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TRANSFORMER TECHNOLOGY MAG

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Mitigating Transformer Supply Chain Risks with Online Monitoring
Adoption of Asset Health Monitoring Solutions for Power Grid Equipment
Saving the Day: **On-line DGA Monitoring Case Studies**

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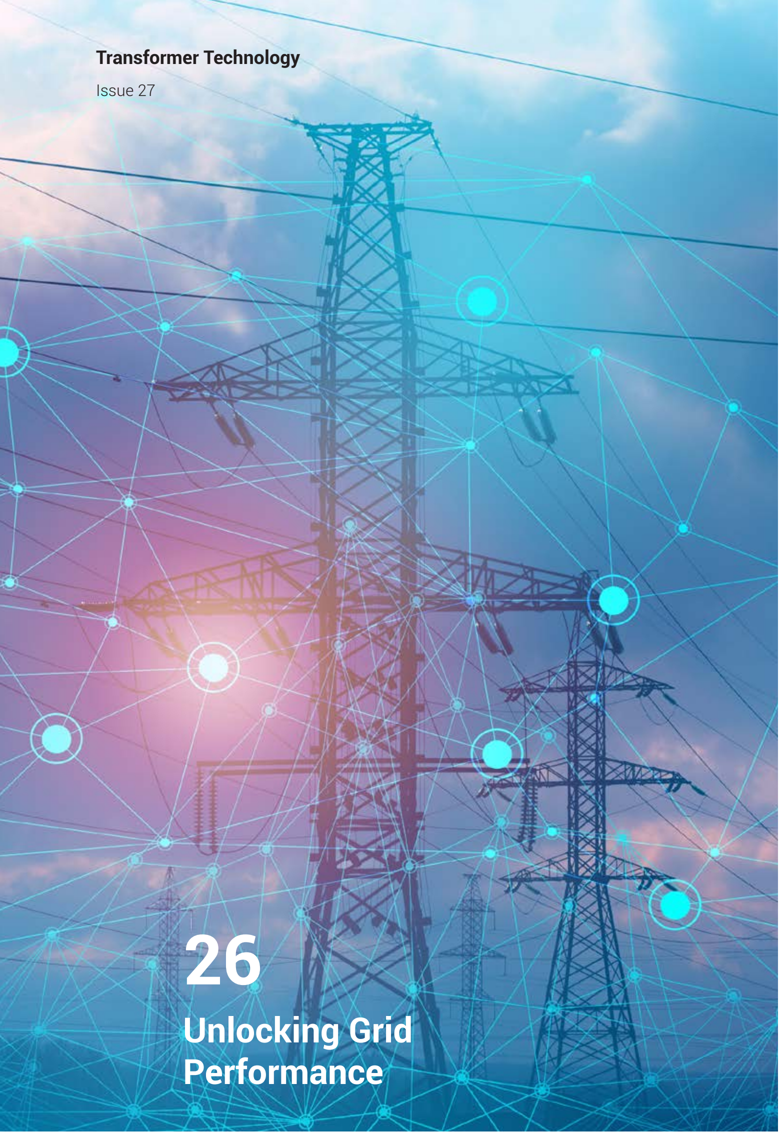

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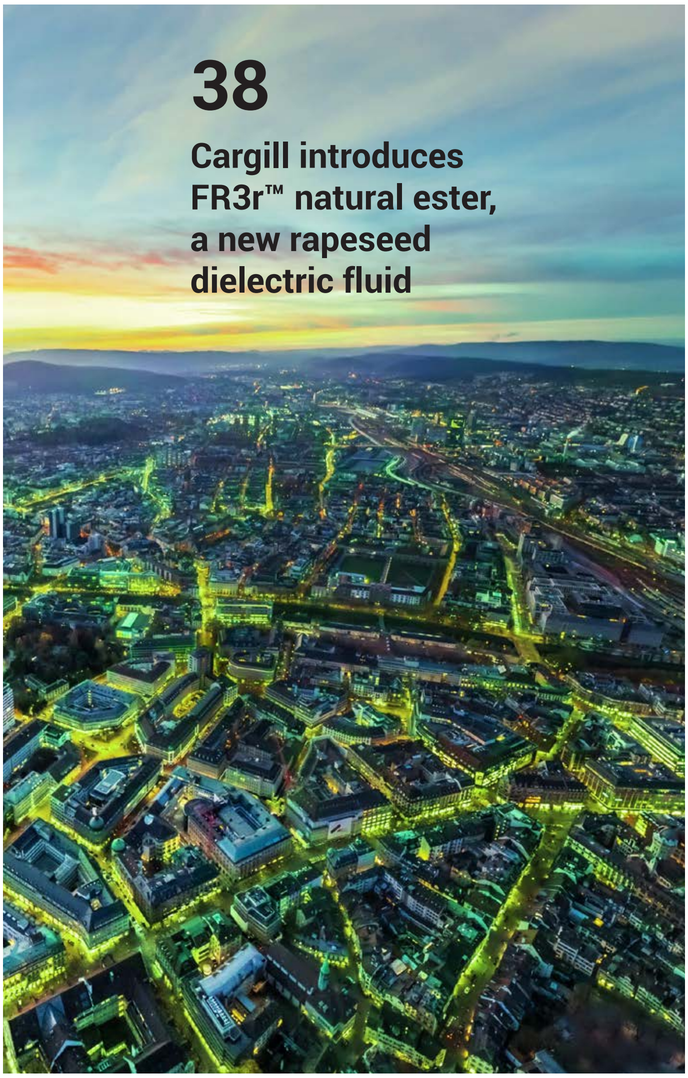

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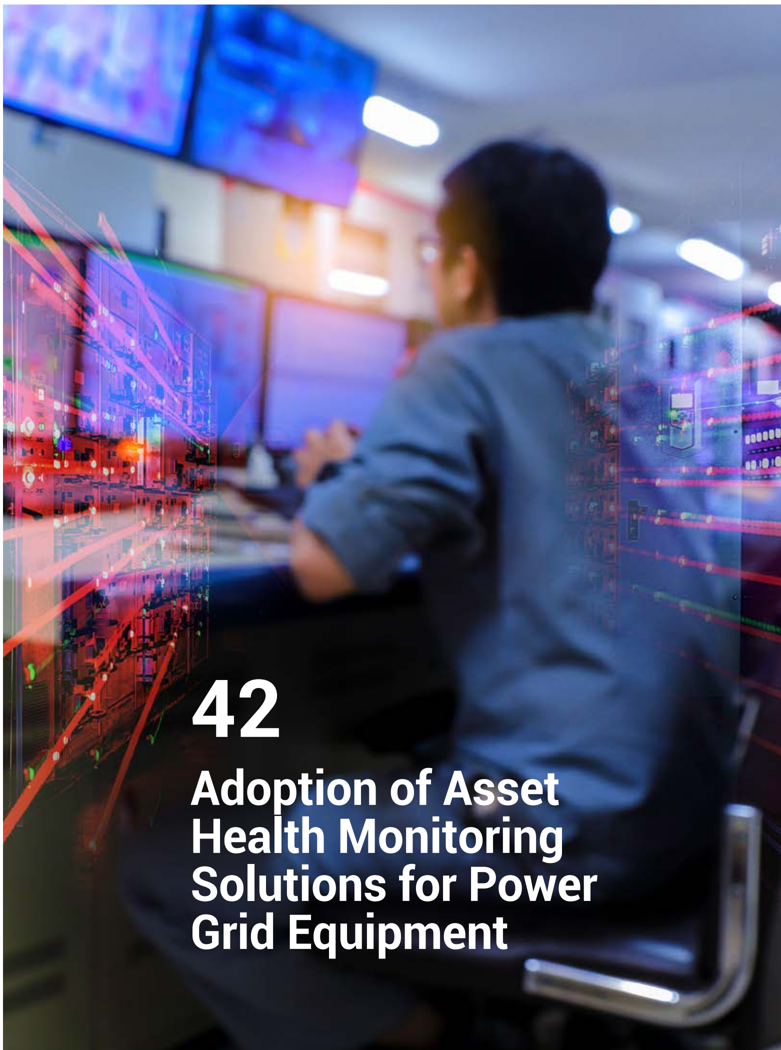

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Impressum

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High voltage bushings & insulators

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Dear Readers,

I have had the great fortune of interviewing some special subject matter experts (SME's) at the recent DistribuTECH International conference and three things stood out as important. First is the amount of change taking place in the power industry globally. Distributed Energy Resources (DER) is creating a changing landscape and new problems for grid operators, as they try to make adding the generation from wind and solar. While that is nothing new, the pace and scope of that change has increased dramatically.

While supply chain issues are still around, the biggest supply chain issue that cannot be resolved in the short term is the supply of the most important resource we all have, the human resource. The pool of engineers, data scientists, and more importantly tradespeople is not keeping up with the demand, both demand from growth and from a generational shift with more and more people opting for retirement. We are not the only industry suffering this problem, but it compounds our ability to decarbonize, decentralize and digitalize.

While supply chain issues are still around, the biggest supply chain issue that cannot be resolved in the short term is the supply of the most important resource we all have, the human resource.

Some solar and wind projects have gone from 2 years to get approval to over 4 years in some markets. Getting permits has been complicated by the difficulty of studies from grid operations on the impact and feasibility of new connections. In the US, the government has made a major commitment to green energy, but all that money won't solve the problems of an aging grid and the difficulty of making long term plans when so much has changed in the short term.

The second thing we heard was about the rapid increases in technology that will help create a reliable and resilient grid. Solid state, digital technology is being used throughout the grid in ways we could only dream about. It was at the vendor showcase that this became more pronounced with companies both large and small displaying new advanced technologies, several being represented in this issue with technical articles, many focused on monitoring most of the assets within the grid.

Martin Robinson of IRISS presents a unique perspective on the issue in his article based on how monitoring can help alleviate some of the problem through Operator Driven Safety and Reliability (ODSR). By giving operators the ability to see problems through condition-based maintenance systems rather than time-based, we use the monitored condition of the asset to guide our maintenance teams making them more responsive and less bogged down doing time-based actions that likely only make things worse and waste a tremendous number of resources.

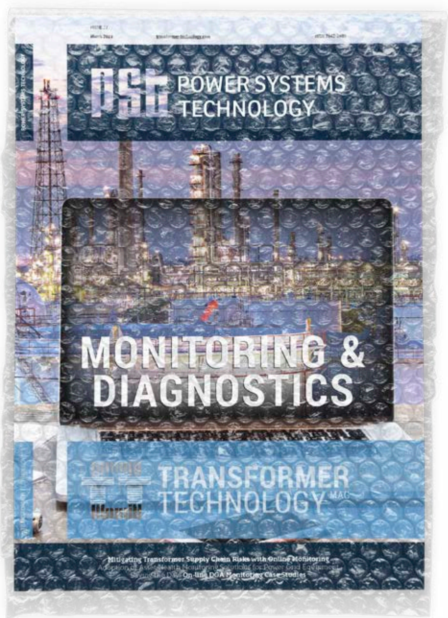
The overall sense that we walked away with from the event is that the amount of change we are going through as an industry has rapidly increased. Changes around us force us to change internally for the best way to respond. The rapid increase of monitored assets and more importantly monitored systems will change the way we rebuild the grid in every country and in every neighborhood.

Monitoring will once again help us to focus reduced human interaction on a mostly remote asset.

Alan M Ross

For instance, the electrification of transportation alone will require significant changes to how we respond and how we monitor remote assets designed to support recharging both at home and for public consumption. DER, while not new, is creating its own issues, where monitoring will once again help us to focus reduced human interaction on a mostly remote asset.

As always, we thank the experts who were willing to take the time to unselfishly share their knowledge, understanding and wisdom with our community and, as always, we thank their companies for supporting them in these efforts.



Alan M Ross
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Mitigating Transformer Supply Chain Risks with Online Monitoring

by **Dan Roth**

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There are many challenges that utilities face today in the never-ending goal of continuing to provide safe and reliable power. These challenges include trying to improve the resiliency of the grid to natural disasters, replacing aging infrastructure and making power delivery more efficient, all while integrating renewable energy sources.

One key element of these initiatives is the large power transformer, which is a critical building block to the grid [1]. New transmission lines will require substation upgrades, including power transformers. New renewable energy plants will require power transformers to interconnect to the grid. The average age of a large power transformer is 40 years old, which is at the end of its designed service life [2]. This increasing demand for units is being met with a volatile supply chain struggling to keep up.

Power transformer lead times have gone up across all kVA sizes including large substation units to small distribution pole tops. In many cases, these lead times are reported to be 2-3 years [3]. Coupled with these increasing lead times is the significant cost of replacement, as the natural economic forces of supply and demand have driven up the price far greater than inflation or commodity increases would predict.

Dan Roth is currently the Sales and Marketing Director for Dynamic Ratings based in Sussex, Wi. He received his Bachelor of Science degree in electrical engineering from the University of Illinois at Urbana-Champaign. He possesses more than 20 years of industry experience having previously been employed at Eaton (Cooper Power Systems) and Schweitzer Engineering Labs. His career has allowed for a wide range of experiences from relay system protection, feeder automation, communicating smart sensors to distribution line installation and protective equipment. Mr. Roth has contributed several papers and patents to the industry in that time.

There are some very real compromises that utilities have been forced to make to meet this demand. These often include using new suppliers, non-standard designs or refurbishing units. All three will have an impact on the performance of that power transformer, increasing the risk of unexpected failures and potentially leading to a shorter service life.

Large Power Transformers are largely dependent on the availability of grain-oriented electrical steel (GOES),) which accounts for roughly 25% of the unit's cost. Most of this material is imported into the United States with only one domestic supplier [1]. With a significant decline in domestic manufacturing of large power transformers and cores and concerns over the national security of bulk power systems, the presidential administration implemented Section 232 Tariffs on Steel. While this did improve the financial stability of domestic suppliers, it was disruptive to the large power transformer industry supply chain. This flux in competitive balance caused by the 25% tariff was magnified by the labor impacts because of the global pandemic. The net result of these two major market impacts is that the average large power transformer lead time has doubled and the cost has increased substantially [3].

Procurement departments at large utilities, renewable energy producers, and other large industrial customers are faced with approving alternative suppliers. Many of these alternative

suppliers are not commonly used in the supply of large power transformers for the US bulk power system because of design limitations and reduced quality controls. When the legacy supplier lead times were not acceptable, these customers were forced to take on the additional risk of transformer failure to maintain power delivery. The same risks exist when a nonstandard design is sourced that may have a reduced capacity, or when a unit is refurbished with an unknown history.

Demand for new transformers and replacement of existing transformers is going to increase soon. Large power transformer consumption in the United States is expected to grow 20% between 2019 and 2027 [1]. This is being driven by the upgrading of existing infrastructure to better serve the increasing demand and penetration of renewable energy. Over 70% of the United States large power transformers are over 25 years old [2]. If the average service life of a large power transformer is 40 years, this equates to more than 150 large power transformers that will need to be managed for end of life each year [2].

The bulk power industry must maximize the service life of large power transformers as demand continues to outpace supply over the next decade. The answer to extending asset life cannot simply be more maintenance. The increased energy costs (up 8% in 2022) are challenging utilities to find savings through Operations and Maintenance (O&M)

With a significant decline in domestic manufacturing of large power transformers and cores and concerns over the national security of bulk power systems, the presidential administration implemented Section 232 Tariffs on Steel. While this did improve the financial stability of domestic suppliers, it was disruptive to the large power transformer industry supply chain.

Photo: iStock, Shutterstock

The bulk power industry must maximize the service life of large power transformers as demand continues to outpace supply over the next decade.

budget cuts, so the funding can be repurposed into new investments [4]. Therefore, more and more utilities, renewable energy producers and large industrials are turning to online transformer monitoring to extend the life of large power transformers and reduce the risk of unexpected failures. The real-time measure of operational parameters provides visibility into the condition of an asset. This allows for better confidence in loading transformers, planning maintenance, and proactively detecting changes in performance.

Most transformer failures occur shortly upon energization or after meeting design service life. Monitoring aging transformers will help extend the life of an asset which approaches that designed service life.

If large power transformers are being procured through new sources, online monitoring can also be used to mitigate the risk of infancy failures. Often infancy failures are fast-developing failure modes that occur before first scheduled maintenance and online monitoring is the ideal solution to catch these before the interruption of power.

Utilities are leveraging digital technologies to continually improve the efficiency of the grid. It is important to realize that online transformer monitoring is a critical component to ensure successful management of these critical assets. The return on this investment has never been easier to justify with the current impacts on large power transformer supply chains.

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Bidesh Kar

Director of Product Management at Sentient Energy

Interview with **Bidesh Kar**

> If you are replacing your aged infrastructure overhead with underground, you are fixing the aging infrastructure problem at the same time you are also building resilience.

Photo: Sentient Energy

Alan Ross: My guest is Bidesh Kar. Bidesh is the Product Manager for Sentient Energy.

We're going to get into product management, because that's right now kind of exciting, there's a lot going on. But first off, tell me a little bit about your background in the power industry. How long you been in it? How did you get in it?

Bidesh Kar: Absolutely. First of all, thank you, Alan, for having me here. I have been in the power industry since 2003, so just over 20 years now.

And back in time, right out of college, I had no idea about the power industry. I was just pushed into it in my first company and never looked back since then. I've worked in companies that provide products and services from substation to metering.

I've worked with companies like Itron, which does smart metering and grid edge stuff. I've worked with companies like S&C Electric, which does switching/protection equipment in the distribution grid. And my last four years been a fantastic journey at Sentient Energy. I'm responsible for the whole underground product portfolio as well as the software platform.

AR I love that we got a lot to talk about with the Underground portfolio. But first of all, when we were here last year and when we were at IEEE doing interviews, and when we did them at RE+, the number one problem last year was supply chain issues. Everybody had them. They're not gone, but we are working on them. But the problem that we have today is the dynamics of change. For instance, Bloomberg have just announced that their prediction for the adoption of EV charging was way off. It's going to be 2.4 to 2.6 times what they said it was. That's a lot of change. So, there's a lot of new demand on utilities. They're going to maintain the old grid, which is aging. With supply chain issues, it takes sometimes two and a half to three years to get transformers. And that's not the only problem. The demands on the utility are greater than they've ever been — maintain the grid, be reliable, be resilient, get ready for DER, make sure you're green, decarbonization.

From your perspective, talk about all of those demand changes and a little bit about how that equates to your job in product management at Sentient.

BK You highlighted two key things that stood out as you were explaining this. Number one, as you said, the supply chain issue is not gone for us. It's going to stay here. The macroeconomics of it, the geopolitical situation of it, it's beyond any company's control. So, leaving that aside from the utility perspective, I think the aging infrastructure paired with the extreme weather conditions has a very detrimental effect. Now, from our perspective, there's good news too it if you look at it.

Companies like Florida Power & Light have proven that undergrounding improves reliability and resilience. So, in the back-to-back storms last year, when the areas with overhead were down with power for several days, the areas with underground barely had any outages. What this means is other companies can look at this example and build a strategy towards undergrounding. And how this helps is if you are replacing your aged infrastructure overhead with underground, you are fixing the aging infrastructure problem at the same time you are also building resilience.

Sentient has a vast portfolio of underground line sensors which covers your whole distribution grid, from the feeder to the last mile on the lateral residential. So, that brings in visibility that otherwise it wouldn't have for your underground networks.

AR Underground makes sense, especially in fire prone areas, because then you don't risk fire ignition when you run the lines underground.

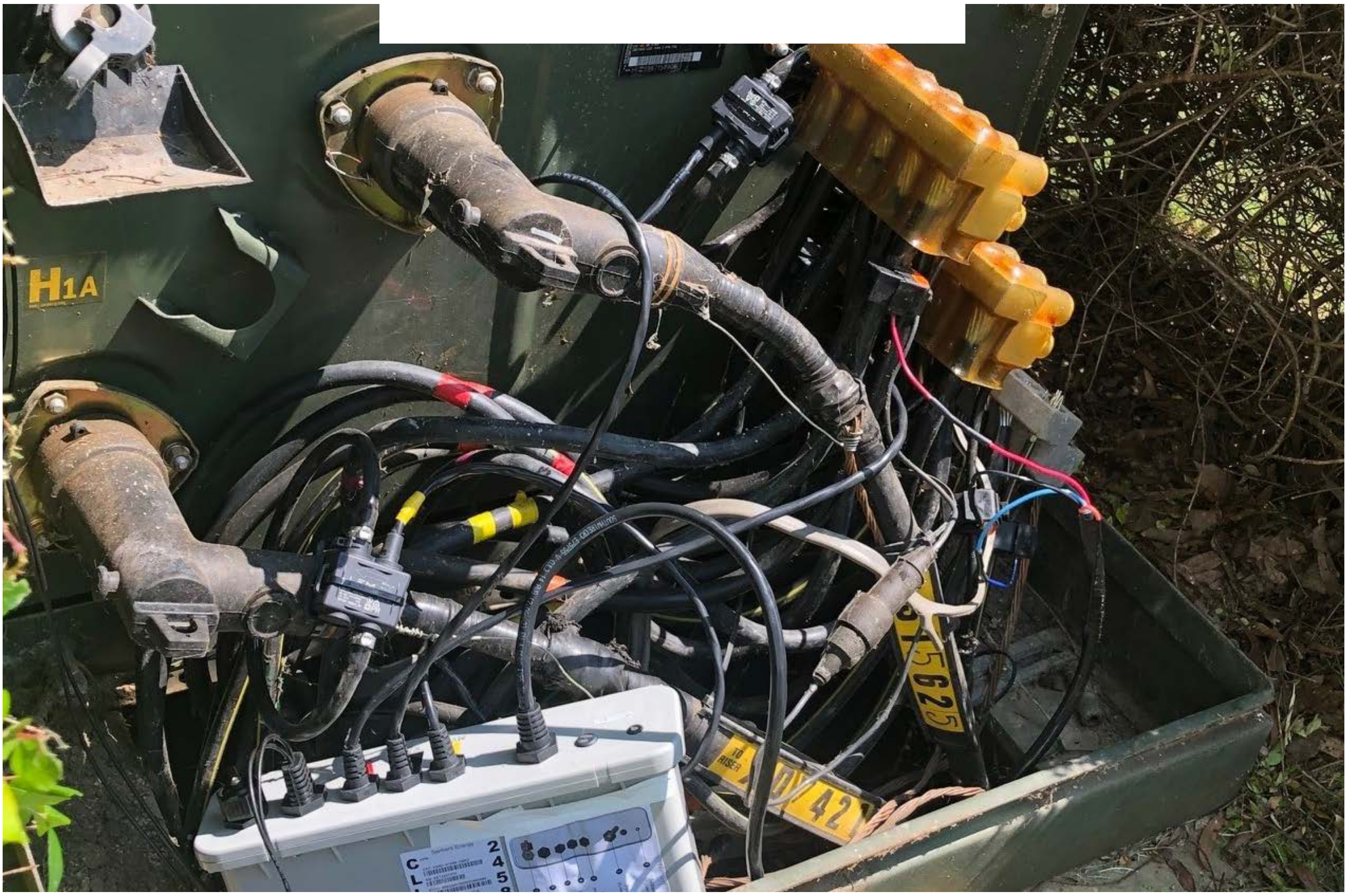
There's a cost to undergrounding. What is the cost differential between overhead and undergrounding? I used to hear that it was about four times. Is that still the case or not?

BK Well, there's a difference. You cannot look at the cost of just undergrounding at once. You need to look at the total lifecycle cost. So, Sentient Energy is a partner member at PDi2 (Power Delivery Intelligence Initiative). It's a nonprofit organization. We have done a lot of research and models where utilities can look at it and say, "What's my total cost of ownership of underground?" It's not just the $200,000 or a million dollars per mile of underground conversion, but imagine once you have undergrounded and there is a storm or a tornado, it's not getting those lines down three times in ten years. So, you add that up, you add up the safety aspect of it, then it makes sense in most of the cases. Otherwise, PG&E wouldn't have gone for 10,000 miles of commitment.

AR Most utilities are state regulated, right? They have to go to the Public Utilities Commission, and a lot of rate-based things are

Photo: Sentient Energy

Sentient has a vast portfolio of underground line sensors which covers your whole distribution grid, from the feeder to the last mile on the lateral residential.

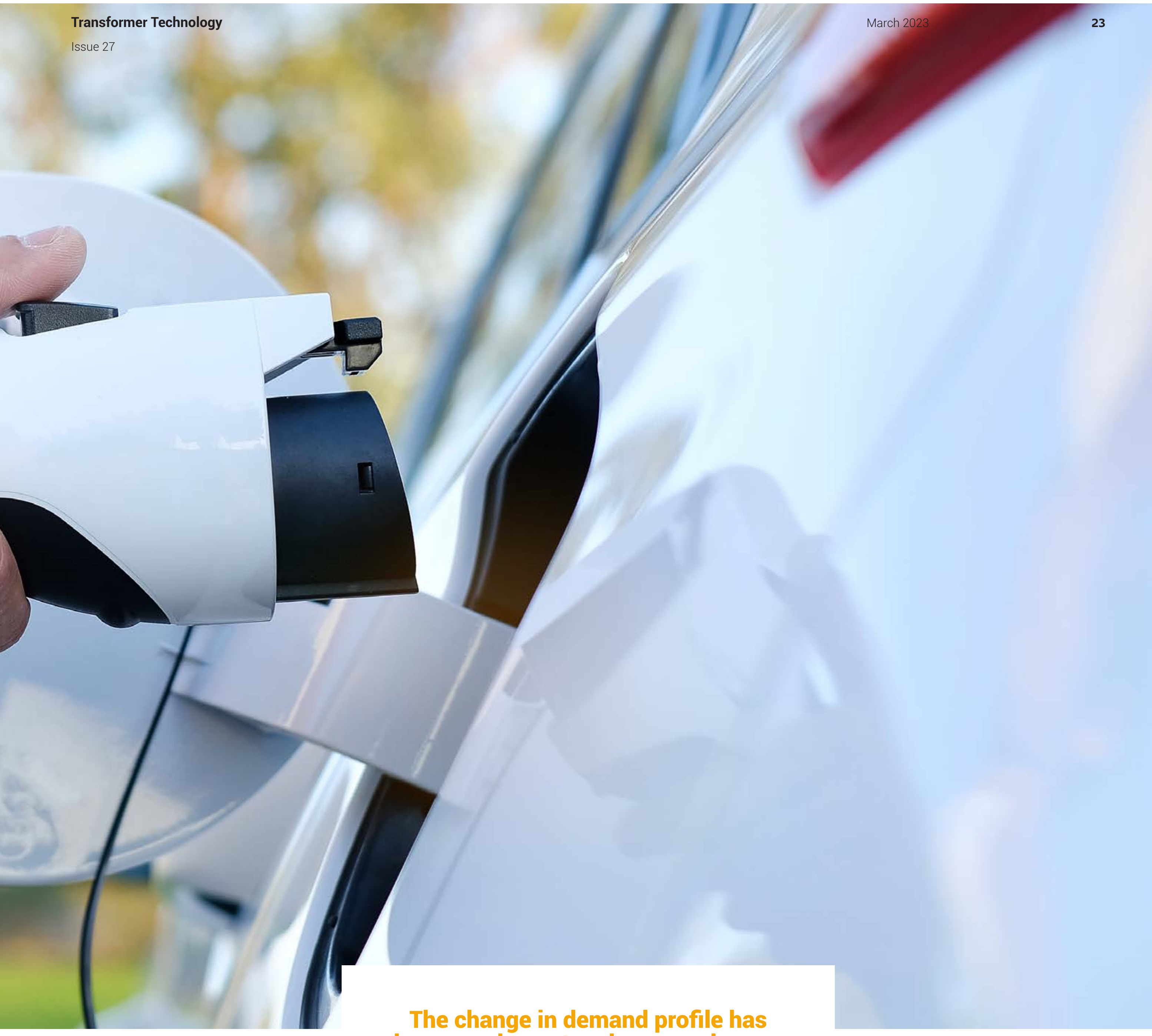


based on capital spending. Is most of the cost of undergrounding covered by capital?

