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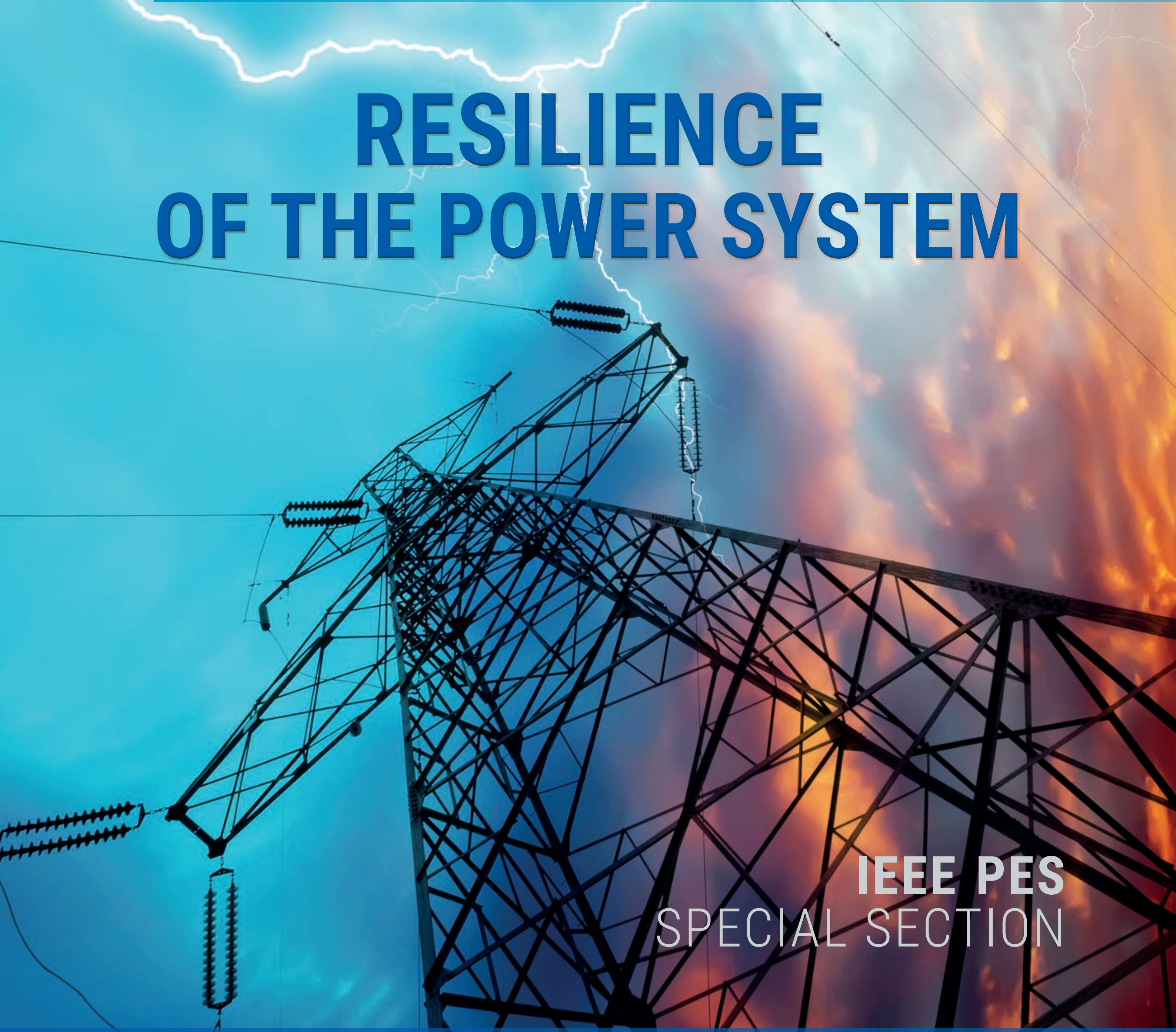

RESILIENCE OF THE POWER SYSTEM

IEEE PES SPECIAL SECTION

Kenneth Peterson of LUMA Energy on Rebuilding the Puerto Rico Grid

Building Resilience in the Transformer Industry by **Georgios Giovanakis** thyssenkrupp Electrical Steel CEO

Interview with **Andreas Schierenbeck** Hitachi Energy CEO

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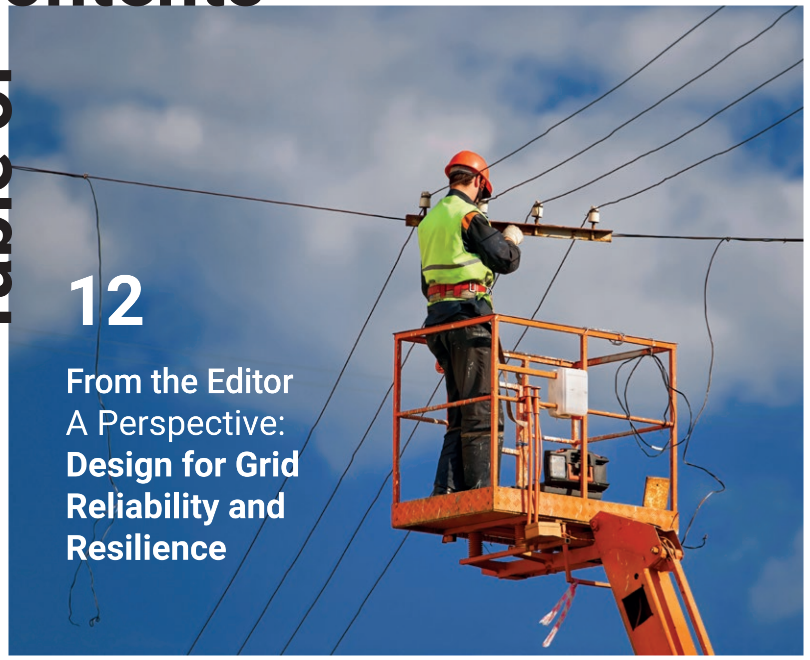

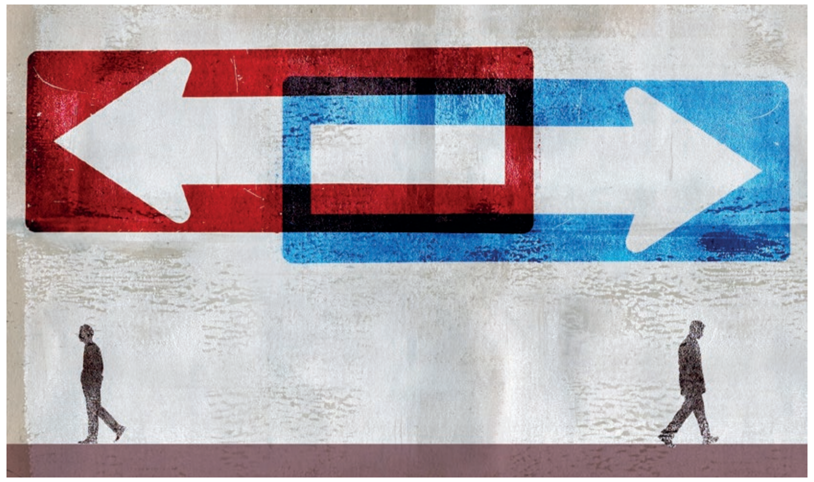

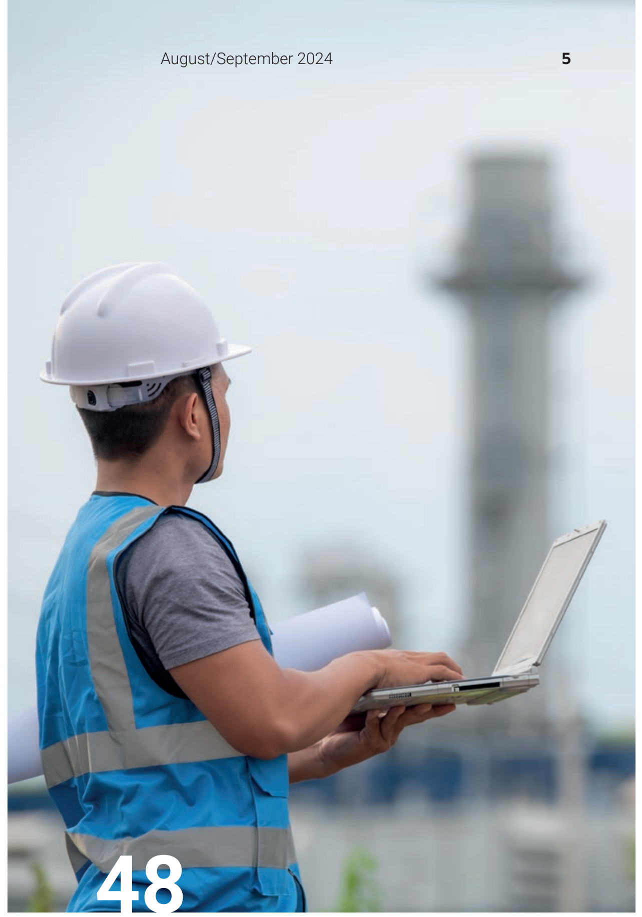

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Design for Grid Reliability and Resilience

Grid resilience is a critical issue facing the Department of Energy (DOE) and the energy sector as a whole. The grid, which is responsible for delivering electricity from power plants to homes and businesses, is facing increasing challenges due to aging infrastructure, extreme weather events, cyber threats, and the integration of renewable energy sources.

These challenges have highlighted the need for the DOE to prioritize grid resilience in order to ensure the reliability and security of the nation's electricity supply.

One of the main challenges to grid resilience is the aging infrastructure of the grid. Many parts of the grid were built decades ago and need upgrades and modernization. This aging infrastructure is more susceptible to failure and can be difficult to repair quickly in the event of a disruption. The DOE must prioritize investments in grid modernization to improve the reliability and resilience of the grid.

While it is obvious that extreme weather events, such as hurricanes, wildfires, and winter storms, are also a major challenge to grid resilience, it is less obvious that for future development we should use “DfRR” Design for Reliability and Resilience guidelines.

We know that these events can cause widespread power outages and damage to the grid infrastructure.

Yes, the DOE must work with utilities and other stakeholders to develop plans and strategies to mitigate the impact of extreme weather events on the grid which may include improving the resiliency of critical infrastructure, such as substations and transmission lines, and implementing new technologies to better monitor and respond to weather-related threats.

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Cyber threats are another significant challenge to grid resilience. As the grid becomes more interconnected and reliant on digital technologies, it becomes increasingly vulnerable to cyber and physical attacks.

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These attacks can disrupt the flow of electricity, compromise the security of the grid, and pose a threat to national security. The industry must prioritize cybersecurity measures to protect the grid from malicious actors and ensure the integrity of the electricity supply.

For physical attacks, which are on the rise, there are methods underway to mitigate attacks.
At a recent TechCon Conference in Sacramento, I had the honor of moderating a panel with representatives from SMUD, PG&E and Idaho Power, where the presentations they made were simply startling as to the problem and quite brilliant as to their future solutions.

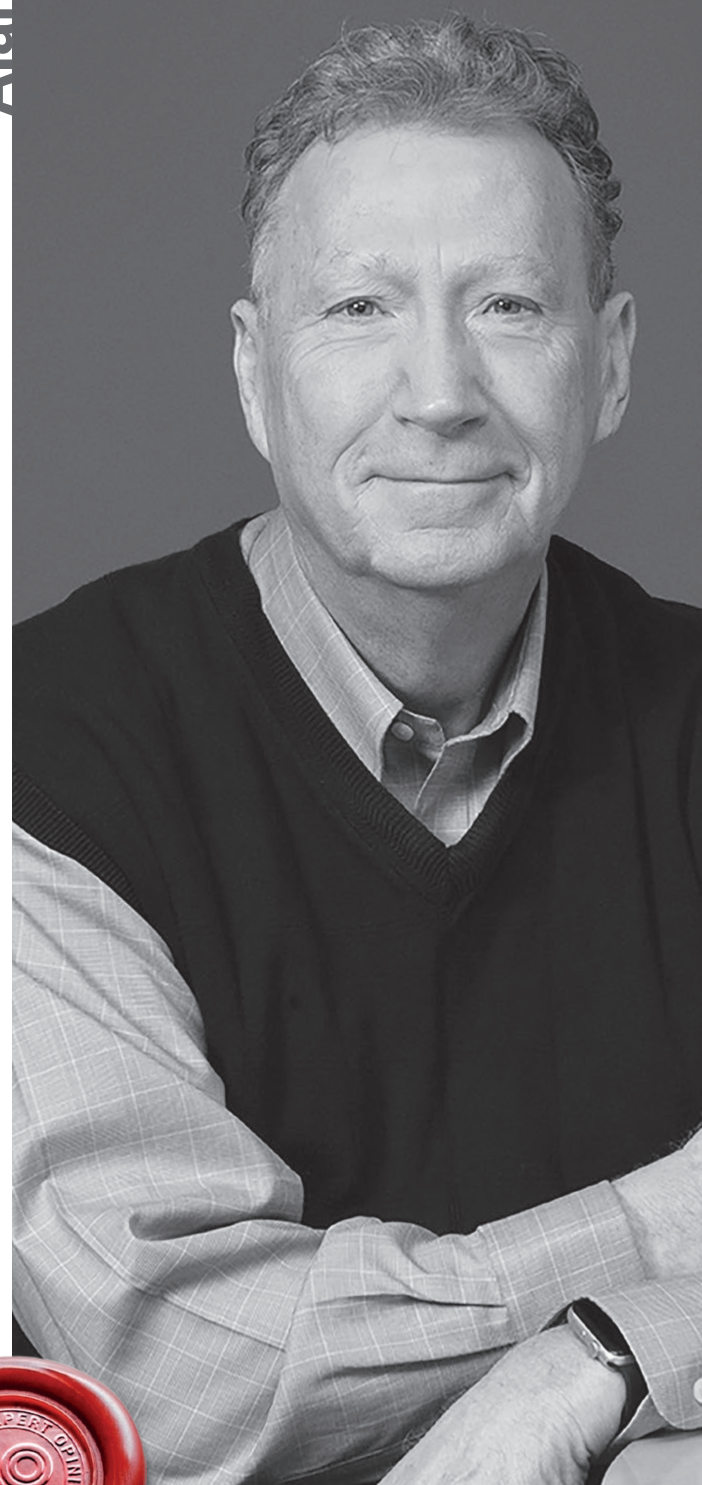
The integration of renewable energy sources, such as solar and wind power, also presents challenges to grid resilience. Since these energy sources are variable and intermittent, it creates challenges for grid operators in balancing supply and demand and maintaining grid stability.
The industry must prioritize investments in grid flexibility and storage technologies to accommodate the growing share of renewable energy on the grid.

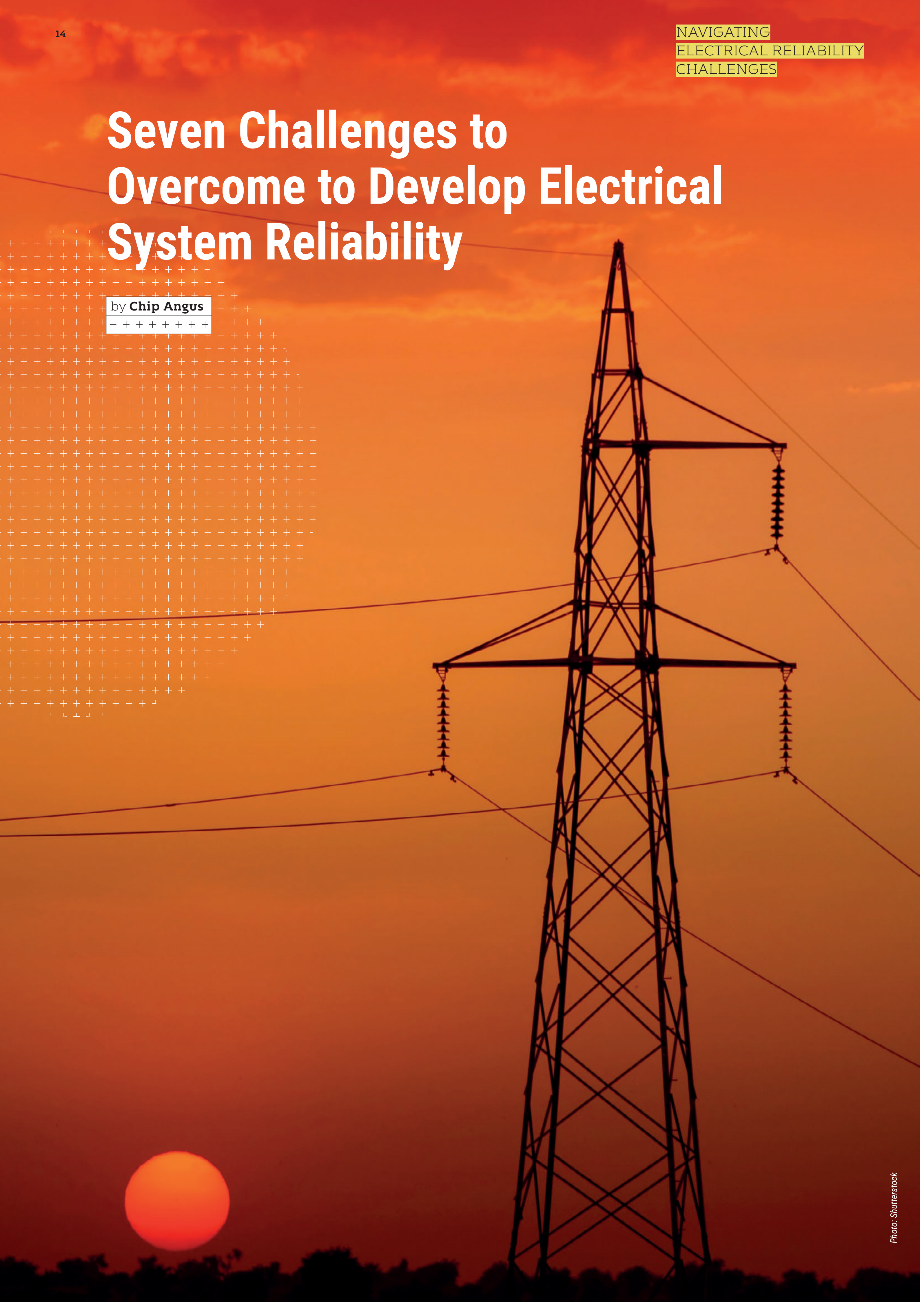
In conclusion, grid resilience is a complex and multifaceted issue that requires the attention and prioritization of the Department of Energy and by the entire utility family. By addressing the challenges posed by aging infrastructure, extreme weather events, cyber and physical threats, and the integration of renewable energy sources, then we can help ensure the reliability and security of the nation's electricity supply. It is essential that the DOE work with utilities, regulators, and other stakeholders to develop comprehensive strategies and solutions to enhance grid resilience and protect the grid from future threats.

By addressing the challenges posed by aging infrastructure, extreme weather events, cyber and physical threats, and the integration of renewable energy sources, then we can help ensure the reliability and security of the nation's electricity supply.

Alan M Ross
CRL, CMRP
Managing Editor
APC Media
Technical Director

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





Seven Challenges to Overcome to Develop Electrical System Reliability

by **Chip Angus**

Photo: Shutterstock

Previously published in Efficient Plant magazine in June 2021. With Permission.

Introduction

There are very few organizations that are not concerned with following reliability best practices. It is more efficient and less expensive to prevent a breakdown than it is to fix something that breaks. Monitoring and data management are becoming ubiquitous in the industrial world, the utility world, and across most industries and sectors as we work towards a more reliable and interconnected future. Electric power systems, however, have not been included in this shift away from break/fix and towards data-centric reliability. In our experience as a leading transformer management company, we've found that even within organizations that employ healthy reliability programs for other equipment, there are still some barriers to developing a reliability program for the electrical system that powers them. Some of them are organizational barriers, which arise when there is not enough involvement across different departments within an organization; a tendency to prefer "the way we have always done it" over a new approach to electric power system reliability; fear of a loss of jobs as technology becomes more vital to monitoring and analysis; fear of a loss of control from the plant level to the corporate level; distrust of electric power reliability as a "flavor of the month" idea dictated from the corporate level; unclear expectations; and unclear timelines that do not factor in the complexities of bringing an electric power system back up to where it needs to be. This article provides context for those barriers and offers some solutions that can help an organization overcome them. These solutions can help an organization pursue a reliability program that includes the asset that everything else in the operation relies on the electric power system.

Chip Angus is Electric Reliability National Account Manager at SDMyers, LLC in Tallmadge, Ohio, where he specializes in helping industrial companies develop long-term transformer reliability solutions. Chip works primarily with manufacturing, steel, wind, solar, pulp and paper, and oil & gas customers by aligning their corporate reliability expectations with the realities at the plant operations level. Chip presents at conferences across the U.S. as a resource in the field of industrial electric power reliability. He has been published in a variety of leading trade publications in the electric power reliability space. Before specializing in transformer management and electric power reliability, Chip was the president of Ryco Metals, a structural and plate fabrication firm and service center.

Monitoring and data management are becoming ubiquitous in the industrial world, the utility world, and across most industries and sectors as we work towards a more reliable and interconnected future.

Creating Awareness

Last year we conducted a focus group comprised of reliability practitioners to discuss electric power reliability (Figure 1). Our company works mainly with transformer reliability, but this group was concerned with the reliability of entire electrical systems in the industrial market, including transformers, cabling, breakers, and relays and protective equipment. One of the questions we asked them was whether they had a high-voltage electric power reliability program.

Few did. Only 8.3 percent said that they are well on their way to developing electric power system reliability, with 6.7 percent at the beginning of developing one. One quarter told us that they know they should, but they are not currently addressing it. Most significantly, half of the people in the group said that they have no program whatsoever. Some weren't even aware of the risk.

Every person in the focus group did have one thing in common: they have programs for every other asset class in their organization. They had programs for the servers in their data centers, for example, the steel mill people had programs for their furnace trucks, furnaces, auxiliaries. Then, LMFs and EFS and every industry represented had a CMMS that covered their other critical assets. Most had nothing for their electric power system.

We all know that it is a lot cheaper to prevent a breakdown than it is to fix a repair. But that kind of prevention doesn't tend to happen on electrical systems. Asset owners don't realize that the cost of a breakdown in an electrical system is not the cost of the asset alone. What does that asset power? It could be an entire plant. We've seen downtime and replacement costs in the range of $100,000 to $50 million for the breakdown of a $400,000 transformer. It's not the cost of the asset that's the issue; it's the cost of downtime while you wait for the replacement to be installed.

There is not an organization that I know of that is not trying to implement reliability best practices. A lot of the work I do is to extend that understanding to the electric power system. The first step towards this goal is to categorize equipment by criticality and evaluate the real risk of electric power system failure.

Figure 1. The real risk of electrical system failure is not known to many reliability leaders

Asset owners don't realize that the cost of a breakdown in an electrical system is not the cost of the asset alone... It's not the cost of the asset that's the issue; it's the cost of downtime while you wait for the replacement to be installed.

Categorizing Risk

By defining a fleet of transformers by their criticality and risk, as well as their history (Figure 2), it is possible to prioritize the urgency with which to perform maintenance. We can develop a criticality ranking by asset class and categorize it into four distinct groups: Non-critical, Auxiliary, System Critical, and Mission Critical.

Non-critical transformers

Non-critical transformers can be run-to-failure. Downtime is an inconvenience and an unplanned expense, but failure of these assets does not have a significant knock-on effect to the rest of the operation. Testing is all that is required so that you are aware of the condition of your equipment and you can plan accordingly.

