveraging domestic strengths and international expertise—is the most sustainable path forward. Policymakers and utilities should promote the smart integration of both materials, ensuring they are used in the most effective applications to meet future energy demands.

Electrical transformers have many components, and OEMs are working diligently to secure supply chains to support the expected growth in the next five years. However, all transformer manufacturing hinges on a steady supply of electrical steels. This niche electrical steel is dominated by production in China, and the current supply is at risk with growing worldwide demand.

Photo: JFE Shoji Power Canada

North America's challenge is not to decouple from the global supply chain, but rather to de-risk and balance it.

Chinese mills represent about 60% of the total global supply, followed by Japan, South Korea, and India. Cleveland-Cliffs is the only North American producer, but its output represents a modest portion of total global production today. Chinese production of GOES was negligible 20 years ago, but as they have electrified their country over the past 25 years, they invested heavily in this foundational material.

Global demand for GOES has grown by 10% annually over the past five years, with the most efficient grades for our modern grid growing by 25% annually. This trend is expected to continue and likely increase based on the need for new electrical equipment, and the need to create efficient electrical energy systems.

There is also a lack of planned mill expansions outside of Asia currently. JFE Steel/JSW have an expansion project underway in India, but no new commitments have been made to expand production of GOES in North America or Europe.

Today, North American production of GOES is roughly 50% of what is required domestically, and with increased demand, that rate will decline without capacity expansion.

Geopolitical factors play into the conversation; as our supply chain, manufacturing and electrical grid expansion and renewal should not become over reliant on an unfriendly dominating supply source.

Global collaboration over protectionism

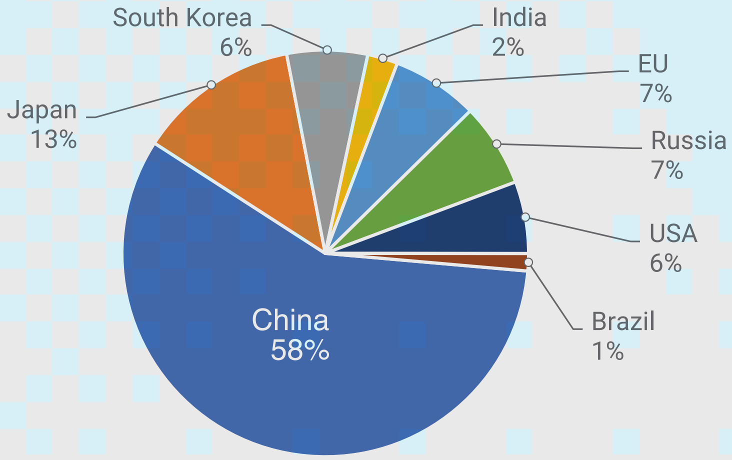
GOES is a specialized, capital-intensive material produced by only a handful of companies globally. Asian producers, most notably Japanese manufacturers, play a critical role in maintaining the global supply of high-performance grades needed for modern energy systems. Japan is a leader in advanced steel technologies and industry innovation. Expanded relationships, continued investments and collaboration with global partners will be essential.

Even if supply constraints are not being felt today, we must anticipate and invest to avoid this possibility.

The global supply of GOES

GOES is difficult to produce and extremely capital intensive, which is one reason why the market has only ten or so key global producers. It was originally developed by Armco (now Cleveland-Cliffs) its technical performance has been significantly enhanced by several global steel companies since then.

In 2024, global production of GOES totaled approximately 4.4 million metric tons, with 80% of supply coming from Asian producers.



Global Production Estimates of GOES

North America's challenge is not to decouple from the global supply chain, but rather to de-risk and balance it.

A healthy ecosystem would require industry partners to:

- Strengthen domestic production capacity for GOES and AM materials
- Deepen ties with trusted and diversified international GOES partners, and eliminate trade barriers
- Set clear standards and trans-parency for imports to ensure that our grid is being supported by domestic and friendly international partners
- Build supply chain resilience—from material inputs like electrical steel to component production to transformer manufacturing—through local capacity supported by global ties
- Invest in workforce development throughout the entire industry

Rather than broad trade barriers, a surgical approach that ensures critical imports are aligned with ethical standards, reliable global partnerships, and real market needs will support both supply security and international cooperation.

Trade policies must align to create the desired outcomes and incentivize local investments in the whole supply chain, while also drawing on the strength of experienced global partners.

Policies must also recognize that creating raw material and fabricated component production capacity takes time. In the short- and medium-term, reliance on reliable global partners must be maximized while local production has the time to be created.

The history of the North American electrical grid

The North American electrical grid is aging. After major investment and installation in the 1970's, demand for electrical power generation and transmission and distribution equipment stayed relatively flat.

During that time, domestic production gradually declined (particularly in the power transformer sector), and distribution transformer producers relied heavily on growth in housing and weather replacement markets to fuel demand.

But now, about 70% of the core grid infrastructure has reached its end of life and it now requires replacement. The ability to continue to expand and update this infrastructure is a critical issue for North America. Long-term energy storage, broader upgrades to the grid, and resilient supply chains to modernize and expand it are all necessary.

Transformer manufacturing companies are expanding production, but they also need to secure a resilient supply of GOES and AM to do so.

Step Lap Core "E" Assembly

Scaling domestic capacity with purpose

North America must pivot to proactive supply chain planning that prioritizes reliability, ethics, and innovation. A seismic shift in how materials like GOES and AM are produced, sourced, processed, and deployed will be required.