BK Yes, because you're improving your reliability of service. So as a customer myself for PG&E...well, the area I'm in is already undergrounded, but imagine not losing power anymore when there is a high fire threat and there are critical patients and those who need life support. I think it makes sense ratepayers wouldn't mind that increase over time as long as of course it has to be kind of vetted out with different parties.

AR So that is a great connection between what you do and the focus on reliability. At the same time, utilities are dealing with the hockey stick of the demand curve which they have not had to deal with in the last 15 years. There's going to be competing priorities for that. How do you address that? I mean, you're going to compete with people saying let's just get as much power to as many people as we possibly can. Forget about underground. How do you answer those people to say, no, we are a solution that is going to be a better solution long term than short-term reactionary solutions.

BK I think the change in demand profile has immense impact on how you do your asset management strategy. What it means is your typical duck curve doesn't exist anymore, and here is why: we are pushing for more EV. That means that when you come back home from work, at five, six in the evening, you are plugging in the EV, so your load profile just increased dramatically. Let's say you don't plug in at 6:00 p.m. You have it programmed to run late at night. The power consumption of an EV to fully charge is equivalent to a fully running



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The change in demand profile has immense impact on how you do your asset management strategy.

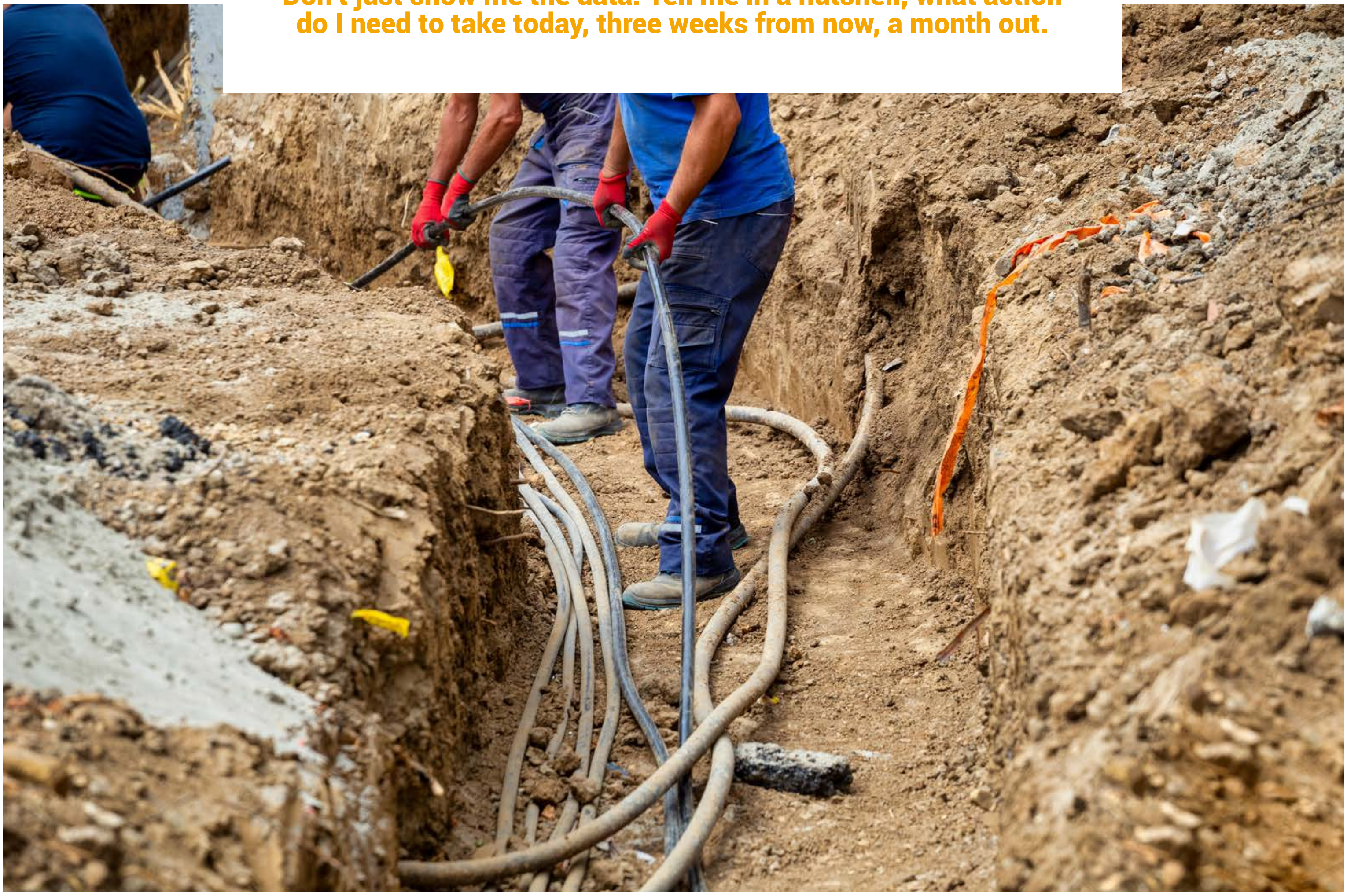
home, which means your load didn't drop after midnight. It actually stayed at the same level, because now, even though the lights are off, your EV is charging, so it's still pulling the load. How do you balance that? The typical grid, the traditional grid, was planned for single directional power flow. If I pick a transformer, a 50 kVA transformer typically would have seven customers. Now all of a sudden, all the seven homes plug in EVs at the same time. That wasn't what it was planned for.

While a transformer can operate at beyond its nameplate rating, you do not want to do it day over day, week after week, year after year. So that's where we come in as an end-to-end solution. We have one of our newest products UM1 - it monitors for fault in our underground system, but also monitors for your loading of the transformer. One of our customers was recently flagged as having the transformer overloaded 150 times over eight months. And the peak loading was 212%. Average was 126%. That's something you don't want. Now with this data they can upgrade it to a 75 kVA transformer before it fails. This is what we call data-driven asset management strategy - don't just wait for the transformer to fail.

AR So given the fact that you're in product management, you have to be looking ahead at what's coming. What are the issues that the industry is facing that you're solving?

BK There are a couple of things that come to mind. Number one, utility companies. I feel for them because they are under a resource constraint. They have a ton of projects to work on and they can only focus

Just having gigabytes and petabytes of data means nothing unless it's actionable. So, one of the challenges I think needs to be solved over the years is what are the actionable insights. Don't just show me the data. Tell me in a nutshell, what action do I need to take today, three weeks from now, a month out.



on so many things. A solution to that is as they are dealing with all these different software platforms and data points from all different kinds of devices, they need to look at more at what cloud capabilities they can leverage, so that the in-house team doesn't need to focus on managing, doing the cookie-cutter task of system management, but they can focus on how to optimize their business processes and have other vendors kind of take care of cloud-based solutions and deal with the data. And the second thing, very linked to that, is an immense amount of data. Just having gigabytes and petabytes of data means nothing unless it's actionable. So, one of the challenges I think needs to be solved over the years is what are the actionable insights. Don't just show me the data. Tell me in a nutshell, what action do I need to take today, three weeks from now, a month out — so that something that's likely to get impacted further along the line I can delay, and then I can prioritize my workforce.

AR Since you just talked about that big data - I know a utility that I spoke with recently mentioned that they hired more utility and data scientists that year than they hired electrical engineers. And they said that was a first for them, which is kind of an indication of what you're saying. There's just going to be a huge need for people that help us, because data scientists don't make a decision. They just create data that allows us to make the decision. The demand for electricity is doing this, the amount of data with all of these wired systems and wireless systems is doing that too.

Okay, so we're on an airplane, we're at 35,000ft. Let's assume that we mitigate the supply chain issues, that we begin to really integrate DER into the whole network. We are decarbonizing, we are putting more utility work underground so that we can create a much more resilient grid. What do you think are the storms on the horizon that we ought to be looking at now that are going to be coming in ten years, if we could predict them?

BK Well, that's a hard one. We are thinking that, you know, just bringing in solar PV and EVs is going to decarbonize, but you still need to look at the variations those bring in. You know, the sun is not shining 365 days a year at the same level, so you still need your traditional means of generation in place. How do you balance all of that without impacting your service levels?

The second thing is that a lot of these product solutions work on their own. So, what the utilities would need to think of is how do I minimize or optimize the information that I'm getting from all these systems? How do they work in an integrated fashion? I don't want to jam my communication network with millions of devices out in the field. Can some of them talk to each other? I think what we're looking forward to is that different vendors like Sentient and other companies would need to partner together and have those devices talk to each other locally and make grid edge decisions — and what that means is open protocols and open communication, standardized communication mechanism and data exchange across devices.

AR Does that not increase the risk for cybersecurity?

BK Of course, it does. But we do have the technology to make it cybersecure. You can have them all communicate within the utilities. Private LTE is the utilities network. They can manage it as long as all these devices talk within their network, that's absolutely fine.

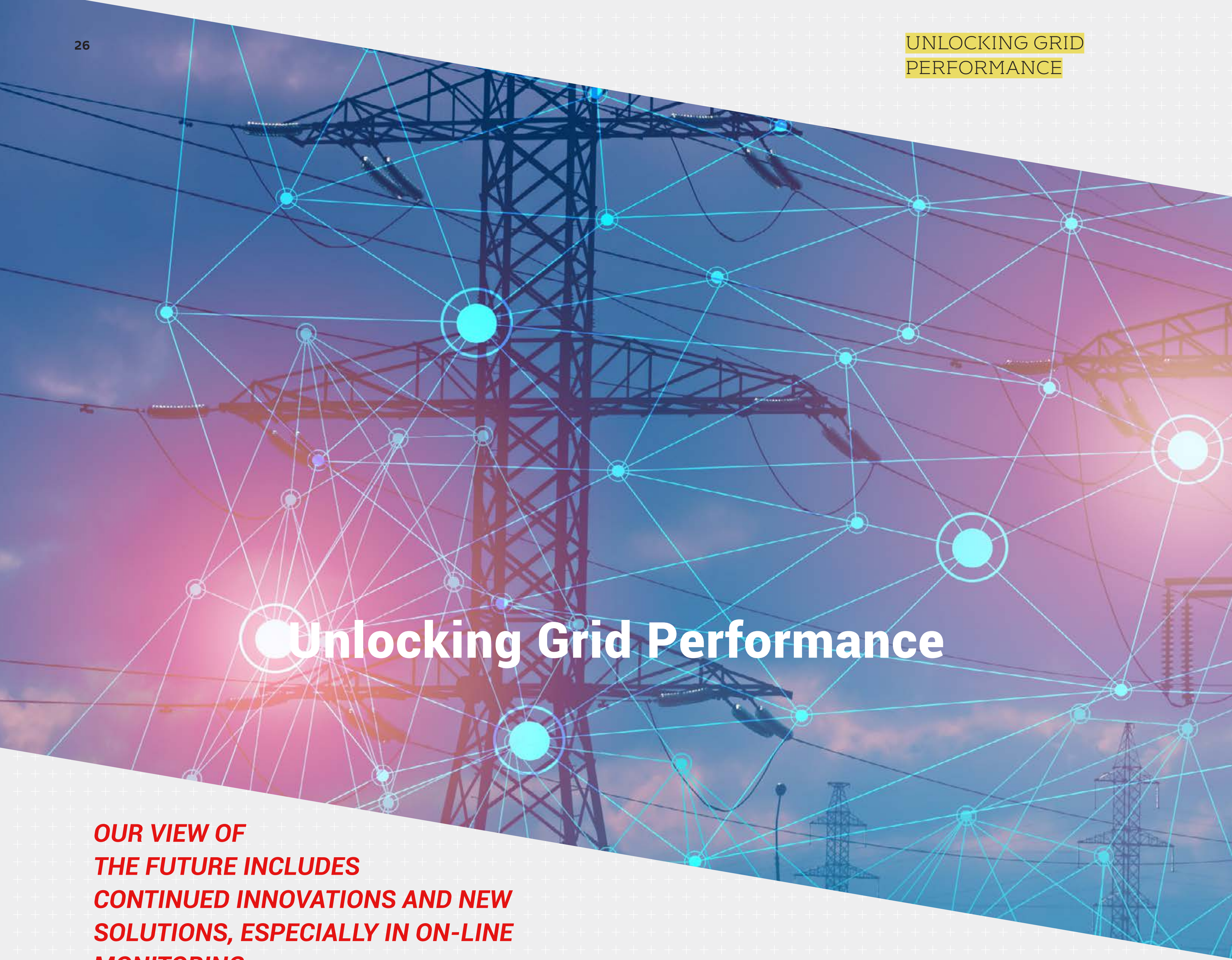
AR EVs and EV charging - most of that is underground. You don't see overhead lines going to you. So, they've already adopted the charging technology, but they haven't adopted a standardized approach to plugins. I mean, I rented an EV, and I could not charge it at the Tesla charging station because my connector didn't work with the Tesla. So how does Sentient work within the industry to do open architecture, open protocols? Everybody has a part of the solution. Where do you come together to create standardization of those kinds of things?

BK There are areas where things are very well defined. DNP3 protocol is a very common protocol used for communicating across all these devices. That's just at the device level, however, how different systems interact. For example, our analytics platform can ingest data from a completely unknown device. I think that's the kind of standardized interaction or integration that must be in place. We are thinking ahead in terms of building open application programming interfaces, which is called APIs, so that anybody can consume the data. We are thinking along those lines where we publish a message, anybody within the secured network can actually subscribe to it. I think we'll see more of those changes coming in down the road. And to your point about EVs, yes, absolutely. We want it to be like a gas station. You know exactly how it works. So, on the EV side of things, all these manufacturers have to go towards the standard.

AR Excellent. Bidesh, thank you for joining us. It's been a delight and I wish you good success at Sentient.

BK Thank you, Alan. Nice speaking to you.

Photo: Hitachi Energy



Unlocking Grid Performance

OUR VIEW OF THE FUTURE INCLUDES CONTINUED INNOVATIONS AND NEW SOLUTIONS, ESPECIALLY IN ON-LINE MONITORING.

It's nothing new that the electrical industry is changing, with new challenges and trends appearing all the time. It's therefore essential that those in the industry keep up with the changes and meet these challenges head on. To that end, Megger has made it its mission to offer you a wide range of solutions to meet your needs, as well as the trends and demands of the market. Megger has a wide range of supplemental technologies for condition monitoring and predictive maintenance to improve reliability and optimise your grid performance. Indeed, the grid is under more strain today than ever before, with stressors coming from renewable resources, varying power generation and consumption, and extreme weather conditions, to name a few. As such, increasing the visibility of your grid has never been more important.

Megger's evolution in testing, diagnostics, and condition monitoring

Megger has been a leader in the electrical industry for test and measurement equipment for over a century. Megger's instruments are used globally by power utilities, repair shops, and industrial production plants. Thanks to modern trends, such as electrification and decarbonisation, they are also used in a range of other industries including transportation and renewable energy.

We never stop evolving and it is essential that we understand the changing needs of our customers so that we can continue offering modern, comprehensive, and relevant solutions. As such, we work closely with our customers, listening to their feedback and ideas and, in response, constantly develop and invest in new technologies, all so that we can provide them with the solutions they need.

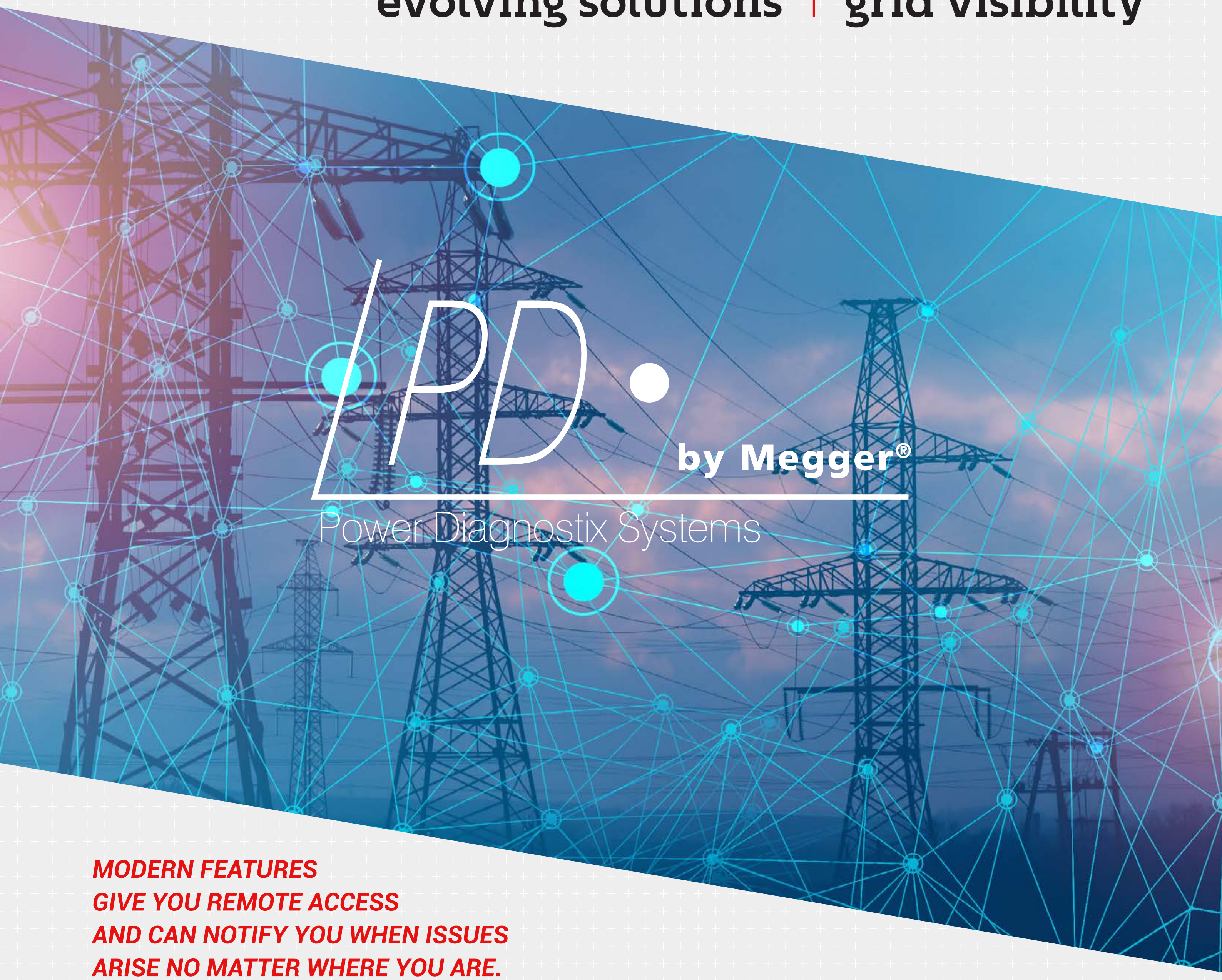
Our view of the future includes continued innovations and new solutions, especially in on-line monitoring. We also want to give you a closer look into our monitoring business and show you how you can benefit from Megger's Grid Performance Solutions, such as with our Grid Analytics Solutions.

Unlocking visibility by monitoring your grid with Megger

Off-line testing devices are essential for asset condition analysis; they allow flexibility and manipulation of testing voltage, ensuring that assets will perform well under stress and giving you a comprehensive picture of their present performance, as well as predicting their future performance and identifying any risks. Additionally, trending off-line test results provide you with even more insight and analytics, allowing you to be more confident in your decision making.

Photo: Megger

Megger constantly evolving solutions for increased grid visibility



MODERN FEATURES GIVE YOU REMOTE ACCESS AND CAN NOTIFY YOU WHEN ISSUES ARISE NO MATTER WHERE YOU ARE.

However, in between testing phases, unexpected events can occur that may be missed, or their detection delayed. This is where Megger's monitoring solutions can help. Through continuous data collection, they provide real-time fault detection, and can even identify weak spots, allowing you to prevent faults and failures before they occur.

By combining data from various sources, including off-line and on-line measurements, we can help you to increase your grid's visibility and improve your overall grid performance, giving you the detailed information necessary for good decision making and successful asset management.

PD monitoring – What else?

Not only are we well established in the electrical testing industry, but we also have decades of experience in asset monitoring, particularly the monitoring of partial discharge (PD).

The industry has recognised PD as an important indicator in insulation that needs to be detected. We understand that predictive maintenance requires you to know about upcoming problems as early as possible, and there is no method that can detect potential insulation problems earlier than partial discharge measurement.

Additionally, PD results can be tailored to identify the specific type and location of faults. When making decisions for asset management, such as whether to replace, repair, or extend the life of a particular asset, PD monitoring results are an important factor in the decision-making process.

Permanent PD monitoring allows for live condition monitoring and predictive maintenance. When you constantly measure PD, you are made aware of insulation concerns immediately instead of needing to wait months or years between maintenance schedules, and you don't need to risk interrupting operations to gain a view of insulation condition.

When a fault triggers the alarms, you can plan an outage safely so that PD can be measured off-line enabling you to perform further investigations that are only possible with off-line PD testing. This means PD monitoring can enable you to avoid asset failures.

Our monitoring solutions, such as the ICM*monitor* and GIS*monitor*, provide a continuous view of your insulation's condition. Modern features give you remote access and can notify you when issues arise no matter where you are. Integration with digital systems, for example, via IEC61850 protocol, give you ultimate visibility via the Smart Grid and give you remote access for service and support.

We also offer hybrid solutions, which cover both portability and on-line monitoring. The portability and ruggedness of the instruments allow for on-line measurements to be recorded over a period of time ranging from days to months, before moving to another electrical asset for another period. This allows users to prioritise their needs and decide which asset is most critical for PD measurement at a given time.

As technology continues to evolve, we must keep our eyes open for opportunities to improve grid visibility. As such, we know that partial discharge is not the only important parameter to be monitored to improve grid visibility, and this why it is our mission to provide on-line monitoring for multiple additional sources.

Our next chapter: Grid Analytics Solutions

Due to recent trends, the Smart Grid requires constant monitoring and analysis of valuable information required for operations and maintenance. Distributed Energy Resources (DER) require maximum grid flexibility, as operational and loading requirements change constantly depending on many external factors, such as wind and sunlight. Climate change and associated extreme weather events, as well as an aging grid infrastructure, add to these growing concerns, while the digitalisation of the Smart Grid contributes to solutions for improved reliability.

The role of Distribution System Operators (DSO) is becoming more critical as power-flows are becoming more complex and energy is constantly imported and exported by prosumers.

To tackle the challenges that arise from the modern power system, Megger offers Grid Analytics Solutions, which is composed of Smart IoT sensors - the MS5000 - that constantly monitor the electrical grid to find faults quicker and reduce the number of outages. After easy installation, the sensors start to immediately communicate with each other and share information. Electrical faults are detected in real time, immediately notifying operations and maintenance crews when a fault has been located, thereby decreasing the time needed for fault location, identification, and service restoration (FLISR). This enables you to decrease your System Average Interruption Duration Index (SAIDI), an important metric for measuring grid performance, thereby ensuring the best uninterrupted service to your customers in the face of the energy transition.

Not only does Megger offer help to minimise the duration of faults, but they also help you prevent faults, improving your System Average Interruption Frequency Index (SAIFI). By identifying weak spots in the grid based on anomalies, predictive maintenance can occur, preventing permanent faults in advance. Thanks to modern innovations in sensor and communication technology, grid sensors can serve multiple roles in addition to fault location. These features can assist with power quality analysis, informed data-based decision making, and can even reduce the risk of wildfires.

From the arctic circle in Northern Europe to the rural areas of South America, our customers around the world face similar challenges and share the need for improved grid visibility to unlock their grid performance. We have proven, together with our customers, that locating faults in difficult to access regions, in extreme weather conditions, and on-line and in real-time, can be made easier and more efficient. This requires flexible communication options, including direct cellular communication, mesh-radio, and/or integration with SCADA/DMS, and cybersecurity provisions to protect your data with the highest security standards.

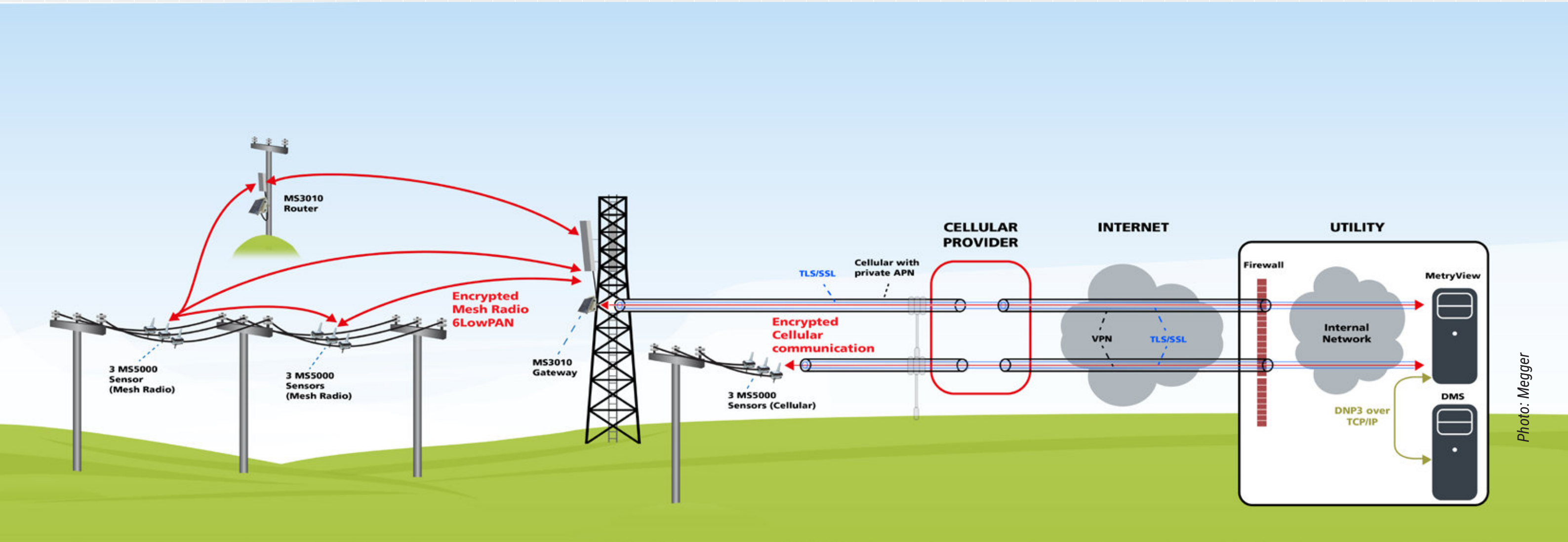


Photo: Megger

Enterprise Asset Management (EAM) and Asset Performance Management (APM)

Planning for the future is a core part of Megger's strategy and is essential for us to reach our goal "to provide electrical utilities with innovative solutions to meet the challenges of enabling and improving electrical grid performance". Our recent strategic partnership with IPS (Intelligent Process Solutions), a company based in Munich, Germany, brings together a strong combination of intellectual capabilities, opening doors to new solutions that enable increased efficiency and effectiveness for electrical utilities in maintaining the grid network, reducing costs, and minimising downtime.

IPS and Megger Group announced their strategic partnership in September 2021. IPS Energy is a leading provider of enterprise asset management, asset performance management, and workforce management for the global energy supply industry. As partners, we're working together to improve the operational efficiency of power and combined utilities by leveraging our collective intelligence to help the power industry reliably measure its own performance and act to minimise unplanned downtime and system outages. By combining our knowledge, the IPS Intelligent Data Lake was born; a unique solution enabling each party to contribute their expertise towards creating a final product.

Combining IPS's sophisticated software solutions, AI expertise, and easy integration with Megger's test and measurement expertise produces a greater and more powerful predictive dimension to electrical utilities' testing methods, enabling true condition-based maintenance practices.

This allows us to translate our insightful measurement results, such as partial discharge measurements (off-line or on-line), tan delta (power factor), dissolved gas analysis (DGA), grid analytics, and much more, to an asset health index and risk profile.

IPS Energy is our answer to the question "What do I do with the data?". Together, Megger and IPS provide an unrivalled and compelling solution for public and private sector utilities.