Auxiliary transformers

Auxiliary transformers power equipment and structures which are important to the operation of your business, but an unexpected loss would not cause significant disruption of a line or the shuttering of a facility. These transformers require regular testing and interpretation of test data, regular field inspection, and transformer management training for key staff. For auxiliary transformers, reactive maintenance is acceptable.

System-critical transformers

System-critical transformers power production lines and hospital wards; places where a loss of power is unacceptable and creates substantial losses in revenue or poses a real danger to life and limb. These transformers require regular testing and interpretation of test data, regular field inspection, electrical testing, and advanced transformer management training for key staff. Predictive maintenance is required for system-critical transformers. This equipment requires single-gas real-time monitoring to detect insipient faults and allow for an immediate response to prevent downtime.

Mission-critical transformers

Mission Critical transformers are pieces of equipment so vital to the overall operation of a facility that failure could be catastrophic to the entire operation of a business or organization. These transformers require regular testing and interpretation of test data, regular field inspection, electrical testing, advanced bushing and PD monitoring, engineer evaluation and review, and advanced transformer management training for key staff that covers the lifecycle of the equipment, from installation to decommissioning. Preventative maintenance is required for mission-critical transformers. This equipment requires multi-gas real-time monitoring to detect insipient faults and to provide immediate data on what is causing the fault.

Overcoming Barriers

Organizational barriers

Your organization is set up to run very efficiently. Things don't get done unless there is a standardized process and everyone in the system not only knows their role, but also excels at it. Organizations are structured in this way because, for productive operational processes, it makes sense to be as effective and as streamlined as possible. What organizations are not set up for, however, is cross-departmental and cross-hierarchical sea-changes in culture. Every challenge I've laid out in this list is about communication, and each can be met, challenged, and overcome if we get everyone on the same page.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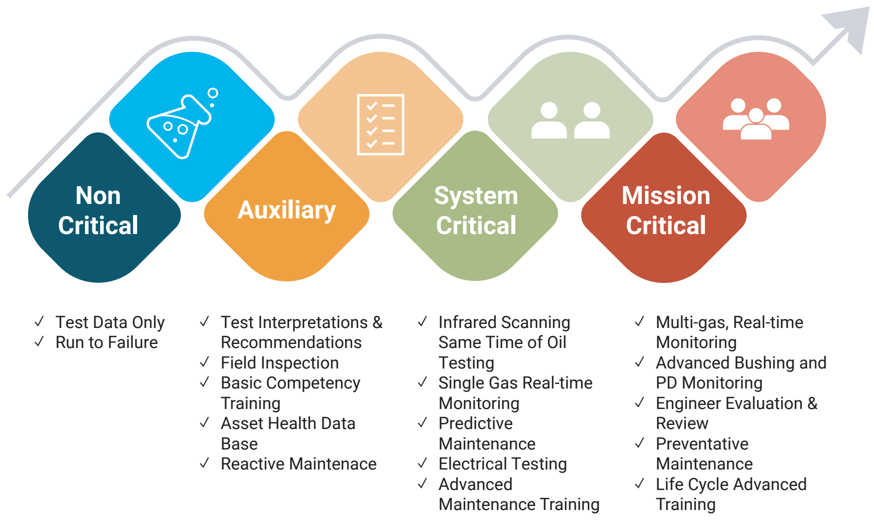

Figure 2. Best practice for transformer reliability should be based on criticality, history, and risk

Anyone who is not part of the solution could potentially be a barrier. In Figure 3 I show everyone who can influence the process of culture change in terms of electric power reliability. I'll focus here on the challenges with Procurement versus Purchasing, why it's important to involve IT from the beginning, and the benefit of using Risk Management professionals to lend expert credence to the concept of electric power system reliability. In my experience, these areas are where many of the major barriers arise.

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Procurement vs. Purchasing

One of the main challenges is the difference in the way purchasing and procurement people approach solutions. Purchasing people tend to be interested in one thing: lowest price. Procurement people, however, are interested in acquiring the best solution for the problem. We need to ensure that the procurement people become part of the reliability team, because their influence will impact the plant management and E&I people more than anything. I've had a lot of success bringing procurement people in and involving both procurement and purchasing in the process from the outset.

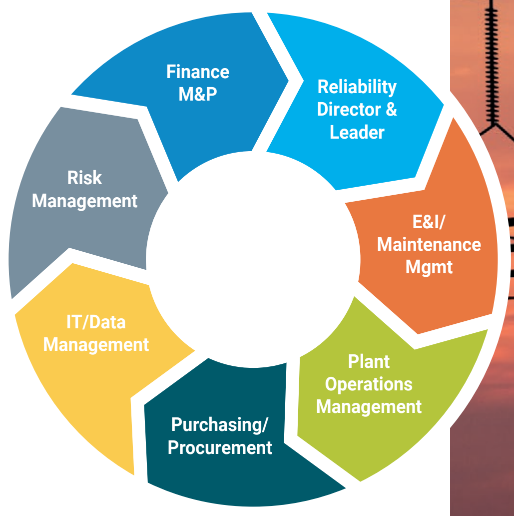


Figure 3. Organizational barriers to overcome to Develop electric power system reliability

In one meeting we had the procurement and purchasing people together in the same room, and we were discussing how to approach securing $1.2 million for the maintenance required to bring the electric power system up to speed. "Could you get that approved in date in one year?" I asked, and the procurement person looked to the purchasing person… who immediately said "no."

"How about if you did that over three or four years, at around $300,000 or $400,000 annually?" That response came back almost as quickly as the first: "Absolutely."

I like to work with the procurement person from the very beginning and include purchasing in the discussion. Procurement is looking for the best solution, not the cheapest price, and not a solution that just meets specs. Involve both teams from the outset when you can.

Photo: Shutterstock

Information Technology
The minute that you start talking about monitoring - IT must be involved. Part of their responsibility in your operation involves cybersecurity, so there's a natural tendency here for more cautions professionals to say that monitoring can't be done securely. But it can be done, and it is being done all across the industrial world. In fact, it must be done to effectively protect your electrical assets and prevent unexpected failure. Convincing IT of this isn't difficult once you start the conversation, but you have to involve them in the process from the beginning—you can't just spring it on them at the end. With communication and involvement, they become part of the solution rather than a challenge to overcome.

Risk Management
At some point, risk management will get involved. Whether that's the insurance expert that comes in and walks through the plant as a consultant, or whether it is your own internal risk management expert, at some point they're going to need to be brought in to the project. Risk management professionals are an excellent resource when you're trying to bring about culture change because they can bring the awareness and understanding of the real risk of not investing in reliability and deliver it right to the C-suite.

TTWWHADI
One of the biggest barriers we face is not with the data or logic of the concepts we lay out, but with mindsets. People often prefer the tried-and-tested way of doing things. We affectionately call this resistance to change "TTWWHADI"—or "That's The Way We Have Always Done it." Plants are run by experts, and maintenance teams have followed processes that have kept production at peak efficiency for years. Communication here is once again essential. They haven't been doing it wrong; the success and strength of your operation is testament to a job consistently well done. But with critical electric power systems, there are ways to protect that efficiency that go way beyond the current mode of thinking. Changing hearts and minds might be the most challenging barrier to overcome. But it's an essential one.

Fear of loss of jobs
When new processes challenge TTWWHADI — the standard way of doing things — the first assumption for many at the plant level is that technology will replace people. Far from it. We're in the business of maintaining production and profitability, not removing expertise. The most important aspect of any reliability program is wisdom, and we need to communicate this from the beginning.

Fear of loss of control from plant to corporate
Plants managers own their PnL, and I've experienced a reluctance from plant managers to allow corporate decision-making to impinge on that metric. This reluctance is almost always assuaged when we can show plant managers that a transformer reliability program is in their best interests. A reliable electric power system means that a plant can continue to operate at peak efficiency and maintain its profitability.

Again, the importance here is in communicating the value of long-term system reliability over quarterly figures. This is a delicate balancing act that requires involvement from all levels during reliability discussions, and a focus on collaboration rather than working in silos. For us, silos are a constant fight. The only way to overcome them is by communicating.

Flavor of the month
When an organization decides to make significant process changes, such as implementing a transformer reliability program, it's important to emphasize across the entire organization that those changes represent more than a just a novel way of doing things; they represent an organization-wide culture change. Buy-in is essential, from the boots on the ground at the plant level to those in the C-suite. If reliability is seen as another "flavor-of-the-month" from corporate, rather than as real culture change, there will always be friction and resistance. Get everyone involved from the beginning and make the expectations clear to all.

Buy-in is essential, from the boots on the ground at the plant level to those in the C-suite. If reliability is seen as another "flavor-of-the-month" from corporate, rather than as real culture change, there will always be friction and resistance. Get everyone involved from the beginning and make the expectations clear to all.

Unclear expectations
If we know that silos stifle the implementation of electric power reliability programs, then it stands to reason that they will also create confusion if expectations are not communicated thoroughly across the organization. In an organizational structure that is scaffolded around efficient processes, it's imperative to make sure that everyone knows their role. The concept of culture change begins with laying out expectations at every level. Who owns the asset and what is the current state at the start of this analysis? Who is committed to support the effort? How are they committed to it? Are you going to have monthly meetings? There must be a team with representatives from every part of the organization to ensure expectations are stated, communicated, and met.

Unrealistic time frames
If a problem has developed in an electrical system over a timeline that is measured in decades, it is unrealistic to expect that the problem can be resolved in a matter of months. The focus should be on criticality and deciding which issues are most important to resolve.

You can't solve these problems overnight. Transformer reliability—and, by extension, electric power system reliability—is achieved through the execution of a long-term strategy that is based on standards. SDMyers has developed standards for transformer health, and we've worked alongside companies that specialize in cables, relays, and breakers, each of whom have developed standards based on their respective sets of data.

These long-term strategies require multi-year budgets and an appreciation of lifecycle management. From purchasing through monitoring, inspection, maintenance, and repair, it's important to note that a multi-million-dollar electric power system reliability program is more cost-effective than a plan that involves massive capital expenditure every few years.

Conclusion

There are challenges to overcome to develop electrical system reliability, and most of them involve communication between either the solution provider and the organization, or between silos within the organization itself. It is first important to define what the real risk of failure is, and this can be illustrated by developing a criticality ranking by asset class. Use past and current data (or gather additional data if you don't have recent and accurate information) to prioritize the current needs of the equipment based on that ranking. Develop long-term standards using unit criticality, failure impact, current condition and rank each unit for priority service and next step. Create a multi-year maintenance budget and a plan to extend the life of these assets and minimize downtime losses. Create capital budgets over a 3- to 5-year timeline to maximize ROI and minimize downtime losses. During this process, ensure that everyone involved is aware of the risks of doing nothing, and that decisions made during this process will impact not only medium- to long-term reliability, but the entire culture of the organization.

Transformer reliability—and, by extension, electric power system reliability—is achieved through the execution of a long-term strategy that is based on standards. SDMyers has developed standards for transformer health, and we've worked alongside companies that specialize in cables, relays, and breakers, each of whom have developed standards based on their respective sets of data.

Andreas Schierenbeck

HITACHI
Inspire the Next

Photo: Hitachi Energy

Today, the renewables are often far from consumers, making the grid essential. That is leading to huge investments and growth in the industry.

Hitachi Energy

CEO of Hitachi Energy

Interview with **Andreas Schierenbeck**

GI - GPQSS GPG - SVC Light® Transpower in NZ_2023_04

SVC Light® STATCOM for Transpower in New Zealand

GI - HVDC GPG - HVDC Light® Valve Hall (Skagerrak) Interconnection Denmark Norway

High-Voltage Direct Current (HVDC) Light® Valve Hall Interconnection in Denmark and Norway

HV_Digital_Services

A service engineer performing on-site support using a digital kit to provide customers with efficient and swift resolution.

Photo: Hitachi Energy

Alan Ross: Andreas, it's good to meet you. Thank you for doing this interview. My first question is: what is your background? Talk a little bit about your industry background and talk a little bit about your career arch that got you to this point.

Andreas Schierenbeck: To keep it short, I'm an electrical engineer. After university, I worked at Siemens in the T&D business for about 15 years starting with software for control centers and SCADA EMS systems to substation automation, protection relays, control center for distribution systems - actually everything that was there in the industry. Then I switched from T&D to the building sector. That was the first points in time when we talked about smart grids, having consumers like buildings - more flexible, integrating renewables on buildings, on campuses, etc. I spent 10 years in that - optimization of buildings, CO_2 avoidance, energy performance, saving contracting… Then I switched to the elevator sector where I spent seven years. Not so energy related because what goes up, goes down - highly efficient, but a strong focus on digital and service in the industry. I led Uniper for 3 years, one of Germany's largest utilities. A lot of generation - around 45 gigawatts of installed base in Europe, UK and Russia - all types, from lignite, hard coal, hydro and nuclear - the complete portfolio and the trading desk. After that, I spent three years in startups around green hydrogen, solar and electrolysers. Now for nearly a month, I have been with Hitachi Energy.

AR Great, so you're an engineer. You know how engineers are, we are like the Marines. We run to problems, not away from them, because we are problem solvers. You have been around the industry, both on the utility side, on the supplier side, and on the smart building side, so what do you think are the biggest challenges the industry is facing right now? What are the key issues you'll need to tackle in your new role at Hitachi Energy?

AS I think that's a complex question because there are issues and then there are also many positive things. I remember when the market was flattish, with little growth, and everything was predictable and easy-going. If you needed some equipment, you asked for it and got it in four weeks, but times are now different from a lot of perspectives. We were all talking about the energy transition and changing things - this is now really happening, and this is changing the way we behave and how we're doing business. The reasons for that are quite a few.

First of all, we see more demand because there's a lot of electrification with CO_2 abatement driving that, which could address up to 80% of the issue. The other 20% is probably molecules - green hydrogen, green derivates, but we will definitely use more energy. Along with that we need more renewables which also means more problems because they are volatile, and volatility is driving what we're seeing today. It's volatile during the day, during the year and storage solutions have to be managed and installed. The grid is playing a completely different role from maybe 20 or 30 years ago, because as I see it in former times we had power plants built near large consumers, and the grid was there as a backup to provide power in case something happens but the grid was not that essential. Today you're building generation where you have renewables. Offshore wind and very sunny areas that are very far from the consumers, so the grid is becoming more and more essential.

So, you now need long-term transmission, and you need to deal with volatility, you need storage, and that drives how we operate grids and assets and how we're installing it. That is leading to huge investments which is leading to growth in the industry and just managing the growth is a challenge by itself because we have not seen, as an industry, growth for a long time.

> **Today, the renewables are often far from consumers, making the grid essential. We need long-term transmission, and we must deal with volatility, which drives how we operate grids and assets. That is leading to huge investments which is leading to growth in the industry and just managing the growth is a challenge by itself because we have not seen, as an industry, growth for a long time.**

AR You have nailed it Andreas. Something that is positive is also creating something negative. For instance, the U.S. Department of Energy did a study showing that power problems are costing the industry over $100 billion annually, in the U.S. alone, due mostly to increased transients from DER. Change begets all kinds of issues. You've been at Hitachi for 30 days. Hitachi has gone through a lot of change recently with the acquisition of the Power Grids division of ABB. What did you expect and what are you finding that you didn't expect?

AS It was a positive surprise to see the portfolio - being market leader in HVDC, which is very much needed for these changes at this time and having very good solutions for SF6-free equipment in the market. I know that we are the market leader in a lot of areas, but this focus on sustainability and problem solutions going forward was really a good thing to see.

AR Larger utilities, and now even smaller ones, are looking for trusted solutions and trusted companies to bring a larger portfolio of solutions. That is what Hitachi brings to the equation, as you mentioned. For instance, in California, they're realizing that they used to have rate payers, then they went to consumers, and now they are prosumers. How do you see Hitachi preparing for all these challenges and serving a changing industry at a time where the demand on suppliers is increasing as the demands on the utilities are increasing?

AS Being a part of Hitachi is an advantage because it brings the financial firepower to run big projects. We are talking about massive investments that drive growth which is good. Of course, if you look from the financial side, yes - I am an engineer, but I have a strong financial background and I know exactly how banks are looking at that. All the covenants you need, all the bonds, all the financial firepower that is needed to do that. With Hitachi, it's great to bring that to the game. This is needed because you're not investing significant amounts of money if you're not sure and confident that you're in good hands. We are able to deliver all these projects as Hitachi; we are backing them up with a lot of investments and it's public news that we are investing $1.5 billion in just the expansion of transformer factories and another $4.5 billion for the rest of it. I don't think the industry has seen so many periods of time where the question was, 'how do I spend all the money and how do I do it quick and increase capacity'.

AR I'm glad you said transformers because I have transformer oil in my blood. Without transformers you can't bring about all this change.

Let's also talk about data centers: they have huge power demands and need exceptionally reliable power and need 5-9 reliability, 99.999. At the same time, they're not willing to do triple redundancy anymore, but rely on reliability, resilience and suppliers who can provide consistent power to manage data. What is the impact on data centers and what is Hitachi doing to approach that market?

AS We have a strong focus on data centers as Hitachi because we bring a lot to the table. On the other hand, it's worth mentioning that the trend toward data centers was probably not really the first thought everybody was thinking about. A small datacenter with 5 to 10 megawatts was neglectable, but now they're growing and consuming significant amounts of energy, and the growth curve of data centers is completely different from the growth curve in the traditional business, so it was completely underestimated, especially now with Generative AI. These data centers are bigger, and they have a completely different load behavior. When they start to learn, the energy consumption goes up in seconds, and if they stop learning, it goes down so it's a completely different animal.

> **We are striving for standardization because if every data center is built different with a different approach for redundancy and reliability, it will be a constraint to growth. Data centres need reliable and available energy, without relying on triple redundancy.**

We are striving for standardization because if every data center is built different with a different approach for redundancy and reliability, it will be a constraint for growth. We have to work together with the data center providers and our customers, the utilities, on how we tackle the issue because data centres don't want to have triple redundancy - they don't want to deal with that - they just want to have the energy, always readily available. But they're now too big to fail, but on the other hand, too complex to ignore them.

AR Let's move to another subject of change - electrification of transportation. It is perceived to be in a slowdown, but we have

Photo: Hitachi Energy

HV_Factory_EconiQ_DTB

World's first eco-efficient EconiQ™ 420-kilovolt Dead Tank Breaker (DTB).

Hitachi_Energy_South Boston_factory_Power_Transformer

Hitachi Energy large power transformer at South Boston Transformers factory, United States.

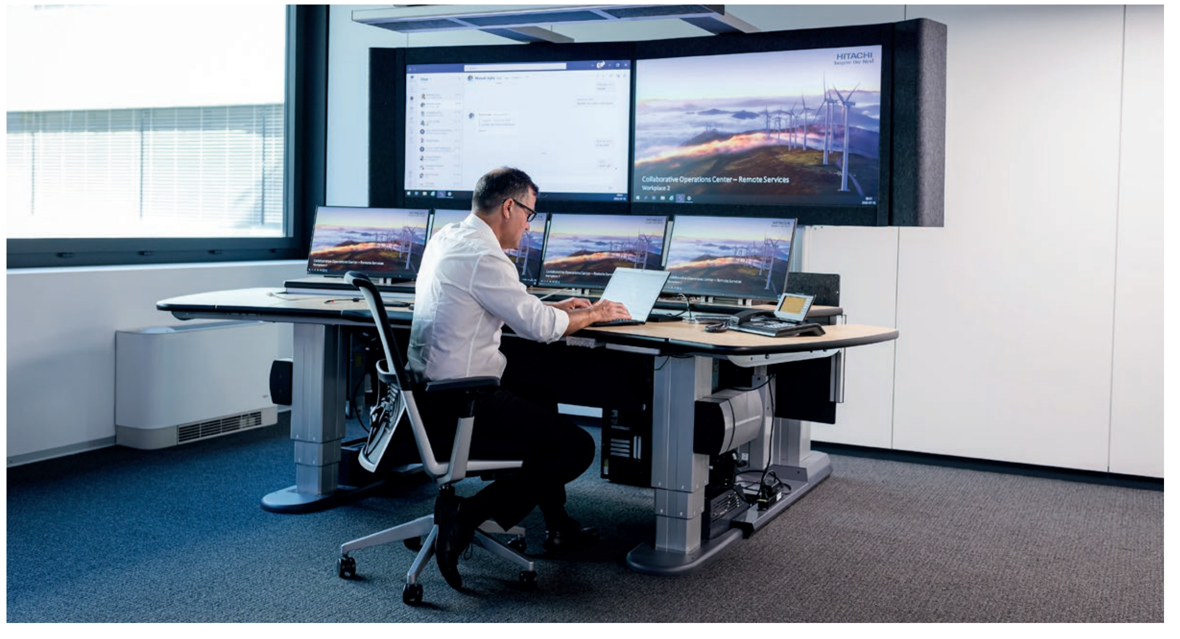
Hitachi_Energy_Project_Mutkalampi_Finland

Hitachi Energy power transformers in Mutkalampi, the largest wind farm in Finland.

Dubai Airport Control Room – Network Manager

Network Manager enables advanced automation and reliable, efficient power supplies for the world's busiest international airport, Dubai International.

Collaborative Operations Center – Baden



A Collaborative Operations Center (COC) expert in Baden, Switzerland provides remote services for customers' Grid Automation solutions installed base.

SEV Faroe BESS

A view of Hitachi Energy's battery energy storage system (BESS) in the Faroe Islands that provides full backup for SEV's Porkeri Wind Farm.

Photo: Hitachi Energy

a lot more manufacturers, so in reality car sales are more spread out. Large-scale electrification, buses, trucks, all those things are happening as well. How is Hitachi Energy approaching the electrification of transportation?

AS I think it's a very complex issue. Let's put the problem into different buckets. If you are a city running your collection trucks or your buses, you have to take a decision whether you go electrically or you go for hydrogen. It's probably manageable because these cars, trucks and buses come back every night to the station and get charged. However, for long-distance transport and 40-ton trucks, it's a different story. Firstly, the technology is still open and on the other hand replacing a normal gas station with electrification, we're talking about adding a small city at every gas station where you want to have them charged. This is definitely a completely different investment case and challenge because this means you have to invest heavily into the infrastructure and that's completely new. And I'm not talking about all the complexity coming with the charging behavior and DC charging. You need a couple of different layers to optimize that.

AR The US government and the DOE has announced a lot of infrastructure build, but it might be too little too late, at least in the short run. Even if you invest billions of dollars in it, without more people buying electric cars, it is a zero sum game. You also mentioned hydrogen. We may think we might have skipped electrification and moved to hydrogen power, but we didn't. We moved first to electrification and then hybrid.

Are electrolyzer fuel cells viable now? Why does it work and what's Hitachi going to do about it?

AS Where I'm coming from, if you want to decarbonize, you must go for electrification first. That will bring a big part of the solution to the problem, but there are big parts that you can't decarbonize with electrification. First of all, you need high temperature applications, or you need chemical molecules such as kerosene for jet fuels, where you need hydrogen and that can only be replaced by molecules so there is a niche for hydrogen there.

Then, when you add more renewables into the system, you have volatility. How we're dealing with volatility today is that we are switching it off and having re-dispatch costs which are billions in Europe and in Germany, because you can't transport that. So, using surplus energy and making a molecule out of it which you can store - can be hydrogen, could be something else, but at the moment I only see hydrogen because the technology is there - has a lot of advantages. You take these peaks of energy which you are wasting today, transform that into green hydrogen that can be stored or used to make derivatives and used later for electricity generation or for transportation and that goes hand-in-hand. With renewable electrical energy alone, we will not solve the equation.
You need green electrons, and you need green molecules.