To meet this demand, U.S. and Canadian OEMs must be supported and incentivized to expand transformer manufacturing capacity. Utilities can play a key role too, by aligning procurement practices with North American production capabilities and importing only what is needed to supplement domestic shortfalls.

This approach will:

- Drive investment in local jobs and capacity
- Mitigate reliance on volatile trade flows
- Support national security and grid stability

Incentives could include capital investment grants, tax credits, and workforce development programs to enable OEMs to scale at pace with demand. Public-private partnerships and long-term volume agreements would give manufacturers the confidence to invest and grow.

Building the future grid together

The modernization of the North American electrical grid depends on a resilient, diverse, and transparent supply chain for transformer core materials. The solution is not about choosing between GOES or AM, or domestic versus global—it's about creating a stable and scalable supply chain ecosystem.

This requires:

- Investment in **domestic e-steel, component and transformer production**

Photo: JFE Shoji Power Canada

Wound Distribution Transformer

The solution is not about choosing between GOES or AM, or domestic versus global—it's about creating a stable and scalable supply chain ecosystem.

- Support for the **growth of AM as a dependent material**
- Continued **partnership with trusted global supply partners**
- Clear **trade policies** that encourage ethical, sustainable sourcing
- Collaboration between **industry, utilities and government**

Many North American transformer producers are already investing in expanding domestic manufacturing, showing that the path forward is achievable. But a consistent supply of core materials—and the policies that enable them—must follow.

Metglas is demonstrating the kind of forward-looking investment needed to meet the DOE's ambitious efficiency targets. As demand for high-efficiency transformers grows, continued support for domestic AM innovation and production capacity will be critical to ensuring both energy performance and supply resilience. To support proactive investments in AM production industry partners must commit to the development of this critical supply chain with long term agreements.

Shared responsibility, shared opportunity

Meeting future energy needs, reducing carbon emissions, and safeguarding economic security are shared goals that will require shared responsibility.

If transformer and electrical steel shortages persist, utility projects will be delayed, renewable energy integration will stall, and electrification goals will remain out of reach, or too dependent on dominant production regions outside of North America.

OEMs must build deeper, longer-term relationships across the supply chain. This includes sharing demand forecasts, collaborating on materials development, and committing to longer term volume contracts that reduce market uncertainty. The more aligned both ends of the supply chain are, the more efficiently resources can be allocated and risks mitigated.

Many companies are investing heavily in U.S. manufacturing facilities to meet growing demand and leading the way in expanding the domestic production of transformers.

But a steady supply of GOES and AM material will also be necessary to meet the demand. Relying on a single source or region for critical materials poses significant risks.

The GOES shortage is not just a supply chain issue; it is quickly becoming an economic one.

Leadership and collaboration between industry and policy will be necessary to act.

Power Transformer Core

Editorial Report: DISTRIBUTECH International 2025

At the recent DISTRIBUTECH International 2025 Conference, we met with a number of subject matter experts and key thought leaders who discussed the unprecedented transformation currently sweeping the power industry. As Bala Vinayagam, President of Qualitrol, puts it, this is the "best time to be in this industry, and for the foreseeable future, it's a high-growth industry". The same theme was shared by all of the other 50+ professionals we spoke with at the conference. There is an overwhelming agreement that our normally staid and often static industry has become very dynamic, changing to meet the demands of a changing world.

- **Data Centers:** The explosion of data centers, particularly those supporting AI that require immense amounts of power (sometimes measured in gigawatts, comparable to small cities). Alan Swade, GM for the North American commercial team for GE Vernova's Grid Solutions Power Transmission business, observed that this demand "seems like it wants to stick around...for a 10-, 15-, or even 20-year run" globally, but especially in the US. AI is noted by Alan Swade as "a big thing that we didn't have our eye on as how much demand that was going to drive".

A central theme is the sudden and significant spur in load growth, following decades of little to no growth. The surge is driven by several factors, including:

- **Electrification of Everything:** From electric vehicles to buildings, the general trend is electrifying everything.

- **Re-industrialization/Onshoring:** Factories and manufacturing require significant power.

This rapid increase in demand, coupled with a shift toward renewables like wind and solar, is putting immense stress on existing electrical infrastructure and generation capacity.
Bala Vinayagam indicates a need to "double the electrical infrastructure in the US - which took almost 80 years to build - in the next 15 to 20 years". Marcos Carreras of Dynamic Ratings notes similar increasing demand and need for cleaner, reliable energy in Latin America, driven by industry and people.

Photo: Shutterstock, APC Media

Some other key infrastructure challenges discussed at the conference include:

- **Transmission Constraints:** Getting more power from point A to point B is essential, but transmission lines are often at capacity, and building new ones can be challenging. Upgrades to existing networks (345 kV, 500 kV) and the potential emergence of a 765 kV backbone are needed to move more power. Alan Swade noted the importance of placing substations at the intersection of high-speed fiber and transmission lines, as "you need power, and you need to move the data". Marcos Carreras highlighted transmission as critical in Latin America, where energy resources are often located far from demand centers.

- **Supply Chain Management and Subject Matter Expertise:** The industry faces challenges with talent (both in terms of an aging workforce and training new personnel) and supply chain issues, leading to long lead times for critical equipment like power transformers (three to five years out) and bushings (two years).

In response to these challenges, the industry is undergoing a significant shift in approach. Utilities, traditionally insular, are becoming "more open to at least hear what suppliers have to offer", according to Brian Nelson, who manages the renewable energy segment for ABB in the United States. The openess marks a shift from transactional, process-based interactions to outcome-based solutions.