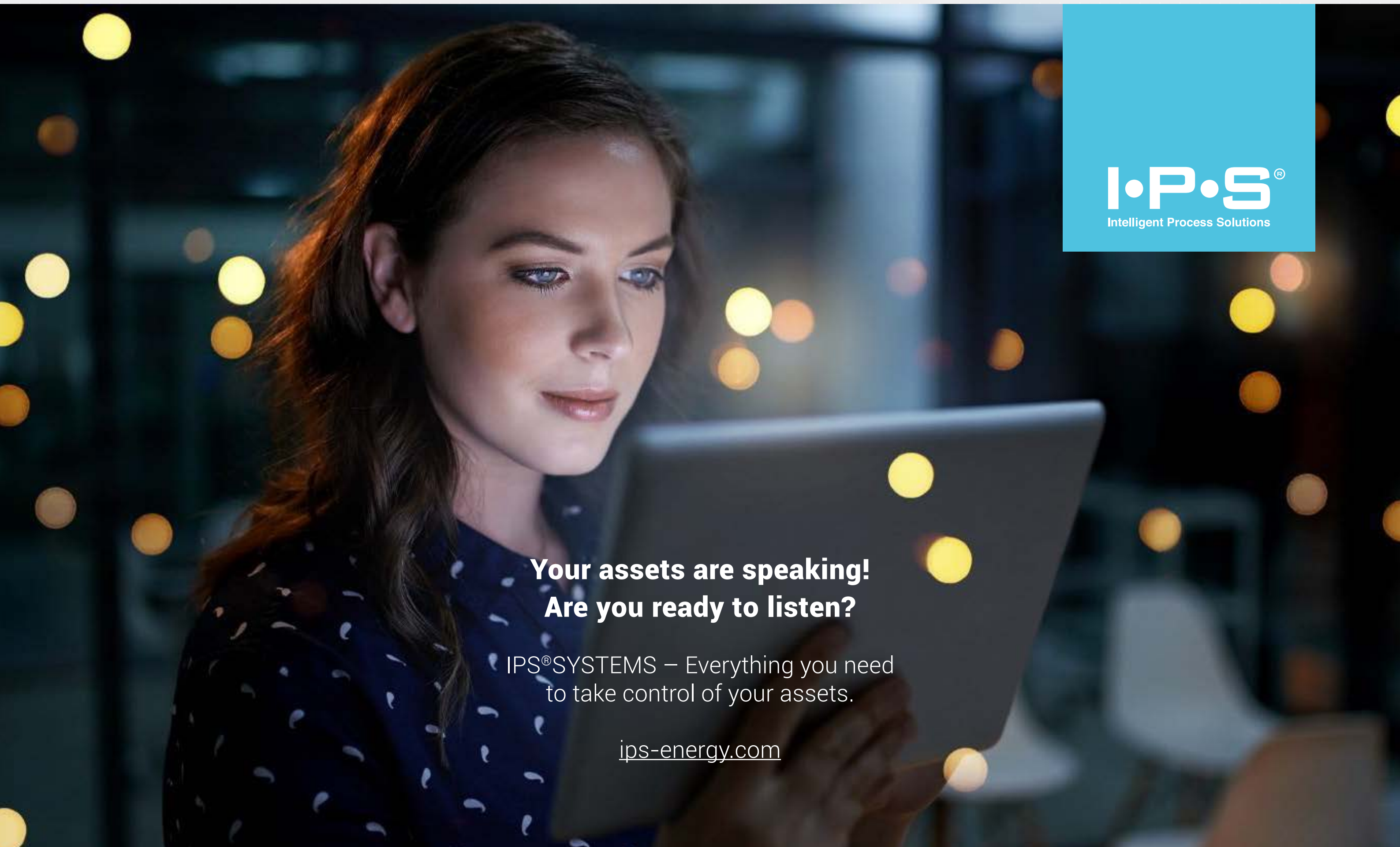
As the energy industry is rapidly changing and facing many simultaneous challenges, condition-monitoring and predictive maintenance have increasing urgency. Optimal grid performance is achieved with the support of powerful measurement hardware and software tools. Off-line testing instruments, on-line monitoring solutions, and AI-driven software and analytics provide valuable insights and efficiencies to meet the challenges of the ever-evolving grid.

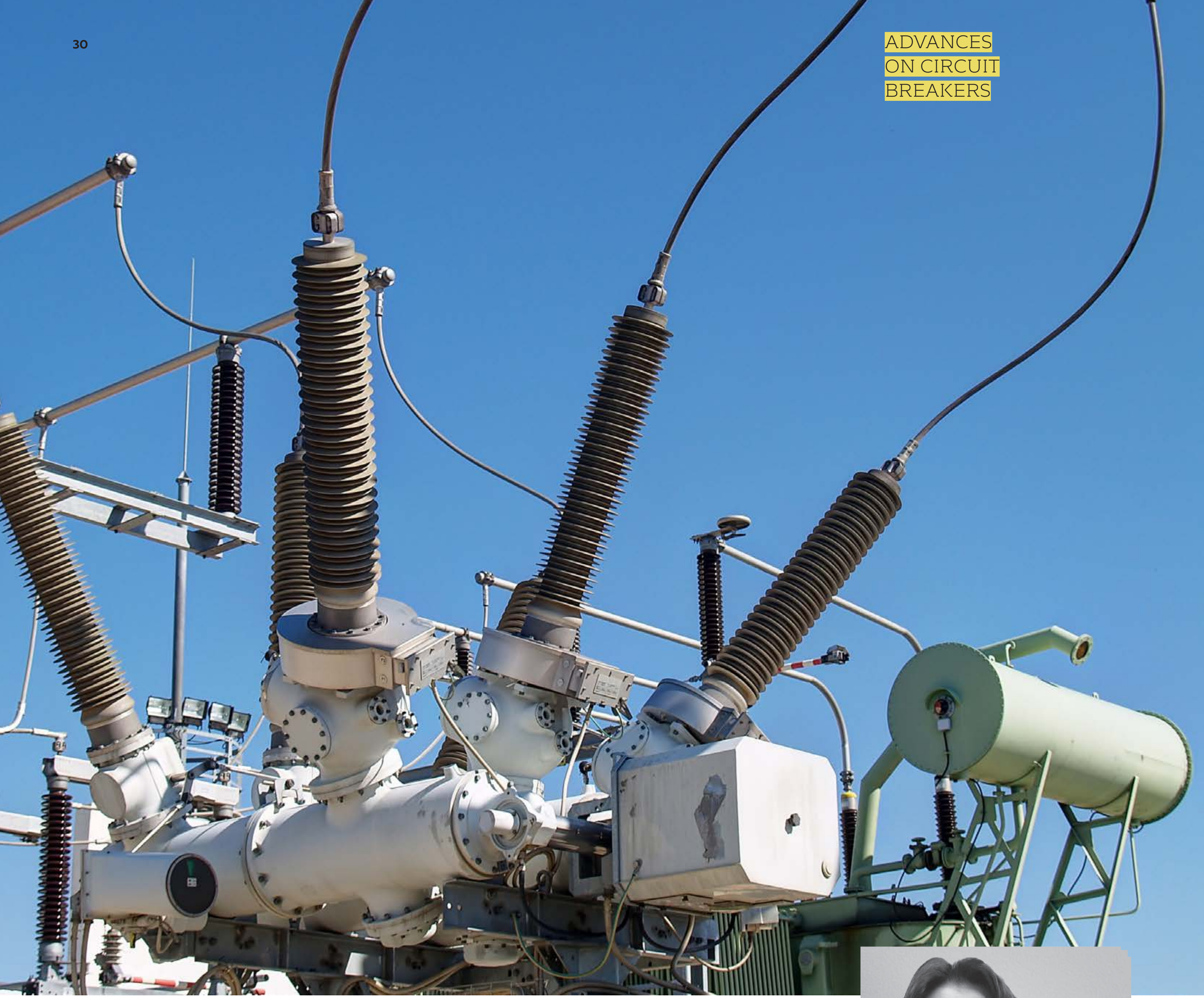
Megger is here to support you on your journey to unlock your grid performance

For more information, visit our websites.

Grid Analytics solutions

IPS energy





Automated real time ML-based Circuit Breaker Trip Coil Analysis

by **Marco Tozzi**
and **Michael Skelton**

A key requirement from electricity networks is to provide safe, efficient, and reliable power to customers. When faults occur due to weather, equipment failure, or accidental damage, then the Circuit Breaker must quickly disconnect the fault to protect the network upstream and maintain supply to the majority of customers. Therefore, the Circuit Breaker can be considered the guardian of the power network.

Marco Tozzi received the M. S. degree in Electrical Engineering from the University of Trieste in 2005 and the Ph. D. degree in electrical engineering in 2010 from the University of Bologna. From 2007 to 2011 was Project Manager and Technical Advisor in Techimp, Italy, being involved in research activity on diagnostic of insulating systems by Partial Discharges analysis. From 2012 to 2022 was Product Designer and then Senior Product Manager for Camlin Energy, involved in designing solutions for holistic transformer monitoring. Since 2022 he is Sr. Technical Advisor for Camlin Energy, involved in asset diagnostics, consultancy services and optimisation of monitoring and maintenance programs. He is author or co-author of more than 40 technical and scientific papers.

Photo: Shutterstock

Circuit Breakers can be slow to operate, or fail to trip due to defects in the trip coil and operating mechanisms caused by friction, often due to lack or wrong type of lubrication. International statistics indicate that 80% of the observed failures are linked to operating mechanism and auxiliary control circuits [1]–[4], possibly causing catastrophic failures [5-6].

The traditional offline test and inspection can be difficult to plan due to the operational constraints and require a significant amount of time and resources, while leaving the problems that arise in-between regular inspections unnoticed. Moreover, the standard test could not detect the causes of a slow trip. Before an off-line test is performed, the breaker is first tripped, and then isolated from the system. Then the offline test kit is connected, and the breaker is tripped again. However, the first trip, which was not recorded, could show a longer opening time due to a mechanical defect. The issue could be cleared after the first operation and show no criticality during off-line testing. For example, faulty lubricants and/or questionable lubrication practices [7] often create a sticky compound causing slower movement of the mechanism during the first trip and, very likely, normal timing during the second trip.

To prevent the breaker from failing to trip, it is recommended to periodically test the operating mechanism through a planned trip operation with the breaker online and without affecting customer supplies. This can be done with a hand-held device by recording the first trip current profile, the DC battery voltage, and the three AC interrupted currents. This procedure has been carried out successfully for years, as documented in [8]: "circuit breaker signature analysis can be used as an excellent tool to assess the condition of our breaker operators, prioritize maintenance and minimize equipment outages".

The interpretation of the data requires an expert operator to compare the recorded curves with "reference" ones to identify the malfunction of the breaker: this can be challenging considering the test devices could be used by any operator in the substation, even without the necessary experience.

The following article proposes a new Machine-Learning-based method able to provide a diagnosis and suggested action automatically by comparing the last recorded trip operation with a reference profile generated with advanced AI techniques using a statistical population of curves relevant to breakers having the same trip coil mechanism.

The diagnosis is done in less than 5 seconds, and the field operator, even if inexpert, can understand if a major or minor maintenance is needed. They can then provide feedback to the asset manager from the field, and open a workorder immediately. This removes delays caused by waiting for data analysis and reduces the time-to-action to seconds.

The basics and the importance of the First Trip Analysis

The method enabling the assessment of the operating mechanism health by monitoring the current flowing through the trip coil was developed back in the 90s [9], extensively described in literature, and widely adopted in the utility industry [9-14].

The trip coil circuit is an electro-magnetic circuit with reluctance in the magnetic part, and inductance and resistance in the electric part. The mechanism consists of a solenoid around a movable plunger, a latch, a spring and a mechanical connection to the main contacts; once the control circuit receives a command signal, the coil is energised (typically from station DC batteries) causing the plunger to move and hit the latch mechanism as shown in Figure 1. This activates the movement of the operating mechanism and discharges the compressed spring mechanically connected to the main contacts, which open. After a short delay the auxiliary contacts open and disconnect the coil from the substation voltage, causing the coil current to go to decay to zero. As the plunger moves, the reluctance of the magnetic part reduces, increasing the inductance of the electric circuit. As the rate of inductance increases, the rate of change of current decreases.

Therefore, if a DC Hall Effect probe is clamped around the coil current

+ +

Circuit breaker signature analysis can be used as an excellent tool to assess the condition of breaker operators, prioritize maintenance and minimize equipment outages.

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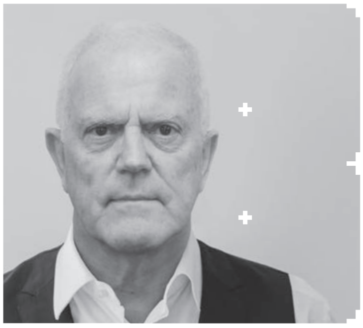


Michael Skelton has been working for Northern Ireland Electricity (NIE) for over 33 years and has extensive experience in the planning, design and operation of distribution and transmission networks. He joined the Camlin Group in 2009 as Product Manager for the High Voltage Monitoring and Testing products, such us DGA monitoring, Bushing monitoring and Circuit Breaker testing equipment. He is now consultant for Camlin Energy, working in the Technical Advisory Group and his current activity involves diagnostics on Circuit Breakers (CB) and the application of ML/AI analytics on the CB First Trip data.

Photo: Kelvatek (Camlin group)

Coil energized, Plunger begins to move (A)

Plunger strikes the latch (C,D)

Latch unlocked, plunger strikes buffer (E)

Main contacts starts to open (E-F)

Main contacts open (F) Auxiliary contacts open (G)

Trip coil de-energised (H)

Figure 1. Step by Step process of a trip mechanism

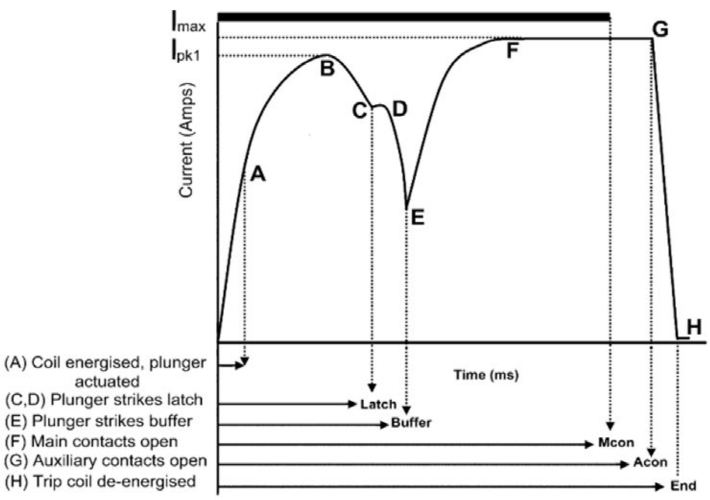


Figure 2. Trip current profile

circuit, a current profile can be recorded during the trip and close process which increases and decreases over the time depending on the changes in the reluctance and inductance: the recorded profile of the current will have a shape similar to that shown in Figure 2, with an increasing current reaching a peak, a plateau, and then a rapid decrease.

By comparing the actual trip/close profile with a reference one (depicting normal operation), we can understand if there are delays causing a slow trip and, most importantly, the cause of the slow trip.

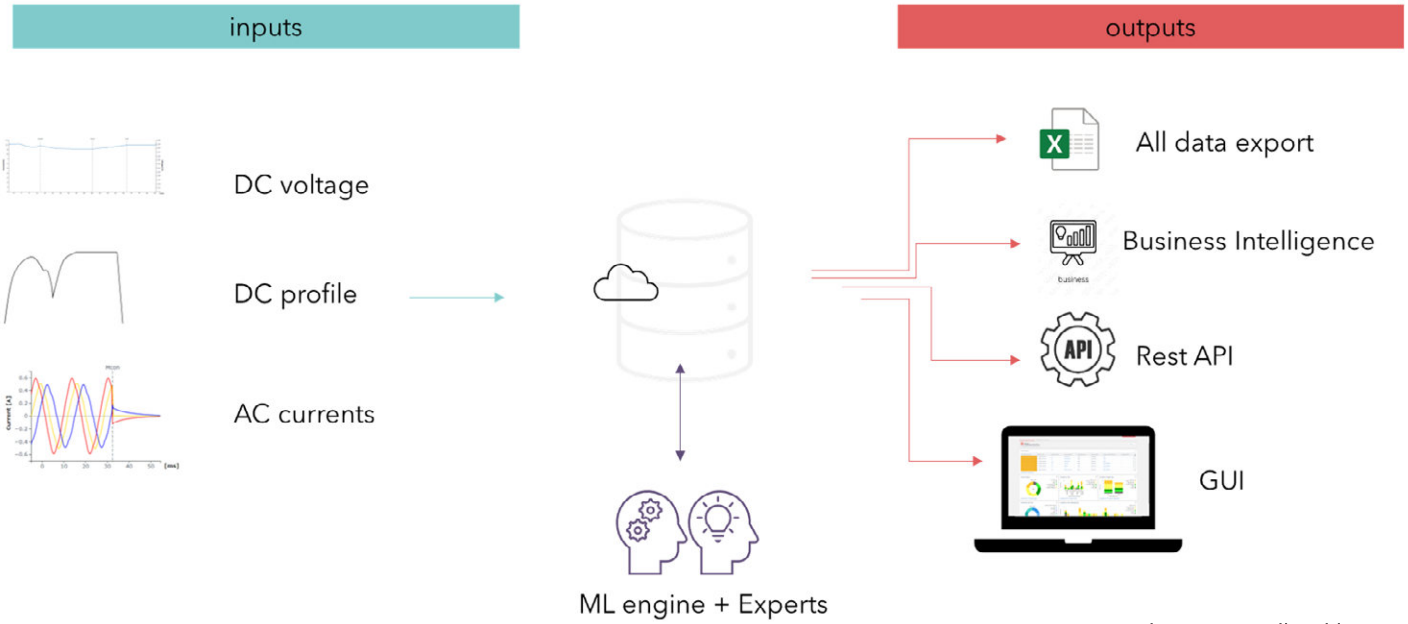


Figure 3: overall architecture

Some of the failures that are usually detected result from:

+ Supply Voltage (too high, too low, inconsistent, battery issues, poor connections)
+ Trip/Close Coils (increase or decrease of resistance, degraded contacts, CB fitted with incorrect trip coil, misalignment of coil, insufficient lubricant)
+ Auxiliary Contact Performance (auxiliary bounces, faulty operation)
+ Latch mechanism (friction or insufficient lubricant)

Application of Machine Learning to Current Profile Data

The challenges: do the right thing at the right time

The assessment of the breaker capability of tripping within the right time is done by comparing the latest recorded curves with a reference one, which represents "normal" behavior.

The reference template can come from:

+ Factory test, OEM provides the trip curves
+ Commissioning test
+ Historical data
+ First vs second trip

There are however challenges in the data interpretation:

1. The reference curve can change over the time due to degradation of components
2. The analysis is very subjective and requires skills and knowledge of data interpretation and circuit breaker operation
3. If the analysis is deferred to the Subject Matter Expert (SME), delays can occur between the test and the suggested action, after the (often over-burdened) SME has received and analyzed all the data
4. Inexperienced operators could fail to connect the sensors properly, and realize this days later upon data analysis

The solution: an augmented intelligence tool

These challenges can be overcome by using an intelligent digital solution that ingests the recorded data while the operator is still in the field, processes it in real time, and provide immediate feedback on:

+ quality of data
+ possible defect
+ suggested maintenance action

The solution is created by analyzing a significant amount of historical data coming from families of breakers having the same trip coil mechanism, using Machine Learning and advanced analytics combined with the experience of the SME labelling the data and providing feedback after the maintenance.

The overall architecture (Figure 3) consists of a centralised cyber-secure data center where the data are collected and processed combining an ML engine with human expertise. The role of the human SME should not be underestimated, being crucial in the training and assistance to the AI-based automated system. The cloud-based database ingests data from various sources, including online monitors, and provides actionable outputs, including prescriptive actions, that can be sent to Work Field Management systems via a standard API mechanism.

In terms of implementing the solution (Figure 4), it is necessary to select a family of breakers with the same operating mechanism and gather the historical current profile, even from different users, to generate a template. Then features are automatically extracted whenever a new record is processed, the data are compared to the template and processed to identify defects and classify severity according to a Health Score.

Figure 4: Step by step deployment of an automated digital solution

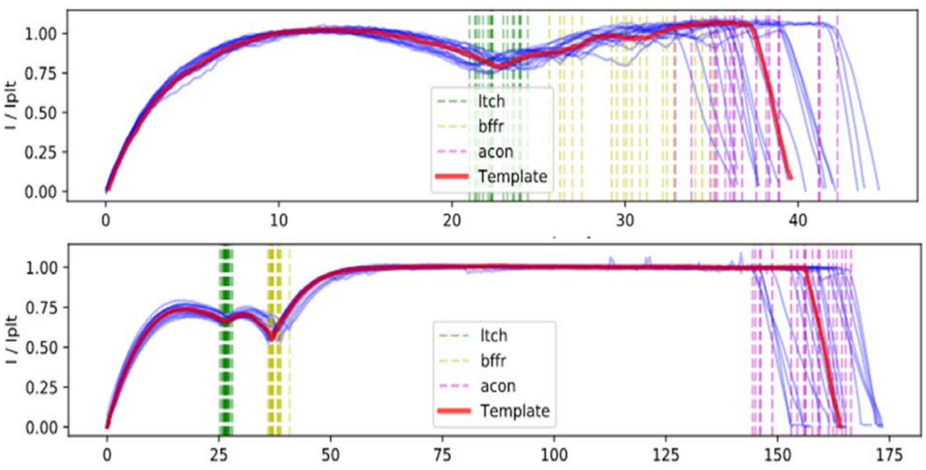


Figure 5: Template extraction from a number of profiles coming from the same type of breaker

Figure 5 shows the overlap of tens of current trip profiles of two specific types of breakers labelled by the SME as "normal" in terms of health. The red trace is the template generated by the algorithm used from now on to compare with any new data. The template could still change and improve over time, learning from the new data and feedback. This is a key advantage of the proposed solution: the ability to generate and dynamically improve a template that is the best fit within a number of different "normal" profiles of the same breaker type, based on a statistical population of curves; this is more effective than using just one curve, since it takes into account a certain variability of the key-points due to standard operation and ageing.

Defect List
No defect
Defect in trip coil operation
Defect in auxiliary contacts operation
Defect in the battery
Defect in the battery circuit
Defect in main contacts opening

Table 1: Example of possible defects

In the final stage maintenance instructions for Asset Management are created automatically.

Action List
No action
Repeat Test
Lubricate the trip coil
Lubricate the operating mechanism
Identify the cause of battery voltage drop and rectify
Check battery charger operation and replace it if necessary
Check alignment of the auxiliary contacts and clean them
Replace the Trip Coil
Clean and lubricate the operating mechanism

Table 2: Example of possible actions

Condition Group	**Urgency**
1. Good	No action
2. Suspect	Test again within 6 months
3. Defective	Inspect in the next planned maintenance
4. Critical	Plan an emergency maintenance

Table 3: Example of urgency

CASE #1: Healthy HV breaker

The grey trace represents the template generated by the automated algorithm, while the colored trace is the most recent trip current profile.

The color of the last trip depends on the status of the breaker and is determined by the algorithm; here it is green, showing there are no issues.

Buffer, Acon (auxiliary contact) and End (trip coil de-energized) timings are automatically extracted, and the keypoints are visualised overlapped to the trace

The profile shape analysis indicates that the breaker is opening with a small delay within 4 ms, which is acceptable, and results from the natural inertia when a circuit break has been inoperative for a long time.

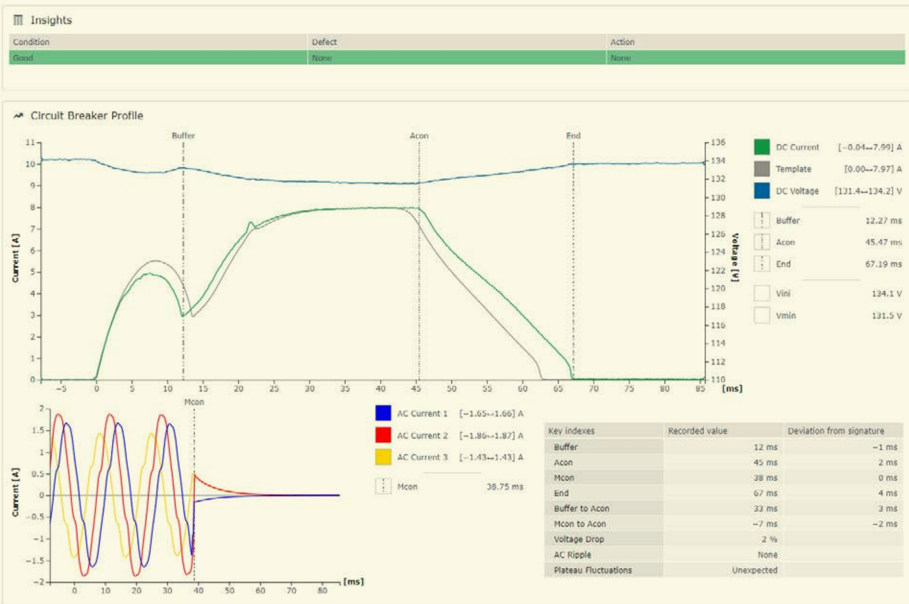


Figure 7: Normal healthy trip

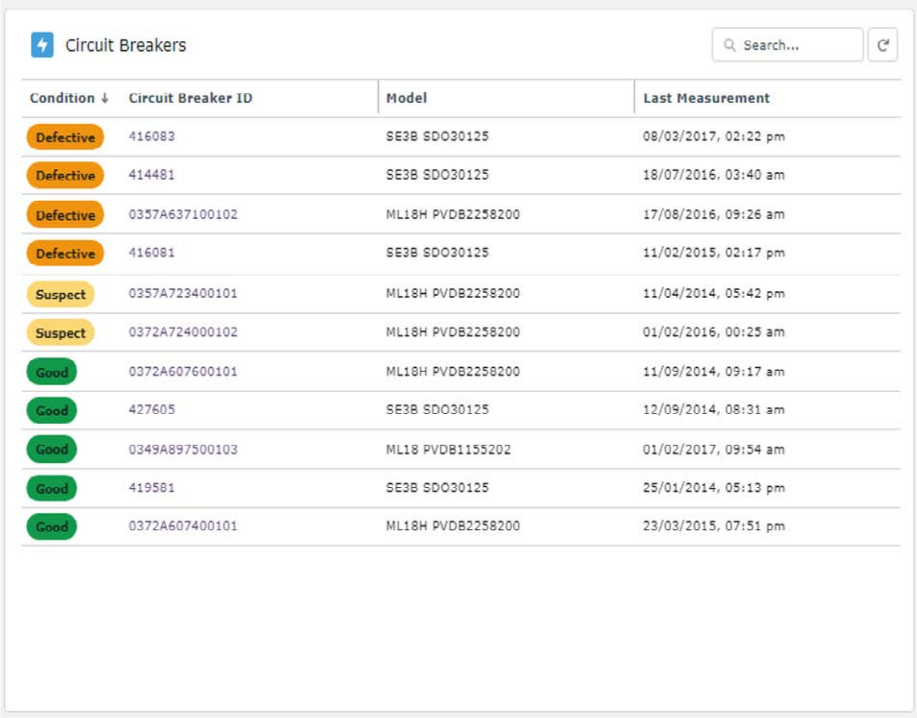
Automated prescriptive actions

The algorithm is able to evaluate the possible defect, suggest an action, and assign a health score to the breaker to provide a priority list to the end user. Tables 1 and 2 showcase some of the defects and actions automatically generated by the algorithm. Table 3 shows the health categories with the relevant urgency.

Real Cases

The following cases were collected by processing hundreds of trip coil profiles captured with a hand-held tester, collecting the AC currents, the DC current of the trip/close coil, and the DC Battery Voltage. The results were generated in real time upon loading the data to the web-portal.