AR "Green electrons and green molecules" should be copyrighted! I love that! Whether you're storing power or hydrogen, utility-grade storage has not been there. We are wasting a lot of power that we generate when we can't use it. How do we then build up this massive storage? Every car, truck and bus is not only a vehicle, but a storage mechanism. What is Hitachi doing and what are you looking at as the emphasis on storage?

> **You can have the product portfolio, the best market, but if you have the wrong culture, it's worth nothing because the financial plans will not work out. So, the culture is actually the enabler for growth and for success in everything, for your company, for your customers, and for the society.**

AS We are the enabler for the storage whether it's hydrogen, electrical or battery electric systems by making the grid ready for plugging in these systems. And of course we have milder level approaches, from my point of view. It makes a lot of sense to put batteries beside big solar or wind parks for storing energy but will only be optimized for a day and not more than that because batteries should be charged and discharged quite frequently. Long-term storage is not viable. From that point of view, hydrogen can be stored. We are also focused on enabling prosumers which is a challenge we are addressing. So, we are enabling the distribution networks where everybody can store energy in their electric cars or draw on it or set up their own solar system which needs automation and enablement.

We are not developing our own electrolyzers or our own batteries, and not going into the green molecule area, but the enablement for that where you can plug and play and stabilizing the network is what we are doing.

AR You are a prosumer yourself. Fortunately, you're coming into Hitachi Energy at a time when you can help lay out that culture because so much has changed. Could you say a little bit about the culture you are envisioning for Hitachi Energy?

AS First, I have to learn about the culture which I find - less than 30 days is probably not enough to assess the culture we have. From my point of view, culture is one of the most essential ingredients for growth or being successful in business. You can have the best product portfolio, the best market, but if you have the wrong culture, it's worth nothing because the financial plans will not come through. So, how you interact with your colleagues, people, and customers - what are the ways you are sharing, is quite essential for being successful. Especially in a time of growth - especially if you are not used to growth, this would mean that we have to move away from a strictly hierarchical system to a more open, flexible and federal system to manage the growth, like in a start-up actually, where I spent the last three years. In a start-up you cannot define all the processes, and if you don't trust your colleagues next to you, it could end in disaster. So, the culture is actually the enabler for growth and for success in everything, for your company, for your customers, and for the society.

AR One of the things you are inheriting is the collaboration environment at ABB. We did an interview with Dr. Luiz V. Cheim, Senior Principal R&D Engineer within Hitachi Energy's Transformers BU who developed the TXplore™ transformer inspection robot. It took four years to develop in four different departments. That is an incredible value that a company has - to be able to bring different departments together. What are some of the other values that you would point out for people to understand?

AS Values is an interesting topic you have to first find out what values you have already and which are the values you want to develop. We have a great culture because we are a successful company, but we now have to adapt to change, and that makes it difficult.

Because the way we have done things in the past - cost controlling, being very cautious, managing cost quite carefully because the market was flat - was decisive. Managing that in an area of growth is different. You have to be a little bit bolder; you have to look to more collaboration, exchange of communication, working together at an even bigger scale, and also look for new solutions. In the last 15-20 years the portfolio was mainly flat. You know what you have to do, you know how to run your network, but now we have a lot of unknowns. To discover those unknowns, you need a special skillset and mindset of being that explorer - going there together with your customers because they don't know the answers completely neither - there is no state-of-the-art solution.

> **Being open for new solutions, being brave enough to try and test that, and to use everything that we have at hand with our customers, that is a huge challenge because it is transforming the things you are doing.**

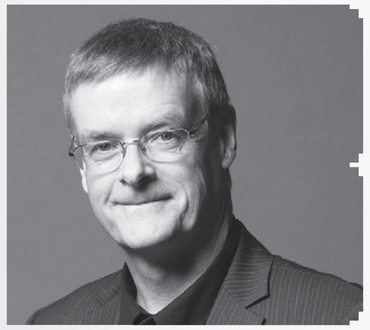
Talk about inertia. If you have more renewables, you have less rotating masses, you have more problems with voltage and frequency behavior. So how do you deal with that - in a mechanical way, with power electronics or through some other ways? Being open for new solutions, being brave enough to try and test that, and to use everything that we have at the hands of our customers, that is a huge challenge. It is transforming the things we are doing, and every transformation is change and change is normally what people don't like. Nobody likes change, because it means leaving your comfort zone and that's not comfortable. Having that culture and HR values that says we are here to leave our comfort zone to try something new for the betterment of society, customers and the company is probably the biggest model, from where I stand.

AR That's excellent. Collaboration, innovation, communication, boldness, adapting to change and Customer-Centric are the values you have mentioned. Thank you very much Andreas. It has been a pleasure.

AS Thank you Alan.

Asset Managers and Technical Experts: Divided by an Uncommon Language?

WHAT A DELIGHTFUL THING IS THE CONVERSATION OF SPECIALISTS



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.

Edgar Degas
"The Dance Foyer at the Opera on the Rue Le Peletier"

Tony McGrail Doble
Engineering Company's Solutions Director

Photo: wikipedia

Quotation Central

The famous artist, Edgar Degas, probably had it right when he said: *"What a delightful thing is the conversation of specialists!"*

Which sounds good on its own as a statement, as specialists do get passionate about their specialism [1]. But Edgar went on: *"One understands absolutely nothing, and it's charming."*

What Edgar is saying is that we may nod appreciatively as we know the specialists are talking, communicating, whatever… but do we have any idea what they are really saying? Likely not…

And there we have the essence of the communication problem: how do we ensure our message is getting through as intended? That it means the same for the receiver as it does for the sender? In terms of managing technical assets, I believe it was the Australian engineer John Hardwick who put it most succinctly [2]:

"The role of the asset manager is to talk technical to technical people and to talk finance to financial people, and be able to translate for the two groups."

Simple Examples

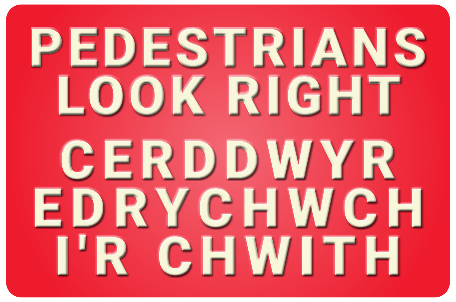
There is a requirement in Wales that road signs are in both English and Welsh languages as shown in pictures [3]. Welsh, English, and place names in Welsh do not need to be translated – and there are two in picture 1. (Quite how one is supposed to pronounce the place names is a separate challenge…)

Picture 1: Welsh/English Roadsign

And a famous example of the need for 'someone' to understand both languages is given in picture 2. The local authority was putting up a new sign to restrict large vehicles from entering an estate and needed a translation into Welsh [4].
So, they sent the text to their inhouse translation service, and the service responded with the Welsh you see below in the sign: text used as received to make sure there were no copying mistakes… Unfortunately, the Welsh actually says: *"I am not in the office at the moment. Please send any work to be translated."* The sign was taken down within days. Nobody involved in the production of the sign seemed to speak both languages.

Picture 2: English/Welsh Roadsign

Amusing though the road sign may seem to be, there are cases where a mistranslation could, in practice, be dangerous. Take the sign in picture 3: if you speak just one of the two languages there is clarity of message, however, if you speak both you'll know that the Welsh actually says "Pedestrians Look Left", which is the exact opposite of the English [5].



Picture 3: English/Welsh Instructions for Pedestrians

And that mistranslation could be highly dangerous: what if you cross a busy street having looked the wrong way?

The Curse of Knowledge

If you have ever played the game 'Charades', a miming game where one participant tries to act out silently the title of a book, or a song, or a movie… it can be SO frustrating when it's perfectly clear in your own mind how your actions relate to the words of the title, but the audience are 'just not getting the message'. That is known as 'The Curse of Knowledge' in that the audience doesn't know what you know, or at least hasn't made the connection yet [6].

A similar effect was seen in a game run at Stanford University where one person, the 'tapper', tapped out a specific and well known tune using a pencil tapping on a table and the other person, 'the listener' tried to guess what the tune was [7]. The tapper was asked what percentage of the time they thought the listener would be successful, which they estimated to be about 50% of the time. In practice the listener guessed correctly about 2.5% of the time. Why were the estimates from the tapper so poor? Because they have the tune in their heads, and once you know something it's hard to 'not know' it, and that means we tend to assume that the listener will also know it. That, once again, is the curse of knowledge. In the business world, managers and employees, marketers and customers, corporate headquarters and the front line, all rely on ongoing communication but suffer from enormous information imbalances, just like the tappers and listeners. Leaders can thwart the curse of knowledge by "translating" their strategies into concrete language. What do we mean by 'concrete'? Common, well understood and agreed terms, with continual feedback to make sure they are common and well understood.

One thing that may bring the curse of knowledge into focus is a review of high school lesson effectiveness: teachers who present lessons almost invariably overestimate how effective the lessons are compared to the students who receive those lessons!

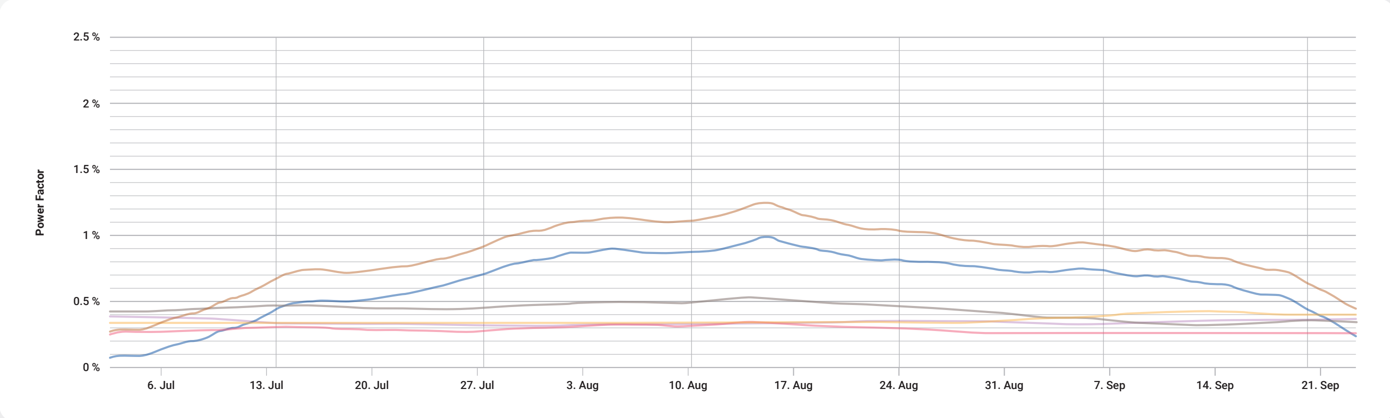
The cases presented here are both real and practical: when living through the events at the time, with both uncertainty and without the benefit of hindsight, decisions are often complex, and outcomes unpredictable.

Alerts/Alarms May Be Straightforward, but Context Is Important

There's a difference between condition monitoring for 'detection' and condition monitoring for 'diagnostics': the former seeks to identify that we have 'a problem' while the latter seeks to identify also what the problem is. In both cases, contextual information is important.

Take, for example, a domestic fire alarm going off at 8 in the morning, while breakfast is being prepared, and someone is making toast… do we call the fire brigade immediately, or go check the state of the toast in the toaster? Likely the latter: the condition being monitored is smoke and the toast is, well, probably toast. What about the fire alarm going off in a hotel at 2 a.m.? My response would be to leave immediately – probably taking ID, wallet and laptop with me as they're light, and an overcoat in case of rain/snow. And, yes, this has happened to me several times (not always at exactly 2 a.m.) and

Photo: wikipedia



Bushing Power Factor Deteriorates, and then improves?

I am always surprised that I leave my room and see other people, heads poking out of their doorways, asking the question "is it a real alarm?" Well, I don't know, but the downside of staying where I am in my room may be so bad that I'll go with the discomfort of leaving the hotel via the fire escape and standing outside for a while, waiting for the all clear.

Fire alarms are almost always a detector of particular conditions but they can 'communicate' that they have found something, and we do well to 'listen' and act, but context is important in our response.

And what if we have a rising trend for Hydrogen in a power transformer through an online DGA detector? Hopefully, limits for alerts/alarms were agreed and implemented when the monitor was installed, limits which reflect both industry standards for DGA levels and our expectations for this particular unit. And hopefully, there is an agreed response plan for every alert/alarm from every monitor on every asset… and we 'just' follow the plan. That would be 'ideal'! Everyone knows what the monitor does, what the alert means and what the interventions will be, from the technical folks who make recommendations to the spreadsheet/finance folks who make decisions. Unfortunately, it doesn't always work like that in practice and the limits aren't agreed/set well, and the response plan isn't detailed, and if it is detailed it may not be followed. To get the best from a monitor we need to understand what it does, and what the data means and have a plan which is agreed by all stakeholders and followed: and someone needs to know what's going on [8]!

But It Got Better!

What happens if an alert comes in from an online bushing monitor, indicating that the power factor of a bushing is rising gently [9]? Again, hopefully, there is a plan of how to respond – usually to take the transformer offline and test the bushings to confirm the readings. An outage is planned, but before it happens, the bushing seems to improve: the power factor is falling gently, back towards an acceptable value! A non-technical decision might be that as the readings have recovered, there is nothing to be concerned about as the monitor is no longer giving an alert. A technical decision would more likely identify a scenario whereby the deterioration has continued but changed character and there is now an internal tracking on the surface of the conductor within the bushing. But how to convince the asset manager that the monitor is perfectly OK, but taking the readings at face values means we are deceiving ourselves. Someone has to know what is, or may, be going on. But how do they communicate that successfully to someone who knows very little about bushings?

Asset Health Indices (AHI) and Data Compression

An AHI compresses available data down into a simple index or code which is used to support decision making. In compressing data we lose a lot of information in the hope that the benefit of said index outweighs the loss [10]. To start with: what question does the index address? Is it for asset replacement, maintenance, refurbishment or something else? How does the index address this? What does the index mean? So, let's take an example where we have an index based on an analysis of available data which assigns a percent health score with 100 being perfect and 0 being the opposite: no health at all. What would 60% mean? Is that a 40% chance of failure? In the next week? Month? Year? What is the raw data which means that we have a less than perfect specimen? Knowing the index tells us very little about the asset, unless we can dig into the data, the analyses and the algorithms, and work out what it means in practice: detection of a problem and diagnostics thereafter.

An AHI is not the asset itself, it is not even the true condition of the asset, it's a model of the unknown value, 'asset condition', which has its own imprecision and inaccuracy. It was the late Tom Rhodes of Duke Energy who said [11]: And there lies the problem: the technical interpretation of an AHI comes with an understanding of the inherent imprecision, the likely inaccuracy, and the need for interpretation of any index because it is a model of the asset. And as all models are wrong, and only some are useful, we need to know how far wrong our model is before it becomes unacceptably wrong [12]. To quote "The map is not the terrain", or maybe "the chart is not the patient"… [13]. If we only know the numbers, and not where they came from, and how they are derived we may confuse the model and the asset, the map and the terrain.

If It's in the Red Box It Must Be Worse Than the Ones in the Orange Box

One big advantage of a risk matrix is the simplicity of the matrix itself: straightforward axes for probability and consequence, easy to interpret colors, sometimes with qualitative 'small – medium – large' categories rather than quantitative numbers we need to calculate with. Easy? Actually, not easy! If we use a risk matrix to communicate where we need to focus, which risks to address first, we may be sending exactly the wrong message.

To identify issues with communicating risk I'd suggest starting with "The Risk of Using Risk Matrices" as a discussion of how risk matrices can be misleading [14]. Also, a technical paper which shows how the matrix does not even prioritize risks based on risk magnitude resulting in more urgent situations being de-prioritized [15].

In the risk matrix shown in picture 4, the axes are given numerical ranges, which is good, but we can still be misled by the way the matrix works. Asset 1 has a higher risk magnitude, but falls in an orange box, while Asset 2 with a lower risk magnitude is in the red. Once we have that situation it is very difficult to convince someone that they should address Asset 1 first because it's in an orange box, and Asset 2 is red!

Asset 1: *Prob* 1 = 0.005, *Con* 1 = 900*k*$: risk mag: P1 * C1= *R*1 = 4.5*k*$
Asset 2: *Prob* 2 = 0.002, *Con* 2 = 1100*k*$: risk mag: P2 * C2= *R*2 = 2.2*k*$

Prob\Con(*k*$)	≥ 0, < 10	≥ 10, < 100	≥ 100, < 1000	≥ 1000
≥ 0.01				
≥ 0.001, < 0.01			A1	A2
≥ 0.0001, < 0.001				
≥ 0, < 0.0001				

Picture 4: Example Risk Matrix and inappropriate prioritization

And a famous example of the need fIt was Sapolsky who noted in a lecture that we, as humans, like to think in categories, and that comes at a cost: we tend to think that all things within a given category are similar to each other but also very different to things in other categories [16]. And it becomes very easy to inappropriately categorize risks with a simple colored risk matrix.

So, if we wish to communicate risk priorities from a technical point of view to a less technical audience, we may be in trouble if we use a risk matrix: especially if the matrix has qualitative values for axes rather than quantitative values as there is another layer of interpretation required. But even then – how do we know that our message is getting through? Sidorenko suggests managing risks individually and looking at the details of each one, rather than just putting them in boxes – at least then we are looking at the raw data and can see the precision, the accuracy, and the pitfalls of the colored boxes.

Good Decision, Bad Outcome?

The following case illustrates good communication relating in the way technical data was analyzed, contextual and industry data used to support conclusions, and a specific asset risk was managed by a cross functional team [17].

One of two Self Contained Fluid Filled (SCFF) transmission cables serving an urban station failed, putting the system at N-1 and the company at risk of having to shed load.
An analysis was performed using a cross-functional team to look at available data including, but not limited to: spares on hand, lead times of new replacements, second hand cable availability, condition of the present cables on the system.

With no spare readily available, the system was held at N-1 while a system study scenario-analysis was performed to help identify and plan mitigations should the second cable fail. In parallel, analysis of historic and industry SCFF cable data showed an annual failure probability of ~3.4%.

A replacement cable of XLPE construction was ordered, with extra spare cables for contingencies.
Three weeks later the second cable failed, bringing the system to N-2 and requiring network system operators to implement a mitigation, with back-feeding to support load and developing extra stress on a number of system assets.
The scenario analyses were good, the failure probabilities low, but the failure hazard was realized and had to be managed.

This is an interesting case as the cross-functional teamwork meant that any issues regarding communication of meaning, risk and analysis were identified early and addressed promptly. The team all had a common understanding that the probability of a second failure was low, and that 3.3% was equivalent to correctly predicting the roll of a 29-sided dice. The fact that the risk was realized meant that the mitigation plans were followed, and load shedding was not required.

Plan for the worst, and hope for the best, but a good decision can still have a poor outcome.

Discussion

We likely only know we have a 'failure to communicate' when something goes wrong unexpectedly. Confirming that a message has been received and understood requires continual checking and rechecking that, as they say, 'we are on the same page': we must do more than talk, we have to listen, and listen carefully.

A few years ago, while making an asset management presentation in the USA on power transformer assessment and ranking using heath indices, I realized that most of the audience didn't really know what a power transformer was – many of them were nodding sagely but I could tell: yes, they've seen my pictures and heard me talk about 660 MVA units, but these devices were still abstract to them. I had to make it 'real', make it 'concrete', something which they could relate to. So, I talked about big cars, like a GMC Yukon SUV which weighs about 2 tons… and imagine trying to push that to the top of the Empire State Building in New York City. That would take a lot of effort… and now imagine doing that with 99 more! Then dropping all 100 cars onto the streets below, resulting in a lot of damage when they hit the ground. That energy, which causes all the damage, is the amount of energy which goes through a 660 MVA transformer every second. The car analogy, and the work to push it to the top of the building made things much more relatable, more real, and I could see it in their response.

And one last quotation which really sums up the need to check and recheck that what we think of as clear communication is in fact clear; to paraphrase William Whyte, who also coined the term 'groupthink' [18]: *"The great enemy of communication is the illusion that it has taken place."*

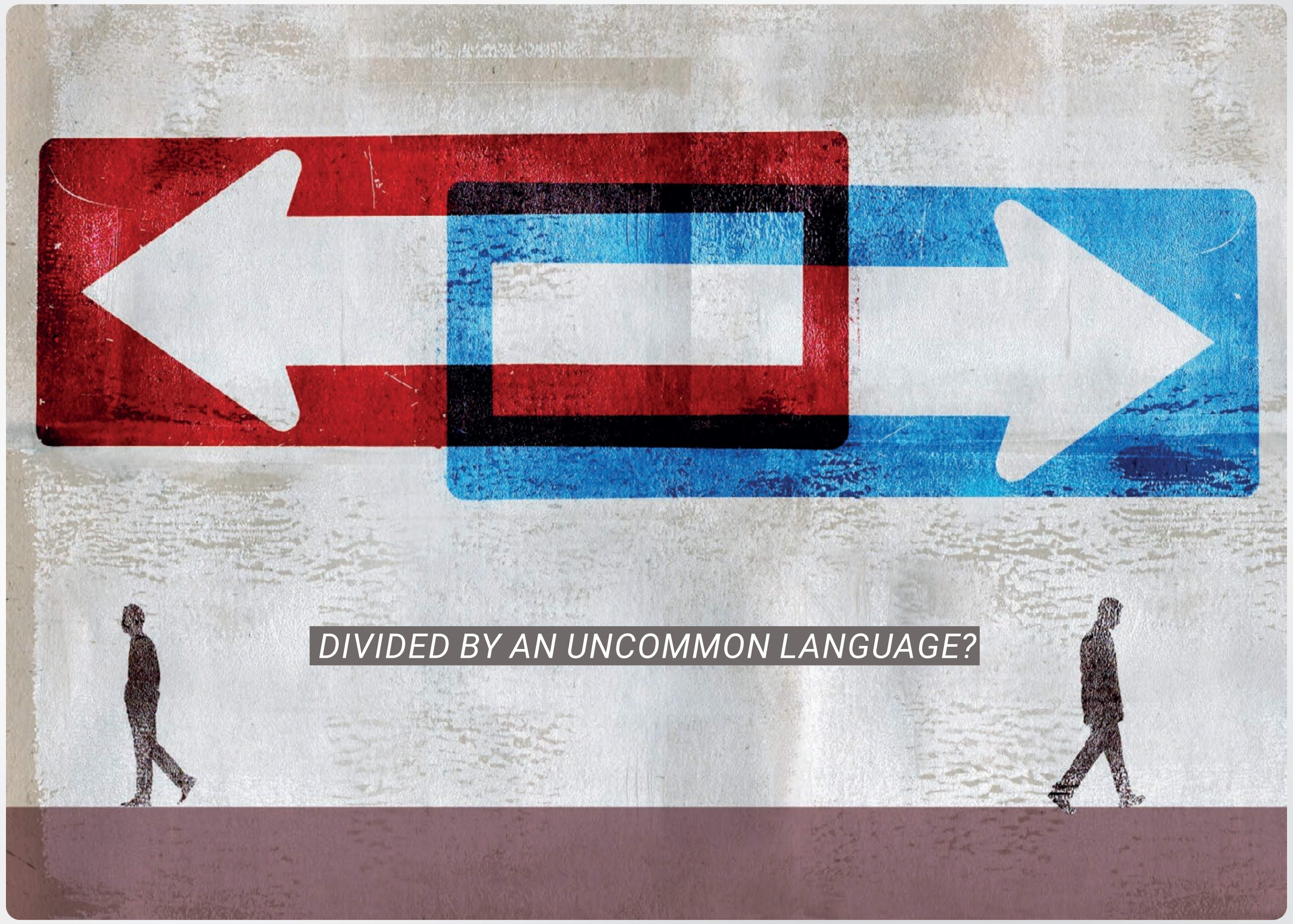


Photo: Ikon Images

Acknowledgments

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EXTEND THE SERVICE LIFE OF TRANSFORMERS

MAINTENANCE-FREE DEHYDRATING BREATHERS EXTEND OPERATING TIMES AND SAVE COSTS

Photo: Maschinenfabrik Reinhausen

Abstract

Power transformers are complex and critical components of power transmission and distribution systems. The continuous extension of operating times in conjunction with an ever-increasing current density impact power transformers and lead to increased demands on quality and reliability as well as a reduction in the life cycle costs of transformers and their accessories. Simple and practicable solutions are therefore required when converting and retrofitting transformers.