John Gounaris, Global VP of Marketing for G&W Electric, similarly states customers are saying, "Here's our problem... Come in and help us design the solution". Suppliers now need to listen to and understand the unprecedented problems utilities are facing, leading to the need for suppliers to focus on listening first.

Nearly every supplier we met with had the same conclusion, their approach to the industry is much more collaborative, and includes open discussions with other suppliers, either currently working with the customer or who the utility is looking at to provide a specific solution. It is not quite open architecture, but utilities are clearly trying to avoid one supplier dominating their system. Open platforms seem to be the future, allowing others easier access.

> **The approach to the industry is much more collaborative, including open discussions with other suppliers, either currently working with the customer or who the utility is looking at to provide a specific solution.**

According to Claudia Cosoreanu, Chief Technology Officer at GE Vernova "digitalization is key to solving these challenges".
It encompassess:

Claudia Cosoreanu, Chief Technology Officer at GE Vernova, at DTECH 2025

- **Instrumentation and Data Collection:** Adding sensors to the grid for better visibility. Marcos Carreras mentioned different ways of collecting data from transformers (temperature, flow, gasses, partial discharge) and other assets (bushings, LTCs, tanks, hotspots).

- **Connectivity:** Reliable transmission of data to control centers.

- **Analytics and AI:** Using AI/ML to understand

network behavior, predict load, and recommendations to act. While some might see it as a hype, Alan Swade points out AI's growing importance: "AI is real", and not just a hype for the industry. Bala Vinayagam agrees, stating AI "now kind of unleashes new avenues" for pattern recognition and analytics. Marcos Carreras notes Dynamic Ratings uses AI for processing data faster and predicting what might happen.

- **Data Management:** Marco Simiano, GridBeats™ Product Portfolio Executive for GE Vernova's Grid Solutions business, and Bala Vinayagam both note that utilities often "drown on data but starve on analytics". They suggest gathering siloed data into consistent data lakes for fusion and cross-correlation. Marcos Carreras mentions Dynamic Ratings' approach includes data management and diagnosis.

- **Condition Monitoring:** Implementing comprehensive monitoring of electrical assets (like transofmers, for example) extend their life and manage risk. This provides actionable intelligence for various personnel (planners, operators, and maintenance). Bala Vinayagam notes that customers want to know the outcome, such as whether a transformer can be loaded more and what will happen to its life if it is. Deia Bayoumi, SVP of Marketing & Sales for Transformer Digital and Components at Hitachi, highlights comprehensive condition monitoring as "needing to shift from minimal to comprehensive for utilities".

- **Digital Twins:** Bala Vinayagam describes modeling the physical behavior of assets over time based on data to understand aging and guide actions, representing the difference between the "as-designed system and... as-operated system". He sees AI unleashing new avenues for digital twin technology.

Reliability and resilience are critical outcomes the industry is seeking. Reliability is about keeping the power on, while resilience is about "getting

Photo: DTECH, APC Media

back up when it does [go down] for whatever happens to it", as defined by Brian Nelson. Deia Bayoumi acknowledges that events will happen, and the focus is to "manage the risk" by reducing the frequency and impact of events and speeding up recovery time. Technologies such as intelligent devices, connected systems, and even augmented reality are pointed out as tools to enhance resilience. Brian Nelson highlights microgrids as a way to provide reliability and resilience, especially for critical customers. Marco Simiano described GE Vernova's GridBeats™ portfolio aiding resilience by allowing autonomous control of sections of the grid during outages. Marcos Carreras underlined that providing resilient power is absolutely critical in Latin America due to extreme weather conditions and other events.

The conference emphasized the urgent need for speed and scalability in deploying new systems. Projects need to be completed much faster than traditionally done. Solutions also need to be affordable, as stressed by John Gounaris, and "the investment of the customer needs to be into future-proof solutions", designed with flexibility to adapt to changing grid dynamics, according to Marco Simiano. Given the long lead times for new equipment, extending the life of existing assets through condition-based maintenance and providing solutions that allow for retrofits to add intelligence and communications to existing equipment are crucial approaches.

The power industry is navigating an era of unprecedented load growth and energy mix change by embracing digitalization, analytics, AI, and collaboration.

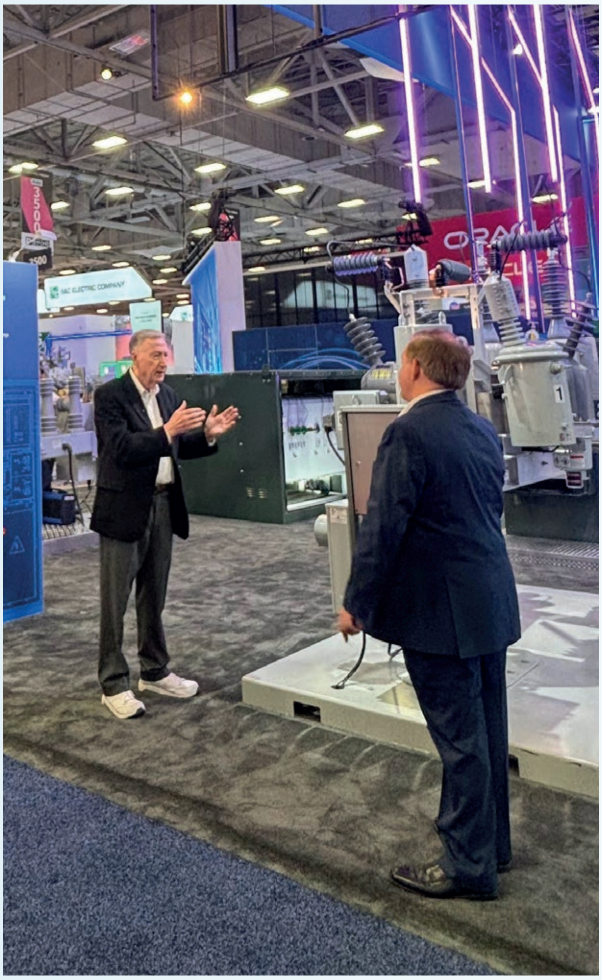
At DISTRIBUTECH 2025, key solutions and technologies discussed included a range of innovations aimed at modernizing the energy grid:

- Substation equipment and digital substation solutions.
- Software-defined automation and grid digitalization platforms.
- Condition monitoring and diagnostic solutions for electrical assets, including diagnostic-as-a-service offerings.
- Advanced sensors, communications, and analytics for improving asset capability.
- Modular equipment designs that facilitate affordability and flexibility.
- Microgrid solutions, potentially including DC microgrids.
- Services for transformer and substation maintenance, life extension, and recovery.

DISTRIBUTECH 2025 made one thing clear: the power industry is facing a pivotal moment. As it grapples with unprecedented load growth and rapidly changing energy mix, utilities and innovators are turning to digitalization, advanced analytics and scalable energy systems - while also tackling challenges around infrastructure, supply chains, and workforce development. And speed and affordability are no longer optional - they are essential. We want to thank all of the expert thought leaders who we interviewed at the event, particularly those who contributed to this report.

To view the full interviews with these leaders and more, click on this link.

The Editorial Team



Practical Strategies for Undergrounding and Monitoring Cables

by **Ben Lanz**

The cable scanning specification provides a proven solution to lowered by installation upfront costs, extending cable life, and accelerating workforce training, all while eliminating future truck roles, improving safety and reducing O&M and revenue loss.

Introduction

Many utilities in North America are strategically undergrounding medium voltage lines as a resilience solution against extreme weather events and wildfire. Those opposed to undergrounding frequently cite costs and concerns about future outages. How can underground line scanning technologies address these concerns?

With over 30 years in the electric power and energy industry, **Ben Lanz** is responsible for Osmose (Osmose.com) technical outreach and education efforts, is a past Chairman of the Board of the Power Delivery Intelligence Initiative (PDI2.org), a nonprofit dedicated to disseminating grid investment best practices, and is an Executive Advisor for Power Systems Technology Magazine . He is a senior member of IEEE PES and ICC, and a voting member of DEIS, IAS, ACP, CIGRE & NETA. He has chaired IEEE technical committees associated with power system reliability, protection, and testing, and has published over 100 papers, articles and technical conference contributions on the subjects of power system reliability, resiliency, asset management, design, lean work practices, longevity and diagnostics.

Photo: IMCORP

The Power Delivery Intelligence Initiative, (PDI2.org) has done much to address these concerns and put forward solutions in a recent report called the "Utility Underground Life-Cycle Cost Guide." For example, did you know that by deploying the PDI2 recommended cable commissioning specification (offline 50 or 60Hz partial discharge (PD) test with 5pC sensitivity) and investing a few percent of construction cost, utilities can, triple their cable life span, significantly reduce up-front costs, enable workforce training, and reduce future operating cost/revenue loss and boost reliability and safety by 10 times? This article covers some practical strategies to select an effective cable test specification and achieve the aforementioned goals.

Cable Commission Helps Utilities Reach Life-Cycle Goals

The Utility Underground Life-Cycle Cost Guide's cable commissioning specification is based on industry peer reviewed experience including thousands of defect dissections and hundreds of thousands of cable condition profile scans in the 5kV to 500kV class range over the last couple decades. The cable scanning specification provides a proven solution to lowering installation upfront costs, extending cable life, and accelerating workforce training, all while eliminating future truck roles, improving safety and reducing O&M and revenue loss.

Lowering Installation Upfront Costs

Some utilities have outdated specifications that limit pull lengths, require splices every few hundred feet, and are reluctant to change due to fear of damaging systems with longer pulls. These extremely conservative limits may have made some sense with legacy paper insulated lead covered (PILC) cable or unjacketed cable in dense urban areas with frequent load points and no method to scan the line for damage after the pull. However, with modern conduit and pulling techniques with lubricant, thousands of feet/meters can be pulled with relative ease. An accurate commissioning test typically finds only about 1% of cable segments (not counting accessory defects) have damage and need to be replaced. A defectively installed splice is 4 times more likely to occur than a damaged cable. Imagine the savings and risk reduction of 3 times fewer, vaults, splice boxes, and cable splices

If a utility wants to further reduce costs and maintain reliability, directly buried cable can be installed at a much lower cost than cable in conduit. Provided the cable system is commissioned with an effective commissioning technique the cost savings can be realized without significant installation damage risk.

Extending Cable System Life

Most future failures are due to anomalies existing during installation or caused by extreme duty-cycle during service. With proper specifications and operational procedures, utilities have control of these risks. Studies show that nearly 40% of new cable system segments (cable and accessories) have at least one defect.