The condition of the breakers is summarised in the following table:



Circuit Breakers

Condition	Circuit Breaker ID	Model	Last Measurement
Defective	416083	SE3B SDO30125	08/03/2017, 02:22 pm
Defective	414481	SE3B SDO30125	18/07/2016, 03:40 am
Defective	0357A637100102	ML18H PVDB2258200	17/08/2016, 09:26 am
Defective	416081	SE3B SDO30125	11/02/2015, 02:17 pm
Suspect	0357A723400101	ML18H PVDB2258200	11/04/2014, 05:42 pm
Suspect	0372A724000102	ML18H PVDB2258200	01/02/2016, 00:25 am
Good	0372A607600101	ML18H PVDB2258200	11/09/2014, 09:17 am
Good	427605	SE3B SDO30125	12/09/2014, 08:31 am
Good	0349A897500103	ML18 PVDB1155202	01/02/2017, 09:54 am
Good	419581	SE3B SDO30125	25/01/2014, 05:13 pm
Good	0372A607400101	ML18H PVDB2258200	23/03/2015, 07:51 pm

Figure 6: Circuit Breaker fleet view sorted by health condition, automatically generated

CASE #2:
Defective HV breaker

The last trip recorded is yellow, since there is an anomaly.

The profile shape analysis indicates that the breaker is slightly slower than expected (16ms).

The delay on the auxiliary contact is only 4ms. The voltage seems to be slightly unstable, while the AC currents are not recorded due to poor connection of the sensors, or missing load during the test.

The breaker can still be operated as normal, however there are a few actions to be planned and automatically provided by the system:

+ Check the voltage stability of the battery charger. This can be deferred to the next planned maintenance
+ Repeat the test in 6 months to verify if the delay has increased. In that case a maintenance of the trip coil is required
+ While repeating the test, make sure there is sufficient load to capture the AC current waveforms (check the sensors or try to trip the breaker while on-load)

Condition	Defect	Action
Defective	Medium amplitude AC ripple	Check voltage stability of the battery charger in the next planned maintenance.
Suspect	Small delay in trip coil operation	Possible issue in the trip coil but testing again within 6 months will determine if deteriorating trend.
Unknown	MCON information not available	Repeat test verifying procedure and connections

Key indexes	Recorded value	Deviation from signature
Buffer	19 ms	5 ms
Acon	48 ms	4 ms
Mcon		
End	79 ms	16 ms
Buffer to Acon	29 ms	−1 ms
Mcon to Acon		
Voltage Drop	2 %	
AC Ripple	Medium	
Plateau Fluctuations	Unexpected	

Figure 8: Slower than normal breaker, still good to operate but with possible issue in the battery and trip coil

CASE #3: Suspicious LV breaker (<33 kV)

In this case the last record is in two colors: orange and green, indicating that the trip coil mechanism is operating correctly and the delay is due to the main mechanism.

The profile shape analysis indicates that the breaker is about 10ms slower than expected.

According to the SME and the expert algorithm, the breaker can still be operated as normal, however there are signs of possible issues with the main mechanism.It is suggested to re-test within 6 months, since this could point to degradation over time.

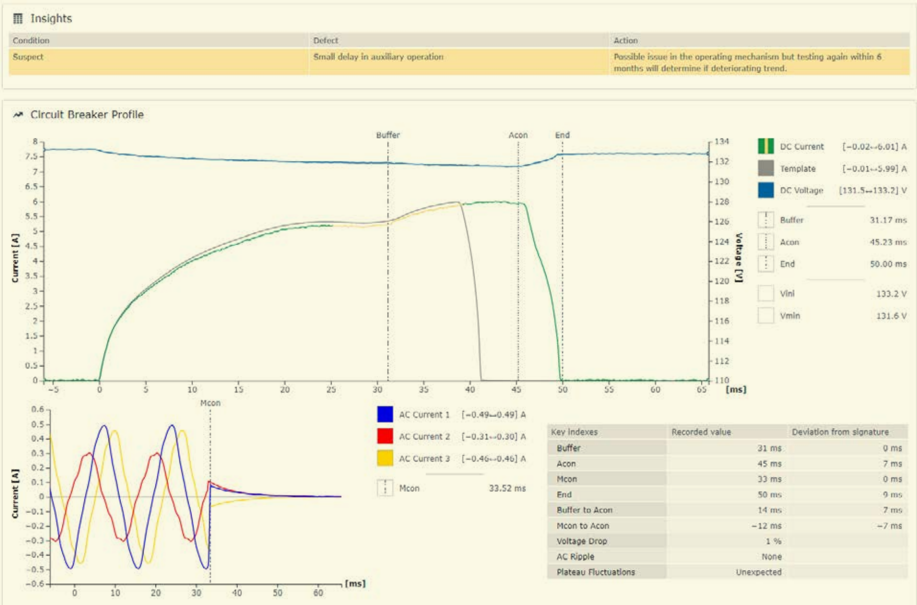


Figure 9: Slower than normal breaker, still good to operate, but with possible issues in the main mechanism

CONCLUSIONS

The analysis of the first trip current profile, the battery voltage, and the AC currents is an established technique to assess the braker's capabilities to trip within the expected time, and thus protect the upstream equipment on the power grid.

Challenges in the interpretation and the time needed to prescribe a suggested action can be overcome utilising a digital solution that can ingest data and automatically overlap the measured records with "normal" templates generated using an AI engine and human experience. The solution can indicate the health of the breaker, identify the defects, suggest an action and relevant urgency.

This solution allows inexperienced operators to perform the test in the field and have immediate expert feedback with clear suggested actions. Work orders can be generated on the field and minor maintenance can be carried out immediately.

The overall solution improves the pace of decision-making minimising the time-to-action and optimising the maintenance schedule. In particular, the proposed approach leads to major benefits:

+ Improving circuit breaker performance
+ Minimizing damage to plant and risk of injury to personnel
+ Enabling a condition-based maintenance strategy
+ Reducing operational costs
+ Reducing the time between the test and the action.

The overall solution improves the pace of decision-making minimising the time-to-action and optimising the maintenance schedule.

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Cargill introduces FR3r™ natural ester a new rapeseed dielectric fluid

Cargill, the global ag and bioindustrial firm, has launched FR3r™ natural ester, a new transformer insulating fluid derived from more than 95% rapeseed oil.

Utilities, transformer manufacturers and commercial building owners around the globe seeking a higher performing, more reliable and more sustainable insulating fluid than mineral oil now have a 100% biodegradable natural ester option made from the renewable rapeseed plant.

"As the original natural ester manufacturer, Cargill continues to expand our portfolio of highly renewable plant-based solutions for industrial needs around the globe and the launch of FR3r fluid is another example of how we're meeting the needs of our customers to achieve their sustainability goals," said Javi McGuiggan, global category leader in Cargill's Bioindustrial group. "Developing more natural ester options for the power generation and distribution industry provides better alternatives for customers around the globe who continue to expand their sustainability efforts while also looking for higher performing products."

Compared to traditional mineral oil, FR3r fluid continuously dries paper insulation without creating any harmful by-products or sludge, which makes transformers more reliable to help meet the challenging and growing demands placed on the power grid, and contains no petroleum, halogens, silicones or sulfurs. FR3r fluid's superior moisture management extends insulation life up to eight times longer compared to mineral oil, increasing the life of the transformer, and requires no maintenance under normal operating conditions.

AS THE ORIGINAL NATURAL ESTER MANUFACTURER, CARGILL CONTINUES TO EXPAND OUR PORTFOLIO OF HIGHLY RENEWABLE PLANT-BASED SOLUTIONS FOR INDUSTRIAL NEEDS AROUND THE GLOBE AND THE LAUNCH OF FR3R FLUID IS ANOTHER EXAMPLE OF HOW WE'RE MEETING THE NEEDS OF OUR CUSTOMERS TO ACHIEVE THEIR SUSTAINABILITY GOALS.

Javi McGuiggan

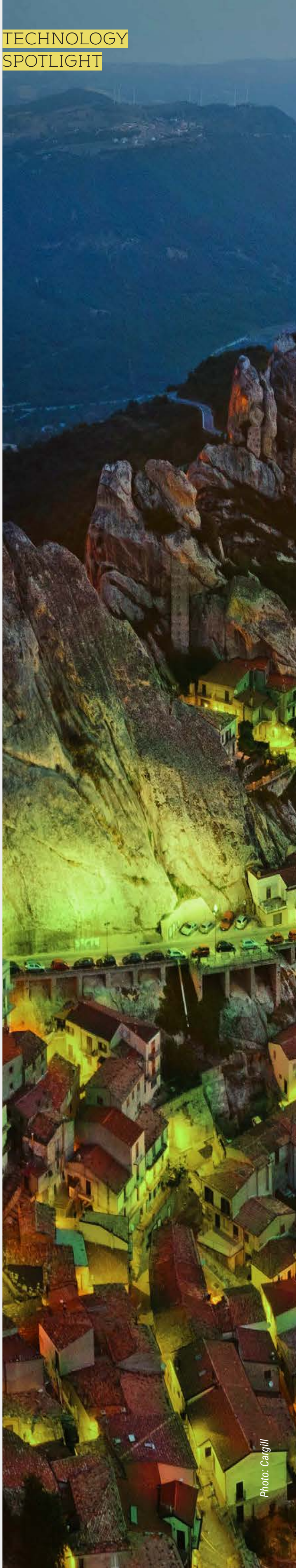
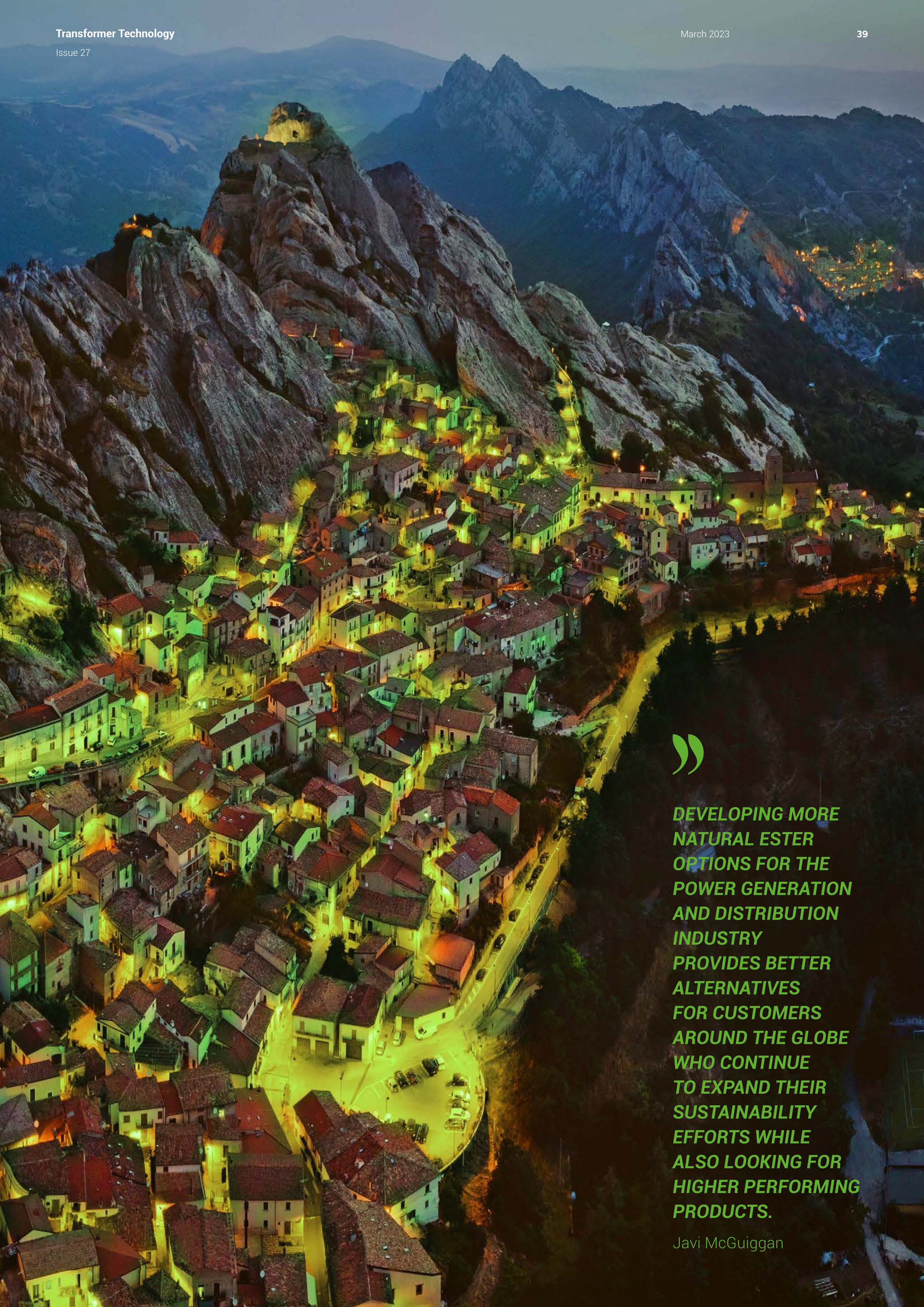


Photo: Cargill



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DEVELOPING MORE NATURAL ESTER OPTIONS FOR THE POWER GENERATION AND DISTRIBUTION INDUSTRY PROVIDES BETTER ALTERNATIVES FOR CUSTOMERS AROUND THE GLOBE WHO CONTINUE TO EXPAND THEIR SUSTAINABILITY EFFORTS WHILE ALSO LOOKING FOR HIGHER PERFORMING PRODUCTS.

Javi McGuiggan

Plant-based natural ester continues to replace traditional mineral oil in transformers around the world as users seek more sustainable and more reliable solutions. Along with being 100% biodegradable, FR3r fluid is also non-toxic in soil, water, and to humans and wildlife.

FR3r fluid is K-class certified, helping mitigate the risk of fire because of its exceptionally high flash point of 360°C compared to only 160°C with mineral oil. Because of its excellent high heat capabilities and up to 140°C top fluid operating temperature, FR3r fluid filled transformerscan achieve up to 20% more loading capacity compared to mineral oil, meaning transformers can be designed to be more power dense and be smaller with the same loading capacity, the same size with up to 20% more loading capacity, or anywhere in between.

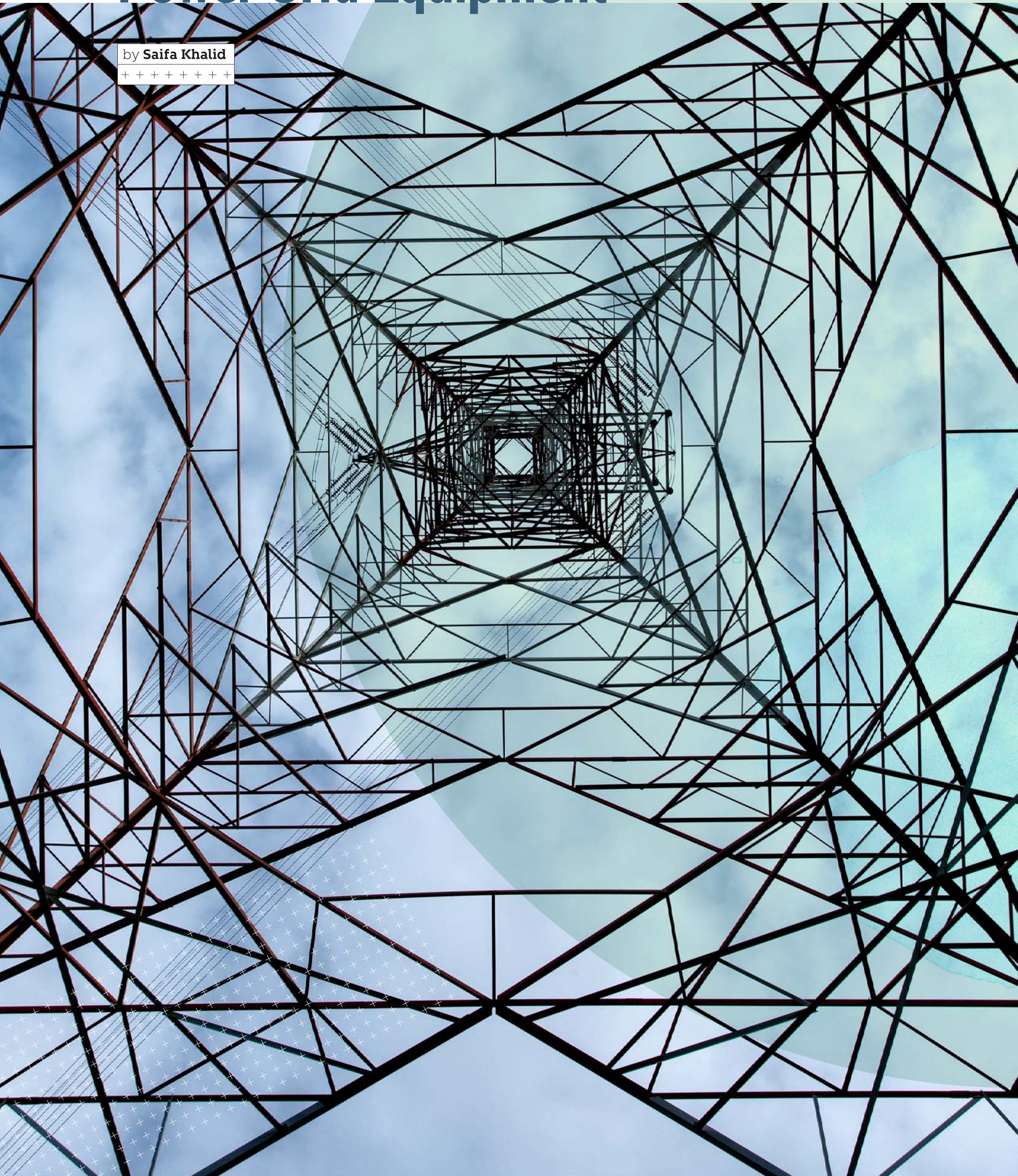
Photo: Cargill

Backed by Cargill's extensive technical and manufacturing expertise from over 25 years of successful applications of the original natural ester (FR3™ fluid), FR3r natural ester meets or exceeds all IEC 62770 and IEE C57.147 standards.

FR3r joins a diverse portfolio of Cargill Bioindustrial plant-based solutions for a variety of manufacturing needs including asphalt rejuvenation, immersion cooling, adhesives and binders, wax and lubricants.

Adoption of Asset Health Monitoring Solutions for Power Grid Equipment

by **Saifa Khalid**



- *Power transformers and HV switchgear are usually the most valuable assets in a substation, requiring proper monitoring and maintenance.*
- *Cost-benefit analysis is a vital tool that helps electric utility companies, regulators, and grid operators in making informed investment decisions.*
- *In the coming years, asset health monitoring is expected to become a key focus of utilities on a global scale.*

Saifa Khalid is a senior analyst at PTR Inc. Her main area of focus is power systems. Currently, she leads the power grid research team in developing PTR's syndicated power grid services and manages custom research projects for Fortune 500 clients globally. The topics under her mandate include HV switchgear, MV switchgear, power transformers, distribution transformers, etc. Saifa comes from a technical background and has a BSc. degree in Electrical Engineering.

Power transformers and HV switchgear are usually the most valuable assets in a substation, requiring proper monitoring and maintenance. Therefore, optimizing the life of an aging transformer and HV switchgear equipment is a major cause of concern for utilities and industries that have a significant installed base of transformers and HV switchgear. In some cases, this equipment dates back to the 1950s, and, ergo, needs to be consistently monitored through asset health monitoring (AHM) solutions that ensure optimum network performance and longevity.

Cost-benefit analysis is a vital tool that helps electric utility companies, regulators, and grid operators in making informed investment decisions. When it comes to the cost-benefit analysis of installing AHM solutions for costly electricity grid equipment, such as power transformers and HV switchgear, savings outweigh the associated costs. That is precisely why electricity grids in advanced economies, that can afford the upfront investment cost, are opting for AHM solutions and are reaping the benefits in terms of improved network reliability standards.

AHM solutions help save money by optimizing performance/maintenance, extending the life of the equipment, and predicting failure. Associated costs with AHM solutions include consultancy fees, the cost of software, and sensors.

There are usually five maintenance strategies that are adopted for an electric grid asset in the maintenance industry, namely: run to failure, time-based, usage-based, condition-based, and predictive maintenance. Power Technology Research believes that, as the maintenance strategies for HV switchgear and power transformers shift towards condition-based and predictive maintenance, savings can be increased significantly (through life extension and optimized performance).

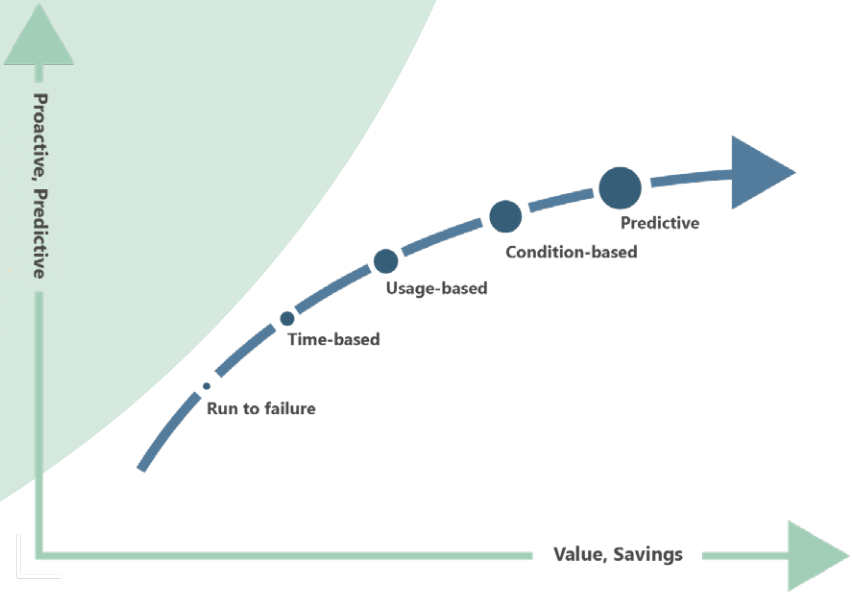


Figure 1: Maintenance strategies for an electrical grid asset.
Source: PTR Inc.

Photo: Shutterstock

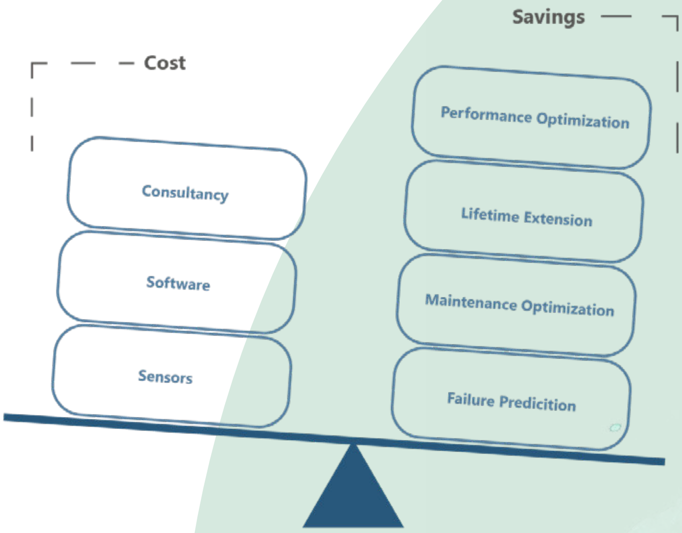


Figure 2: Cost benefit analysis of AHM solutions. Source: PTR Inc.

Efficiency

1) Improves the performance and increased utilization of the asset by converting information into actionable intelligence.

2) Reduces the total cost of ownership of the grid asset.

3) Provides dynamic fleet management and benchmarking.

4) Active network management capabilities for deeper renewable penetration in the energy mix.

5) Caters to the fluctuations in the grid in an intelligent manner, with a short response time.

Reliability

1) Carries out the monitoring and diagnosis of the asset in real-time, focused on preventing forced outages and failure of equipment with timely warnings.

2) Enhances the integrity of equipment through condition-based and predictive maintenance.

3) With remote access and online asset management facilities, the exposure of human resources to substation environment may be reduced, therefore improving safety.

Future-proof investment

1) New industry-standard: digitally integrated and ready to connect.

2) Modular and scalable platform with the full ecosystem of smart devices, software, and service solutions.

3) Building block for digital substations and state-of-the-art cyber security.

Features of Asset Health Monitoring

The major features of an asset health monitoring solution for HV switchgear and power transformers include reliability, efficiency, and future-proof investment. These are discussed below in detail.

ABB	General Electric	Siemens
Circuit Breaker Sentinel • CBS • CBS Lite • CBS Lite CSA • CBS-F6	CB Watch 3	Assetguard PDM
Generator Circuit Breaker Monitoring System GMS600 • GMS600-G • GMS600-GT • GMS600-GA • GMS600-GTA	DWatch	Assetguard GDM
Modular Switchgear Monitoring (MSM)	B Watch	
Switchsync PWC600	PD Watch	
Asset Health for Switchgear (AHS)	BA300	

Figure 3: Product portfolio of asset health monitoring solutions for HV switchgear. Source: PTR Inc.

With remote access and online asset management facilities, the exposure of human resources to substation environment may be reduced, therefore improving safety.

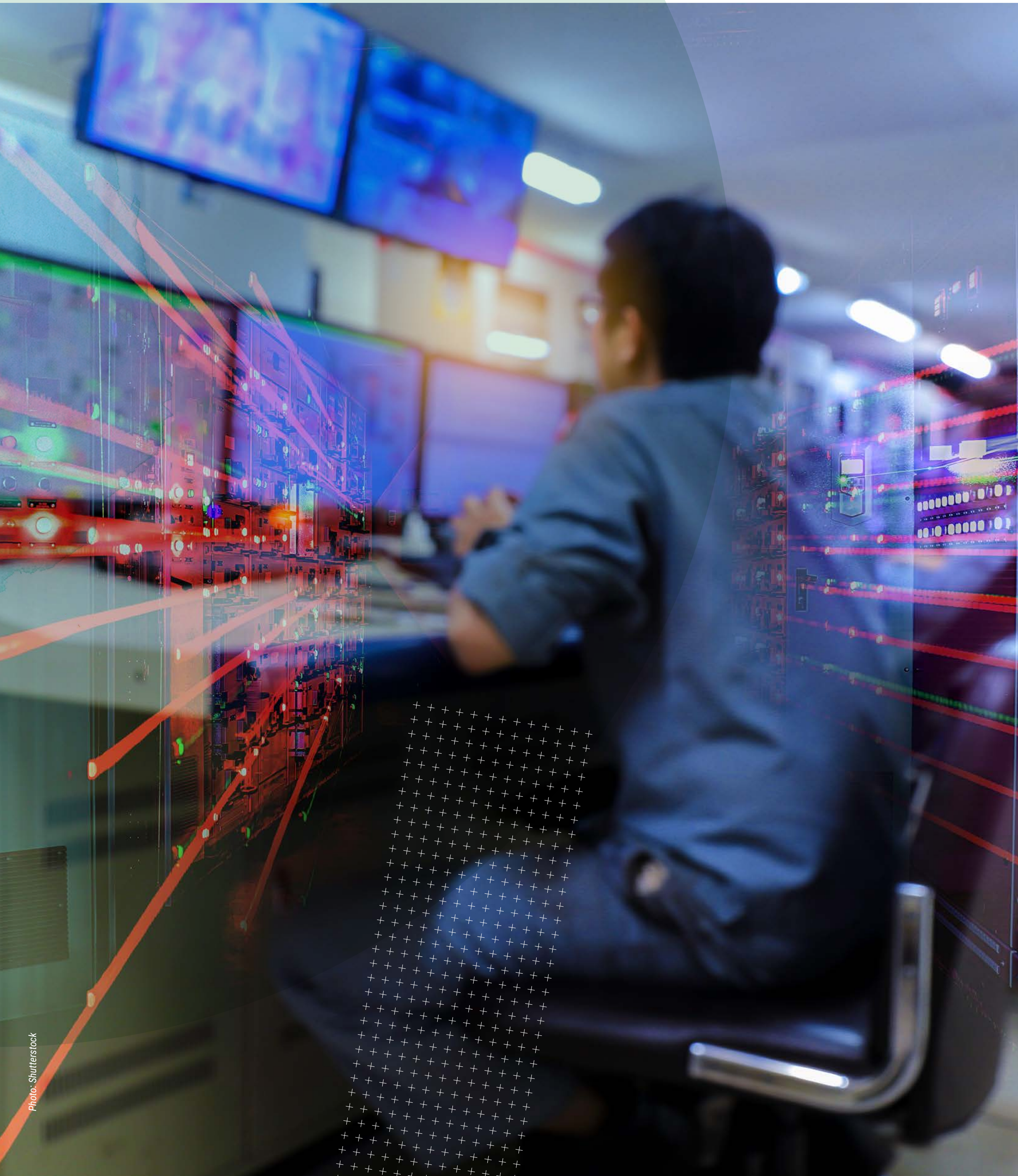


Photo: Shutterstock

A digital transformer is not a product in itself, but a solution that requires the integration of existing transformers with physical sensors and a digital platform.