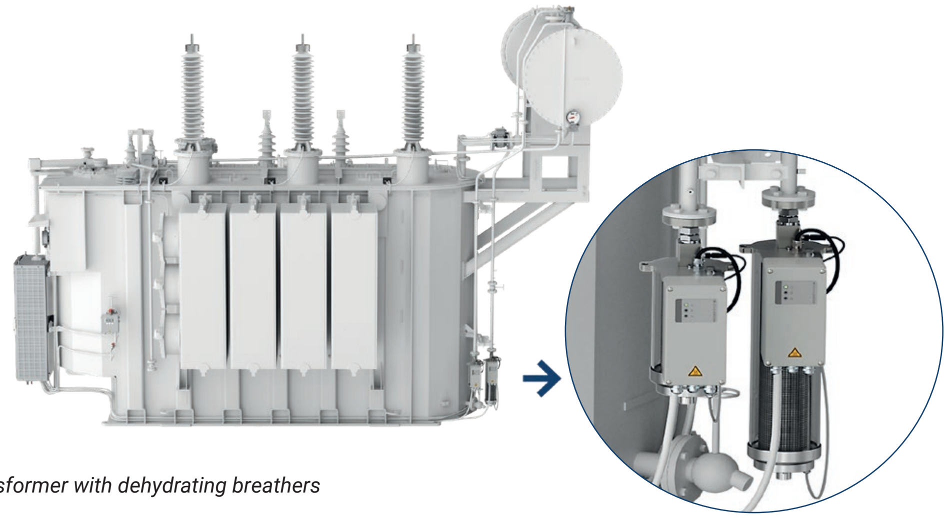
Comparison of a conventional (left) and a maintenance-free dehydrating breather (right).

The service life of transformers is closely linked to the service life of the oil-paper insulation system because if the mechanical stability of the oil-paper insulation is lost, there is a risk of electrical failure and therefore overall failure of the transformer. In addition to the influencing factor of temperature, humidity has increasingly proven to be an important catalyst for the aging process of transformers.

In order to ensure the longest possible service life, the primary aim is therefore to reduce this aging factor or to avoid its influence from the outset. These effects can be achieved through the use of dehydrating breathers for the oil expansion tanks which can therefore have a significant influence on the technical service life of transformers.

In typical applications conventional dehydrating breathers filled with silica gel are still used in many places today. The adsorption capacity of the desiccant is used up over a period of 3 – 12 months. The desiccant must then be replaced, as the silica gel will be completely saturated with water and therefore no longer able to absorb any additional moisture. Together with the disposal of the old and acquisition of new desiccant, the necessary periodic visual inspections and maintenance in regard to these breathers represent considerable cost factors.

In contrast, maintenance-free dehydrating breathers avoid frequent replacement of silica gel by measuring the humidity level of the air in the pipe system and forward the results to control unit. Thanks to a self-learning algorithm, the control system determines the exact time window in which the transformer "exhales" in order to regenerate the silica gel during this phase, then “bakes out” the absorbed water and thus makes the dehydrating breather ready for a new drying period. This system works autonomously, significantly reducing maintenance visits and the associated costs.

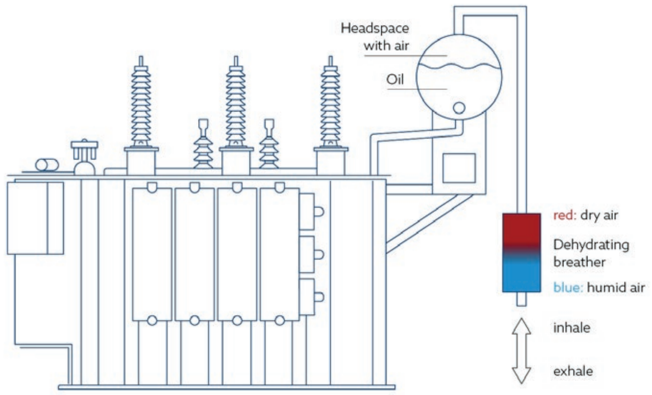


Transformer with dehydrating breathers

The Central Function of Dehydrating Breathers in Transformers

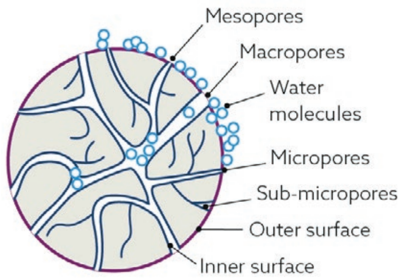
Moisture threatens the stability of oil-paper insulation and therefore the service life of power transformers. It is not only a component of the ambient air that meets the insulating oil in the transformer's expansion tank but is also itself an aging product of the insulation paper. The absorption of moisture follows the thermally induced cycles of expansion and contraction of the oil volume caused by operating temperature fluctuations in the transformer.

By design, each transformer has at least one expansion tank that is connected to the main tank to provide a compensation reservoir for the oil volume during temperature fluctuations. During these thermal cycles, efficient ventilation is crucial for controlling the changing levels in the expansion tank. Since the ambient air has a higher relative humidity than the insulating oil inside, dehydrating breathers are essential for dehumidifying the ambient air before it enters the expansion tank.



Typical setup for a free-breathing power transformer with dehydrating breather

Most transformers therefore make use of dehydrating breathers which contain silica gel to absorb moisture from the incoming air. The silica gel desiccant used in dehydrating breathers is characterized by its very porous structure which enables effective adsorption of water molecules. This high adsorption capacity with an internal surface area of several hundred square meters per gram makes it possible to effectively bind water molecules and remove them from the incoming air.



Typical structure of silica gel

Photo: Maschinenfabrik Reinhausen

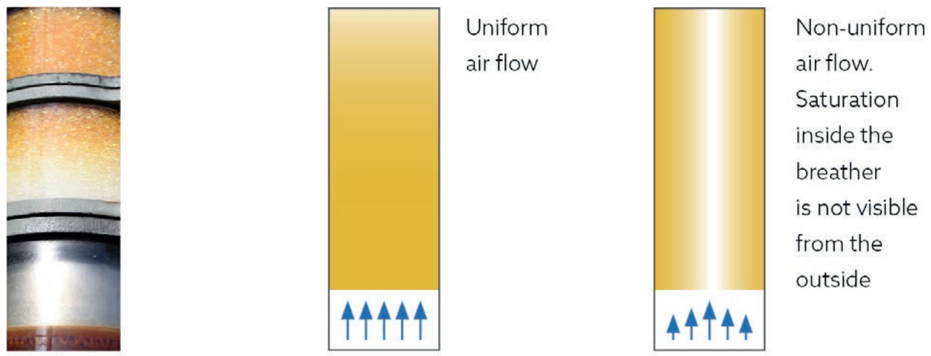
The water absorption capacity of silica gel is significantly reduced when around 15% of its own weight has been absorbed by water. It is therefore recommended that the desiccant in conventional dehydrating breathers is replaced when the color indicator changes from orange to colorless. This serves as a visual indication for the operator to change the silica gel in good time to prevent moisture from penetrating the transformer and avoid unnecessary maintenance costs.

In a typical free-breathing transformer, humid air flows from the outside via the de-hydrating breather into the expansion tank of the insulating oil. In the inlet area of the dehydrating breather, the air reacts with the silica gel, which adsorbs the moisture. This interaction causes the desiccant in this area to become saturated more quickly. Over time, this saturation zone in the dehydrating breather expands further.

The silica gel should be replaced at the latest when the color changes by 2/3 of the column in order to prevent unacceptable moisture from entering the transformer. Furthermore, an uneven color change in conventional dehydrating breathers generally indicates leaks between its individual chambers. Since the air flow through the dehydrating breather is often not uniform, the silica gel inside can become saturated and therefore no longer be able to absorb moisture even though this is not visible from the outside.

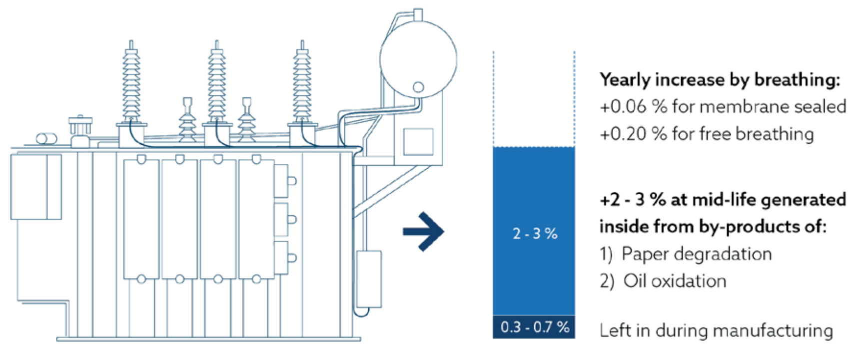
A color change starting from the top indicates that the insulating oil has already reached high relative humidity values due to the degradation of the paper and possibly late maintenance of the dehydrating breather and indicates that the transformer exhales moisture when heated.

Conventional dehydrating breathers with color change from orange to colorless



Conventional dehydrating breathers with non-uniform air flow

Percentage of water by dry weight of paper accumulated over transformer lifetime



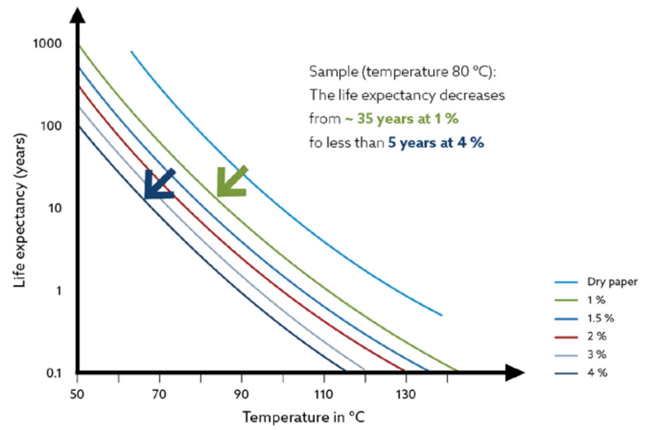
Overview of typical sources of moisture in a transformer [1]

Why Moisture in Paper Insulation Reduces the Life Expectancy of Transformers

Maintenance cost for dehydrating breathers can be high, and with negligent maintenance and the resulting increased ingress of moisture into the transformer, the use of such components can cause very costly and sometimes irreparable damage that cannot always be detected immediately. Excessive moisture in the paper insulation therefore considerably shortens the service life of transformers and optimum dehumidification is crucial for the trouble-free operation of transformers.

An important aspect in this regard is the irreversible aging process of the paper insulation for which, in addition to temperature, water plays a significant role since moisture considerably weakens the insulation system, and electrical and mechanical strength is reduced with increasing water content.

Expected service life of solid insulation and its dependence on humidity and temperature[2]



Expected service life of solid insulation and its dependence on humidity and temperature[2]

Studies have shown, for example, that at an operating temperature of 80°C and 1% moisture content in the paper insulation, a transformer's service life is around 35 years. At 4% moisture, however, the service life could be reduced to just 5 years.

The aging of transformers is primarily influenced by operation and the associated changes in the oil-paper insulation. A deterioration in the insulation properties, characterized by a reduction in electrical and mechanical strength, is a clear sign of advanced aging.

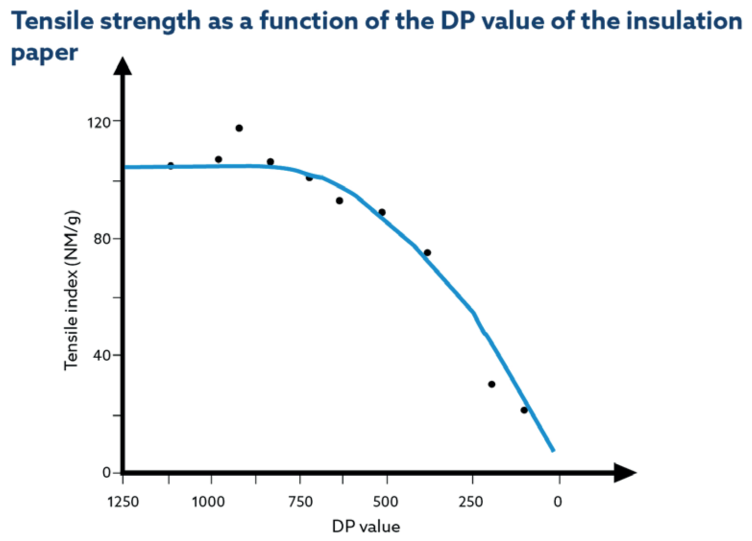
Photo: Maschinenfabrik Reinhausen

Insulation Systems in Transformers

The insulation system of a transformer essentially consists of insulating oil and insulating paper. Insulating oil fulfills a critical dual role: it dissipates the heat generated during operation and at the same time serves as part of the insulation system for the high-voltage-carrying parts of the transformer. The oil must meet stringent requirements, including high dielectric strength, chemical stability and good thermal conductivity – even at highly fluctuating temperatures.

Insulating paper is made of robust cellulose. In combination with the insulating oil, this material contributes to both the electrical insulation and the mechanical stability of the transformer active part. The number of rings in the chains of the cellulose molecules, the so-called degree of polymerization (DP), describes the aging condition of the solid insulation. A new paper typically has a DP value of 1200 to 1400.

The DP value and the tensile strength of the material also indicate the degree of aging: When a value of 200 is reached, the brittleness of the paper increases dramatically. As the tensile strength of the paper weakens, the risk of the transformer failing in the event of grid fluctuations also increases. For this reason, a poor condition of the cellulose is often regarded as an indicator of the end of the transformer's life, as it is not practical to restore or replace the paper insulation.

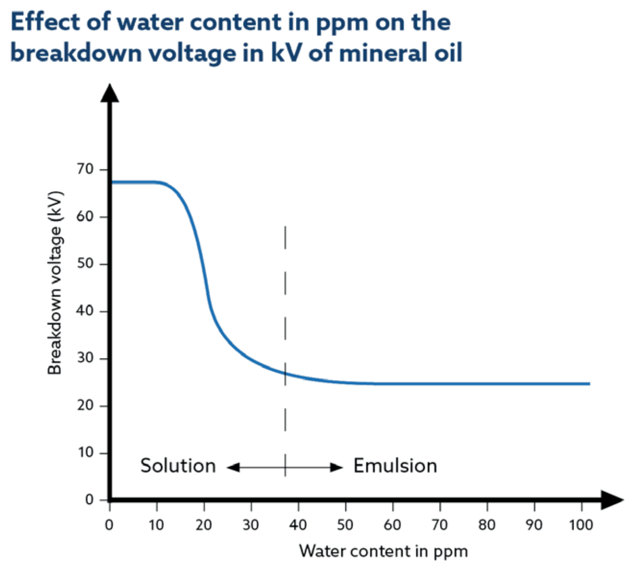


Tensile strength as a function of the DP value of the insulation paper

The aging of transformers depends in particular on the temperature and the presence of water in the oil. Water significantly influences the aging process of cellulose through hydrolysis. Cellulose is a highly hygroscopic material and can therefore absorb a large amount of moisture, which further accelerates the aging process. Drying is therefore essential before using cellulose as an insulation medium in order to minimize the moisture content. In the case of a new transformer, this is well below 1% after drying.

The insulating oil serves as a carrier medium for water during operation. Although the aging of the oil is hardly affected by water, the electrical properties of the oil suffer as a result. Due to the increasing water content, the breakdown voltage of the oil decreases from 65 kilovolts (kV) to 25 kV. This value does not deteriorate further as the oil ages.

Appropriate measures to reduce the absorption of moisture can help to slow down the aging process and maintain the availability of the transformer. This is where dehydrating breathers come into play, which reduce the moisture from the ambient air in the transformer.



Effect of water content in ppm on the break-down voltage in kV of mineral oil

How Maintenance-Free Dehydrating Breathers Make Transformers Last Longer

The service life of expensive, important transformers that can only be produced with long order times can be significantly extended by using maintenance-free dehydrating breathers. They automatically regenerate the used silica gel and thus relieve the operator of all maintenance costs for the dehydrating breathers.

In addition, humidity and temperature sensors can be used to analyze transformer operating cycles to determine the optimum time for regeneration, and the bake-out process can be initiated automatically if a saturation limit is exceeded.

A self-learning algorithm can also be used which determines the correct time to start the bake-out process to ensure that the transformer is in an "exhale" phase so that no moisture can enter the expansion tank. Additional data recordings can also provide more detailed information about the operation of the transformer. More than 100,000 units of dehydrating breathers have already been installed worldwide and are proving their worth even under extreme climatic conditions.

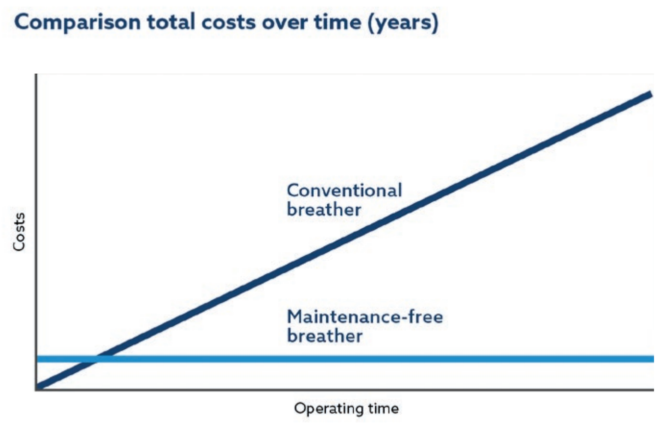
How Transformers Can Be Retrofitted in a Future-Proof and Cost-Efficient Way With Maintenance-Free Dehydrating Breathers

The devices can be easily installed on transformers with conventional dehydrating breathers in accordance with DIN 42562 / EN50216-5, as they do not require a large installation space and can be connected to any data platform with little effort.

They are primarily aimed at operators of electrical systems, energy suppliers and industrial companies. As a rule, their service or asset managers are looking for reliable dehydrating breathers to retrofit their existing transformer fleet.

The Advantages of Maintenance-Free Dehydrating Breathers at a Glance:

+ Actively protects the insulation medium from moisture
+ Reduces operating costs and increases operational reliability
+ Condition-dependent and self-learning algorithm
+ Compliance with the IEC 60076-22-7 standard at all times
+ Significantly higher efficiency than market competitors
+ Easy to integrate into ETOS® (Embedded Transformer Operating System)
+ Simple retrofitting to existing equipment
+ Operating status display (LED)
+ Test function (button for triggering the test for heating, sensors and displays)
+ With app for easy data readout



Comparison of investment and operating costs for conventional and maintenance-free dehydrating breathers

Maintenance-Free Dehydrating Breathers Pay for Themselves After Just a Few Years

Maintenance-free dehydrating breathers significantly reduce moisture absorption in the paper insulation - as the dehumidification performance is higher than that of conventional dehydrating breathers – and can extend the service life of transformers by up to 50%.

Taking into account acquisition, maintenance and servicing costs as well as the efforts involved, the cost advantage of maintenance-free compared to conventional dehydrating breathers can be up to 65% and, despite higher initial investment, the maintenance costs saved usually lead to a return on investment (ROI) after less than three years.

Investing in maintenance-free dehydrating breathers also helps to achieve ambitious sustainability targets since there is no need to dispose of the used silica gel and the elimination of regular maintenance trips can lead to a significant reduction of an operator's CO_2 footprint of up to 92%.

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[1] CIGRÉ Technical Brochure 349 "Moisture equilibrium and moisture migration within transformer insulation systems", 2008
[2] Aging of Oil-Impregnated Paper in Power Transformers, Lars E. Lundgaard, Walter Hansen, Dag Linhjell, and Terence J. Painter, IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 19, NO. 1, JANUARY 2004

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SPECIAL SECTION:

Insights from IEEE PES

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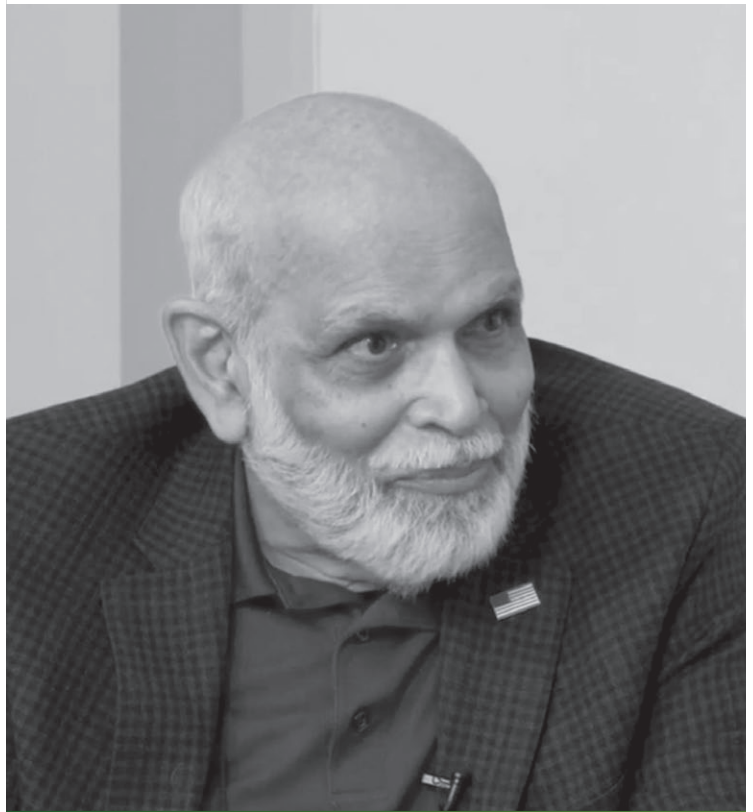
IEEE PES Power & Energy Society®

Billy Lao, General Manager
DILO Company, Inc. & DILO Direct

Damir Novosel, President
Quanta Technology

Joshua Yun, Senior VP of Sales & Marketing
Virginia - Georgia Transformer



Nand Singh, CEO
MinMax Technologies

Wayne Bishop, Vice President at Quanta Technology
and Past Vice President of Meetings of IEEE PES

Alan Ross, Managing Editor
APC Media

At the most recent IEEE PES T&D Conference and Expo in Anaheim, CA, we were able to interview industry thought leaders about the value that IEEE PES was to them personally and to the industry as a whole. Below, excerpted and edited for clarity, are many of those responses. We were proud to be a media partner with IEEE PES for the fourth time, including the IEEE PES Grid Edge Conference and Expo, which was held for the first time in 2023 in San Diego, and which will be held in San Diego again in 2025 on January 21-23. We will be there again, creating dynamic video interviews with thought leaders who are shaping the future of the power industry and as you will read from their comments below, IEEE PES is a major driving force for our industry. Enjoy!