The first cable failure is most often caused by an installation defect. The intermittent erosion process associated with modern solid dielectric insulation deterioration

Studies show that the failure risk during the first few service can be lowered by 100 times with effective commissioning and repairs of anomalies.

can take years and sometimes decades to fail. However, once an aged cable fails, studies show that it is 10 times more likely to fail again due to extreme voltage transients caused by the fault, fault location and reenergization, and finally, the errors introduced during the emergency repair. Studies show that the failure risk during the first few years of service can be lowered by 100 times with effective commissioning and repairs of anomalies. Removing the biggest risk, installation defects, and protecting the cable system from extreme voltage with proper arresters (IEEE C62.22.1-2024) and extreme loading with proper over current protection, reliability can be improved by 100 times. Economic returns on this approach are in excess of 500% and simple paybacks can be achieved in a couple of years when comparing the upfront commissioning and fully burdened future failure costs.

Workforce Training Acceleration

According to a 2023 study by the Center for Energy Workforce Development (CEWD), over 60% of line workers have less than 10 years of experience. Experts who train splicers frequently find they cannot identify common defects. One cannot completely blame installers since training is often inconsistent and defects (incipient faults) can easily pass legacy commissioning tests, like DC HIPOT and VLF withstand tests. These tests detect less than 1% of defects, and utilities using these commissioning tests have unknowingly been giving workers a false sense of security and reinforcing poor workmanship. The Utility Underground Life-Cycle Cost Guide recommended practice of an offline 50 or 60Hz PD test with 5pC sensitivity objectively addresses the training issue. This approach locates over 99% of insulation defects and provides instant feedback to installers on the job site so they can learn what a "defect looks like" and develop functional repair techniques. Utilities can now employ junior employees with confidence that an effective commissioning test will give them the feedback they need and protect the underground cable investments from future O&M and revenue loss.

Why the Offline 50 or 60Hz PD Test Specification?

The Utility Underground Life-Cycle Cost Guide recommends an offline 50 or 60Hz PD test with 5pC sensitivity due to the efficacy demonstrated over the last couple decades in large scale industry studies from both a reliability and return-on-investment point of view. There are other specification options that have been considered but most of them are less than a 10% solution as compared to the cable and accessory manufacturers' standards (Table I) and are thus not recommended. However, there is sometimes confusion around why strict specification is needed, leading some cable owners to consider using lower cost damped AC (DAC) or very low frequency (VLF) voltage sources, or a test with a detection sensitivity in the range of 100pC without understanding the implications.

CABLE AND ACCESSORY MANUFACTURERS' STANDARDS

Cable Component Standard	Parameters (50/60 Hz only)
IEEE 48 Terminations	No PD >5 pC up to 1.5 Uo
IEEE 404 Joints	
IEEE 386 Separable Connectors	No PD >5 pC up to 1.3 Uo
ICEA S-97-682 / 94-649 Cable 5 kV-46 kV	No PD >5 pC up to 4 Uo*
ICEA S-108-720 Cable 69 kV-500 kV	No PD >5 pC up to 2 Uo

Table I
**4 Uo is actually 200V/mil or 7.9 kV/mm.*
Field tests are limited to the level of system overvoltage protection (2 to 2.5 Uo)

Photo: Pexels

Test Voltage Frequency Implications.

PD is a "micro arching" that does not bridge the insulation. Its behavior is sensitive to the frequency of the test voltage source. All manufacturers' standards (Table I) require the cable be energized with a continuous 50 Hz or 60 Hz AC voltage and often applied for longer than 10 seconds but shorter than a minute. Testing at power frequency allows cable owners to observe the systems under typical operating frequency conditions. Frequency of the test voltage source is a direct factor in a defect turn on voltage or PD inception voltage (PDIV) and turn off voltage or PD extinction voltage (PDEV). PDIV and PDEV performance and measured values are the basis of all design and production quality control tests for modern power cable system components. VLF solutions which test at very low frequencies (0.1 Hz to 1 Hz) act more like DC than power frequency and are unlikely to excite PD in many cases. Damped AC voltage and Cosine rectangular voltage sources, with a controlled polarity reversal slope change, rely on charging the cable system with DC first followed by a short impulse which is only a fraction of one 50/60Hz cycle. The DC associated with these voltage sources introduce so called "space charges" in the insulation causing a significantly different electric field distribution at the defect location. Additionally, the resulting impulse is less than a full 50/60Hz cycle, and the frequency content is typically in the hundreds of hertz. In summary, performing a PD test with less than 1Hz, charging with DC first, at hundreds of hertz, or a duration shorter than the typical standard duration (10 to 60 seconds), produces conditions that can change the PDIV in the range of 150 to 200% and render the test results erroneous and impossible to compare to industry standards.

Pre-detection Noise Removal

When manufacturers perform PD tests, the standards require each component be placed in an electrically shielded room (typically steel walled) that provides a radio frequency (RF) free environment prior to checking for PD, effectively providing "pre-detection noise removal." In the field, the manufacturers' standards equivalent test emulates the shielded room by removing background RF noise through an assemblage of techniques and processes. This starts with a high-frequency measurement connection method to the medium voltage cable which of course is designed for a power frequency (50/60Hz) application. This is followed by a broadband signal coupler capable of decoupling the high frequency signals while it is operating at power frequency during the test. The system digitizes the data at a high enough rate to determine PD charge measurement, and lastly the captured digital data is processed through advanced iterative digital signal processing (DSP). All the above elements effectively replicate the "pre-detection noise removal," while preserving signal integrity for PD detection. Most field PD tests employ generic connection techniques and couplers to the cable. The equipment is often the same model commonly used in a low noise laboratory setting. In the field, this approach attempts to detect PD first before using DSP to help remove the remaining noise, effectively post-detection noise removal. This practice provides significantly less sensitivity and often yields results typically only achieving 100 to 200pC sensitivity, missing over 90% of cable defects as compared to the 5pC requirement of the cable and accessory manufacturers' standards (Table I).