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Product Portfolio and Case Studies

As far as the product portfolio of digital transformers is concerned, it is significant to note that a digital transformer is not a product in itself, but a solution that requires the integration of existing transformers with physical sensors and a digital platform. For instance, when the existing power transformer (from Hitachi ABB or any other manufacturer) is integrated with TXpert™ Ready Sensors (from Hitachi ABB or any other manufacturer) and with TXpert Hub (Hitachi ABB), it becomes TXpert enabled.

The product portfolio of AHM solutions for HV switchgear is given in the figure below. This suggests that the product range offered by ABB and General Electric is greater than Siemens, which only offers two products (Assetguard PDM and Assetguard GDM).

Several case studies, illustrated in Figure 4, explain how the deployment of asset health management solutions for HV switchgear and power transformers in various parts of the world has improved electricity network reliability.

Looking Ahead

In the coming years, asset health monitoring is expected to become a key focus of utilities on a global scale. This is especially true for advanced economies that can afford to make a significant initial investment in AHM solutions. Power Technology Research carried out a Europe-wide study of 35 transmission system operators in order to establish a relationship between network reliability indicators and the adoption of AHM solutions. It was observed that countries that have better network reliability indicators, such as lower SAIDI (System Average Interruption Duration Index) or SAIFI (System Average Interruption Frequency Index) values, were actually more inclined towards the adoption of digital solutions for AHM.

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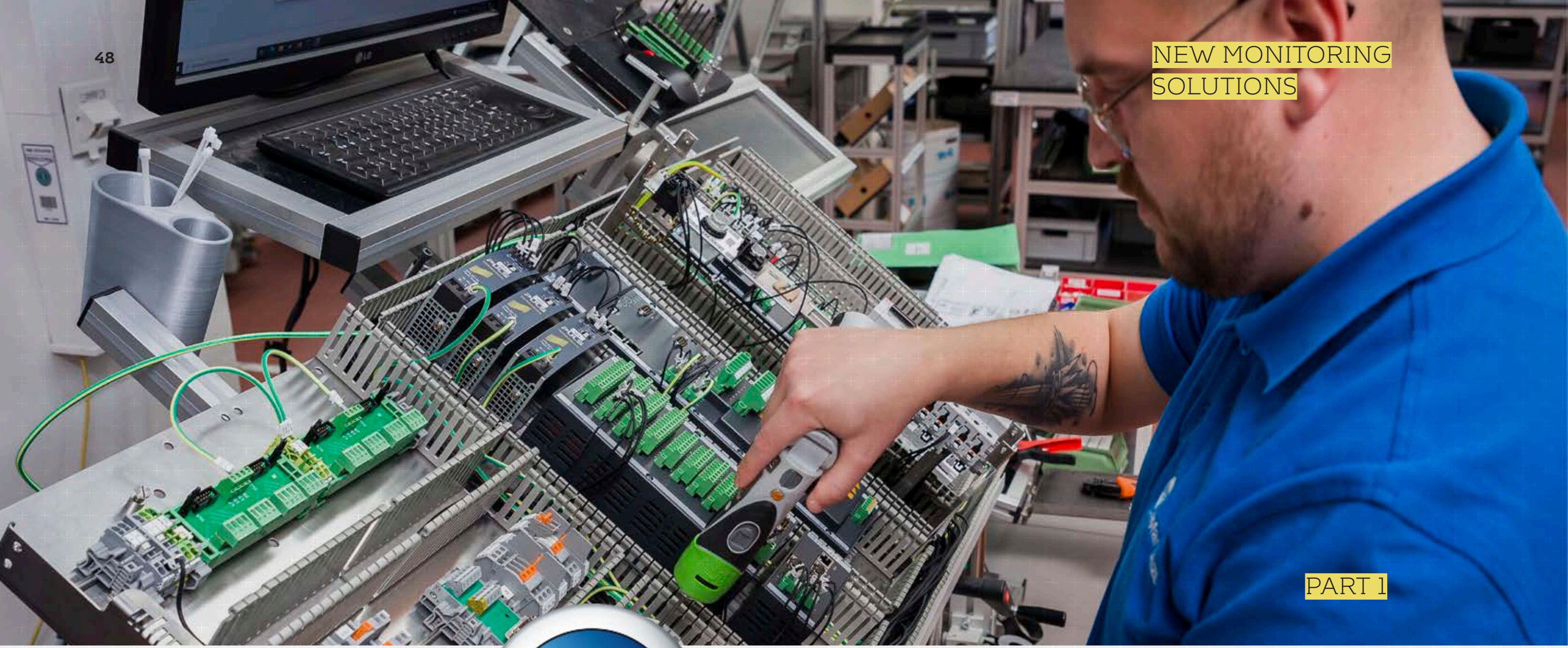
Region	Company	Case Study
South America	ABB (ASEA Brown Boveri)	**Problem:** A customer required a reliability-centered program built around condition monitoring, data analysis, and spare parts inventory management in South America for a fleet of 550 kV 30-year-old BBC GIS. **Solution:** The local service center collaborated to develop a solution for the legacy equipment which would keep it reliable well into the future at a cost that was far lower than alternative options. Data from condition monitoring devices allow for strategic as well as proactive decision-making for prioritizing maintenance to the assets that need it, while leaving alone the assets that are healthy. It also assists in the replacement planning of failing assets.
The U.S.	ABB	**Problem:** The challenge was to lower greenhouse gas/SF6 emissions, as a part of an aggressive "Green" initiative within a strict deadline. Field retrofitting monitoring devices on installed breakers was not possible within that time frame. **Solution:** ABB's well-trained field service staff met the project deadline by enabling early SF6 gas leak detection using remote monitoring by CBS-F6, eliminating costly and unplanned outages. CBS-F6 – works with any brand OEM HV circuit breaker.
Egypt	Siemens	**Problem:** The aim was to boost the energy reliability and efficiency of the Nile Delta's 500/220-kilovolt Kafr El Sheikh and New Zagazig governorates (highly loaded link of transmission grid of Northern Egypt). **Solution:** Sensformers were provided to the Egyptian Electricity Transmission Company (EETC) by Siemens which dealt with the network reliability and efficiency of the delta area.
Italy	Hitachi ABB	**Problem:** The challenge was to achieve a more sustainable grid and improve power quality in the well-known mountain resort of Cortina in Northern Italy. **Solution:** In Enel's substation of Cortina D'Ampezzo, TXpert™ Ecosystem for the digitalization of transformers was deployed to increase the reliability of the electricity grid and reduce the risk associated with the consequent life extension of power transformers.

Figure 4: Case studies of AHM solutions for HV switchgear and Power Transformers. Source: PTR Inc.



PART 1

NEW TECHNOLOGIES CAN HELP COMPENSATE FOR THE LOSS OF PERSONNEL KNOWLEDGE AND THE INCREASED DEMANDS ON OPERATING EQUIPMENT

New technologies in monitoring and diagnostics help compensate for the loss of personnel knowledge and the increased demands on operating equipment. Also, energy transition is posing enormous challenges for the power supply: Infrastructure conceived decades ago suddenly must transport electricity in a different way. Power grids are aging, and with maintenance strategies that have been the norm up to now, there is an increasing need for renewal, entailing further expense. One solution lies in intelligent, data-driven utilization concepts that enables the use existing infrastructure more efficiently and extend the lifetime.

To achieve this, a balanced portfolio for the different automation levels is necessary (see Figure 1).

Sensors continuously record the signals at the process level. All measured data is then communicated to a central communication node in the field level for further processing and enrichment. Thus, fail-safe and centralized information on maintenance and health status is resiliently available on site. On the control level a global classification can be carried out and risk-based maintenance strategies are enabled. For a holistic system for the diagnosis of power transformers, modular and manufacturer-independent solutions must be found to ensure the best possible application.

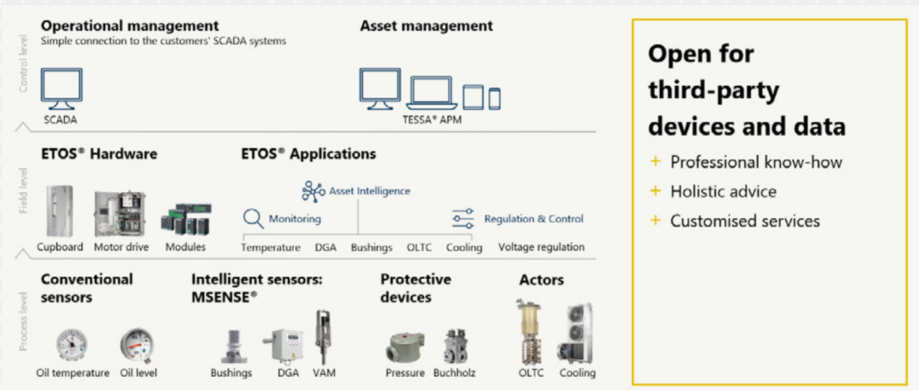


Figure 1:
MR's System solution for maximum operational reliability

How these solutions can look in practice is demonstrated by the following applications.

Simplifying and enriching sensors in their use on transformers

To make the best possible conclusions about the health of transformers, it is useful to work on accuracy and reliability of data sources (sensors). The following examples show how this has been done for monitoring the various components on the transformer.

DGA – Dissolved Gas Analysis

The analysis of dissolved gases in the insulating oil in the gas phase is carried out using various analysis approaches: semiconductor sensors, electrochemical sensors, infrared spectroscopy, or gas chromatography. An extraction of the gases from the insulating oil takes place prior to the actual analysis for all methods. These two essential processes are influenced by external factors such as oil and ambient temperature, humidity, air pressure, and other chemical components, which often lead to very high measurement uncertainties and incorrect analysis results. One method for counteracting this is to keep the conditions of gas extraction and detection constant. Detection can also be improved by separating interfering components from the actual target gases. All of these measures require additional components in a DGA analysis system, which significantly increases both its cost and complexity.

Another approach includes mathematical-statistical methods from the toolbox of machine learning or artificial intelligence. The correlation between the actual target variable (in the case of a DGA – the gas concentrations in the insulating oil), the sensor signal, and the disturbing influences is determined using a training data set. The training data set should represent the entire data space of the application to the greatest extent possible. For a DGA, this means recording the temperature range of the insulating oil and the environment, the humidity range, the ambient pressure, and all relevant chemical disturbance components, and thus taking their influences into account as completely as possible in the mathematical model. Other methods such as support vector regression (SVR) are also conceivable. The advantage of this approach, as implemented in the MSENSE® DGA 2/3, is a much simpler and less expensive design of the measurement system. While more effort is needed in the development phase, the customer receives a robust, easy-to-operate, and more cost-effective analysis system.

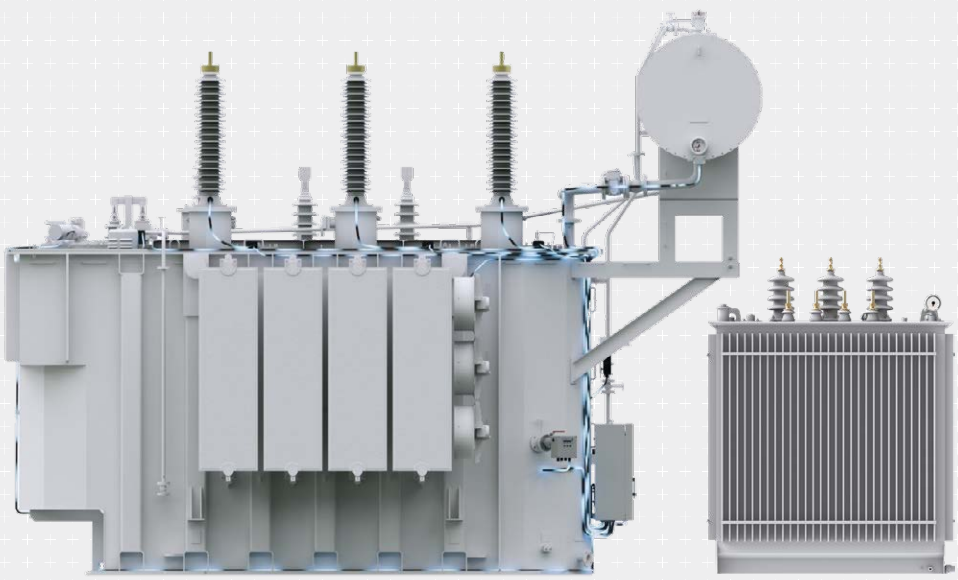


Photo: MR

Another advantage of this approach is the possibility of self-adjustment of the analysis system during operation. With the aid of a reference point, the analysis system can auto-calibrate using machine learning methods and existing measurement (measured-data memory of the analysis system) in order to adapt to the individual conditions on site. In this way, effects such as sensor drift, aging of the insulating oil and the like can be compensated for and consistent measurement repeatability can be ensured.

OLTC DGA

In the CIGRÉ publications CIGRÉ Technical Brochure 443 and CIGRÉ Technical Brochure 771, the gas patterns of on-load tap-changers are interpreted using the gas ratios of methane, ethylene and acetylene according to Duval (Duval triangles) and classified into fault classes or normal operation.

The interpretation of gas patterns of tap changers remains difficult compared to transformers and requires expert knowledge about the functionality of the respective tap changer type and its mode of operation. Nevertheless, the condition assessment of a tap changer by means of DGA is a powerful tool and helps to optimize maintenance measures within the framework of condition-based maintenance and to indicate deviations from normal operation in good time.

For continuous online monitoring, as with transformers, the use of multi-gas online DGA sensors for fault diagnosis is usually not necessary. Often, trend analysis of a few key gases such as hydrogen, carbon monoxide or acetylene/methane is sufficient to detect deviations from normal operation at an early stage. Our investigations showed that with vacuum tap changers of the built-on more than 80% of the deviations from normal operation could already be detected with the monitoring of hydrogen.

The interpretation of DGA data from on-load tap-changers remains difficult, since further information on the operation and function of the on-load tap-changer is required. Therefore, deviating from the previously known approaches, an interpretation approach is proposed, which uses statistical-mathematical algorithms. In addition to the gas concentrations, information on the tap changer is used as input variables, such as tap changer type, number of switch operations, and more. As a result, a diagnosis with an indication of the probability is obtained (see Figure 2).

In the example shown (Fig. 2), normal operation is assumed with a high degree of probability (the greater the proportion of the gray area, the greater the uncertainty of the statement made). Here, it was possible to provide a lot of supplementary information on the tap changer, so that the reliability of the statement is high.

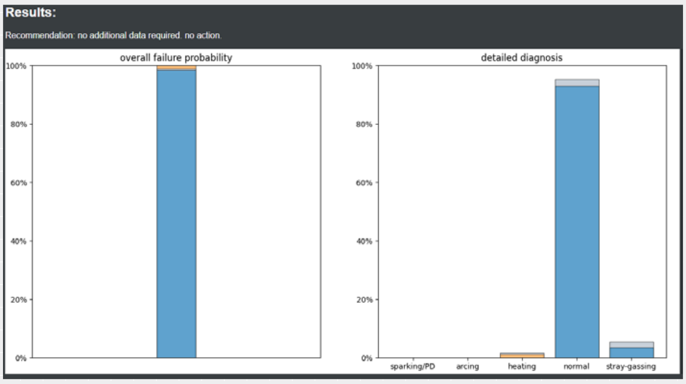


Figure 2:
Example of a DGA interpretation of a vacuum tap changer based on a statistical approach.

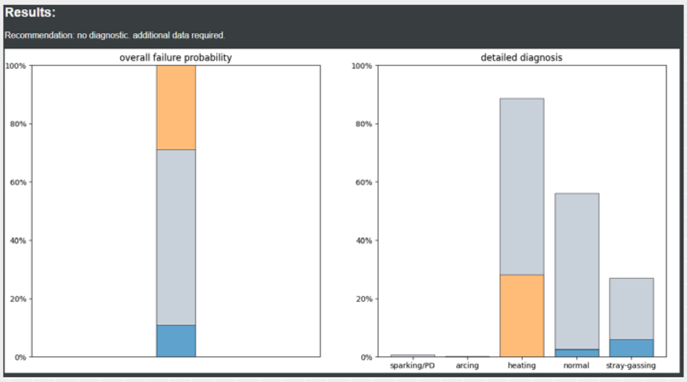


Figure 3:
Second Example of a DGA interpretation of a vacuum tap changer based on a statistical approach.

The example shown in Fig. 3 illustrates how, at the same gas concentrations as in Fig. 2, the reliability of the statement decreases when only very little information is available on the tap changer. The proportions of the gray areas (uncertainty ranges) are very large. This also indicates that a diagnosis based on too little data is not meaningful.

As part of the condition monitoring of on-load tap-changers, the online DGA is a valuable tool for detecting deviations from normal operation at an early stage and thus avoiding damage or failures. It contributes to a cost-optimized condition-based maintenance strategy. For continuous trend monitoring, the analysis of a few key gases using cost-effective and robust online DGA systems is sufficient. Caution should be exercised when interpreting DGA data for fault diagnosis, as the most accurate knowledge of the operation and function of the on-load tap-changer under consideration is additionally required and should be taken into account in the interpretation.

Oil moisture and breakdown voltage

In insulating systems for electrical equipment moisture is undesirable. Excessive moisture in insulating oil or insulating paper impairs their insulating strength. Water promotes degradation reactions of the insulating oil and the insulating paper and reduces the service life of a transformer or on-load tap-changer.

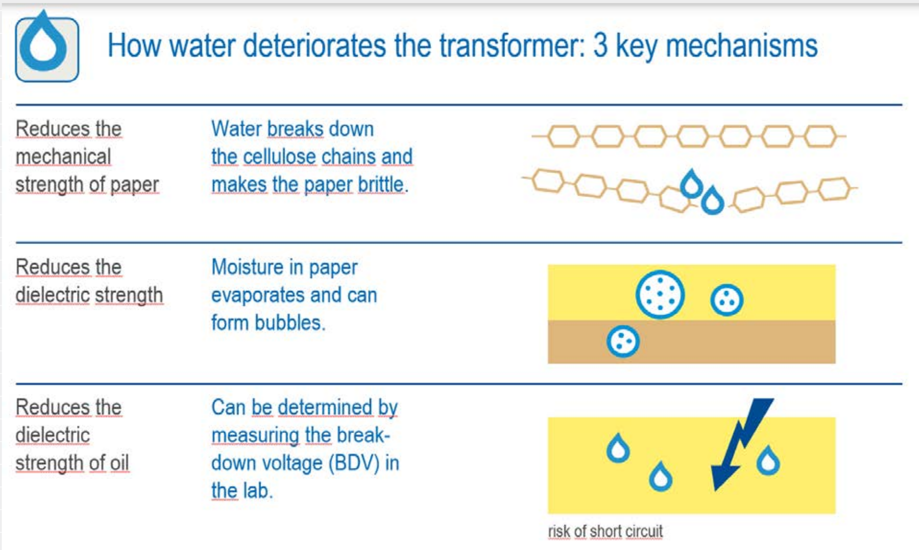


Figure 4:
Deterioration of insulating materials because of water

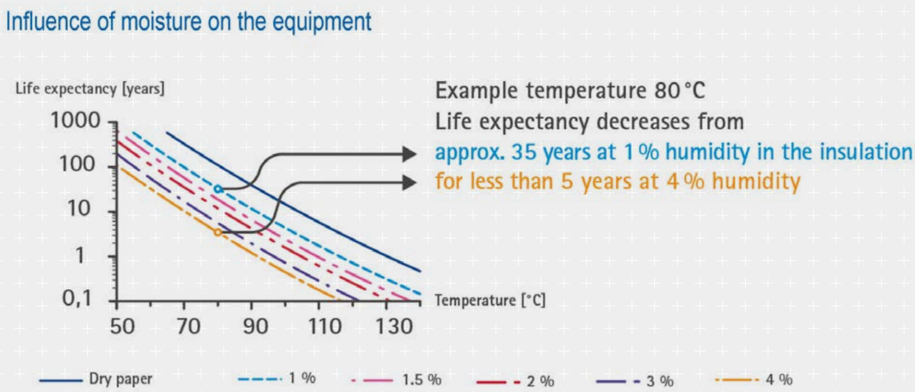


Figure 5:
Loss of lifetime because of increase water content

This results in two aspects regarding to moisture: a) The penetration of moisture into the transformer or tap changer should be avoided. This is done by appropriate handling of the insulating materials and by using dehumidifiers to dry the air breathed in by the transformer or tap changer. b) The moisture content of the insulating oil should be continuously monitored. Since it is not possible to monitor the moisture content of the insulating paper directly while a transformer is in operation, this is also done indirectly via the moisture content of the insulating oil. The insulating strength of the liquid insulating medium is determined by means of the breakdown voltage in accordance with appropriate test standards such as IEC 60156 or ASTM D 1816. For this purpose, a defined quantity of the insulating oil is filled into a test chamber, where there are two electrodes at a defined distance - in the case of IEC 60156 this is 2.5 mm. The test voltage between the two electrodes is continuously increased until breakdown occurs. Several test runs are carried out from which individual values of the breakdown voltage are determined by averaging in kV. According to the requirements for a fresh insulating oil in IEC 60296, the breakdown voltage must be at least 30 kV. Fresh insulating oils usually have breakdown voltages between 60 and 80 kV. A major influencing factor on the breakdown voltage, as a characteristic parameter for the insulating strength, is the moisture content of the insulating oil. The breakdown voltage of an insulating oil is thus another important parameter for assessing the condition of the liquid insulating medium and thus of the transformer or tap changer. Continuous monitoring of the breakdown voltage is therefore recommended.

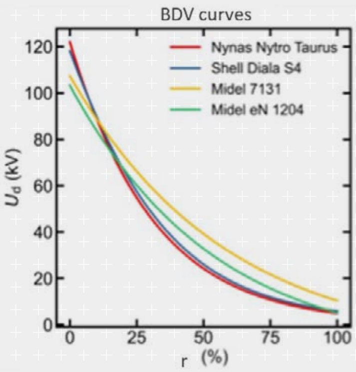


Figure 6:
Resulting BDV models for different oil types

The methods described in the relevant test standards for determining the breakdown voltage are not suitable for online monitoring. The construction of a device that can be used in the field is complex and expensive, and breakdowns in the oil would be provoked, which would damage the insulating oil with time. A relatively simple way of implementing online monitoring of the breakdown voltage makes use of the influence of the moisture in the insulating oil on the breakdown voltage. The relationship between relative oil moisture, oil temperature, and breakdown voltage can be described using statistical methods from the machine learning toolbox. Here, the data for the breakdown voltage at different oil temperatures and humidities are determined experimentally using a reference method, IEC 60156. A mathematical model is trained with these data. The model is validated and optimized using test data that are independent of the training data.

Since the test standard used to determine a breakdown voltage in the laboratory already has a large measurement uncertainty, it is advisable to divide the results of the BDV calculation into classes based on the IEC 60422 standard, and display the information in the form of a traffic light. This is considered sufficient for long-term trend monitoring. Integrated into a higher-level monitoring system, a condition assessment of the equipment is thus obtained, taking into account other characteristics of the equipment.

Bushing monitoring

Based on the CIGRE study working group A2.37 and A2.43, "Transformer Reliability Survey" and "Transformer bushing reliability", almost 18% of all failures documented for substation transformers can be tracked down to malfunctions related to transformer bushings. Those numbers show how critical and important monitoring of transformer bushings can be.

The most efficient way to estimate bushing condition based on on-line monitoring is to control the change of the main capacitance C1 and the associated dielectric dissipation factor tanδ. It is proven that humidity and aging are impacting capacitance only at higher temperatures. A short circuit between elementary condensers will increase the capacitance independent of temperature. Change of the tanδ and PF is temperature dependent. Increase of tanδ indicates a higher loss in the bushing's insulation system and is often caused by introduction of moisture or ageing.

Limits for the change of C1 and tanδ depend on the system voltage and technology used for bushings construction.

The tanδ measurement is much more sensitive to external factors (temperature, weather condition) than capacitance due to the very small value of angle δ. Bushing condition evaluation based on tanδ measurement depends on the bushing insulation type and construction. Two evaluation methods can be applied: based on the specified tanδ value or a relative tanδ change.

Sum of current method: The amplitude and phase angle of the current at all of three bushing taps are measured and compared to each other. Simple current amplitude changes with change of the capacitance and the phase shift with the dielectric loss factor of the bushing assuming that the summation of the currents of the three bushing of the different phases under consideration of its phase angles is zero. In that method the measurement is very strongly affected by the fluctuation of the system voltages and phase. Monitoring system utilizing that method can be easily installed on the transformer. Less technical effort and simplicity are the main advantages; however, the results are impacted by the imbalance and external factors.

Comparison method: to avoid problems recognized in the sum of currents method, the comparison method was introduced. This method uses a signal from voltage transformers installed on the same phase as a reference. The voltage transformer is not affected by the defects and aging that typically affects bushings. Monitoring systems utilizing this method need additional technical effort to connect the reference signal. In most cases the VT are placed far away from the transformer, however the results are not affected by network imbalance and external factors.

Measured voltage signal can be additionally compared with other phases of the same transformer, improving immunity to external factors like temperature or weather condition.

The double-reference method improves the voltage comparison method and capacitance measurement if the reference voltage is not accessible (voltage change during tap changer switching).

Bushing monitoring system in most cases can utilize the same decoupling devices for electrical Partial Discharge (PD) measurement. Signals in different frequency ranges can be used for PD activity recognition and early warning. The electrical measurement on bushing is strongly affected by external noise, which can be compensated by combining it with the UHF method (antennas installed on the transformer tank) for better PD recognition.

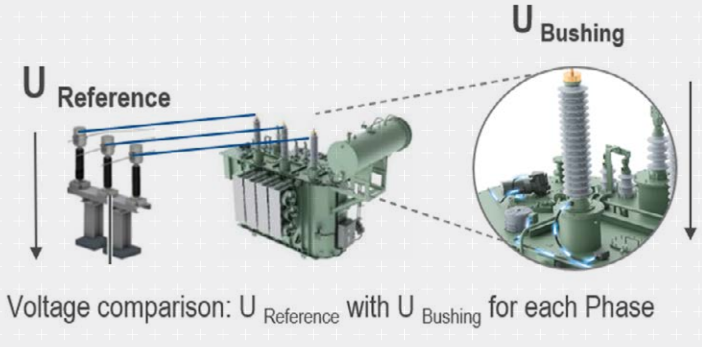


Figure 7:
Voltage comparison method can be easy and cost effective integrated with ETOS® or work as a stand-alone (MSENSE®BM) providing best solution for bushing monitoring.