> IEEE and ITSLC groups work closely with technical committees and academia to guide the industry in making proper decisions, including investments.... A key role of IEEE is to align carbon goals with technical realities, ensuring that industry advancements truly benefit society.
>
> **Damir Novosel**

> Grid edge technologies and solutions aim to create a more efficient, resilient, and sustainable energy system by leveraging advancements at the distribution level and empowering end-users to play a more active role in energy management.
>
> **Wayne Bishop**

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Our first guest was Damir Novosel, CEO of Quanta Technology.

Alan Ross: I know you were the past President of the EAC, the Executive Advisory Council for IEEE PES. That is This Council directs the future of IEEE, correct? You recently mentioned to me your passion for collaboration and the importance of IEEE PES in that process. What do you think the future of IEEE PES looks like?

Damir Novosel: Our industry needs IEEE to provide independent and objective perspective on important energy topics not only to our industry but to society. When I was President of the Power Energy Society along with the Vice President of New Initiatives, Shay Bahramirad, we formed the Executive Advisory Council (EAC) and the Industry Technical Support Leadership Community (ITSLC) to address practical and important industry topics on a fast-track.

There is the misconception that IEEE is too academic—it is not correct as 70% of our members are from industry.

IEEE's practical impact is clear through our standards and regulatory outreach, including partnerships with US NERC, FERC, and DOE and other global organizations. Academia and industry need to work very closely together. But to emphasize the industry, component, we first IEEE creates standards, and that is what IEEE does.

IEEEEAC and ITSLC groups work closely with technical committees and academia to guide the industry in making proper decision, including investments. Very often politics and some business goals influence the discussion, leading us in a direction that is really not beneficial for society. A key role of IEEE is to align carbon goals with technical realities, ensuring that industry advancements truly benefit society.

AR Collaboration is probably my one of my favorite leadership themes. Is it safe to say that IEEE is the glue that causes collaboration?

DN You're absolutely right. IEEE is the glue. That's why I think when I was giving the CIGRE interview with you last year, I mentioned IEEE.

AR And now you have mentioned CIGRE in an IEEE PES interview. Brilliant!

DN These two organizations have different models, but they complement each other very nicely. It is important to mention that the problems we face are global. There are many players, and even though "I" stands for international, one player cannot solve all the problems. It is a global solution, and you need global organizations like CIGRE, and IEEE to come together to solve problems and define the future.

We are proud that our teamwork with the Parliamentary Society, the Governing Board and others showed that we are really pulling in the same direction. Over 50% of IEEE members, like EAC for example, are outside North America, making it a truly global organization.

The important part is that to have once a year a meeting with global executives that will be global and try to bridge it together. That's the future.

AR We are going to do this again at Grid Edge, right, so I want to schedule our next interview there and get an update. We'll get some interviews there with the global thought leaders.

DN That's a great idea. The key is to promote what we do and communicate the message so all our membership can really hear about it and get more engaged. My plea is to get more people to become engaged, to take leadership roles, to be active. There are so many things to do. We would like to have new and fresh thinking.

AR You've just made a great plea. I really appreciate the fact that IEEE PES not only allows us to do this, but also sponsors us to do this. The next time we're together, we're going to do this again, and we're going to go to the next step in that process. Thank you, Damir.

DN And I really appreciate you and APC Media. Thank you, Alan.

Our next interview was with Wayne Bishop, Immediate Past Vice President of Meetings for IEEE PES and a good friend.

AR I know how passionate you are about IEEE PES, and now as the Chair of the IEEE PES Grid Edge Conference and Exposition in San Diego next year, you remain a committed volunteer leader. Talk a little about what we can expect next year in San Diego.

Wayne Bishop: Built on the huge success of last year's event, we are pleased to announce the 2025 IEEE PES Grid Edge Technologies Conference and Exposition. It is being held January 21-23, 2025 in the San Diego Convention Center and San Diego Gas and Electric is the utility host.

AR Wayne, what is Grid Edge as you define it?

WB "Grid Edge" refers to the technologies, processes, and business models that are deployed at the edge of the electric grid, typically where the utility infrastructure meets the customer premises. This includes innovations and solutions that optimize the generation, distribution, and consumption of electricity. In summary, it's at the grid edge where so much of the excitement and transformation is happening in our industry.

Key aspects of grid edge include:

1. Distributed Energy Resources (DERs): Such as solar panels, wind turbines, energy storage systems, and electric vehicles that generate or store electricity locally.

2. Smart Grid Technologies: Advanced metering infrastructure, sensors, and communication networks that enable real-time monitoring and control of electricity flow.

3. Demand Response: Programs and technologies that adjust the demand for power rather than adjusting the supply, helping to balance load and reduce peak demand.

4. Energy Management Systems: Tools and software that allow consumers and businesses to manage their energy use more effectively, often in real-time.

5. Microgrids: Localized grids that can operate independently or in conjunction with the main grid, providing increased resilience and reliability.

6. Electric Vehicle Integration: Infrastructure and technologies that support the integration of electric vehicles into the grid, including vehicle-to-grid (V2G) systems.

Overall, grid edge technologies and solutions aim to create a more efficient, resilient, and sustainable energy system by leveraging advancements at the distribution level and empowering end-users to play a more active role in energy management.

AR What should we expect by attending the Conference?

WB Participating in this event also provides a unique platform for Clean Transportation Companies, Fleet Management, and EV charging manufacturers to showcase their cutting-edge solutions in the rapidly evolving electrification landscape. Key topics include:

- Fleet electrification challenges and opportunities
- Development of e-mobility and charging infrastructure
- Evolving policies and regulations shaping the industry
- Technology roadmaps and advancements like bidirectional charging

There will also be an **Electrification Stage on Expo Floor** with panels and keynotes being given by utility executives and industry thought leaders. Our technical program includes more than 100 panels and tutorials with most of them taking place on the Expo Floor to increase your traffic and visibility.

By joining us, you will have the opportunity to engage with industry leaders, utility executives, policymakers, and potential customers, gaining invaluable insights and feedback. The IEEE Grid Edge Conference and Expo is an excellent chance to enhance your brand visibility and position your company as a key player in the energy transition.

AR Thank you, Wayne, I look forward to seeing you there.

WB Thanks Alan and thank the folks at APC media for their continued support.

We also spoke about IEEE PES with Nand Singh, CEO of MinMax.

AR Nand, thanks for joining me. Talk a little about IEEE PES and the value it is an has been to you personally. How did you first get involved?

Nand Singh: I was a student member at joining. IEEE is a tremendous organization. In the power industry, it's hard to imagine operating without being part of IEEE PES. After 17 years with EPRI, I saw IEEE as our validation platform—everything we did was checked against what IEEE was saying. Quoting IEEE standards brings instant credibility to any organization.

When I quote IEEE, all the research and all the pundits and gurus that talk on behalf of IEEE, it lends a lot of credibility to what you are saying, to what you're doing. Running an organization, IEEE becomes a de facto sounding board for me.

AR What are some of the key values that IEEE brings to you and to industry?

NS The word that keeps coming in my mind collaboration. IEEE acts as the glue for bringing together diverse organizations and

Photo: Shutterstock

professionals, including vendors and utilities. Even smaller munis and co-ops can benefit from the IEEE guidelines and findings.

IEEE's value lies in its focus on the benefit of society, not just companies or shareholders. As an IEEE PES member, this has been very evident to me.

Oftentimes, people equate IEEE with standards. But we shouldn't forget that they also publish a lot of guidelines as well. These guidelines should be adopted as best practices, turned into proven practices, and shared with customers.

AR Excellent. Nand Singh, thank you so much.

NS Thank you Alan and I look forward to seeing you at our client conference in Dallas.

Billy Lao of Dilo provided input on IEEE PES as well.

Billy Lao: I'm blessed to be a part of the K-Zero working group and I'm also part in substations and the switchgear side. The value of IEEE is the standards and guidelines that we're writing. I'm currently finalizing the SF6 Gas Handling Guide that had to be renewed from 2011. The value is giving a reference that can be read by anyone from a field user to the engineering level on how to safely handle it.

The mobile substation guide offers detailed specifications for mobile substations, including insulating gas, transformers, and gas handling equipment and monitoring. This guidance is invaluable, providing a comprehensive reference to an individual who may not have prior exposure to these topics.

AR So, they are able to turn to these experts without having to talk to each one of them?

BL Yes, right. The document can be accessed electronically or in hard copy and they can develop a specification or create a process on how to safely handle SF6 or other insulating gasses. This addresses a significant gap, as very few people have this detailed knowledge. By creating these documents for individuals who need to know but don't have the ability to go to all these meetings, they can just reach out and access it.

AR One of the things of IEEE PES is for is the benefit of society. And Billy, you epitomize it, lifelong learners, lifelong givers. Thank you so much.

BL I appreciate you too Alan. Thank you so much.

Joshua Yun of Virginia Transformer also talked about the value of IEEE PES.

AR Joshua, talk about the value you see from IEEE PES.

Joshua Yun: I've been a member since college—three decades now—and actively involved with the IEEE PES Transformer Committee 25 years ago. There is about 250 of us and we meet twice a year, spring and fall. It is a very unique organization where people from different backgrounds; manufacturers, consultants, professors, government agencies, and utilities. We meet twice a year, and we don't talk about commercial aspects which are strictly forbidden, but strictly work toward creating standards and guides that could help the whole industry. I'm proud to be a part of it.

The beauty of these standards is that what we bring to the table basically becomes a foundation, a rule, or a building block how everybody should design, build, test, maintain and then repair transformers out in the field. It levels the playing field.

It's challenging for individual companies to address issues like reverse power flow in battery energy storage systems, where power flows in both directions. The IEEE Transformer Committee is developing standards to guide these changes, outlining dos and don'ts and providing essential guidelines. Without that, it will be very challenging for individual companies to come up with their own versions. I think it's a tremendous help, not only to the end user, but also the manufacturers, and everybody who is involved.

AR That's excellent. Joshua, thank you so much for joining.

JY Thanks Alan, I really appreciate it.

> The beauty of these standards is that what we bring to the table basically becomes a foundation, a rule, or a building block how everybody should design, build, test, maintain and then repair transformers out in the field.
>
> **Joshua Yun**

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Our Offerings:

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Commitment to Safety: Safety is the cornerstone of Pittman Power's operations, woven into every aspect of our business. We believe a safe workplace is a fundamental right for every employee, contractor, and partner. Our commitment to safety begins with leadership, who prioritize safety in all decisions and empower every team member to take ownership of their safety and that of others. We adhere to stringent industry safety standards, creating a culture where safety is ingrained in our daily routines. Our comprehensive safety programs include ongoing training, certifications, and regular drills, ensuring preparedness. We conduct thorough risk assessments and hazard analyses before every project, effectively managing potential risks. Pittman Power leverages cutting-edge technology, including advanced monitoring systems and predictive maintenance tools, to prevent safety issues. This proactive approach ensures smooth operations and minimizes incidents, safeguarding our workforce, clients, and the communities we serve.

About Pittman Power:

Pittman Power is a leader in engineering and electrical services, blending decades of experience with

a forward-thinking approach. Our technical expertise and customer-focused solutions allow us to excel in electrical maintenance, repair, and operations (MRO) services. Our skilled team tackles industry challenges with precision, whether modernizing power infrastructure, managing outages, or delivering high-performance services. We continuously invest in our workforce, ensuring our technicians and engineers are equipped with the latest tools and knowledge, which strengthens our leadership in the industry.

Customer satisfaction is at the core of our operations. We collaborate closely with clients to tailor our services, building lasting partnerships based on trust and transparency. Committed to safety and reliability, Pittman Power upholds the highest service standards, ensuring maximum uptime and efficient, long-lasting solutions. In a dynamic industry, we remain dedicated to powering the future with innovation and excellence.

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Strategic Undergrounding for a More Resilient and Sustainable Grid

by **Ben Lanz**

What is the life-cycle cost of our electric infrastructure per capita? What is the cost to society to have our power turned off proactively by our utility to protect us from wildfire threats or reactively due to natural disasters? Our industry stands at a critical juncture. Our aging infrastructure struggles to consistently withstand natural disasters or even strong weather events, even as electric power becomes increasingly essential for critical tasks. According to the U.S. Energy Information Administration (EIA), the average American endures seven hours of electric service outages annually. Furthermore, the U.S. Census indicates a growing percentage of the population is choosing to reside in areas at high risk of fire or storm damage. As we aim to electrify more of our residential energy needs, natural disasters and strong weather events repeatedly highlight our vulnerabilities. Many households are unable to maintain safe temperatures, protect homes from damage, support in-home medical devices, prepare and preserve food, perform job-related tasks, communicate with loved ones and emergency personnel, or operate electric vehicles (EVs) for daily use or emergency evacuation. So, what can we do to improve our infrastructure and ensure resiliency?

The Power Delivery Intelligence Initiative (PDI2.org) is a nonprofit organization on a mission to challenge the way we think about power infrastructure decisions. PDI2's purpose is to drive maximum power grid resiliency and reliability at the lowest life-cycle cost.

Photo: IMCORP

OUR INDUSTRY STANDS AT A CRITICAL JUNCTURE. OUR AGING INFRASTRUCTURE STRUGGLES TO CONSISTENTLY WITHSTAND NATURAL DISASTERS OR EVEN STRONG WEATHER EVENTS, EVEN AS ELECTRIC POWER BECOMES INCREASINGLY ESSENTIAL FOR CRITICAL TASKS.

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

PDI2 FOUND SUCCESSFUL PROGRAMS ESTIMATED INITIAL COSTS, FUTURE SAVINGS, AND RISK REDUCTIONS INSTEAD OF USING OUTDATED AND SIMPLISTIC RULES-OF-THUMB.

The organization gathers and disseminates information to help utilities, regulators, and our society as a whole determine which power delivery solutions to employ. For generations we have installed most of our grid overhead, and while there are many solutions to improve the resilience of overhead lines, more utilities are now turning to undergrounding their lines as a sustainable resiliency solution. What has changed and how are utilities justifying the investment? Late last year PDI2 issued a research report called the "Utility Underground Life-Cycle Cost Guide" to help answer these questions. While this guide was written for electric utilities in the U.S. and Canada who are searching for facts to address most common misunderstandings of undergrounding and a structured approach to capture the lowest life-cycle cost for line segments, the fundamentals are applicable globally.

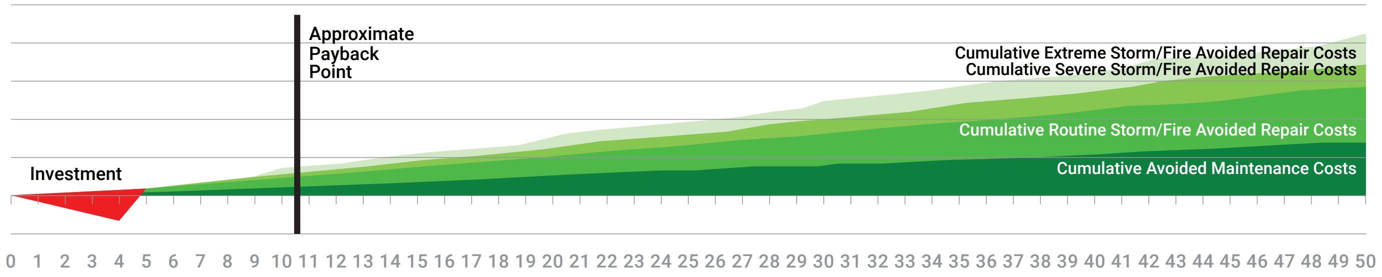
So why are utilities strategically undergrounding? The simple answer is a convergence of technology and a need for resiliency, the ability to withstand high impact low probability (HILP) events with little or no customer outage, has created a new decision landscape. PDI2 researched large scale, bell weather undergrounding programs at Dominion, Florida Power & Light, Georgia Power, San Diego Gas & Electric, PG&E, PEPCO, and WEC Energy Group and found various underground program drivers including performance efficiency, new materials, methods and technology, aesthetics, maintenance reduction, vegetation management, safety, levelized capital spend and rate base growth, and customer satisfaction. The research identified utility goals to underground nearly 40,000 miles in the next decade in all parts of the US. The primary misunderstandings these utilities had to address were initial vs. life-cycle costs, challenges with installation, and fears of frequent and difficult to locate failures.

PDI2 found successful programs estimated initial costs, future savings, and risk reductions instead of using outdated and simplistic rules-of-thumb. Some of the potential factors to consider in the life cycle analysis of undergrounding are: ten times higher reliability, two to three times longer life, ten times less operating and maintenance costs, the value of capital investment with a consistent rate of return, nearly ten times safety improvement, and state or local gross domestic product (GDP) protection. PDI2 research found a simplified internal rate of return (IRR) analysis can yield a positive value over a ten to twenty-year timeline. This was achieved by looking at the avoided future costs as returns, integrating avoided annual maintenance impact, demonstrating accelerated recovery, repair, and replacement after routine storms, and avoidance of the frequency and severity of system impact due to severe or extreme weather or fire risks. It is important to note that the positive return was achieved without incorporating multiple factors such as adjustment in rates, GDP impact, safety benefits, inflation, capital vs. maintenance and revenue loss, reinvestment in maintenance savings, and life beyond 50 years.

Photo: IMCORP

Simplified IRR Analysis of Life-Time Performance of Undergrounding

Demonstration that conservative modeling yields a positive IRR between year 10 and year 20 for a 5-year "Strategic" undergrounding program.



PDI2 learned that successful undergrounding programs availed themselves to modern technology to address installation challenges and failure concerns. Improvements in cable system technology allowing for shallow trench or directly buried cable with longer spans between splices, reduced material costs, easier accessory installations and two to three times longer life even in fully submerged conditions. Some examples of cable system technology improvements are low resistance jackets for longer pulls, range taking cold shrink accessories and shear bolt connectors which make installation faster and easier, and high quality, thinner insulations which lower costs. Improvements with installation technologies such as vibratory plowing, directional drilling, and massive rock saws are now commonplace and accelerate installation in all types of geology. Technologies under development promise tunneling with specialized high energy plasma boring and drone guided direction drilling to lower the civil construction cost even further. And finally, sensor technologies give us 'eyes' underground to help us proactively detect defects and reactively locate failures immediately. Some examples of these technologies are online sensors which can detect and communicate failure location, specialized meters and above ground scanning technology that can detect low voltage cable failures and contact and stray voltage in progress, drones that can scan underground vaults for risks, and factory comparable PD test (a.k.a. an offline 50/60Hz PD test with 5pC sensitivity) that scan medium and high voltage lines and locate defects proactively to predict future performance.

In the past, utilities could dismiss proactive measures to address resilience as too costly. However, today in our hyper cost sensitive industry the data is clear, reactive measures such as mobilizing thousands of line workers after a storm or investing in never-ending tree trimming expenses are not sustainable. Whether utilities have overhead or underground lines, there are numerous ways to proactively improve resilience which can not only benefit the utilities' bottom line but society as a whole. The advancement of technology, the frequency and duration of outages, and fact-based life-cycle analysis is driving more utilities to consider undergrounding. For this generation's engineers and planners who are looking to address many of the legacy rules-of-thumb and discover reasons to consider strategic undergrounding, PDI2's complimentary "Utility Underground Life-Cycle Cost Guide" is a valuable resource.

Photo: IMCORP

IMPROVEMENTS IN CABLE SYSTEM TECHNOLOGY, ALLOWING FOR SHALLOW TRENCH OR DIRECTLY BURIED CABLE WITH LONGER SPANS BETWEEN SPLICES, REDUCED MATERIAL COSTS, EASIER ACCESSORY INSTALLATIONS AND TWO TO THREE TIMES LONGER LIFE EVEN IN IN FULLY SUBMERGED CONDITIONS.

Kenneth Peterson

Director of Substations
at LUMA Energy

Interview with **Kenneth Peterson**

Photo: LUMA Energy

> It's exciting to be able to do what we're doing within the industry at this magnitude, but rebuilding an entire grid within a utility to this magnitude of scale, nobody's ever done it.

Photo: Shutterstock

***Editor's Note:** At the time LUMAof this interview, conducted at the TechCon North America Conference, Kenneth Peterson was heavily engaged in rebuilding the Puerto Rico grid, after the 2023 hurricane. As of this writing, Hurricane Ernesto made land in early August making it even more difficult for the people of Puerto Rico and of course Kenneth is once again helping rebuild.*

Alan Ross: My guest is Kenneth Peterson. Kenneth Peterson is the Director of Substations at LUMA Energy. Thank you for joining me. You are heavily engaged in rebuilding the grid in Puerto Rico, right?

Keneth Peterson: Yes, we are rebuilding the grid.

AR Kenneth, Puerto Rico has had two hurricanes and flooding? You've got a lot that you're dealing with down there. But I would like to start with something else first. You've been in the industry long enough, and it just seems to be that the pace and scope of change has become much more dramatic since COVID. We're electrifying North America and the world, we're decarbonizing... We got all these things going on. From your perspective, what are the greatest changes you think we're undergoing in the power industry?

KP I'd say two of the biggest challenges are the intense competition for material and labor pool. First, in Puerto Rico, we're doing a very large project on the whole island. We're competing with everybody in North America doing the same thing within the utilities. Beyond that, there is an issue with the labor pool. We're seeing it at LUMA and across the industry as well. It goes back to the interest of keeping the next generation that is coming into the industry.

AR We just talked to a company that makes radiators. When OEMs plan five years out, it makes things easier, but now they're doing a lot of retro work. We have to keep assets, like transformers, alive longer because we can't get new ones, and this issue affects other equipment too. There's also the labor issue. Most people I talk to are "graybeards," and we need to think about bringing up the next generation.

There are two labor challenges. First, at the engineer level, it's not a problem getting the workforce out of college but advancing them to the next level. The 25 to 40-year-olds view work differently than we do. Second, we've abandoned craft work—shop classes are gone, and unions haven't supported it well. We need craft workers to build custom transformers, but we can't find them. Automation isn't solving this problem, especially in our industry. Field work combines these roles, requiring both supervisor and engineer levels. How are you addressing this challenge, particularly in Puerto Rico?

KP Yes, part of my team is building an internal construction crew to support minor activities as we bring in larger teams from contractors. We're bringing in craft labor from IBEW, and while they're skilled, we're finding a lot of these gentlemen or ladies coming over as craft workers only focus on a certain aspect of things. For example, someone may be great at wiring but lacks experience in rigging or transporting equipment. We're noticing these small gaps as we build.

...we're developing a new workforce development plan. We have a group of EITs fresh out of university, and we're developing a combination of school in class and then OJT. We have LUMA College for the linemen, and we are also expanding it to include substation training...

To address this, we're developing a new workforce development plan. We have a group of EITs fresh out of university, and we're developing a combination of school in class and then OJT. We have LUMA College for the linemen, and we are also expanding it to include substation training, which we're missing. This will help prepare the long-term LUMA substation technicians and engineers.

We're also modernizing, getting a lot of new technologies like IEC 61850. Here is where the engineer will come and make sure that that process and the standards in those protocols are being met.

It's a lot of moving parts, but it all goes back to making sure we have the right education and experience, and to walk everybody through it so everything lines up, like pieces of a puzzle.

AR You are in Puerto Rico now, you're going to have storms and you have to be thinking about having an almost on-island group to maintain the utility long-term. Is your goal to have a permanenent workforce on the island?

KP Yes, the long-term plan involves developing an internal workforce. We will have the college, the laboratory that's going to stay, and the legacy being left behind and the mentorship along the way.

It's not a two-year apprenticeship to come into our substation world in our industry and say you understand everything. Those are long-term goals. We're currently at the five-year stage against that benchmark. We haven't finished getting it developed yet.

AR Let's talk about procurement of transformers. I know you can plan, but actually getting somebody to be making those transformers in a timely fashion and getting them wherever you are, especially on a very mountainous island... it has to be hard, right?