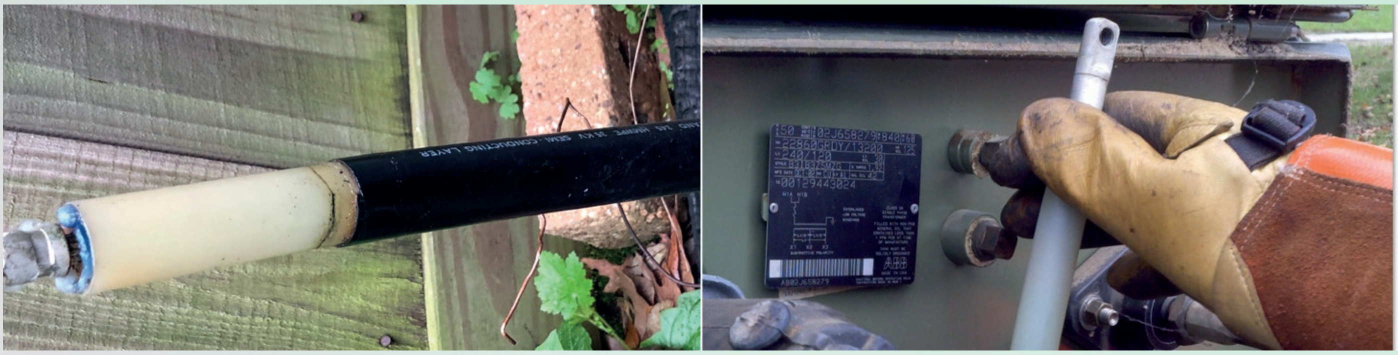
The net result of VLF or DAC PD tests which combine a non-standardized voltage source with a generic signal detector, is typically less than a 10% solution and thus produces less than 10% of the reliability performance value and return on investment.

Comparison Case Studies and Results

In Table II, one can see 13 case studies where controlled "standard-ized Offline 50 or 60Hz PD tests" were compared to experimental VLF or DAC PD tests. In all 13 cases, the result of the VLF and DAC PD test produced erroneous results. These are just a few cases, but they should give the reader sufficient comparison to understand the reason PDI2, American Clean Power (ACP) and IEEE standard 1185 recommended practice specify a standardized offline 50 or 60Hz PD approach to commissioning.

	Control -Industry Standard Reference “Offline 50/60Hz PD test with 5pC Sensitivity”	Experimental Retest “DAC or VLF PD test with >100-200pC Sensitivity Typical”	
No.		**Correct Result?**	**Experimental Results**
1	1 cable defect @1.5Uo	No	No PD
2	5 cable defects @1.5Uo & 2Uo	No	No PD
3	No substandard PD	No	7 substandard cable & termination PD sites 1Uo to 1.5Uo
4	10 splice defects 50 – 100s pC @1Uo to 1.5Uo	No	No PD
5	No substandard PD	No	2 substandard cable & termination PD sites 1Uo to 1.5Uo
6	1 cable defect 424pC @ 1Uo	No	No PD
7	1 cable defect 31pC @ 1Uo	No	No PD
8	No substandard PD	No	5 substandard cable & termination PD sites 1Uo to 1.5Uo
9	No substandard PD	No	3 substandard cable & termination PD sites 1Uo to 1.3Uo
10	1 cable defect 110pC @ 1.7Uo	No	No PD
11	No substandard PD	No	5 substandard cable & termination PD sites 1Uo to 1.5Uo
12	1 cable defect 157pC @ 1.5Uo	No	No PD
13	No substandard PD	No	4 substandard termination & splice PD sites 1Uo to 1.3Uo

Table II



Example defects missed by a non-standardized PD test. Cable Defect (left), Splice defect (right)

Best practice dictates that once a cable system passes this specification, a reliable 40-year performance is expected, provided there are no extreme/physically altering operational events to damage it.

Conclusion

Utilities installing medium voltage lines underground are making massive investments. To lower costs and protect these investments against future O&M and revenue loss, an effective cable scanning commissioning test is recommended. The Power Delivery Intelligence Initiative, (PDI2.org) report called the “Utility Underground Life-Cycle Cost Guide” recommends an offline 50 or 60Hz partial discharge test with 5pC sensitivity. Best practice dictates that once a cable system passes this specification, a reliable 40-year performance is expected, provided there are no extreme/physically altering operational events to damage it. If such an event occurs another baseline scan is recommended. Deploying this specification for less than a few percent of construction cost, utilities can triple their cable life span, significantly reduce up-front costs, enable workforce training, and reduce future operating cost/revenue loss and boost reliability and safety by over 10 times.

Photo: IMCORP

I have had the privilege of sitting on the planning committee for this great conference for several years now. TechCon is one little Gem of a conference that provides some of the best learning for practitioners in the power industry. I also had the privilege of visiting with and recording interviews with thought leaders from many different occupations, but all with one thing in common: A love and passion for what they do every day. I hope you enjoy this compilation of thoughts from great minds.