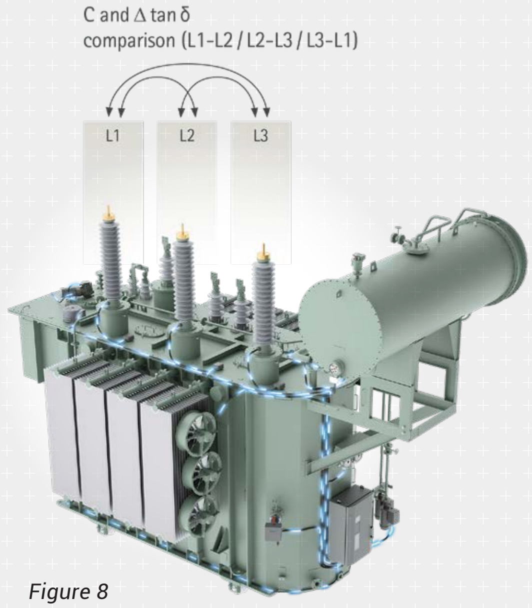


Figure 8

Vibro acoustic monitoring of OLTCs

Since on-load tap-changers are among the most important components of power transformers, it is crucial for network operators to know their conditions at all times. Thanks to more than 20 years of experience in on-load tap-changer monitoring, Reinhausen has developed a unique online diagnostic tool: MSENSE® VAM. "VAM" stands for vibroacoustic measurement and can be used universally for all types and brands of OLTCs. The basis of MSENSE® VAM is a high-resolution vibroacoustic measurement system for detecting vibrations that occur during the switching sequence of an OLTC. Envelope curves are generated from the time-frequency spectra emitted during the switching sequence. The evaluation of these envelope curves is performed with the aid of a dynamic limit value curve which increasingly approximates the envelope curve during each switching sequence by means of a self-learning algorithm.

Assuming a Gaussian probability distribution, the significant peaks of the recorded curve are then expanded. As a result, a limit curve is generated over the sound signal peaks characterizing the tap changer switching process.

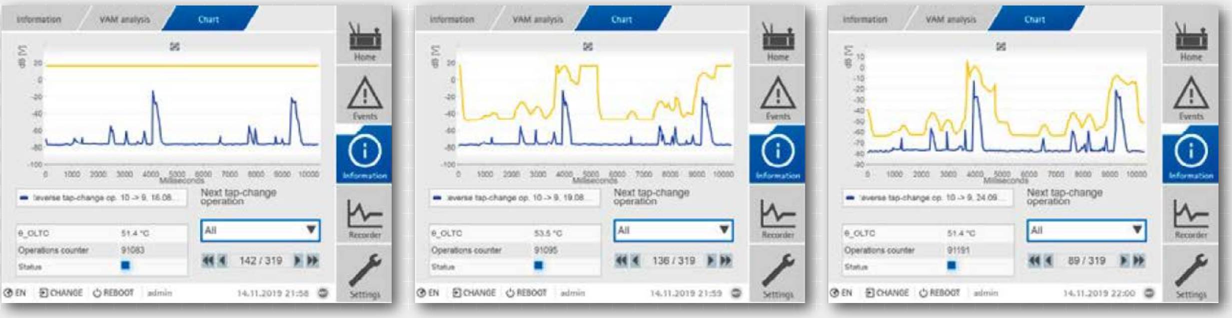


Figure 9:
Self- learning limit value curve for an easy installation

An upper limit value curve is generated from the statistics, which represents an absolute limit value for the acoustic signal. The limit value curves are determined independently by the system using statistical methods on the basis of the stored historical data.

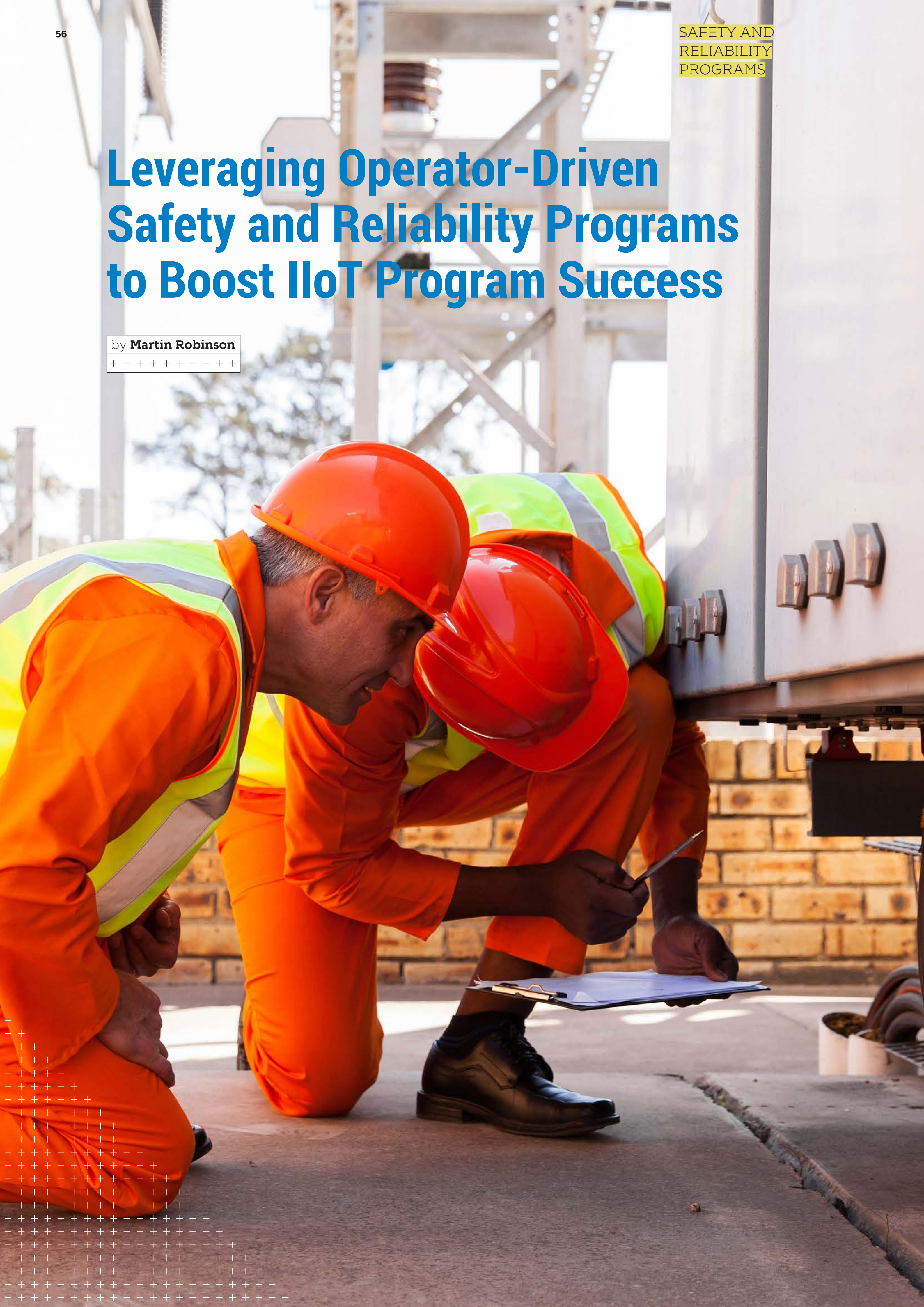
The resulting limit value curve serves as an alarm limit value and is at the same time used for flexible adjustment of the amplitude range that is still permissible. The limit values are thus updated. Through this tracking procedure, the system iteratively learns during the switching operations what the acoustic signature of a correctly operating on-load tap-changer looks like, in order to check the correct course of all subsequent on-load tap-changer switching operations on the basis of the self-generated envelope curve. Whereas in the past it was necessary to determine individual limit value curves via the temperature curve in a test pro-cedure that took months, the system now learns the correct limit value curves for the specific on-load tap-changer.

Tobias Gruber is Automation Portfolio Manager at Maschinenfabrik Reinhausen GmbH, where he has worked for 10 years. He helped develop the current automation systems, i.e., ETOS® for power transformers. He holds MSc. in electrical engineering and is an expert for automation applications responsible for the automation portfolio at MR.

Jürgen Schübel completed a PhD in physical chemistry in 1991 and worked for 20 years in a major European mineral oil company. He is senior expert for insulating materials and analytics at MR, Product Owner of DGA-, Fiber Optic- and Moisture sensors and is an active member of CIGRÉ D1.

Photo: MR

To be continued in our MAY Issue.
In the next article, we will describe the use and integration of typical sensors with more analysis and inside-view and will expand the collection and further analysis by edge devices and central solutions.



Leveraging Operator-Driven Safety and Reliability Programs to Boost IIoT Program Success

by **Martin Robinson**

Martin Robinson is the founder, owner, and CEO of IRISS Inc., a leading manufacturer of infrared inspection windows. Robinson focuses on innovation and is a pioneer of Electrical Maintenance Safety Devices (EMSDs) that help protect technicians from harm while protecting their companies' bottom line. He holds several patents for condition-based maintenance devices and has designed multiple maintenance programs that include infrared, ultrasound, partial discharge testing, non-destructive testing (NDT) and energy management strategies. He holds a NEBOSH certificate in Occupational Safety and Health, an IAM Certificate in Asset Management, is a certified Level III Thermographer, a Certified Maintenance and Reliability Professional (CMRP) and a Certified Reliability Leader (CRL). He is a member of IEEE, NFPA and is a standing member on the technical committee CSA Z463 guidelines on maintenance of electrical systems.

One possible initiative to increase the success of IIoT programs is to use operators to implement solutions into Operator Driven Safety and Reliability Programs.

Photo: AdobeStock, American Public Power Association

Industry 3.5 is a term used to describe the transitional phase between Industry 3.0 and Industry 4.0. It refers to integrating digital technologies into traditional manufacturing and industrial processes to a lesser extent than Industry 4.0. Industry 3.5 involves the use of technologies such as computer-aided design (CAD), computer-aided manufacturing (CAM), and enterprise resource planning (ERP) systems, which enable companies to automate and optimize their manufacturing processes, reduce costs, and improve productivity. Industry 3.5 is considered a stepping stone towards Industry 4.0, as it allows companies to gradually introduce digital technologies into their operations and establish a foundation for more advanced systems.

The Industrial Internet of Things (IIoT) has become increasingly popular, with companies investing heavily in IIoT programs to improve their operations. However, not all IIoT programs have successfully delivered their intended results. While there is no specific data on the number of IIoT programs that have failed to deliver their design intent, several studies have highlighted the challenges associated with implementing IIoT programs and the factors that can contribute to failure. For example, one study by Cisco found that only 26% of companies had succeeded in their IIoT initiatives, with most companies struggling to scale their programs beyond pilot projects. In addition, the study found that the most significant challenges associated with IIoT implementation were data integration, security, and a lack of internal expertise.

Another study by Bain & Company found that the majority of IIoT programs fail to deliver their intended results, with only 5% of companies reporting significant financial benefits from their IIoT programs. The study identified several factors that can contribute to the failure of IIoT programs, including a lack of executive support, internal expertise, and a failure to focus on solving specific business problems.

While there is no specific data on the exact number of IIoT programs that have failed to deliver their design intent, several studies have highlighted the challenges associated with implementing IIoT programs and the factors that can contribute to failure. These studies suggest that companies must be mindful of these challenges and take steps to mitigate them to increase the likelihood of success. One possible initiative to increase the success of IIoT programs is to use operators to implement solutions into Operator Driven Safety and Reliability Programs.

Operator-Driven Safety and Reliability (ODSR):

Operator-driven safety and reliability (ODSR) is a program that empowers operators to take ownership of their equipment and processes. ODSR programs enable operators to identify and address potential safety hazards and reliability issues before they become problems, leading to increased safety, reduced downtime and improved productivity. ODSR programs involve training and support, performance metrics, and integrating equipment inspection system designs and IIOT monitoring systems. ODSR programs can help build a safety culture and improve overall performance in manufacturing and industrial environments by involving operators in identifying and addressing safety and reliability concerns.

ODSR programs can help enhance Industry 3.5 by providing real-time feedback to operators, allowing them to make informed decisions and take corrective actions in response to potential safety hazards and reliability issues. In addition, by involving operators in identifying and addressing safety and reliability concerns, ODSR programs can help build a safety culture and improve overall performance in manufacturing and industrial environments.

How ODSR Programs Can Improve the Success of IIoT Programs:

ODSR programs can help improve the success of IIoT programs by addressing some of the challenges associated with IIoT implementation. For example, a lack of internal expertise is a familiar challenge company face when implementing IIoT programs. ODSR programs can help address this challenge by empowering operators with the knowledge and skills to identify and address potential safety hazards and reliability issues. In addition, by involving operators in the implementation and maintenance of IIoT systems, companies can leverage their expertise and experience to ensure the success of their IIoT programs.

Photo: AdobeStock

ODSR programs can help improve safety and efficiency, reduce downtime, and improve productivity, leading to financial benefits and improved operator job satisfaction.

Another common challenge associated with IIoT implementation is data integration. ODSR programs can help address this challenge by providing real-time feedback on the performance of equipment, enabling operators to quickly identify and address potential issues before they become significant problems. This can help prevent data silos and ensure that IIoT systems are fully integrated into existing processes.

Security is another significant challenge associated with IIoT implementation. ODSR programs can help address this challenge by involving operators in identifying and addressing potential security issues. Companies can reduce the risk of cyberattacks and other security breaches by providing operators with the tools and knowledge to identify and address security issues.

Additionally, ODSR programs can help to address the challenge of scaling IIoT programs beyond pilot projects. By involving operators in the implementation and maintenance of IIoT systems.

In conclusion, the success of IIoT programs depends on several factors, including data integration, security, internal expertise, and executive support. ODSR programs can help address these challenges by empowering operators to take ownership of their equipment and processes and providing them with real-time feedback on equipment performance. As a result, ODSR programs can help improve safety and efficiency, reduce downtime, and improve productivity, leading to financial benefits and improved operator job satisfaction.

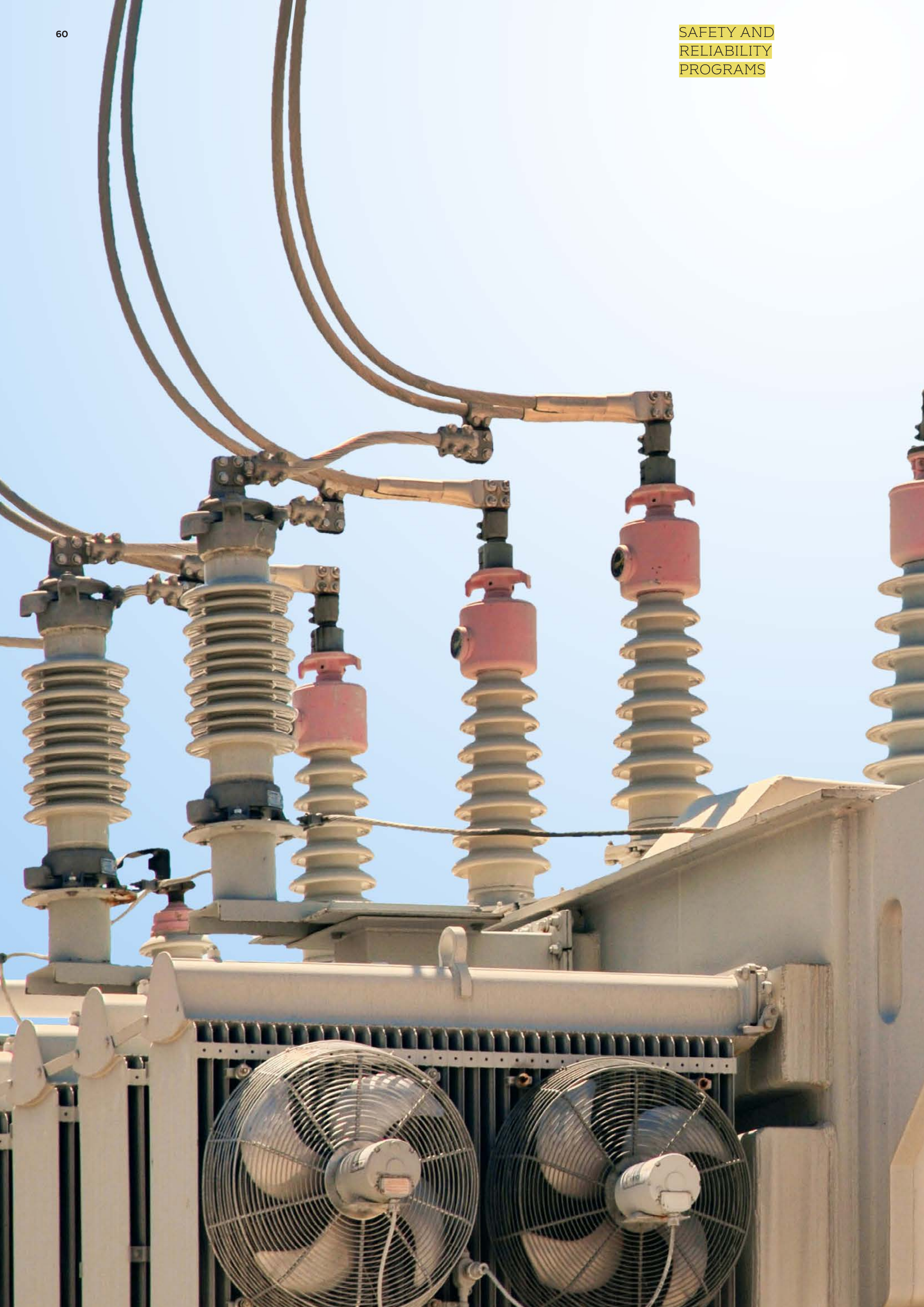


Photo: AdobeStock

By leveraging ODSR programs to enhance IIoT programs, companies can optimize their operations, leading to financial benefits and improved operator job satisfaction.

By involving operators in implementing and maintaining IIoT systems, companies can leverage their expertise and experience to ensure the success of their IIoT programs. Companies can also enhance ODSR programs by adding equipment IIoT monitoring systems and designing or modifying equipment to allow safe access for inspection.

Industry 3.5 is a stepping stone towards Industry 4.0, and ODSR programs are a powerful tool for enhancing Industry 3.5 and transitioning towards a fully digitalized and connected manufacturing environment. By improving the safety and efficiency of operations, companies can optimize their existing processes, leading to a gradual shift towards Industry 4.0.

In summary, ODSR programs can help improve the success of IIoT programs by addressing the challenges associated with data integration, security, internal expertise, and scaling beyond pilot projects. ODSR programs can also enhance Industry 3.5 by empowering operators and providing real-time feedback on the performance of equipment. By leveraging ODSR programs to enhance IIoT programs, companies can optimize their operations, leading to financial benefits and improved operator job satisfaction.

How to effectively address lightning performance and continuously monitor system failures?

by **Florent Giraudet**

Photo: Shutterstock

One possible initiative to increase the success of IIoT programs is to use operators to implement solutions into Operator Driven Safety and Reliability Programs.

500kV Tower in South East Asia

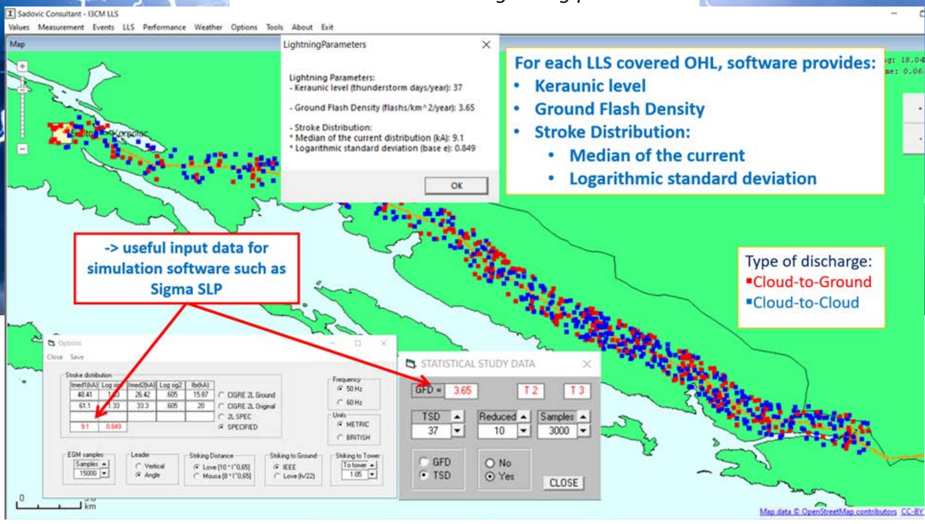
For non-specialists, this double circuit lattice tower might seem conventional, but on closer inspection it is rather unique. Each phase conductor is protected by Line Surge Arresters (LSA).

LSA are used to prevent lightning induced flashovers. In this case, the system operator has adopted an EGLA technology (Externally Gapped Line Arrester). Although the choice of EGLAs is rather appropriate, especially on 500kV lines, some essential questions arise on such installations:

- Is it optimal to protect every phase conductor? Couldn't we find a better optimization?
- How can I assess the condition of my LSA over time? How do I get the confidence they are still effective to protect my line?
- Even better, can I get a confirmation they have done their duty of protection? And how many times?

Florent Giraudet received a Dipl. Ing. Degree in Industrial and Electrical Engineering from CESI in Lyon, France in 2010. He later joined Siemens, Germany as Area Sales Manager for surge arresters application. He then took on additional responsibilities in the business development of overhead line solutions that include applications of transmission line arresters as well as polymeric insulators. He subsequently took over Sales & Marketing responsibilities at Tridelta Meidensha. Currently, he offers consulting for lightning performance and surge arrester technologies. You can contact the author via his e-mail address: florent.giraudet@metarresters.com.

Screenshot I3CM LLS – Lightning parameters



Due Diligence as prerequisite

Many utilities and system operators are often confronted with difficulties in analyzing the lightning performance of their lines but especially in selecting effective and affordable methods to reduce outages.

Very often, the choice of LSAs comes as a last resort because they are considered (wrongly) as too expensive and not reliable enough.

But let us start from the beginning: utilities and system operators normally invest in LSA to reduce the lightning outages which are causing severe financial consequences:

- Financial Damages
- Penalties from clients
- Costs of Momentary Outages
- Grid instability / Continuity of Service
- Intensive use of circuit breaker

The first challenge is to identify the critical line sections and start a due diligence process:

- Identification of lightning induced outages vs. others outages
- Investigation on Ground Flash Density (GFD) and Keraunic level
- Verification of insulation coordination study
- On-site measurement of tower footing resistance
- Inspection of shield wires/OHGW

A decision matrix should help them evaluate the situation and prioritize a list of options to mitigate lightning outages with cost-effective solutions.

This process is NOT easy!

Many biases come into play in the process because data are missing, information is wrong, or because long-held beliefs persist.

Working with real-world data

Lightning detection techniques have been developing and improving in performance in recent years. Modern hardware/software solutions like I3CM LLS can help users record and analyze all lightning activities in the area of interest.

In the screenshot above, a typical 1km buffer has been chosen along the line of interest. Primary information is then extracted for further study:

- Ground Flash Density or Keraunic Level
- Cumulative Stroke Distribution
  - o Median of the stroke amplitude
  - o Logarithmic standard deviation

Having taken care to carry out appropriate field inspections and measurements, it is appropriate to report the grounding conditions that are essential for effective system studies:

- Soil resistivity
- Towers Footing Resistances (TFR)

Simulate and define your target

A simulation software like Sigma SLP can help the users to optimize their investment by running a computation of lightning performance.

Sigma SLP allows the modeling of your transmission line to analyze the effect of lightning strokes on its performance. Simulation can be made on systems without and with LSA. Sigma SLP includes a special feature to run those simulations on a complete line (various TFR and line spans) including an automatic LSA placement. It helps the users minimize their budget for a maximum improvement.

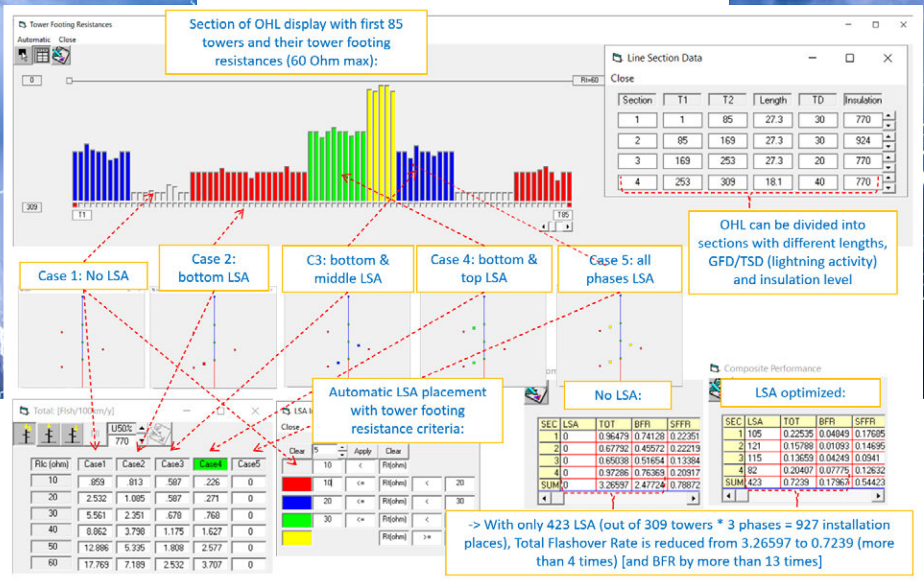
The customized stroke distribution model can be used based on real-world data instead of using conservative (and often excessive) CIGRE models which vary depending on the countries.

Sigma SLP has been first commercialized in the early 2000's. It results from different research works by Prof. Dr. Salih Sadovic in collaboration with international experts.

Utilities and system operators normally invest in LSA to reduce the lightning outages which are causing severe financial consequences.

Photo: Shutterstock

Screenshot Sigma SLP – Composite Performance and automatic LSA placement



The software continues to be supported by Sadovic Consultant. The latest update of Sigma SLP is version 3.1 (2022) that includes the possibility to define the failure rate probability based on specific stroke distribution models.

Users can then easily define their budget (number of LSA) to reach a specific target (performance – outages / 100km / year). Experience often shows that a study of this type can achieve very significant levels of improvement without the need to completely equip a line with LSA. This is a thorough and scientific approach.

The example below shows the following results for a 170kV shielded double circuit line:

- 89.2% improvement (outages reduction) by protecting only 4 phases
- 80.1% improvement (outages reduction) by protection only 3 phases and results in 100% improvement for double circuit outages.

True Digitalization of the Monitoring

Monitoring is a "question" that often comes up, but it is also a concern that is often expressed by utilities and system operators. LSA is often seen as an asset that can fail and must be monitored. When properly designed, dimensioned, manufactured and installed, LSAs should not fail and their reported failures should remain low. When a failure occurs on one LSA, it does not jeopardize the system because other LSAs play their role along the line. Therefore, a preventive maintenance known as condition assessment, which could be costly and complex, should not be justified on LSA.

Nevertheless, monitoring solutions might be required to be effective in maintenance to be able to detect failure and plan the replacement.

Today there are proven technologies which can tackle the challenging process of line monitoring and failure detection:

- Lightning Location System (LLS)
- Double Ended Traveling Wave (TW)
- Synchronization GNSS timestamp
- Weather data analysis
- Online-based software application with dedicated functions

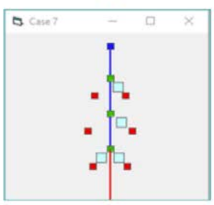
I3CM LLS includes all those technologies. It is a comfortable real-time online monitoring tool intended to facilitate the identification, the categorization and the location of line faults. It goes much further than LSA failure detection. Here are some key features:

- It helps utilities and system operators categorize faults and provide real-time notifications. It supports decisions and helps with prioritization.