KP Most of it comes out of the port in Jacksonville, US. We have some units that come from South America as well. The key is getting it on the assembly line. Right now, we have a lot of projects in the schedule model, and now it's about getting to the manufacturer. However, until we have a guaranteed slot on the assembly line, it remains a challenge. The time of 24 to 28 months working on some of the smaller mVa transformers, now takes 50 or 52 months, coming from the manufacturer. That's a struggle because we're trying to plan construction around it because we're trying to relocate some of our assets out of some of the known flood zones.

Getting it to a construction sequence and getting it back in play with these long lead times is, yes, it's been a struggle.

AR How do you sleep at night?

KP At IEEE, we had a bunch of CEOs from different utilities. One of them said that the CEO that he used to work for said he sleeps like a baby, and somebody got frustrated with that. He says: Yeah, a baby, waking up every hour, right? Sometimes I wake up with those ideas.

AR I've used that before. Where are you housed? Were you housed in Puerto Rico?

KP I am stationed in Puerto Rico most of the time, on site, and then I come back to the US residence from time to time, but most of my time is in Puerto Rico.

AR How does your wife feel about all this time that you're in Puerto Rico?

KP This assignment worked out with the style of our life. She's usually there about half the time with me, so she's relocated most of the time with me there.

AR Now, LUMA is a joint venture with QUANTA Services.

KP And ADCO which is our Canadian joint venture. We have a little bit of both from leadership. We have some of the ADCO leadership and QUANTA Services leadership, and we're developing internal within Puerto Rico.

AR If I were to say on a scale from 1-10, with one being: *this is the hardest thing, and things are just not working,* to 10: *it's a snap, we'll have this done,* where are you with the project now, given all the challenges rebuilding the grid for the next hurricane and making sure that they don't flood in water?

KP I've been around a lot of the really complex projects within other utilities around North America, and I've also worked with a lot of heavy industrials, so we've seen some real challenges. It's exciting to be able to do what we're doing within the industry at this magnitude but rebuilding an entire grid within a utility to this magnitude of scale, nobody's ever done it.

It's exciting to be able to do what we're doing within the industry at this magnitude, but rebuilding an entire grid within a utility to this magnitude of scale, nobody's ever done it. When you think about that, you can get overwhelmed.

When you think about that, you can get overwhelmed. But the number of professionals coming from both parties, the ADCO and QUANTA Services, we have a tremendous amount of knowledge. The challenges are now sequencing our transmission and our substations, just like any other utilities, and long-term project goals.

In my career, it's definitely been the most challenging.

The reliability right now is already increased. It was 35% last year on our reliability scale. That shows it right away. Once we get rid of some of the other outdated equipment which is poor performing, we will continue to reach our reliability goals. And yes, and then getting, of course, the resiliency as a part of that as well.

AR Given the massive power that is coming from storms today, we have that much rain and that much wind, and it is a fast-moving hurricane; when that hurricane comes and decides to sit on the island, a lot of problems happen. Do you think you're making

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progress to hurricane proofing or weather proofing the grid in Puerto Rico?

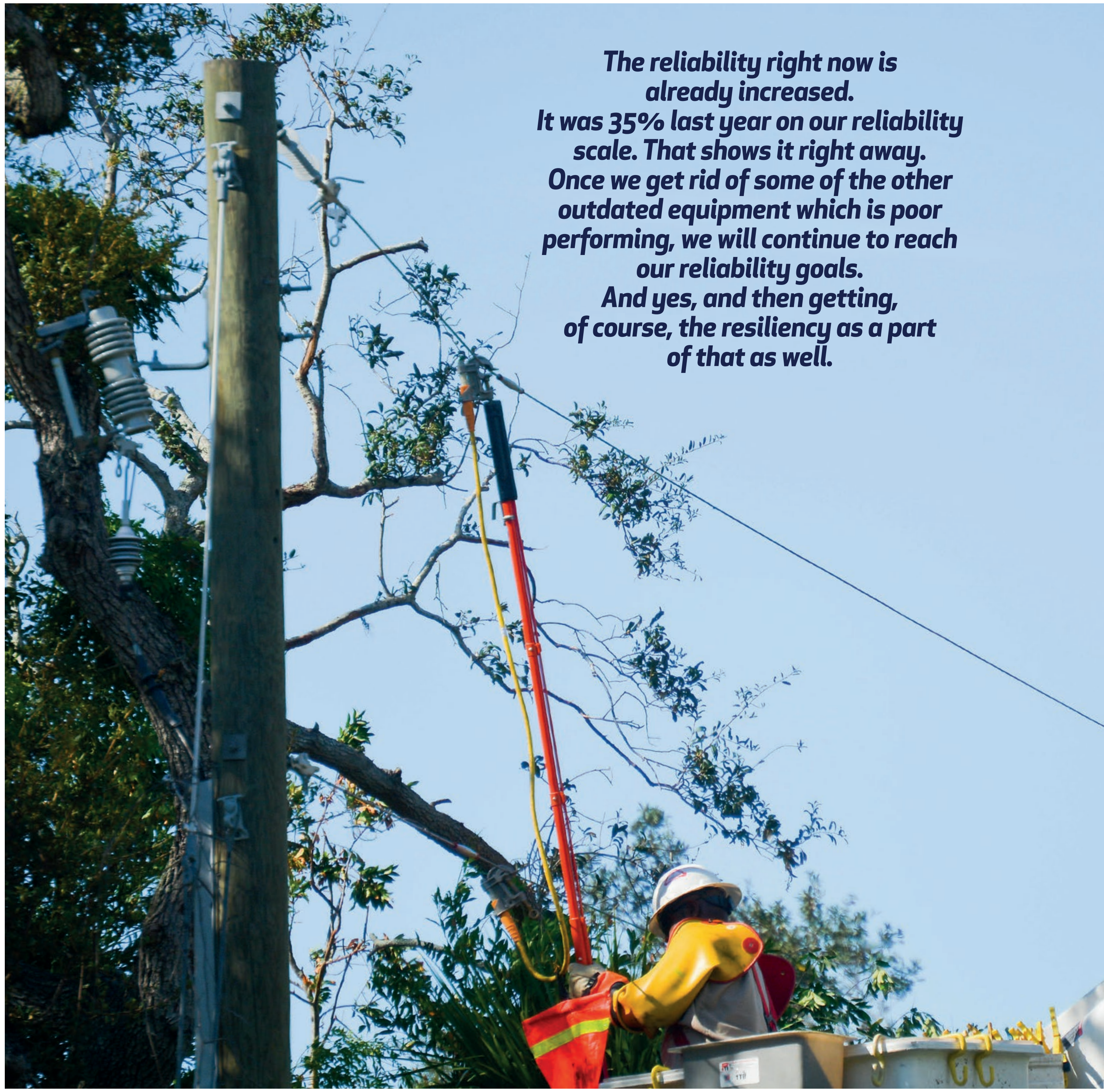
KP I would say it's hard to say we can ever get it so proof from Mother Nature, if you will. We have no idea how the directions and the speeds are going to happen.

AR You had an earthquake, too.

KP Exactly, and the earthquakes, looking at the scale of where we came from after Maria, obviously the largest to hit in the modern history in US, and the longest blackout, we have a lot of aspirations for our new goals. We're going to make an impact.

AR There's a lot of unspoken problems with the grid even before Maria. So, you took this issue in the midst of two hurricanes and in the midst of an earthquake. You've done an amazing job for people in Puerto Rico. I appreciate the magnitude of what you had to do, and so well done, and thank you.

KP Thank you so much, Alan.



PERSPECTIVES

Photo: Shutterstock

Building Resilience in the Transformer Industry: A Call to Action

As one of the leading grain-oriented electrical steel (GOES) producers in the European Union as well as globally, I've witnessed firsthand the challenges and weaknesses our industry faces. With the increasing focus on resilience within the transformer industry, it's time we address the pressing issues in our supply chains head-on. GOES is a critical component of transformer cores, and ensuring its stable supply is essential for the reliability of our electricity grids and the broader goals of energy transition and economic stability. This leads me to the following key takeaways.

The Crucial Role of GOES

GOES is not just another material; it's the backbone of transformer efficiency. Its unique properties allow transformers to reduce energy losses and enhance performance, playing a pivotal role in maintaining the health of our electricity grids. However, the current state of our supply chain is precarious, and disruptions could have far-reaching consequences. Supply chain disruptions, as we have seen in recent years, must be mitigated as effectively as possible. This means that European GOES production plays a key role in this effort.

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The Need for Strategic Partnerships and Policy Support

Resilience isn't built in isolation. It requires a concerted effort from both the private sector and policymakers. Governments must step up with regulatory support to foster growth and innovation within the GOES production industry. Ensuring a fair level playing field in the respective markets must be mandatory. Additionally, fostering collaborations to secure supply agreements will further diversify our risk profile and strengthen our position.

> **Resilience isn't built in isolation. It requires a concerted effort from both the private sector and policymakers. Governments must step up with regulatory support to foster growth and innovation within the GOES production industry.**

A Call for Industry Unity

Resilience in the transformer industry cannot be achieved by individual companies working alone. It demands a unified effort from all stakeholders within the value chain. As we navigate these challenging times, collaboration is more critical than ever. We are already working on initiatives among the supply chain with our customers, but also their respective customers, the TSOs and DSOs, because tomorrow it is too late to tackle these important topics. These initiatives and discussions focus on various important topics within the supply chain of electricity grids, where resilience is one part besides other crucial aspects such as decarbonization. By addressing weaknesses, investing in innovation, and fostering strong partnerships, we can ensure the continued stability and efficiency of our electricity grids.

Photo: thyssenkrup

> **By addressing weaknesses, investing in innovation, and fostering strong partnerships, we can ensure the continued stability and efficiency of our electricity grids.**

Looking Ahead

The future of the transformer industry depends on the strength and stability of our supply chains. As a GOES producer, I am committed to supporting initiatives that create and maintain a healthy environment, one that can withstand potential disruptions. It's imperative that we, as an industry, come together to build a resilient and robust future.

In conclusion, the transformer industry's resilience is not just about safeguarding our operations; it's about ensuring the continuous supply of reliable electricity for generations to come. I urge my colleagues and partners in the industry to join me in this critical endeavor. Together, we can achieve a sustainable, resilient future for our industry and beyond.

Author:
Georgios Giovanakis
CEO
thyssenkrupp Electrical Steel

Georgios Giovanakis has been working in steel, stainless steel and Components Technology since 1988, with a two-year interruption, at thyssenkrupp in different positions within the Finance Community of thyssenkrupp. He has many years of international experience as CFO/CEO in Germany, Italy as well as in China. In October 2019 he joined thyssenkrupp Electrical Steel as the CEO.

Substation Solutions & Power System Dynamics

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Introduction

The Biden-Harris administration targets 100% clean electricity by 2035 and ambitious plans to cut greenhouse gas emissions to half by 2030, reaching net zero by 2050. As a result, the US power grid is anticipated to experience a significant shift from conventional power generation to renewable energy resources, distributed energy resources (DER), and electrification of the transport sector and nearly 3 TW.

To achieve 100% clean electricity, the US power grid must double its renewable generation capacity by 2030. This ambitious target poses a considerable challenge, as the US's existing power transmission infrastructure is already congested and doesn't have the capacity to integrate renewables as required. Currently, the renewable and storage interconnection queue stands at around 2.6 terawatts (TW)[1]. To cater to the interconnection queue, the US power grid must expand its transmission capacity by 1.3 TW (2.5%) annually, posing a great challenge to capital expenditure. Although, in the US, 20 new high-capacity transmission projects have entered the construction phase, which will add approximately 20 GW of transmission capacity by 2030, it will still be insufficient as the interconnection queue is anticipated to increase as well over the years.

Moreover, the Department of Energy expects a surge in annual DER additions from 2025 to 2030, including 20 GW to 90 GW of demand capacity from EV charging infrastructure and 300 GWh to 540 GWh of storage capacity from EV batteries. Additional demand from datacenters is expected to reach 60GW over the same period.

As a response to these challenges, U.S. electric utilities are turning to the automation of distribution feeders and substations.

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This strategic shift addresses existing issues and significantly improves grid resiliency, reliability, and system visibility.

Distribution Feeders and Substation Automation

Concerns over resilience and reliability have pushed electric utilities and in turn federal regulators to act in promoting automation of distribution feeders and substations.
An example of this can be seen with the Smart Grid Investment Grant (SGIC) program under the American Recovery and Reinvestment Act of 2009 (ARRA) funded the installation of 26 distribution automation projects. Similarly, recent initiatives such as the Grid Resilience and Innovation Partnerships Program (GRIP) and the Grid Innovation Program have further accelerated the trend toward automation of distribution feeders.

Moreover, automation at distribution is gaining traction among electric utilities to increase the reliability and resilience by maintaining the critical grid parameters, including achieving voltage stability, active and reactive power balance, and frequency regulation, which are being impacted by the proliferation of renewables and DERs. Similarly, electric utilities are opting for substation automation solutions by widely deploying SCADA (Supervisory Control and Data Acquisition) to remotely de-energize critical equipment during flooding, preventing catastrophic damage that could require weeks to repair or replace.

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Technologies Under the Spotlight

There are several advanced grid technologies available of which we'll focus on: Dynamic Line Rating (DLR), Voltage/VAR optimization (VVO), and substation automation.

Dynamic Line Rating to Tackle Renewables Interconnection Queue Challenges:

To tackle concerns related to the interconnection queue, electric utilities and federal initiatives, such as the Federal-State Modern Grid Deployment Initiative, aim to accelerate improvements to the U.S. electric transmission and distribution network.[2] A significant component of this initiative is the deployment of dynamic line rating (DLR) technologies which optimizes the power capacity of transmission lines in real time by considering factors like weather conditions and line temperatures. This enhances the efficiency and utilization of existing grid infrastructure, reducing congestion and supporting the integration of more renewable energy sources.

The application of grid-enhancing technologies, including DLR, has offered substantial benefits to electric utilities in the US. For example, in the Kansas and Oklahoma portion of the Southwest Power Pool (SPP) grid, combining topology optimization, dynamic line ratings, and power flow control devices significantly reduced congestion. This combination more than doubled the existing headroom for interconnecting renewable resources, adding 3.7 GW of capacity with a payback period of only six months.
This $90 million investment is projected to yield $175 million annually in reduced production costs, highlighting the economic and operational benefits of adopting such advanced technologies.
Key examples of DLR deployment in the US include:

- Since 2022, PPL Electric Utilities has integrated DLR into real-time and market operations, using sensors to optimize transmission line capacity and enhance reliability.[3,4]
- Great River Energy is implementing the largest DLR project in the country by installing numerous sensors to boost grid efficiency.[5]

Diamonds are Paper's Best Friend

Volt/Var Optimization to Perform Voltage and Reactive Power Regulations

VVO is an example of a distribution automation system that increases the efficiency of the electricity delivery system and improves service to end-user customers by performing voltage and reactive power regulation under increasing load and DER integration scenarios.[6] VVO works by adjusting the voltage levels and reactive power flows in real-time or near real-time based on system conditions and operational requirements. It involves deploying advanced control algorithms and smart grid technologies to dynamically adjust voltage set points, control capacitor banks, and manage voltage regulators. By optimizing voltage and reactive power flows, VVO helps to minimize line losses, improve power quality, and extend the lifespan of electrical equipment.[7,8]

1 https://emp.lbl.gov/sites/default/files/2024-04/Queued%20Up%202024%20Edition_1.pdf
2 https://www.whitehouse.gov/wp-content/uploads/2024/05/Federal-State-Modern-Grid-Deployment-Initiative-Principles_formatted.pdf
3 https://insidelines.pjm.com/dynamic-line-rating-activated-by-ppl-electric-utilities/
4 https://news.pplweb.com/2023-07-11-PPL-Electric-Utilities-first-of-its-kind-innovation-improves-reliability,-reduces-costs
5 https://heimdallpower.com/heimdall-power-launches-largest-dynamic-line-rating-project-in-the-u-s-with-great-river-energy/
6 https://www.ilsag.info/wp-content/uploads/SAG-ComEd-VO-Presentation_11-15-23.pdf
7 https://cleanenergygrid.org/wp-content/uploads/2014/08/Integrated-Volt-VAR.pdf
8 https://www.pnnl.gov/available-technologies/voltvar-optimization

Installed Base Renewables Capacity Needed for USA's 100% Clean Energy Target by 2030

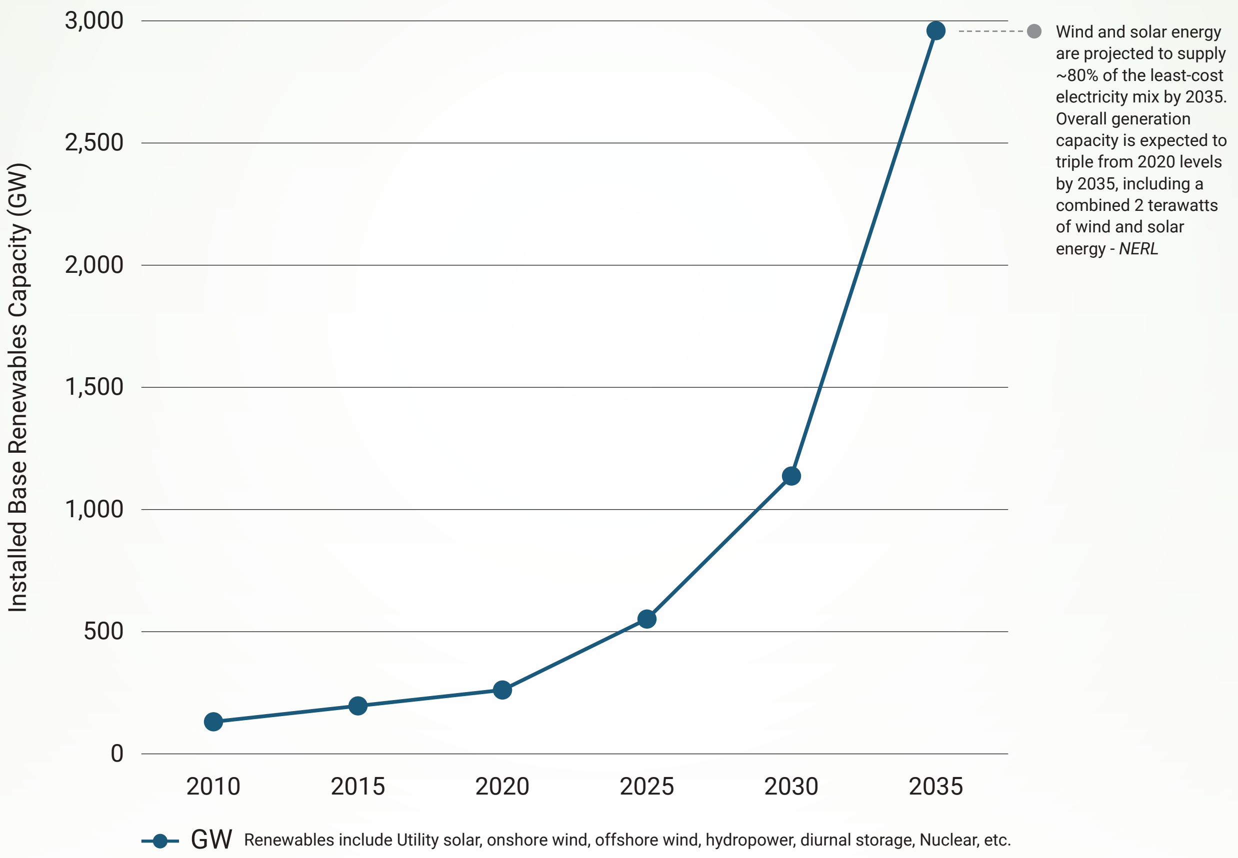

Figure 1: US's Pathway to 100% Clean Energy Targets, Source: PTR Inc.

The application of grid-enhancing technologies, including DLR, has offered substantial benefits to electric utilities in the US.

In the US, Electric utilities have implemented VVO for over a decade; for example, Duke Energy Progress of North Carolina has also installed VVO systems at 315 substations, while Duke Energy Florida has installed VVO systems at 262 substations.

Substation Automation to Cater to the Massive Adoption of EV Charging Infrastructure and Renewables

Substation automation integrates advanced control, monitoring, and communication technologies within substations to enhance operational efficiency, reliability, and responsiveness. It enables utilities to remotely monitor and control various substation equipment and processes, such as circuit breakers, transformers, and voltage regulators, using SCADA systems and intelligent electronic devices (IEDs). In the US, around 35% of the substation automation market is derived from the distribution sector, followed by the transmission sector, accounting for 25%.

Electric utilities across the US increasingly turn to substation automation to effectively manage the surge of EV charging infrastructure and renewable energy integration. For instance, Southern California Edison (SCE) has implemented advanced automation technologies in its substations to accommodate the growing number of EVs and solar installations in its service area. By deploying intelligent monitoring and control systems, SCE has enhanced grid reliability and efficiency, which is crucial for handling the variable nature of renewable energy sources and the unpredictable charging patterns of EVs. This proactive approach ensures stable power delivery and supports the transition towards a cleaner energy future.

Key Features and Adoption Status of Distribution and Substation Automation Technologies

Technology	Adoption Status	Key Features	Grid Issues Addressed
Substation Automation	Mature Technology	• Real-time remote monitoring and control • Advanced protection and control • Automated fault isolation switching operations • Seamless integration with renewable energy sources	• Manual fault detection and isolation • Unbalanced loads and power demand fluctuations • Grid stability and reliability issues due to proliferation of renewables
Volt/Var Optimization	Emerging Technology	• Real-time Monitoring and Control • Automation of legacy equipment (capacitor banks, voltage regulators, and tap changers) • Data analytics and predictive maintenance • Integration with existing SCADA system	• Voltage fluctuations and instability due to variations in load and DER generations • Power losses due to inefficient reactive power management • voltage and reactive power control challenges under high renewables scenario
Dynamic Line Rating	Emerging Technology	• Real-time monitoring and data acquisition based on sensor • Predict the line's capacity under varying environmental conditions and forecasted loads • Integration with grid management systems (existing energy management systems and SCADA)	• Transmission line congestion • Impact of the intermittent nature of renewables on the grid, such as fluctuations in power flows, challenging static line ratings • Operational flexibility and grid reliability issues

Figure 2: Key Features and Adoption Status of Distribution and Substation Automation Technologies, Source: PTR Inc.

In recent years, electric utilities have been integrating VVO into the already adopted substation automation solutions to manage the grid operations better and perform regulations of critical parameters under high-density DERs and renewables regions. A few key examples include Duke Energy, which has deployed VVO and substation automation to improve grid reliability and efficiency. At the same time, Ameren Missouri uses VVO as part of its Smart Energy Plan and leverages substation automation for grid modernization.

In recent years, electric utilities have been integrating VVO into the already adopted substation automation solutions to manage the grid operations better and perform regulations of critical parameters under high-density DERs and renewables regions.

Rising Winds Will Lift All

PTR expects all three technologies covered to grow significantly over at least the next decade as both utility-scale and behind-the-meter DERs continue to develop. Major utilities have planned the following just to name a few:

- PPL Electric Utilities intends to extend its DLR technology across more transmission lines to enhance grid reliability and efficiency further.
- Great River Energy plans to increase its DLR deployment to improve the grid's capacity and operational efficiency.
- Duke Energy and Ameren are committed to expanding their VVO and substation automation projects to support renewable energy integration and overall grid performance.
- Utilities like NextEra Energy, Exelon Corporation, Entergy, Xcel Energy, and National Grid are planning significant investments in substation automation to modernize grid infrastructure to improve real-time data analysis.