Alan Ross
Managing Editor, APC Media

Current State of the Power Industry

We all agree that the power industry is currently undergoing a period of significant and rapid transformation, driven by several key factors. One of the most prominent is unprecedented load growth, due to the rise of data centers and the onshoring of manufacturing. Wayne Bishop, of Quanta Technology explains this shift: *"Oftentimes today you hear the word energy transition. I like to say it is not an energy transition, but an energy transformation because it is that radical of a thing that is happening. We have had more changes in our industry in the last 10 years than we have had in the last 100 years."*

Daniel Diaz of Southern Company highlights the scale of this growth, stating: *"There used to be areas and pockets of the US where we had negative load growth. And now we are talking about 5, 6, 7, and even 8%."* This surge is putting immense pressure on existing infrastructure, from generation to transmission and finally to distribution. Clearly, this will not be our grandfather's grid when all is said and done. A great deal of the load growth of course is from the rapid rise of data centers and particularly those data centers associated with the phenomenon of AI. When we use our cell phone to ask Google a question, it takes X amount of energy. When we ask Chat GPT or any other AI, it takes as much as 1000X amount of energy and AI is still in its infancy for searches.

A great deal of the load growth of course is from the rapid rise of data centers and particularly those data centers associated with the phenomenon of AI.

Another major challenge is, of course, aging infrastructure. Christina Park from Skydio points out: *"All of our infrastructure was built at a time that it was just not meant to take the loads and the weather conditions and things that are happening today."* As a result, reliability is becoming a key concern. And when it was built it was built for the typical large generation facility and sent down the grid to homes and businesses, a basic "step down" system. Renewables, EV Charging, Storage and all the other incredible, fast-moving changes that are taking place, as Wayne suggested above, were not part of equation.

Which also leads to the current demand for resilience, not just reliability. Weather events, fires and physical security threats create the need for resiliency, designed into the system. Reliability is making sure we keep the lights on. Resilience is getting them back on after an event. Resiliency calls for redundancy, flexibility, and advanced analytics to ensure that we react as quickly and as safely as possible.

The industry also faces supply chain constraints for critical equipment like transformers and breakers. Daniel Diaz adds: *"We are hearing from equipment specialist that it is taking—not*

Photo: Shutterstock, Pexels

weeks, not months—but maybe years to get big equipment such as transformers and breakers."

Workforce challenges further compound these issues, with many experienced professionals retiring and difficulties in attracting and training new talent. Kevin Riley of TranTech underscores this shift: *"Over our decades of service in this industry, we have seen so many retirements, but then another generation of people that come in that may not know nearly as much as the person that just retired."*

The transition brings its own challenges, particularly the variability of renewable sources like wind and solar. Mark Lauby from NERC explains: *"When you do not have decent models, you do not study them right... We had voltage excursions—three or four of them within about 55, 60 seconds. The UPS was saying, 'Okay, I got that. I got that.' But then the cooling load was watching what was going on. The UPS said, 'I'm getting out of here, and so that shed that load."* Cooling of data centers requires a great deal of power and AI data centers are even more cooling hungry.

Reliability is making sure we keep the lights on. Resilience is getting them back on after an event.

Policy uncertainty is another major headwind. As Robert Vary of Reinhausen (known as MR) stresses - the legislative engagement is critical: *"It takes so long to get things built, and if we do not meet growing energy demands, it could have national security implications."*

There is growing recognition of the interdependencies between the electric grid and other critical infrastructure sectors—such as natural gas, communications, and water—which adds another layer of complexity to ensuring reliable power.

Looking ahead, the power industry is expected to continue its rapid transformation. Load growth driven by data centers, AI, and electrification is projected to persist and accelerate.

Mark McVey of Dominion Energy warns: *"The data center started out at 50 MVA blocks. Now they are at 200 or 250 MVA. I have three one-gigawatt data centres sites going into an area near South Boston, VA. A typical nuclear site is about two gigawatts—so you are going to blow through that pretty quick."*

Grid modernization will be essential to accommodate this growth and the evolving generation mix. This means not just transitioning but truly transforming the grid through innovative technologies and strategies.

Grid modernization will be essential to accommodate this growth and the evolving generation mix. This means not just transition-ing but truly transforming the grid through innovative technologies and strategies.

Renewable energy sources will play an increasingly significant role in future generation portfolios. But to ensure grid stability, dispatchable sources—such as natural gas and nuclear power—will remain crucial. This includes the emerging potential of small modular reactors (SMRs). Rachel Williams from Southern Company says nuclear is *"definitely one of the arrows in the quiver"*. Battery storage will also be vital to manage the intermittency of renewables.

Microgrids are emerging as a potential solution for large energy consumers like data centers and industrial facilities, while also enhancing overall grid resilience.

Automation and innovative technologies, such as drones for inspections, will become more widespread as utilities push for greater efficiency and better asset management. Christina Park from Skydio calls them *"workforce multipliers"*. The industry is expected to move toward condition-based maintenance, using data and analytics to optimize maintenance schedules and asset lifecycles.

Collaboration and knowledge sharing will be increasingly important in navigating the complexities of the energy transformation.

Photo: Shutterstock, Pexels

Wayne Bishop of Quanta Technology emphasizes this: *"Teamwork is wanting and helping your colleagues to succeed. So, we will take a team of folks at Quanta Technology and then get together with a utility and present a research project, for example, at a conference."* Conferences like TechCon are highlighted as key venues for these exchanges.