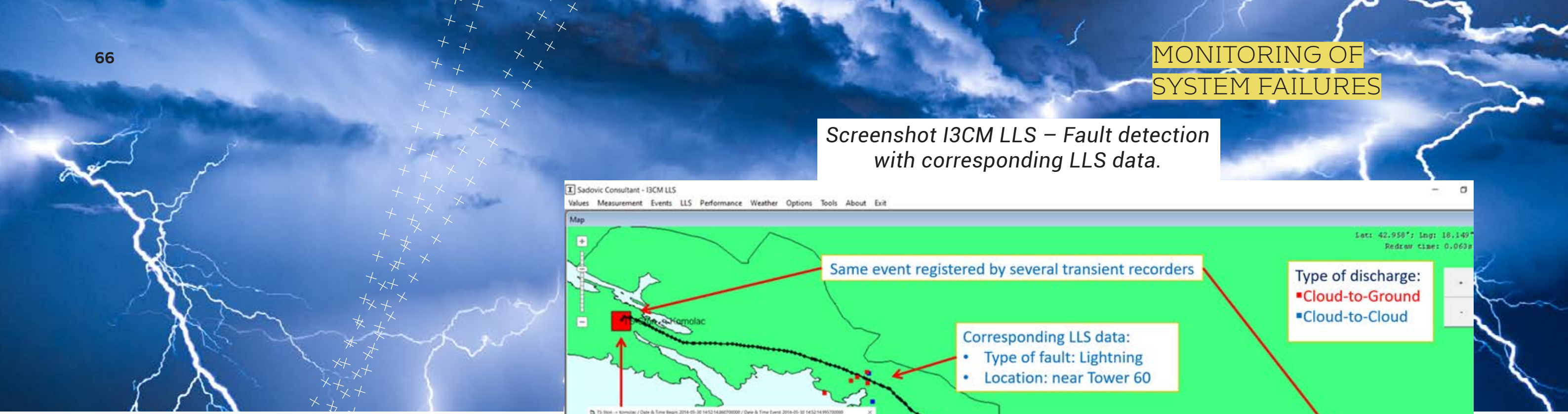
Sigma SLP composite performance study on 170kV system in Turkey – INMR 2022, ADM

Case	LSA Location	Remarks	LSA Qty	FO-rate	Protection effect
1	No	Maximum flashover rates since all phases are unprotected	0	6,84	-
2	L1	LSA on lower phase	35	3,81	44,3 %
3	L1, L4	LSA on both lower phases	70	3,77	44,8 %
4	L1, L4, L2	LSA on both lower phases and one mid phase	105	3,29	51,9 %
5	L1, L2, L3	LSA on all phases of one system	105	1,36	80,1 %
6	All	LSA on all phases	210	0,88	87,1 %
7	L1, L2, L3, L6	LSA on all phases of one system and lower phase of circuit two	**168**	**0.74**	**89,2 %**

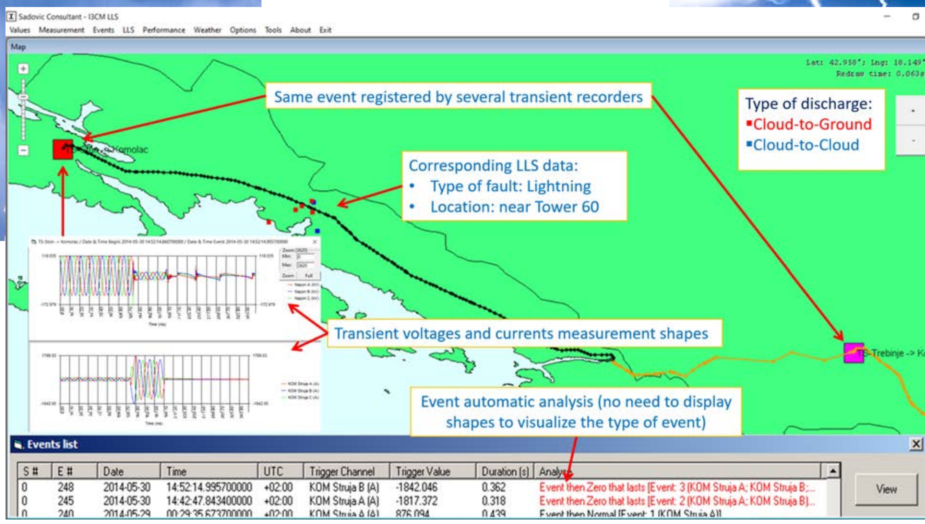
Case 7, see picture:



A simulation software like Sigma SLP can help the users to optimize their investment by running a computation of lightning performance.



Screenshot I3CM LLS – Fault detection with corresponding LLS data.



- Lightning outages can be detected and localized with high accuracy (~60 meters) and their types can be differentiated (Backflashover/ Shielding failure). Weather data providers are queried if LLS data do not match.
- Suspicious faults can be localized precisely and crews can be sent to the exact location for line inspection.
- Digital twin of the line in I3CM LLS can be customized to provide specific features such as LSA failure detection.

Overview of EGLA failures in Japan over 20 years operation

	Type (a) EGLA 1st generation	Type (b) EGLA 2st generation	Type (c) Current Limiting Gaps (CLG)
Approx. Quantity	90,000	160,000	115,900
Overload/Failure	10	36	9
Bird deterioration	0	19	0

Japan — an example to follow in terms of reliability

As per CRIEPI report from 2009, almost 365,900 units are installed in Japan. About 120,000 units are Current Limiting Gaps (CLG), which is a non-metal oxide technology. Therefore, we can estimate about **250,000 EGLA units in operation in Japan since the 1980's**.

Dedicated monitoring of EGLA units does not apply in Japan. Regular inspections are performed on transmission towers, insulators and therefore on EGLA in the meantime. Japanese utilities and system operators are able to localize a fault when a lightning induced outage is detected.

Over 20 years, the total number of overload/failures reported on a total of 365,900 units is 55 units! This is an extraordinary figure that should make you think about the EGLA technology and its reliability in improving the lightning performance on transmission lines compared to biases and misconception.

If we look at the modern EGLA type (compact) made of light-weight polymer housings and optimized ZnO blocks sizes, only 36 failures have been found for 160,000 units installed across the country for a period of 10 years.

Failure rate EGLA Compact = 0.0225 failure / 1000 units / year

In view of the statistical information on failures, there are countermeasures to easily reach low failures rates close to zero by adapting the charge transfer capability of SVU and improve the tightening system of the EGLA sets (better design/ extensive vibration tests).

Conclusion

LSA is still an underrated method for effective lightning performance improvement.

Biases and misconceptions prevent putting LSA in the spotlight.

EGLA experience feedback shows extremely high reliability.

Modern monitoring solutions can help system operators to simulate lightning performance with real word data.

Simulations tools, such as Sigma SLP, can be very effective to optimize investments.

The behavior of lightning is predictable. And so must be the expected performance improvement.

The performance remains stable over time, as opposed to other methods, such as improving grounding conditions. Individual LSA monitoring is not justified economically and remains complex today.

Dedicated real-time monitoring solutions, such as I3CM LLS, have been developed to offer comfortable LSA failure detection among others features, such as fault localization and categorization.

Over 20 years, the total number of overload/failures reported in Japan on a total of 365,900 units is 55 units!

This is an extraordinary figure that should make you think about the EGLA technology and its reliability in improving the lightning performance on transmission lines compared to biases and misconception.

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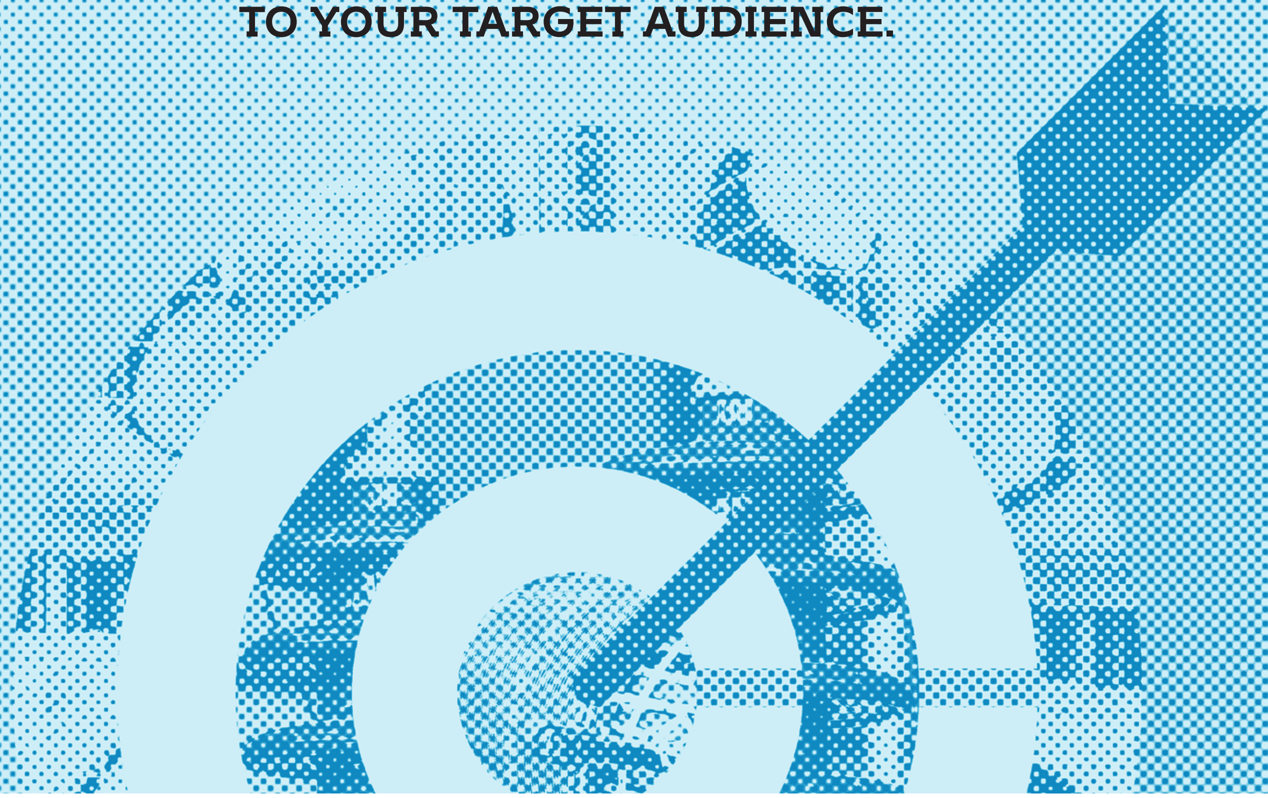

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Julie Rotchell

***Julie Rotchell** is leading Transformer Service operations for Hitachi Energy in the UK, with nearly 4 decades of experience in Power Engineering. She has held various roles in the areas of Engineering, Tendering, Project Management, as well as the role of an operations manager. As the Transformer Service Manager, she leads a team that supports the asset management and maintenance of the transformers they've designed, manufactured, and installed for various applications, including those from other manufacturers.*

She targets the development of her team to support the growth in new and expanding areas, one of which is on offshore renewables. She provides lifecycle management, monitoring, service, and maintenance support to extend the life expectancy of the equipment.

Throughout her working life, Julie has contributed to securing power systems around the world, particularly on improving the reliability and sustainability of the UK power grid. She supports and mentors others in the industry, providing insight into the opportunities available in engineering, applicable to both women and men. Julie has been recognized for her achievements and was even invited to be a part of the female Science, Technology, Engineering, and Mathematics (STEM) exhibition, held at the Science Museum in London.

She is proud to be part of a team that creates an excellent work environment. They emphasize the positive impact their work has on the industry and environment, by improving the electricity system across the UK, and the rest of the world.

WiPS Women in Power Systems

Electromagnetic Properties of 0.18 mm Thin-gauge Grain-oriented Silicon Steel and Its Application in Transformer Cores

The electromagnetic properties of grain-oriented silicon steel significantly affect the service performance of transformer cores. The product (18PTD075) of 0.18 mm thin-gauge grain-oriented silicon steel shows a remarkable thickness uniformity and an excellent electromagnetic property. The iron loss ($P_{1.7/50}$) can be reduced to 0.73 W/kg, achieving a high grade. Thus, the low iron loss can improve the comprehensive performance and energy efficiency level of transformers, save energy, and reduce carbon emissions.

Key words:
Grain-oriented silicon steel; Thin-gauge; Transformer core; Iron loss.

by **Qingsong Zhang** R&D engineer
at Wuxi Putian Iron Core Co., Ltd.
PTTX

Grain-oriented silicon steel is a kind of functional soft magnetic material that is used as the raw material for transformer cores manufacturing. The service performance of transformer cores mainly depends on the electromagnetic properties of grain-oriented silicon steel. Therefore, it is crucial to improve the electromagnetic properties. Thinning the thickness can significantly reduce the iron loss [1]. Therefore, the research and development (R&D) of thin-gauge grain-oriented silicon steel is the trend of the industry [2]. At present, thin-gauge and ultra-thin-gauge product is mainly applied in the transformer under a medium or a high frequency. However, there is less research on the application of thin-gauge product in the large-power transformer under a low frequency. Therefore, this report focuses on demonstrating the electromagnetic properties of the 0.18 mm thin-gauge grain-oriented silicon steel (18PTD075, Figure 1) and its application in the large-power transformer core under a frequency of 50 Hz.

Figure 1. Product of 0.18 mm thin-gauge grain-oriented silicon steel (18PTD075).

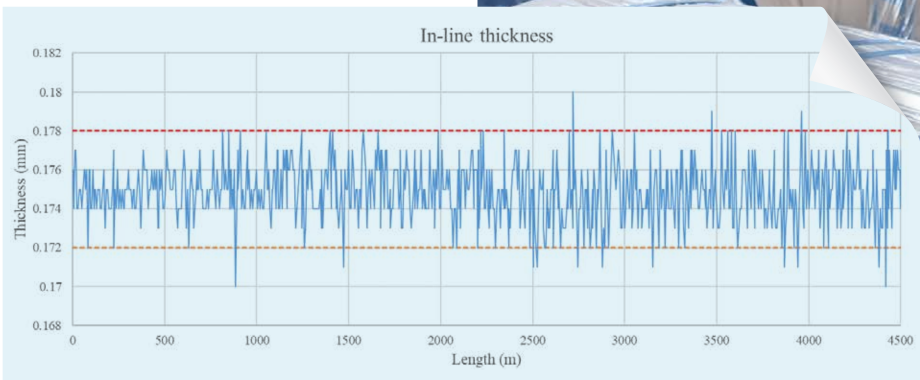


Figure 2. Results of in-line thickness tests.

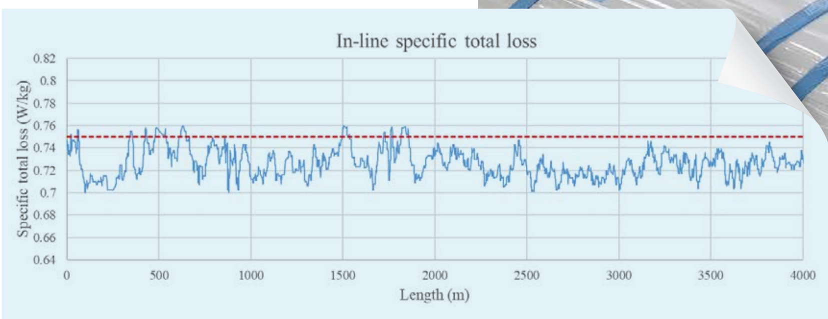


Figure 3. Results of in-line specific total loss tests.

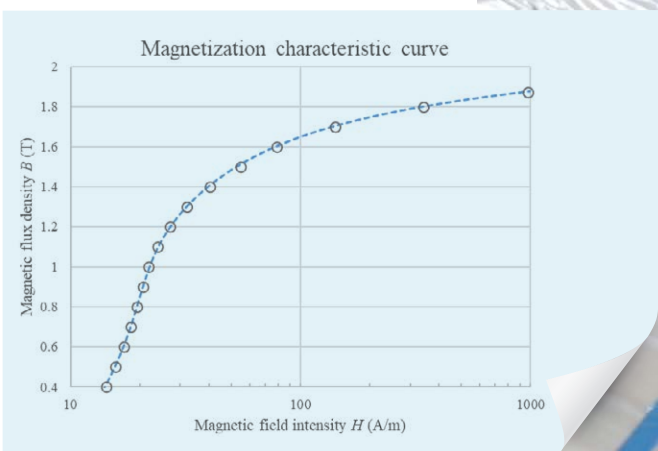
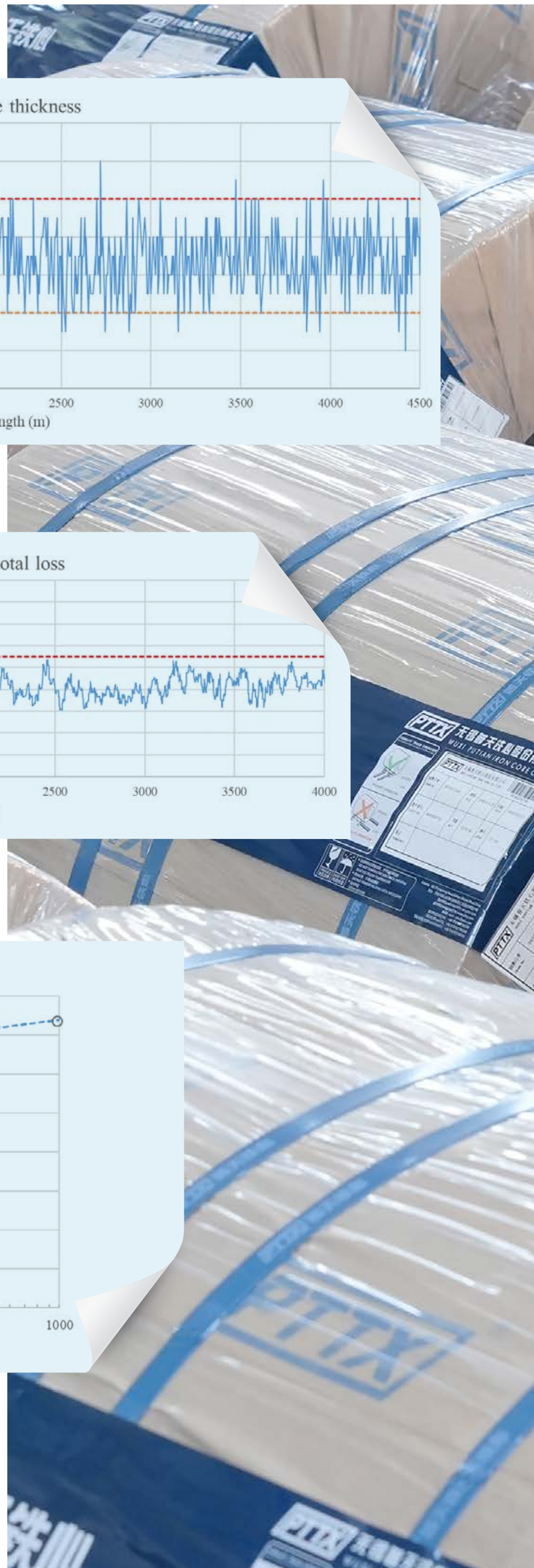
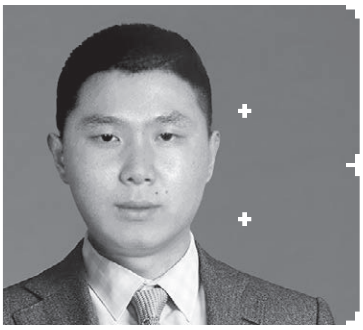


Figure 4. Magnetization characteristic curve of 0.18 mm thin-gauge grain-oriented silicon steel.

Thickness Uniformity

Precise full-process production control technology can ensure the thickness uniformity of the product of 0.18 mm thin-gauge grain-oriented silicon steel. The results of in-line thickness tests of the product are shown in Figure 2, with an average thickness of 0.175 ± 0.003 mm. The thickness fluctuations are small throughout the length, ensuring a superior surface quality of the product.





Qingsong Zhang obtained his Ph.D. degree in Materials Science and Engineering from China Southwest Jiaotong University in 2020. He visited the Spain National Centre for Metallurgical Research during 2019 as a joint training student. He previously worked at China Huazhong University of Science and Technology as a postdoctoral researcher, focusing on service performance and surface strengthening of metallic materials. Then, he joined Wuxi Putian Iron Core Co., Ltd. (PTTX) as a R&D engineer, working on thin-gauge and high-grade grain-oriented silicon steel. PTTX is a world-class power transformer core full process solution provider, with products including global high-end low-carbon electrical steel and materials, large ultra-high voltage electrical transmission and distribution equipment, and smart international logistics services.

Photo: Shutterstock, PTTX

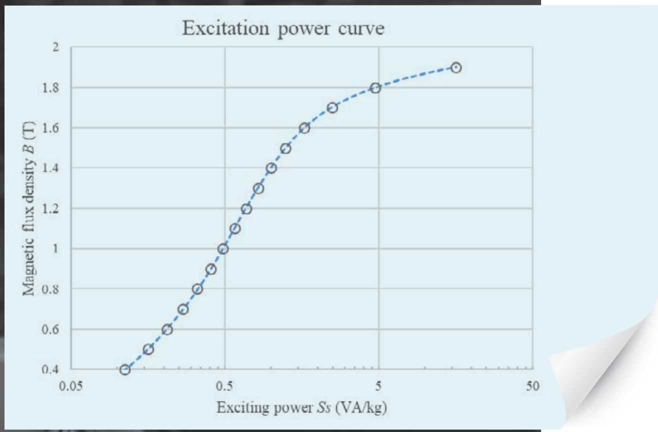


Figure 5. Excitation power curve of 0.18 mm thin-gauge grain-oriented silicon steel.

Figure 6. Magnetic domain morphology of 0.18 mm thin-gauge grain-oriented silicon steel.

The complex mechanism of core loss is related to the specific total loss, core structure, and manufacturing process.

Figure 7. Core loss tests of 50MVA type core at 50 Hz.

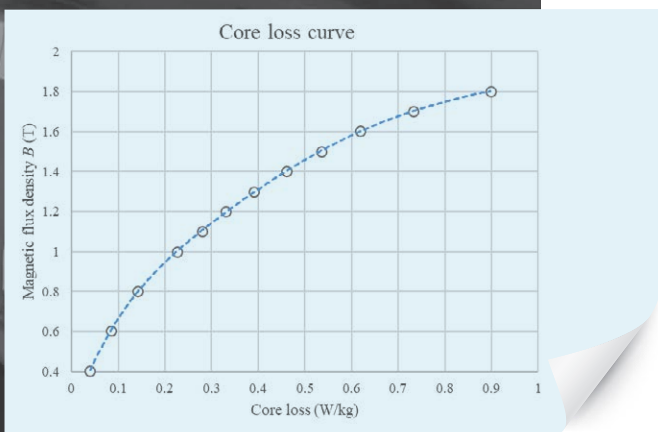


Figure 8. Iron loss curve of 0.18 mm thin-gauge grain-oriented silicon steel.

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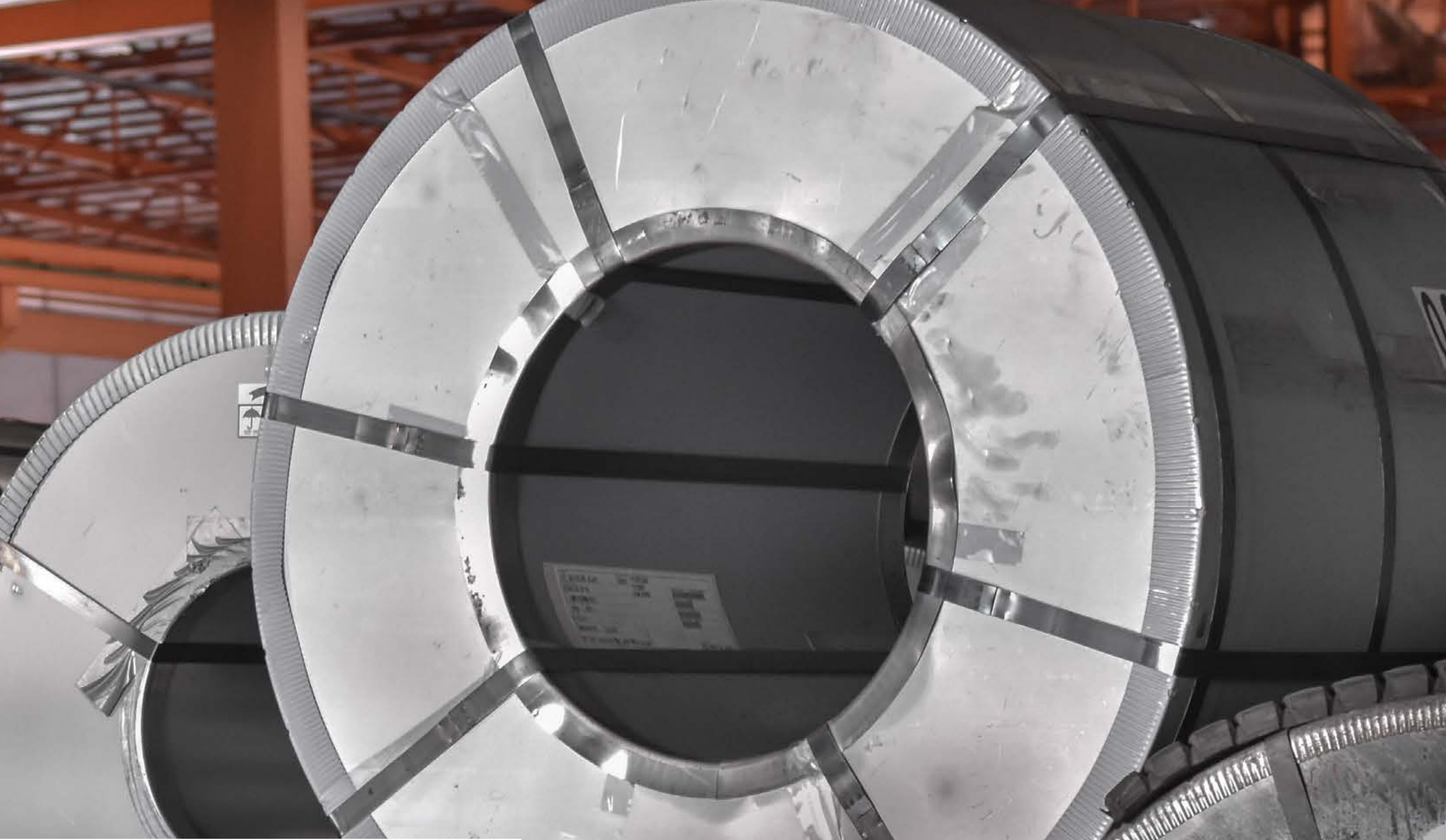
Specific Total Loss

Specific total loss is one of the most important electromagnetic properties of grain-oriented silicon steel and a major indicator of product performance. The specific total loss can be significantly reduced by laser scribing tech-nology [3]. As shown in Figure 3, the specific total loss ($P_{1.7/50}$) of the 0.18 mm thin-gauge grain-oriented silicon steel after laser scribing is less than 0.75 W/kg under a magnetic flux density of 1.7 T and a frequency of 50 Hz. The value achieves a high grade. The low specific total loss means that the 0.18 mm thin-gauge product will have a large market potential and advantage.

Magnetization Characteristic Curve

The magnetization characteristic curve reflects the magnetic flux density (*B*) as a function of magnetic field intensity (*H*), which corresponds to the magnetizability of grain-oriented silicon steel. Figure 4 shows the magnetization characteristic curve of the 0.18 mm thin-gauge grain-oriented silicon steel under direct-current conditions. When the magnetic flux density is 1.7 T, the required magnetic field intensity is 139 A/m.



Excitation Power Curve

The excitation power (*Ss*) vs. the magnetic flux density (*B*) can reflect the magnetizing current of the transformer core under various excitation conditions. It is worth noting that the excitation power should be considered during transformer design. Figure 5 shows the excitation power curve of the 0.18 mm thin-gauge grain-oriented silicon steel under a frequency of 50 Hz. The required excitation power is 2.48 VA/kg under the magnetic flux density of 1.7 T.

Magnetic Domain Morphology

The magnetic domain morphology of grain-oriented silicon steel is closely related to the specific total loss and the magnetostriction [4]. A clear and regular domain was observed in the 0.18 mm thin-gauge grain-oriented silicon steel after laser scribing, as shown in Figure 6. Besides, the direction of the magnetic domain is almost parallel to the rolling direction and the spacing of the domains is also small. Therefore, there is good agreement between the regular magnetic domain morphology and the low specific total loss ($P_{1.7/50}$ <0.75 W/kg).