Automation of distribution feeders and substations has emerged as a critical strategy to tackle the inherent challenges of enhancing grid resilience, reliability, and efficiency.

The ambitious decarbonization goals necessitate this comprehensive transformation of the power sector, with a strong emphasis on renewable energy integration and transportation electrification. Automation of distribution feeders and substations has emerged as a critical strategy to tackle the inherent challenges of enhancing grid resilience, reliability, and efficiency. Advanced technologies like Dynamic Line Rating, Volt/VAR optimization, and substation automation will address current grid constraints while paving the way for a more flexible and adaptive energy infrastructure. Continued adoption and expansion of these technologies by utilities will be essential in supporting the U.S. in achieving its clean energy targets, ensuring a sustainable and resilient power grid for the future.

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Michael Sheppard Mike has 16 years of market research experience designing numerous research practices from scratch while leading over 50 bespoke projects with Fortune-500 companies. In 2016 he co-founded Power Technology Research (PTR) and has since launched new research practices in solar, storage, battery, and e-mobility. In addition to building and growing partnerships, he currently focuses on research around regulation and de-carbonizing efforts. In 2020, he co-founded Matos, an intelligence automation company focused on providing powerful AI-driven tools for the market research sector. In 2023, this business was acquired by PTR. Prior to founding PTR, he spent 8 years with iSuppli/IHS Markit in various analyst and consulting roles where he covered a broad range of sectors including mobile, renewable power and electricity transmission and distribution (T&D).
In his last role, he led the power technology consulting group. He is an expert on the PV industry and having performed numerous competitive dynamics and opportunity assessment projects, covering upstream, downstream, and supply chain topics. In 2008, he obtained a Bachelor's of Science in both Financial Services and in Corporate Finance from San Francisco State University. (sales@ptr.inc)

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The Effectiveness of Different Transformer Maintenance Strategies

by **Thomas Kessler**

While the failure rates are low, the potential consequences of major transformer can be severe, like regulatory information and guardianship, criminal liability, utility legitimation in question /1/, all beside other depending on the financial damage and impact. The goal of this paper is to well balance the failure rates, consequences of failures and preventive measures.

Challenges of the Transformer Lifecycle Management

Power transformers are known to be very reliable assets. Average Global failure rates of 0.53% p.a. for substation transformers and 0.95% p.a. for Generator Step-Up transformers have been reported /3/. While the failure rates are low, the potential consequences of major transformer can be severe, like regulatory information and guardianship, criminal liability, utility legitimation in question /1/, all beside other depending on the financial damage and impact. The goal of this paper is to well balance the failure rates, consequences of failures and preventive measures.

Addressing the Main Business Levers and Performance Areas of Asssets

/2/ provides a starting point for the above-mentioned balancing. These are the main business levers that are shown in table 1: Safety, financial, quality of service, reliability, environmental.

These business values and performance areas are used in the following for the balancing described under III. We start with the estimate of the transformer risk exposure monetizing as financial damage and impact in case of a major transformer failure.

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Example of business values & performance areas	Description
Safety	The company values safety of employees and 3^{rd} parties. The business value „safety" contains performance elements like Lost Time Incidents, etc.
Financial	The company values a sound financial position and system. The business value „Finance" contains financial performance elements.
Quality of Service, Reliability	The company values a good quality of service. The business value „qualily of service" contains performance elements like Customer Minutes Lost, etc.
Environment	The company values the environment. The business value contains performance elements like cost of environmental damage, etc.

Table 1: Examples of the main business levers and performance areas of assets

Transparent Transformer Risk Assessment

Transparent transformer risk assessments to estimate the financial impact and consequences of major transformer failures. They monetize in case of failure as unplanned CAPEX and OPEX spendings.

Table 2 provides a guideline to estimate the risk exposure of transformers.

It needs to be said that thinking the most unlikely to happen and considering all relevant aspects is essential to assess the transformer risk exposure fully and transparently as some practical examples show.

In the U.S. a major utility went bankrupt because long-neglected distribution grids have caused huge woodfires resulting in billion damages and fatalities of people. Aged and poorly maintained distribution transformers in easily flammable areas have been a key factor as cause of fire.

Also, failures of industrial transformers have been reported where the fire and resulting disintegration caused major damages of neighboring transformers, consequentially resulting in a full shutdown of entire production lines. The neighboring transformers have not been sufficiently protected against external impacts.

In the next step measures are being discussed and evaluated that allow the mitigation and reduction of the transformer risk exposure.

Due to its importance the application and benefits of different kind of DGA sensors needs to be discussed. As picture 2 shows the application of H_2 + H_2O sensors is sufficient for the early identification of evolving transformer failures. The detection of all additional combustible and diagnostic gases provides further information about the failure mode but do not provide additional benefits from the risk mitigation perspective /5/.

Finally, the achievable risk mitigation needs to be well balanced with the available CAPEX and OPEX budgets as well as with the remaining risk as explained in the following.

Environmental, e.g.	• Oil volume • Availability of oil collector • Cost for potential oil contamination of ground, water • CO_2 footprint	
Network-related, e.g.	• „n-1" principle applied • „n-1" principle not applied • EMC protection e.g. against harmonics of frequency converters	
CAPEX, e.g.	• Replacement costs • Installation & Commissioning of new transformer	
OPEX, e.g.	• Repair costs • Installation & Commissioning of repaired transformer • Removal costs • Costs-of-Energy-not-Supplied, CoENS	• Penalties • Consequential damages • Re-Dispatching • Availability of spare units
Safety, e.g.	• Costs of injuries • Costs of fatalities • Legal costs	

Table 2: Guideline to assess the risk exposure of transformers.

Goals and Approach

It is assumed that the appropriate maintenance strategy for power transformers shall reduce the risk of major failures /1/ as good as possible. Key for the effective risk mitigation is the early identification of evolving major transformer failures. Picture1 explains the basics of risk mitigation /3/. Essential is the early identification of evolving failures. As shown in picture 1 and further explained in /3/ maximum 30% of evolving failures can be identified in advance by applying onsite diagnostics and manual condition assessments.

Additional maximum 40% of all evolving failures can be early identified by applying different methods of transformer online monitoring as also shown in picture 1.

The diagnostics or online monitoring provide information about the conditional status of the power transformer (Step 1). In this case preventive or improving action needs to be initiated (Step 2). As shown in /x/ the is always a remaining risk of approximately 30% of major failures that cannot be identified in advance. Effective emergency processes are highly recommended (Step 3).

Benefit and Discounted Cash Flow (DCF) Consideration

Picture 3 explains the principle of risk mitigation: Maximum 70% of the over risk related to evolving major transformer failures can be identified in advance, as described under VI. This is the risk mitigation potential. To monetize this risk mitigation potential an invest into preventive measures like diagnostics, online monitoring and maintenance is required. The delta is the benefit or profit. If it is positive the applied risk mitigation is financially feasible for the end-user.

The benefits of risk mitigation are calculated as described in the following. The annual benefit of risk mitigation is calculated as follows:

Benefit = Risk Mitigation potential – Costs of Risk Mitigation by prevention [1]

The Discounted Cash Flow (DCF) generated by the benefits after a period of n years is

$DCF = Benefit/(1+r) + Benefit/(1+r)^2 + \ldots + Benefit/(1+r)^n$, [2]

where r is the annual rate of interest and n the number of years.

Maintenance Strategies and Achievable Risk Mitigation for Power Transformers

Picture 4 shows the different maintenance strategies investigated in this paper. In the following these are declared as maintenance strategies.

Service Level A:
Minimum or no maintenance, replacement of the transformer after 25 years by a new asset

Service Level B:
Annual Condition Assessments, OLTC maintenance every 7 years, preventive bushing exchange, oil regeneration and drying indicated by conditions after minimum 25 years in operation.

Service Level C:
See Service Level B, plus DGA monitoring (Single gas + H_2O or 5 gas). Please keep in mind that DGA multigas does not provide further benefits considering the risk mitigation perspective.

Service Level D:
See Service Level C, plus bushing monitoring.

Service Level E:
See Service Level D, full scope online monitoring system including OLTC monitoring.

Further, it is assumed that all online monitoring components must be exchanged after 17 years in operation, as the lifecycle of electronics is significantly shorter than the achievable lifetime of power transformers, which is supposed to be 50 years /1/.

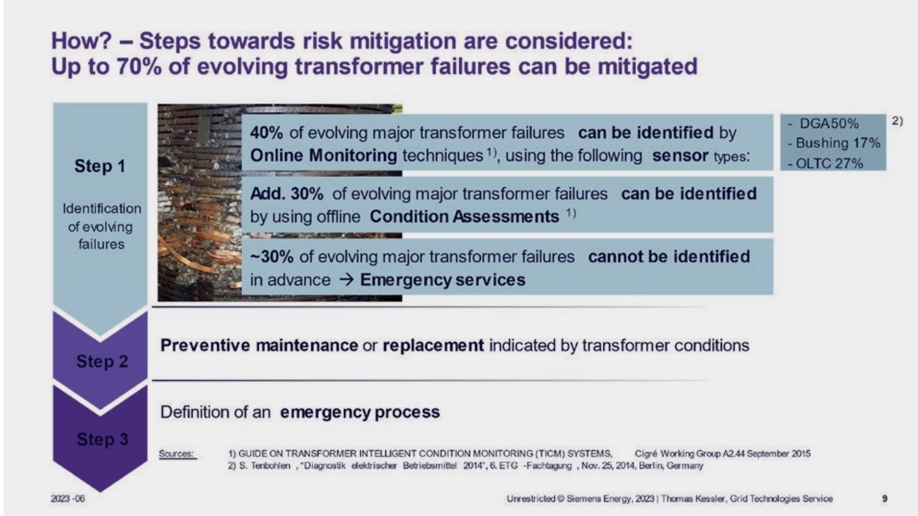
Picture 5 shows the achievable risk mitigation potentials of the described Service Levels A to E, considering the risk mitigation potentials shown in picture 1.

General Assumptions

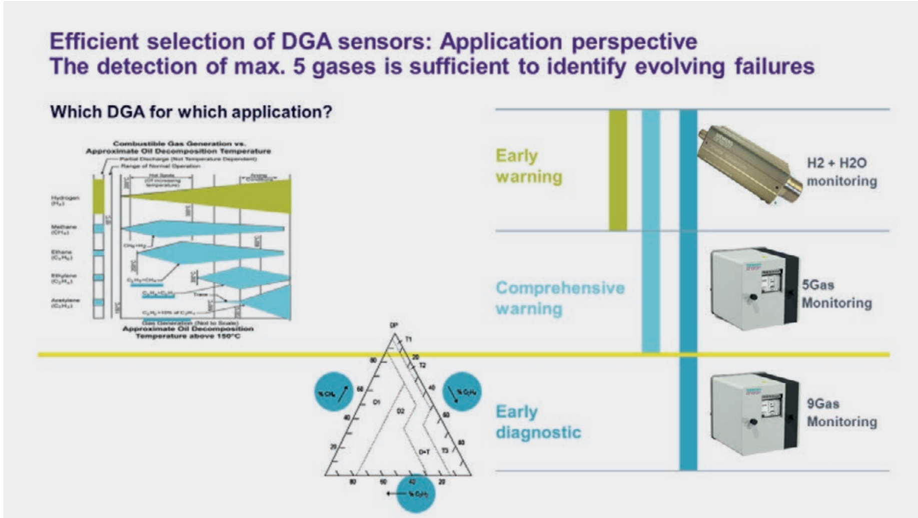
October 2022 is the reference month for all financial figures including the rates for the generation and transmission of electricity, pricing for transformers and services: Oil regeneration and drying, preventive bushing exchange, diagnostics, online monitoring equipment, onload tap changer
(OLTC) maintenance.

Discussion of Maintenance Strategies for Transmission Transformers

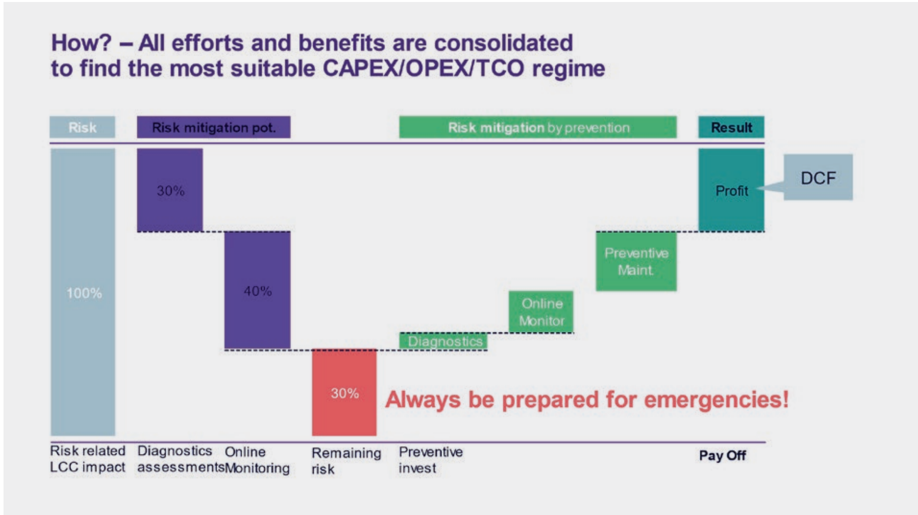
It is assumed that transmission companies are mostly regulated companies. The Return-on-Invest (RoI) on the Regulated-Asset-Base



Picture 1: Principle of risk mitigation for evolving major power transformer failures /3/, /4/.

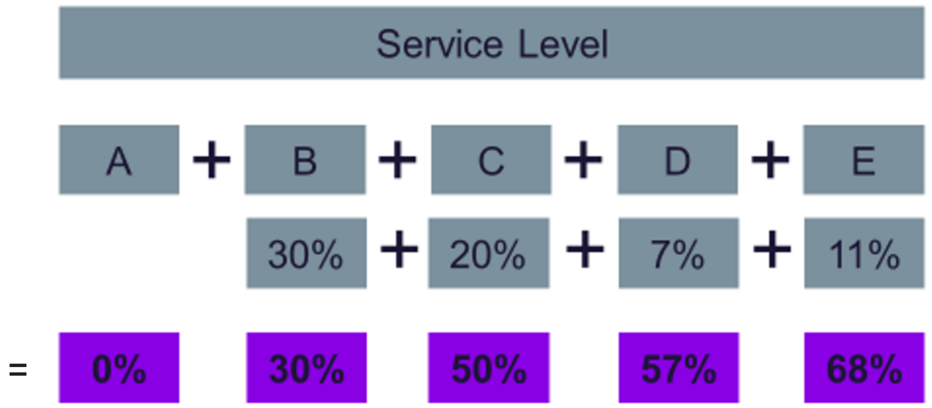


Picture 2: Application of different kinds of DGA sensors /5/



Picture 3: Principle of risk mitigation, showing the risk mitigation potential, preventive efforts and profit.

Picture 4: Overview of Service Levels A to E



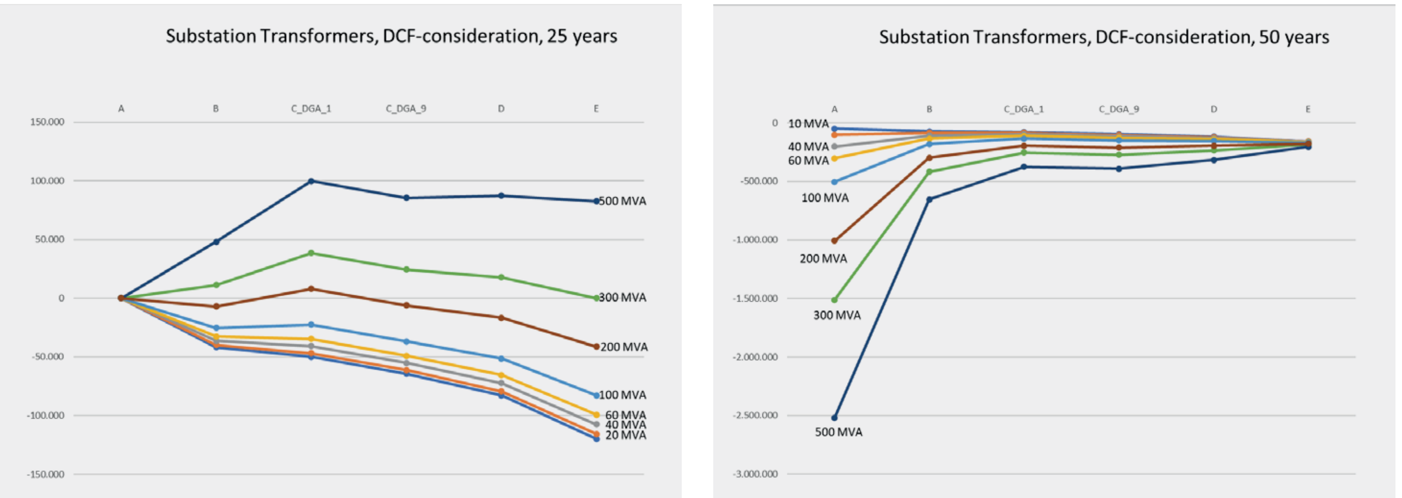
Picture 5: Achievable risk mitigation potentials for Service levels A to E (figures in purple shadowed fields)

(RAB) is their most important source of profits. The average Global failure rate for transmission transformers is 0,53% p.a. /1/, reaching from nearly 0 in the first 25 years to almost 1% in the later life cycle /1/.

The „n-1 principle" is fully applied. This means that no power losses and Costs-of-Energy-not-Supplied (CoENS) in case of transformer failure are considered. In result the risk exposure is limited to the direct damage of the transformer. However additional costs for the necessary re-routing of energy and re-dispatching in case of failure need to be taken into account during the risk assessment. The same applies for the impact of incentive and malus payments due to the applicable regulatory scheme or customer contracts.

The benefits and resulting DCF of transformer maintenance strategies A) to E) have been computed for various types of substation transformers. The following diagrams display the benefits for redundant substation transformers. DCF evaluation periods of 25 years and 50 years (see picture 6) have been computed.

The modelling for 25 years shows that applying preventive measures may only pay off for bigger substation transformers with ratings of > 100 MVA. In these cases, the accumulated costs for risk mitigation are less then the corresponding risk exposure.

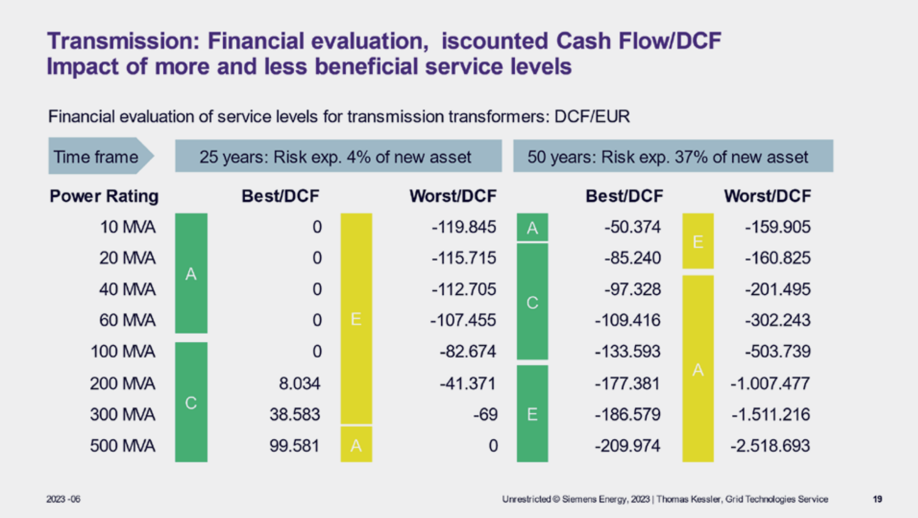


Picture 6: Benefits (DCF, EUR) for various kind of redundant substation transformers for maintenance strategies A) to E), DCF evaluation period of 25 years (Left), 50 years (Right)

For smaller ones the risk mitigation costs are higher than the risk exposure.

The modelling for 50 years changes the picture completely. Although the generated DCF is always negative, Service Level A is the less beneficial for all kinds of substation transformers except very small ones due to the replacement costs of the existing transformer after 25 years. The DCF generated by Service Levels B to E are impacted by significant maintenance costs e.g. for preventive bushing exchange, oil regeneration and drying.

In summary the most feasible maintenance strategy depends on the considered time frame and size of the substation transformer (see picture 7).



Transmission: Financial evaluation, iscounted Cash Flow/DCF
Impact of more and less beneficial service levels

Financial evaluation of service levels for transmission transformers: DCF/EUR

Time frame	25 years: Risk exp. 4% of new asset				50 years: Risk exp. 37% of new asset			
Power Rating		Best/DCF		Worst/DCF		Best/DCF		Worst/DCF
10 MVA		0		-119.845	A	-50.374	E	-159.905
20 MVA		0		-115.715		-85.240		-160.825
40 MVA	A	0		-112.705	C	-97.328		-201.495
60 MVA		0	E	-107.455		-109.416		-302.243
100 MVA		0		-82.674		-133.593	A	-503.739
200 MVA		8.034		-41.371		-177.381		-1.007.477
300 MVA	C	38.583		-69	E	-186.579		-1.511.216
500 MVA		99.581	A	0		-209.974		-2.518.693

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Picture 7: Financially more and less beneficial Service Levels for substation transformers, 25 years and 50 years evaluation

The main financial benefit is that potentially high unplanned OPEX are shifted to the planned OPEX budgets.

Picture 8: Benefits (DCF, EUR) for various kind of redundant GSU transformers for maintenance strategies A) to E), DCF evaluation period of 25 years (Left) and 50 years (Right)

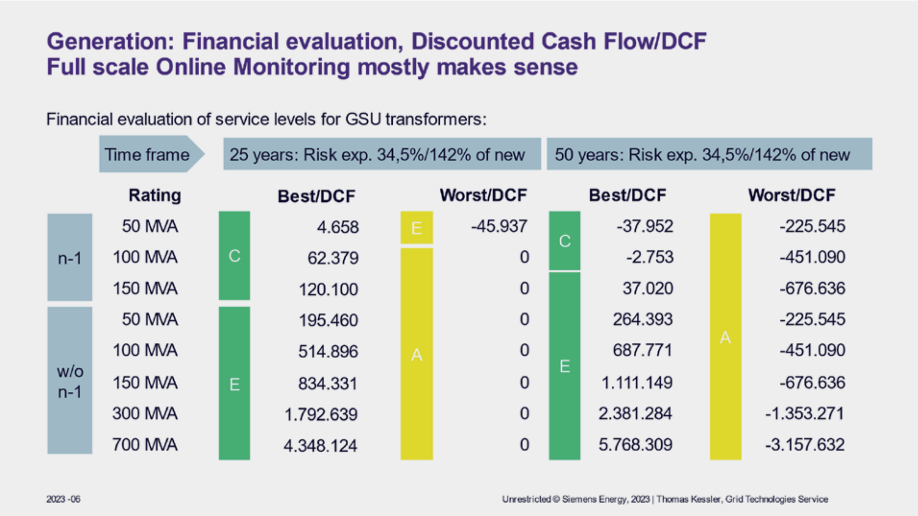
For 25 years and smaller transformers on distribution level preventive measure may stay at the minimum (Service Level A). For bigger ones Service Level C is appropriate.

For a period of 50 years Service Level C makes also sense for smaller substation transformers.
For the big one's full-scale online monitoring system make sense.

Due to the remaining risk of failure (see VI. and VIII.) effective emergency processes are key to further reduce the risk exposure of the transformers.

The main financial benefit is that potentially high unplanned OPEX are shifted to the planned OPEX budgets. This is an "insurance-like" approach.

This is an 'insurance-like' approach.