Lastly, there's growing awareness of the need for coherent energy policy—one that provides certainty and enables investments in infrastructure and emerging technologies. The focus on resilience will also intensify, as the grid faces increasingly diverse threats, including extreme weather and cyberattacks. Mark McVey highlights a shift in approach, referencing *"the development of mobile substations"* as a proactive solution to rapidly restore service. Creating a Mobile Substation fleet with enough flexibility to meet many needs in the field, is becoming a necessity, not a luxury.

Final Thoughts

TechCon is a conference where great presentations and panels are made even greater by the networking and interactive sessions. Industry practitioners, like those we have quoted and so many more we will feature in our future updates, connected with key suppliers and peers to exchange their insights. We strongly urge utilities, as well as renewable developers, operators and suppliers to consider TechCon 2026, supported by Luma Energy, the electric utility for the island of Puerto Rico. Learning from the challenges and accomplishments Luma has experienced offers a compelling example of operational resilience and innovation in action. http://TechCon.info.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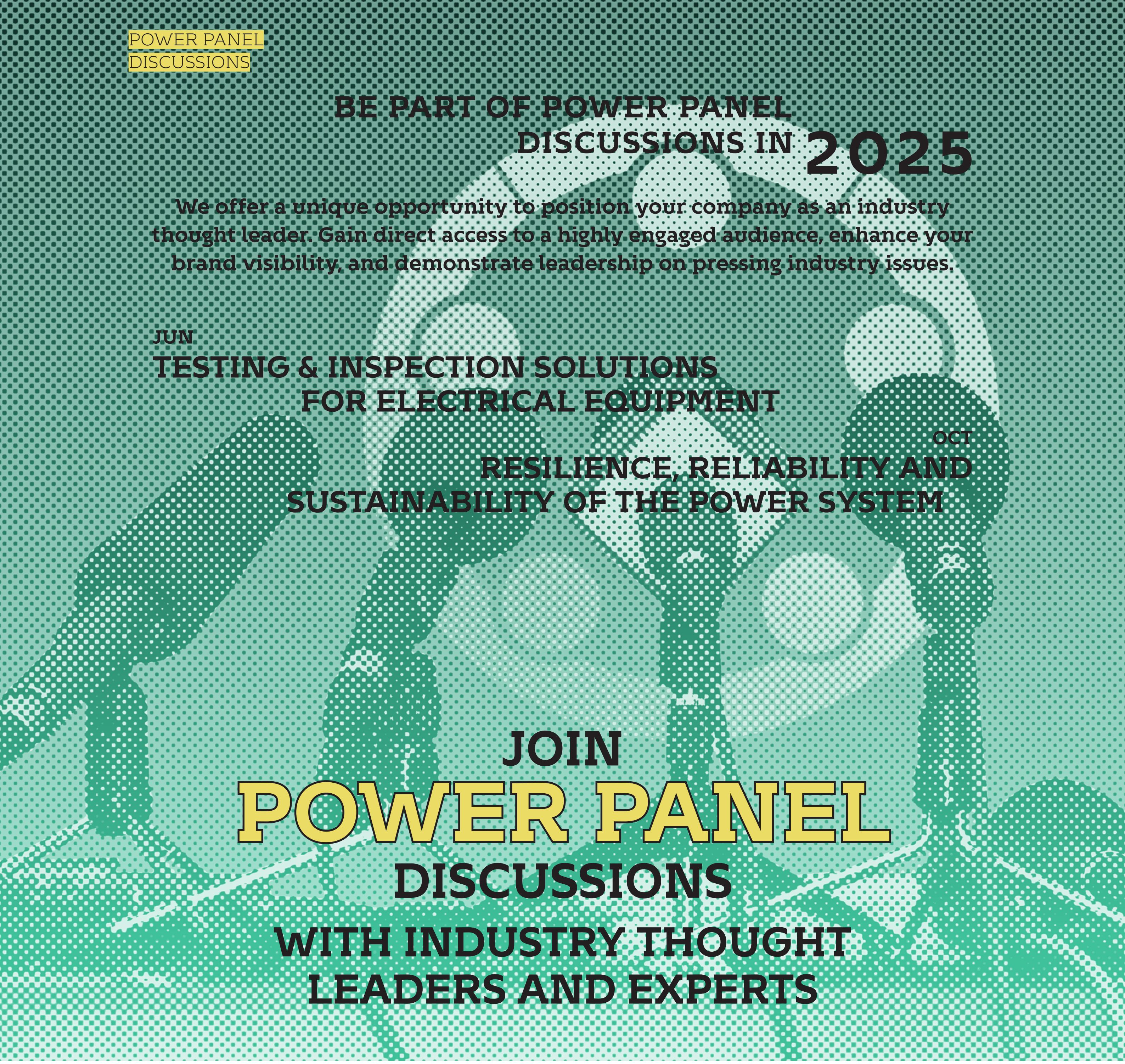
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Discover how smarter design and streamlined manufacturing are enhancing reliability and sustainability across the power sector. We explore predictive maintenance strategies that reduce downtime, cutting-edge transformer technologies boosting efficiency, and the vital role of on-load tap changers in managing grid stability. Learn how advances in electrical steel and testing methods are raising the bar for quality, while new physical and cyber security solutions address evolving threats.

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SUBSTATION SOLUTIONS: DESIGN, AUTOMATION & MONITORING

The edition is your go-to source for innovations in the electrical power sector. Dive into the latest in switchgear technologies, advanced protection systems, and smart asset management strategies. Read about cutting-edge testing & inspection solutions, including the vital role of IR and UE tools, plus key insights into dry-type technology developments. Don't miss our expert guide on best practices in transformer maintenance to enhance system reliability.

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