Generation: Financial evaluation, Discounted Cash Flow/DCF
Full scale Online Monitoring mostly makes sense

Financial evaluation of service levels for GSU transformers:

	Time frame	25 years: Risk exp. 34,5%/142% of new				50 years: Risk exp. 34,5%/142% of new			
	Rating		Best/DCF		Worst/DCF		Best/DCF		Worst/DCF
	50 MVA		4.658	E	-45.937	C	-37.952		-225.545
n-1	100 MVA	C	62.379		0		-2.753		-451.090
	150 MVA		120.100		0		37.020		-676.636
	50 MVA		195.460		0		264.393	A	-225.545
	100 MVA		514.896	A	0		687.771		-451.090
w/o n-1	150 MVA	E	834.331		0	E	1.111.149		-676.636
	300 MVA		1.792.639		0		2.381.284		-1.353.271
	700 MVA		4.348.124		0		5.768.309		-3.157.632

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Picture 9: Financially more and less beneficial Service Levels for GSU transformers, 25 years and 50 years evaluation

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Discussion of Maintenance Strategies for Generator-Step-Up-Transformers

It is assumed that power generation companies are mostly non-regulated companies. Energy sales are their most important source of profits. The average Global failure rate for Generator Step-Up transformers (GSU) is 0,95% p.a. /1/, along the entire cycle /1/.

The „n-1 principle" is rarely applied only to smaller GSU in the area of renewable energy applications. The Costs-of-Energy-not-Supplied (CoENS) is the dominating risk in case of GSU failure. Also the doubling of the major failure rate in comparison to substation transformers is a risk driver. Further additional costs for the necessary re-routing of energy and re-dispatching in case of failure need to be taken into account during the risk assessment. The same applies for the impact of incentive and malus payments due to the applicable customer contracts.

As result the risk exposure of GSU's is significantly higher than for comparable network transformers. The benefits and resulting DCF of transformer maintenance strategies A) to E) have been computed for various types of GSU transformers. The following diagrams display the benefits for GSU transformers. DCF evaluation periods of 25 years and 50 years (see picture 8) have been computed.

The modelling shows that applying preventive measures pay for almost all kind of GSU transformers with the exception of very small and redundant assets. Mostly, the accumulated costs for risk mitigation are far less than the corresponding risk exposure. The modelling for 50 years shows a similar picture. The generated DCF is mostly positive for Service Levels C to E (see picture 9).

The background for both mainly is the mitigation of the CoENS-related risk. The risk mitigation efforts are somehow neglectable in comparison with the CoENS-related risk exposure in most cases.

In summary the Service Level C appears as the most feasible maintenance strategy for smaller GSU's. For GSU's of 100 MVA and bigger Service Level E including full scale online monitoring is feasible (see picture 9).

Due to the remaining risk of failure (see VI. and VIII.) effective emergency processes are key to further reduce the risk exposure also of the GSU transformers.

The main financial benefit is the increase of energy sales. These are enabled by the higher GSU availability as result of the preventive and risk mitigating measures.

Output Oriented Maintenance Strategies

In the following it is described how the Service Levels A to E (see VIII) can be applied to well known maintenance strategies described in /2/ and entire power transformer fleets.

Reliability Centered Maintenance, RCAM
The goal is the maximum availability of the transformers, e. g. in the safety critical industries like the chemical industry or transformers of high relevance, e.g., GSU. There is a high-risk exposure of individual assets. Service Level E appears as the most suitable approach to maximize the transformer availability and risk mitigation.

Risk Based Maintenance, RBM
The focus is to achieve an acceptable performance and risk exposure of a group or fleet of assets. For this the acceptable fleet risk exposure needs to be assessed. The appropriate Service Levels need to be defined per asset. This is an iterative process, starting with the most critical assets.

Condition Based Maintenance, CBM
Service Levels B to E can be considered as CBM for individual assets.

Time Based Maintenance, TBM
Services in fixed time intervals according e. g. to OEM or end user standards.

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A holistic view on the transformer is key, instead of a view on individual components like OLTC or bushings only.

Corrective Maintenance
Reactive service in case of failure. This is similar to Service Level A (Emergency Services).

Typically, CBM, TBM and Corrective Maintenance are subsets of RCAM and RCM

Summary

Power Transformers are very reliable assets. However, the potential damage in case of major failures is very high.
Benefits of and efforts for risk mitigation need to be well balanced. 5 graded Service Levels have been modeled to find the most suitable CAPEX/OPEX/TCO regime by addressing the main business drivers: Safety, Financial, Quality of Service, Reliability, Environment and how to embed them into an overall asset management strategy. A holistic view on the transformer is key, instead of a view on individual components like OLTC or bushings only.

The unavoidable remaining risks requires clearly defined emergency procedures, e. g. emergency agreement with the OEM, to minimize the impact of unavoidable remaining risks.

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Digital Twins 2.0: Transforming the Grid for Tomorrow's Challenges

by **Abder Elandaloussi**

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...we can't expect the tools from even 5 years ago, which were based on a simpler grid, to be relevant in another 5 years, even with incremental innovation.

Abder Elandaloussi is an engineering manager at Southern California Edison in the Grid Technology Innovation team. In his current role, Abder focuses on Transmission and Distribution innovation to modernize the electric grid and prepare it best for all the challenges ahead. Some of his team's areas of interest for innovation include digital twins, machine learning, robotics, advanced sensors, advanced T&D applications, microgrids, and blockchain. Abder and his team are always looking for collaboration with partners to advance the state of the electric grid through development and testing of pre-market technology. They collaborate to demonstrate cutting-edge technologies and their effectiveness to address utility needs. Abder is the chair of the digital twin taskforce under ITSLC in IEEE and has co-authored the first IEEE report relating to using machine learning to enhance power system protection and control. He has over 12 years of experience in the utility sector and has held positions previous to SCE in engineering consulting and R&D. He holds a master's degree in electrical engineering from Kansas State University and an MBA from the University of Kansas. He is a registered Professional Engineer in California and Kansas.

In the electric sector, there has been a sudden surge in the proliferation of digital twin solutions tailored to address distinct utility challenges. Yet, this rapid influx has also unleashed a wave of confusion, as the industry grapples with the varied and often limited definitions of what exactly a digital twin is.

As I started in this journey to better understand and define digital twins specifically for the utility industry, I realized that different entities—both within and across organizations—had varying perspectives on the meaning and purpose of digital twins. Depending on whom I talked to, some viewed it as akin to a grid management systems or power-flow simulation tools, while others saw it equivalent to Hardware in the Loop, 3D visualizations of assets, or machine learning models that leverage sensor data. This diversity led me to conclude that either nobody is correct, or maybe everyone is correct. It had to be one or the other. I'm here to tell you it is the latter.

Stakeholders must leverage the dictionary definition of a digital twin as a starting point, and mold it to their specific use case or need. The definition of a digital twin, maybe, should be loosely defined and open to interpretation. The flexibility of the use and the definition mean that we may have been using digital twins for the past 20 years in our industry! Now, I could either cut the article here and claim success, or I could dig just a bit deeper to ponder the main question in my mind: Is the grid of today or the grid of the future the same as the historic grids that the existing digital twins were built for? Do the future and past grids both have the same challenges and complexities? If the answer for your utility is yes, the rest of this article might be overkill for you. If the answer is no or "it depends", then I implore you to stay with me to understand why digital twins, in the traditional sense, are no longer adequate. After all, we can't expect the tools from even 5 years ago, which were based on a simpler grid, to be relevant in another 5 years, even with incremental innovation.

First, let's understand why the grid of the future, or even the grid of today, is so different from the past. I'll start with the obvious: Our electric grid is becoming a complex, non-deterministic system. With the addition of different technologies and processes in the last 20 years to help manage, protect, and maintain the grid, we have transformed the grid into a multi-dimensional, inter-related system of systems. The digital transformation within our industry has been remarkable. Transitioning from electro-mechanical relays to micro-processor relays, to now having the ability to control DERs to help operate the grid is nothing short of amazing. However, now that we have taken these strides, we must look back on the impact of these incremental changes to our grid and our backend systems.

The current situation for many utilities is that they are sitting on petabytes of data growing exponentially. They have a complex design of their T&D system to improve their company metrics (such as reliability) and are setting ambitious plans to become carbon neutral within 20-30 years through various methods such as adopting various technologies (EV, DERs, building electrification). There are more factors out of the utility's control that impact the grid and should also be integrated seamlessly in the decision-making process (e.g. climate, cyber/physical attacks, load growth, regulations, politics, government incentives).

The customer is becoming an even more integral part of the story and driving utility decisions.

Interestingly, the industry's drive to innovate and solve forthcoming challenges is a must for survival. However, we have yet to understand how these innovations and factors discussed above interact with and impact each other. Many innovations today are developed in silos meant to target a specific challenge, including digital twins in the traditional meaning. This may no longer be a sustainable approach for the grid of the future, and this leads me to pose a new framework to help utilities attain a more holistic view to managing the electric grid of the future. This framework is based on a new definition that goes beyond siloed digital twins (version 1.0), maybe we need to call it Digital Twin 2.0 for the future grid 2.0.

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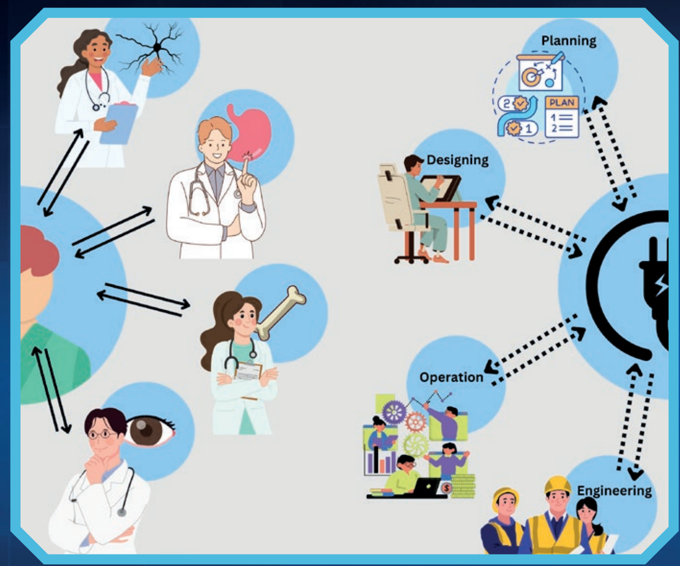
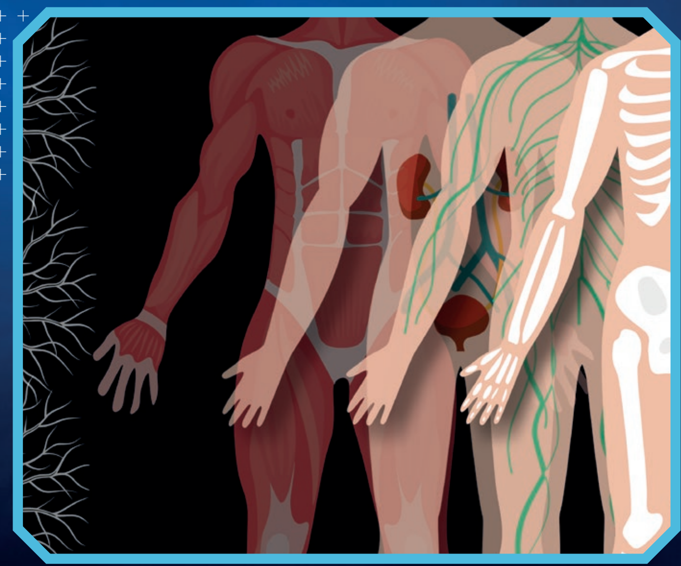
Many innovations today are developed in silos meant to target a specific challenge, including digital twins in the traditional meaning. This may no longer be a sustainable approach for the grid of the future, and this leads me to pose a new framework to help utilities attain a more holistic view to managing the electric grid of the future.

The Grid 2.0 is becoming a living organism, like the human body

Let me begin by illustrating the concept of Digital Twin 2.0 using an analogy from a vastly different system: the human body. This comparison will hopefully drive home the idea that holistic digital twins, which operate cross-domains, are much more effective to understand the full story and make optimal decisions. Let's start by understanding the human body as a complex network of systems and processes. The human body is composed of various loads/ generation sources (organs), a transmission system (nerves, veins), management/ orchestration systems (nervous system, digestive system, cardiovascular system, sensory system, circulatory system), a backbone that protects the body and needs reinforcement (skeletal system, skin, bones, muscle), sensors (eyes, ears, mouth, nose, skin), and nodes that connect various part of the body (joints, valves, etc.). These systems are either transporting, managing, producing, consuming, absorbing, or exerting various fluids and chemicals. Each of these components typically has specialists or professionals that can diagnose, test, and operate on (fix) them by collecting information from the body through equipment or from a patient. Such a complex system, as we all can relate, is a web of interconnected systems that all can impact each other in various scenarios. We have all experienced, in one form or another, how a single injury/action could trigger various pain-points or anomalies across our body's systems. The effects could be experienced simultaneously or in a staggered fashion over time—seconds, minutes, or even longer-term effects. Finally, the human body is exposed to so many environmental factors that could impact it, with only some of those factors within our control.





Learning from The Medical Industry Architecture

In the medical world, the primary physician is responsible for conveying the big picture and providing patients with a wholistic explanation of a situation. Specialists on the other hand, are professionals to whom a patient is referred for further analysis. They focus on specific areas of the body and report back to the primary physician. They essentially act as federates to the central decision-maker and storyteller - the primary physician.

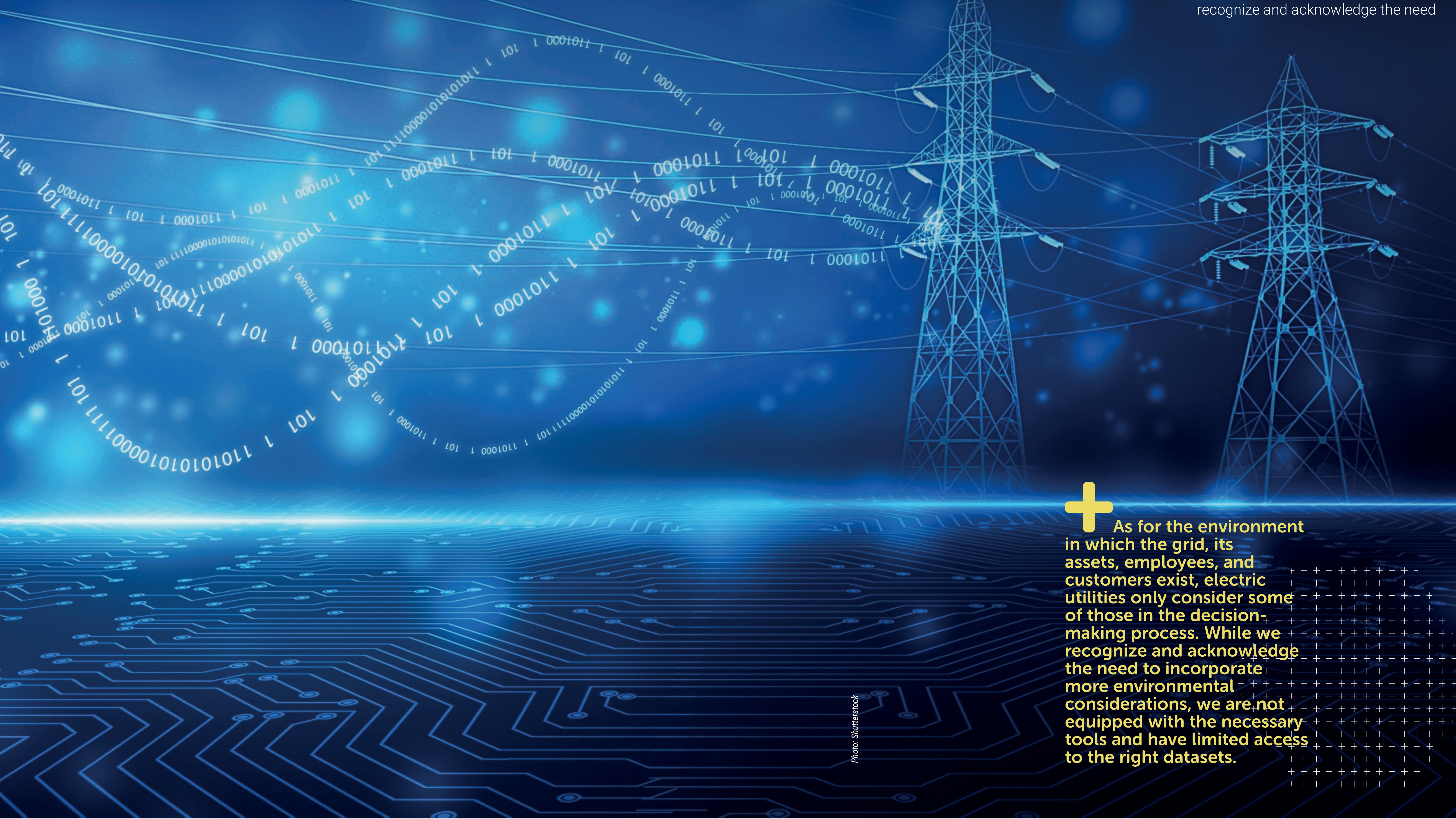
This framework in the medical industry works because it encourages collaboration among different doctors to share results and insights for solving specific issues.

Now, imagine if this didn't exist - a world where you had no primary physician and had to visit every specialist, then collect all the information yourself to come up with a wholistic diagnosis! This collaboration amongst medical professionals may not be automated and doesn't involve a user interface to communicate with the patient, the doctor acts as the analyzer and the storyteller, but it's better than the alternative. It has proven to be essential because the body is so interconnected and sometimes, one perspective may not be enough for an effective diagnosis.

With this existing framework in the medical industry, what if doctors didn't ask us about the environment around us, such as our habits, personal life situation, professional life, etc.? Would they be able to properly diagnose us? I think not. They need to understand context, usually delving deeper into it during a patient's visit beyond the questionnaire to really understand the full picture.

This is an essential component and can be just as crucial as the exams doctors would perform during a visit.

In the electric industry, we've made some progress towards some of these best practices in the medical world, but we've barely scratched the surface. We have different internal groups with experts performing specific functions across domains such as protection, design, planning, operations, maintenance, construction, and more. However, we lack a holistic approach that is only attained by seamlessly sharing insights across these organizations, we don't have a clear primary physician equivalent. The insights today stay trapped within the domain specific functional teams in the organization and no relationships or trends can be drawn across the different domains to drive holistic decisions. Some findings may get shared during meetings in a PowerPoint or in some other text form, but how much of that really is integrated into other business functions? As for the environment in which the grid, its assets, employees, and customers exist, electric utilities only consider some of those in the decision-making process. While we recognize and acknowledge the need to incorporate more environmental considerations, we are not equipped with the necessary tools and have limited access to the right datasets. Now, to be fair to the electric industry, the scale of the electric system, its challenges and the impact of making the wrong decision is a completely different dimension. Nevertheless, it's good to learn from the successes and shortcomings of established industries such as the medical industry, that deals with a system that is complex in its own respect, since it could be a matter of life or death. This metaphor was meant to draw loose but relevant parallels between the human body and the electric grid. Both are reliable today. However, the grid is evolving into a complex, interrelated system of systems that needs to be regarded and managed like the human body. Unlike the human body however, the grid will not naturally sustain itself as it evolves; it will require intentionally designed technologies and processes at the fingertips of utility personnel (the doctors of the grid) to enable holistic situational awareness, planning, operations, maintenance, and design. This lack of natural self-healing/autonomous characteristics in the grid drives the dire need for utilities to identify and replicate the equivalent of primary physicians. This means having the right sensing, design, technologies, and workforce in place to consider the relationships between the different domains that we consider and analyze in a siloed manner today.



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As for the environment in which the grid, its assets, employees, and customers exist, electric utilities only consider some of those in the decision-making process. While we recognize and acknowledge the need to incorporate more environmental considerations, we are not equipped with the necessary tools and have limited access to the right datasets.

Digital Twin Definition

Moving on from the human body, let's delve into the comprehensive definition of a Digital Twin 2.0 (DT) for the electric grid. It is the holistic storyteller of the grid. The DT is a detailed virtual representation of a physical system, ranging from a single grid asset to an entire electric grid within the utility industry. This virtual model integrates an array of information including attributes, GIS, sensor data, economic, societal, customer data, electric asset data, and other relevant datasets across different domains. These can represent and reflect the properties, behavior, and context of the utility's grid, environment, its customers, and its employees.

The data and information are leveraged to develop and maintain surrogate models of different fidelities of the grid, and its assets that enable utilities to run advanced single or multi-domain scenarios. These models can either be physics-based or can be physics models augmented with historical data and advanced machine learning techniques to better reflect the reality of how the grid and its assets behave and interact with each other. This allows users to understand the current state of the system, predict its behavior under different scenarios, and observe the impact of each scenario on the system, along with any potential cascading effects.

The DT can be used in real-time for operations or offline for planning, each requiring different sets of information. A real-time DT provides situational awareness, uses machine learning (ML) models to analyze the system's performance, and considers external dynamic factors such as climate and traffic. An offline DT, on the other hand, can be used for investigations, troubleshooting, and planning studies by learning from historical data and combining physics-based models with ML to reflect real-world conditions of the grid and its surroundings. This holistic approach enables effective decision-making and risk management in the utility sector.

Success of the DT Depends on its Architecture

Through several iterations and years of research and discussions, I have concluded that the digital twin 2.0 cannot feasibly be developed by any single or a few vendors alone. It should be a combination of technologies, algorithms, and processes that communicate with each other based on some common framework and understanding. Furthermore, I'd encourage you to explore how Artificial Intelligence could be used as a tool to enable and support the digital twin 2.0 .

Here are some core Features and dependencies that every utility exploring the digital twin 2.0 should consider:

1. **Use case driven** - A strategic roadmap to build the DT over time is necessary to develop the architecture and ultimate DT vision.
2. **Scalable** - It will grow over time as the use cases increase and vary. They will require various datasets, models, and functionalities. Therefore, the architecture and design choice should account for the scalability over time across these various dimensions.
3. **Inter-Operable** - It will require tremendous collaboration within the industry and research community to develop the proper tools that all can exchange information seamlessly and instantaneously.

Digital Twin 2.0 is not just a tool but a narrative framework that tells the complete story of the grid's past, present, and future.

Core Dependencies

1. **Accurate, Up-to-date models -** Just as for DT 1.0, if the DT 2.0 models that represent the grid are not accurate, your results could be misleading.
2. **A robust, flexible simulation engine -** DT should support running simulations across different domains, using different datasets and models fast and efficiently.
3. **Quality data -** Data used by the DT will be leveraged to generate insights ad inform optimal decision making; it must be ready to be consumed.
4. **Intuitive, User-friendly interface -** All of this will be meaningless if the users can't intuitively and quickly run simulations and process insights and results.

There is a Lot of Work Ahead of Us, but it's Worth It

The journey towards Digital Twin 2.0 is not merely an incremental step but a transformative leap. The complexity of modern grids, with the increase in interconnected systems and external influences, demands a sophisticated, holistic approach. Digital Twin 2.0 is not just a tool but a narrative framework that tells the complete story of the grid's past, present, and future. It requires a dedicated, knowledgeable team to navigate through the industry's existing offerings and discern what truly works and what gaps exist between today's offerings and the north star. As we stand on the brink of this new era, it is only through collaboration, innovation, and a deep understanding of the grid's evolving challenges can we harness the full potential of Digital Twin 2.0. This is the future of utilities, and it is a future that promises to revolutionize how we understand and manage our most critical infrastructure.

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