Transformer Core Loss

The transformer core acts as the application product of grain-oriented silicon steel, and its service performance can reflect the electromagnetic properties of grain-oriented silicon steel. The core loss is the ineffective electrical energy consumed by the core when it is magnetized under an alternating magnetic field of ≥50 Hz. The larger the core loss, the greater the electrical energy lost by the transformer. In addition, the energy efficiency level of the transformer is mainly determined by the core loss.

Figure 7 shows a 50MVA type core manufactured by the 0.18 mm thin-gauge grain-oriented silicon steel and its core loss was tested at a frequency of 50 Hz. Then, the iron loss was calculated by equation:

$$P_0 = \frac{P_T}{(k \cdot m)}$$

where P_0 is the iron loss with a unit of W/kg, P_T is the core loss with a unit of W, k is the technological coefficient of core, m is the core weight with a unit of kg. The relationship curve of the iron loss vs. the magnetic flux density was obtained, as shown in Figure 8. Specifically, when the magnetic flux density is 1.7 T, the iron loss is 0.73 W/kg, reaching a high grade.

Generally, the core loss (P_T) consists of hysteresis loss (P_h), eddy current loss (P_e), and anomalous loss (P_a) three parts. It is worth noting that the complex mechanism of core loss is related to the specific total loss, core structure, and manufacturing process [5]. Especially for the thin-gauge and high-grade grain-oriented silicon steel, the process of manufacture and the mechanism of core loss are more complex. Therefore, the electromagnetic properties of grain-oriented silicon steel should be further optimized to effectively reduce the core loss.

According to the above analysis, the iron loss ($P_{1.7/50}$) of the 0.18 mm thin-gauge grain-oriented silicon steel reaches a high-grade level with the value less than 0.75 W/kg. Therefore, the thickness thinning for the reduction of iron loss has a positive effect and an important significance.

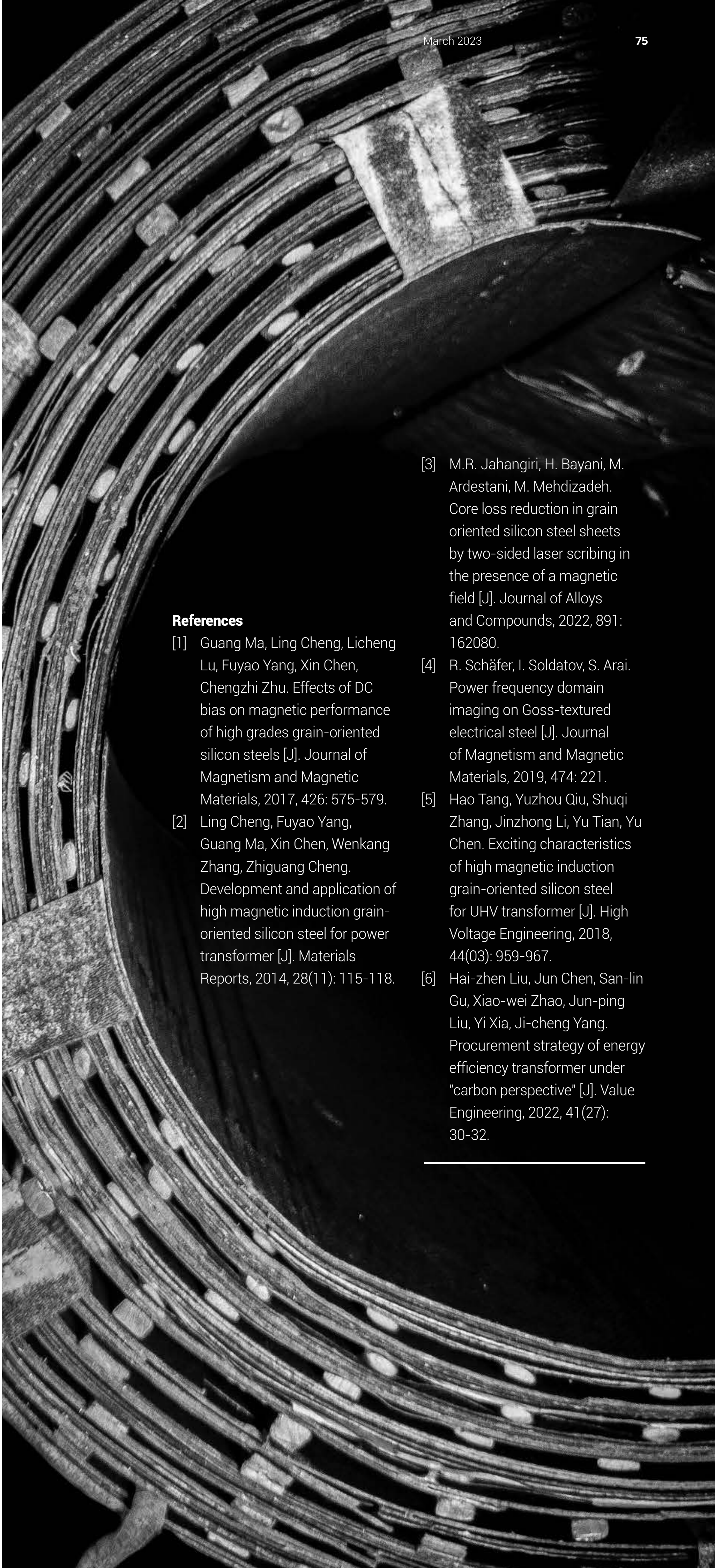
Photo: Shutterstock

Prospect of Transformer Energy-saving

With the rapid development of global technology, low carbon environmental protection and sustainable development have become the social focus. Therefore, it is crucial to save energy and reduce emission. The development of thin-gauge and high-grade grain-oriented silicon steel products through thickness thinning can reduce the iron loss and improve the energy efficiency level of transformer, thus saving energy [2]. It has been proved that the high-efficient transformer made of high-grade grain-oriented silicon steel can reduce the carbon emissions by 13~18% under 50% load [6]. The product of 0.18 mm thin-gauge grain-oriented silicon steel shows a remarkable thickness uniformity, ensuring the safety of the core laminations. The low iron loss decreases the temperature rise of the transformer during service, thus significantly improving the operation stability. In addition, the thin-gauge product also reduces magnetostriction and transformer noise. Therefore, the application of 0.18 mm thin-gauge product in cores can improve the comprehensive performance and energy efficiency level of transformers, thus achieving energy saving and emission reduction.

Conclusion

The mentioned 0.18 mm thin-gauge grain-oriented silicon steel shows a remarkable thickness uniformity, ensuring the surface quality of the product. After laser scribing, the product shows a homogeneous magnetic domain morphology, inducing an excellent electromagnetic property. Such excellent properties can promote the structural optimization of transformer cores, thus reducing core loss. In addition, the iron loss (P1.7/50) of the 0.18 mm thin-gauge grain-oriented silicon steel applied to a large-power transformer core is 0.73 W/kg, reaching a high grade. The application of this product in cores can effectively improve the comprehensive performance and energy efficiency level of transformers, thus saving energy and reducing carbon emissions.



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Saving the Day: On-line DGA Monitoring Case Studies

by **Emilio Morales**

When I first met Emilio Morales, it was at a Comet Conference workshop and he was presenting on Transformer Maintenance and Reliability. Comet, sponsored by Qualitrol, was always one of my favorite industry conferences. I was very impressed with his understanding and the depth of his wisdom on the topic. It was also the beginning of a friendship that reminds me why I love this industry so much; professionals like Emilio are graciously willing to share their knowledge, understanding and insight on things that advance the cause of transformer safety and reliability.

Now more than ever we need people like Emilio to share their decades of experience as we deal with so much change in the power industry Dealing with the addition of so many new "green generation" projects being added to an aging grid, making interoperability and interconnection that much more important and challenging. Thank you Emilio, for your willingness to share with our community as we deal with these challenges. Enjoy everyone!

Alan Ross, Technical Director
and Managing Editor, APC Media

Emilio Morales attended Nuevo Leon State University in Mexico, receiving his bachelor's degree in Electromechanical Engineering in 1980. He has over 30 years of experience in power transformer design which includes transformers up to 500 MVA and 500 kV, furnace and rectifier transformers and reactors. He is member of the IEEE/PES Transformer Committee, IEC and CIGRE. He previously worked with GE-Prolec, Ohio Transformer, Sunbelt Transformer and Efacec. He joined Qualitrol in June 2012 as a Technical Application Specialist in transformer applications. His focus is to support solutions in comprehensive monitoring for transformer applications.

On-line DGA have the unique ability to continuously trend transformer fault gases and correlate them with other key parameters such as transformer load, oil and ambient temperatures, as well as customer specified sensor inputs. This capability enables users to relate gassing to external events, a key to determine the existence or type of a fault. A study has also shown that some on-line DGA tools offer better accuracy and repeatability than laboratory DGA. Specifically, those with on-board automated calibration verification that ensures performance to specification throughout the entire operating life of the monitor. This can improve the transformer asset manager's decision timeliness and confidence when incipient faults are detected.

The ability to automatically populate traditional DGA diagnostic tools with on-line DGA data offers users of on-line DGA monitors unprecedented insight into the nature and identification of developing faults. The tools are typically ratio-based, and the on-line data set enables trending of fault gas ratios over time rather than the traditional static snapshots. Diagnostic outcomes can now be determined quickly and with more certainty than in the past. The use of on-line DGA monitoring has allowed the detection of developing faults in transformers in a timely manner. On-line DGA monitoring has produced multiple case studies that document the development of critical faults, which could cause catastrophic transformer failure if left undetected, in timeframes from a few days to a few weeks, where there was a low probability of capturing these rapidly developing fault conditions with a laboratory or portable-based transformer DGA testing program. This article presents some of those cases.

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The use of on-line DGA monitoring has allowed the detection of developing faults in transformers in a timely manner.

Case 1: It's important to measure Oxygen in DGA

BACKGROUND

An 8 gas monitor is monitoring an old (30+ years) 3-phase 230kV shell-form nitrogen (N_2) blanketed GSU. At midday on Nov 16th, the monitor alarmed for increasing concentration of Oxygen (O_2), which had been stable at 130ppm for an extended period. Over the course of the following 3 days O_2 concentration continued to increase, peaking at 2,150ppm before gradually declining back to a stable 200ppm.

Reviewing the data around the time of the sudden increase in O_2 concentrations using proprietary data management system, no fault is detected using any of the established diagnostic methods.

OUTCOME

The sudden O_2 increase, with no associated change in any other gas indicated that the O_2 originated from the atmosphere. The supporting vendor experts suggested that the transformer may have had an atmospheric air injection and requested the operator to investigate. Upon a physical examination of the transformer, it was noticed that there was a leaky manhole cover gasket and that the pressure of the nitrogen blanket was close to atmosphere. It was determined that a partial vacuum occurred in the transformer during a cool down that resulted in atmospheric air being sucked into the transformer.

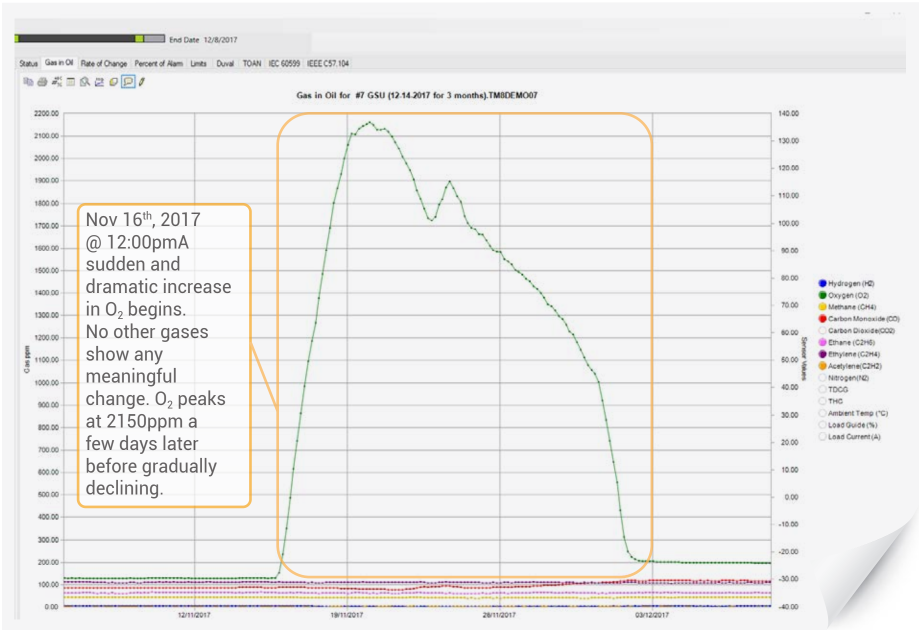
O_2 can facilitate oxidation in the transformer and thus shorten the life of the paper. However, the big concern with a transformer sucking atmospheric air in is that inevitably, it also brings moisture into the transformer.

While none of the modern diagnosis methods explained this sudden increase in O_2 it was possible to detect this incident with online DGA, deduce the cause and implement corrective action. If O_2 was not monitored this process could have occurred many times over without being detected, drawing a lot of moisture into the transformer.

N_2 pressure does not prevent entrance of water – only a good gasket seal does.

NOTE

While this incident occurred on a N_2 blanketed transformer the same vacuum conditions can occur within an operational constant oil preservation system (COPS) transformer. This can occur during cool-down if breather piping to the atmospheric is too narrow or is restricted and air cannot enter fast enough to avoid a vacuum in the main tank. A vacuum can then suck air past a gasket that does not show an oil leak. Another obscure fact is that degassed oil is effectively a vacuum to the atmosphere and in a sealed system can create a vacuum in the gas phase. It's important to give the oil time to reach equilibrium with the N_2 blanket to avoid this situation.



> **N_2 pressure does not prevent entrance of water – only a good gasket seal does.**

Case 2: Hour by hour changes catch a developing fault

BACKGROUND

Once again an 8-gas monitor is used on a single-phase 336 MVA, 500/230 kV autotransformer. The transformer was placed into service in 1979. This transformer is known to have gassed in the past and base levels of hydrocarbons are as high as 100ppm. At 1:00am on June 23rd, the monitor alarmed for Rate of Change increases in concentration of Ethylene(C_2H_6) and Methane (CH_4) both of which had been elevated but stable for several months. Over the next 5 days the operator kept the transformer under load for operational purposes and carefully monitored all gases. When Acetylene (C_2H_2) climbed to an actionable level (10ppm) the transformer was taken off load.

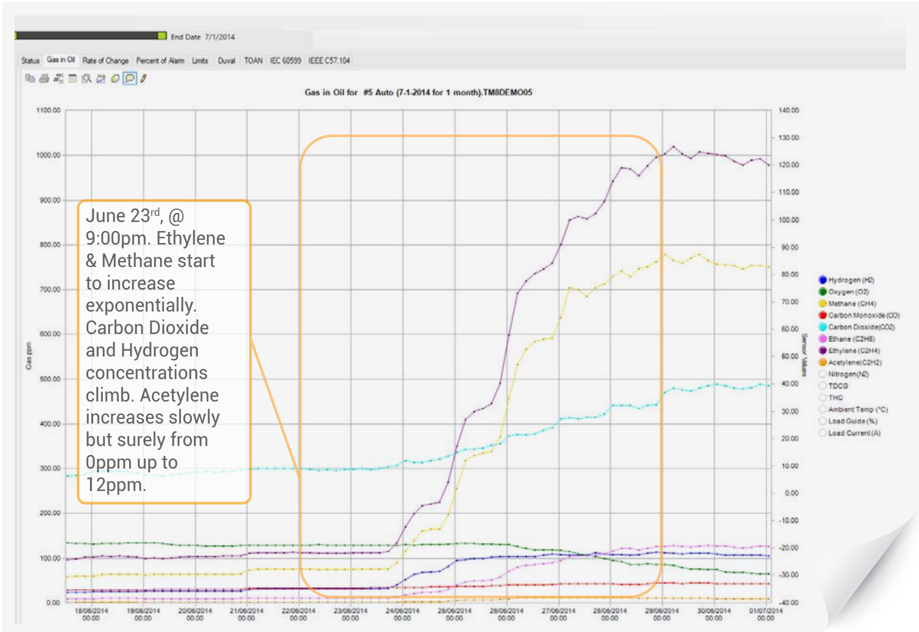
Reviewing the load data around the time of the increasing gas generation rate it was observed that the transformer had been heavily loaded at the time and that increasing load correlated well with increasing gas production. Reviewing the DGA data, Duval Triangle 1 indicated High temperature overheating while Triangle 5 indicated Medium to High temperature hot spots.

However, this diagnosis would have been the same before the exponential increase in gases occurred as can also be seen from the Duval diagnosis. The key to managing this situation was that the user could see the gas levels increasing dramatically over a very short period of time and knew when to take the transformer offline before runaway conditions developed. This is something that periodic offline testing would not provide for.

OUTCOME

The transformer was taken to a repair shop where maintenance personnel found carbon deposits in damaged insulation that is used to isolate the core and coil assembly form the tank. Repairs were undertaken and the transformer was put back into service. Despite the repairs the transformer continues to gas at a slow rate and is scheduled for replacement over the next few years.

In this case the transformer was known to have gassing issues but was needed for operational purposes. Despite its known issues it was used safely because its gassing could be monitored on an hour-by-hour basis. This transformer will continue to be available as a spare together with online DGA until it can be replaced.



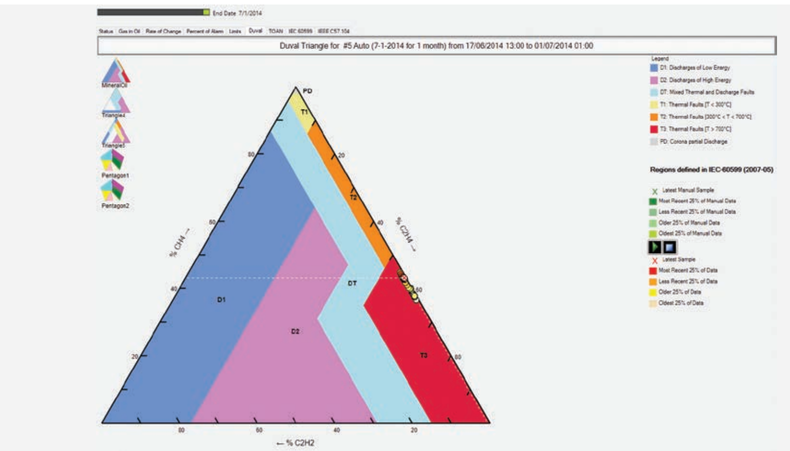


Figure 1: TRIANGLE 1. Thermal Fault >700°C

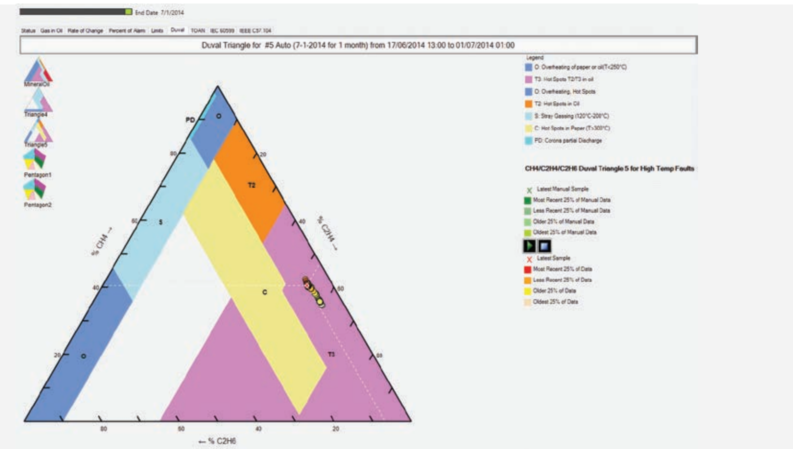


Figure 2: TRIANGLE 5 Hot Spots T2/T3 in oil

Case 3: Runaway fault detected by 8-gas monitor resulting in action to prevent a catastrophic failure

BACKGROUND

An 8-gas DGA monitor was being used to monitor a 3-phase, 1100 MVA, 345 kV GSU transformer. While gas concentration for all gases were relatively high and stable there was a sudden exponential increase on Aug 28th, 2016, at midday. While not recorded in the chart the transformer load was reduced by 50% after 48 hours of gassing and was reduced to zero load 8 hours later when it became obvious that the fault was not manageable by managing load.

Reviewing the DGA data resulted in the following indications at the point in time when the transformer load was reduced to Zero.

All diagnosis systems point to a thermal fault >300°C with some suggestion that there was paper involved. While the ratios of gases before this gas generation event occurred would have indicated the same diagnosis it was the rapid change in gas concentration, as alarmed by the Rate of Change alarming function in the monitor that drove the reduction in load and eventual full shedding of load.

OUTCOME

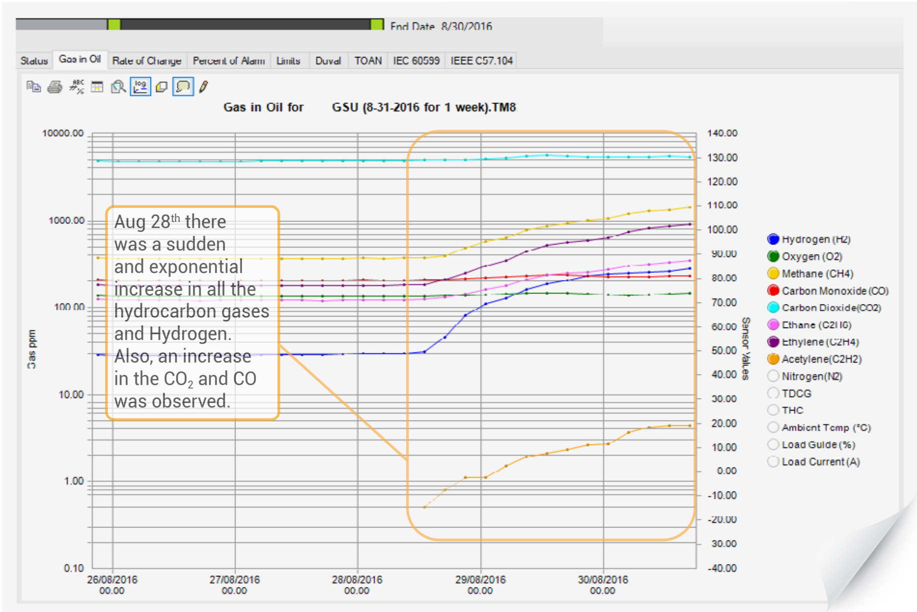
Upon physical inspection it was revealed that localized burning of

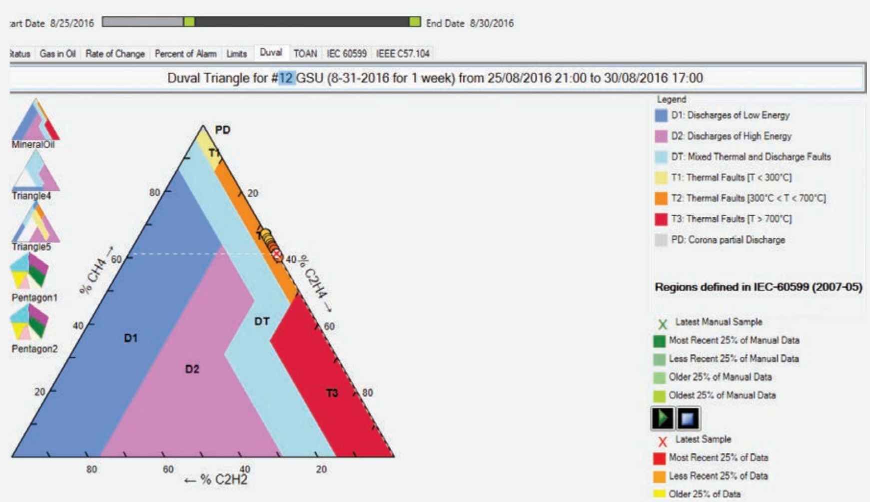
Diagnostic System	Result
Duval Tringle 1	Thermal Faults [300°C < T < 700°C]
Duval Triangle 5	Border of Hot Spots in Paper and Hot Spots in oil
Duval Pentagon 1	Thermal Faults [300°C < T < 700°C]
Duval Pentagon 2	Thermal Fault with carbonisation
TOAN	Overheated Oil: Immediate attention required, consider removal from service. (See Figure 2)
IEC 60599	Condition 2: Thermal Faults [300°C < T < 700°C]
Doernenburg Ratios	Thermal Faults [300°C < T < 700°C]
IEEE C57.104-2008	Condition 4. Immediate action required

paper had occurred. With paper stripped back from the crimped ends of the LV connection there was evidence of hot metal damage. Thus, it was concluded this was the site of the gas production.

The conclusion in this case was that the root cause was a combination of high eddy losses in the crimps, overheating because of over-insulation of the LV crimped connections and poor oil circulation in the crimped bundle areas. Remedial work was undertaken, and the transformer was subsequently put back into service.

In this case the transformer was known to have had historic gassing issues but was stable. After a period under full load the transformer suddenly started to produce large increase in gases which was notified to the user by a "rate of change" alarm on the monitor. Only Online DGA would provide this level of resolution in data, and it was this detailed insight that allowed the transformer operator to take the transformer offline before a catastrophic even occurred.





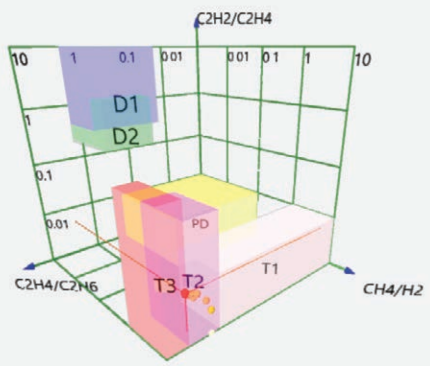


Figure 3: TRIANGLE 1. Thermal Fault 300°C – 700°C

Figure 4: Rodgers Ratio indicating condition T3: Thermal Fault 300°C – 700°C

On-line DGA undoubtedly saves another transformer from catastrophic failure.

Photo: Qualitrol

Case 4: Gradual increase in gases detect a transformer design flaw

BACKGROUND

An 8-gas monitor was monitoring a three-phase 700 MVA, 400kV GSU transformer at a power plant in North America. This online DGA monitor was installed when the operator noticed year-over-year DGA lab data indicating increased levels of hot metal gases and a sustained growth in Carbon Monoxide. Unsure as to the nature of where and when these gases were being generated, a monitor was employed to provide hour by hour tracking of gas generation (Figure 5). Reviewing the DGA data with vendor software resulted in the following fault indications.

Table below represents Results of reviewing the DGA data on a range of common diagnostic systems. This is all performed automatically. All diagnosis systems pointed to a thermal fault >300°C with some suggestion that there was paper involved in the fault.

Diagnostic System	Result
Duval Tringle 1	Thermal Faults [300°C < T < 700°C]
Duval Triangle 5	Hot Spots in Paper >300oC
Duval Pentagon 1	Thermal Faults [300°C < T < 700°C]
Duval Pentagon 2	Thermal Fault with carbonisation
TOAN	Overheated Oil: Immediate attention required, consider removal from service. (See Figure 2)
IEC 60599	Condition 2: Thermal Faults [300°C < T < 700°C]
Doernenburg Ratios	Thermal Faults [300°C < T < 700°C]
IEEE C57.104-2008	Condition 4. Immediate action required

DGA lab data indicating increased levels of hot metal gases and a sustained growth in Carbon Monoxide.

OUTCOME

Physical inspection revealed evidence of significant overheating at the site of a brazed connection at the bottom end of the LV winding lead (Figure 6).

In addition to the discoloration of the metal associated with overheating (the source of the ethane (C_2H_6), methane (CH_4) and ethylene (C_2H_6)) there was also charred / burned paper which would have created CO and CO_2.

This transformer was repaired, together with appropriate design changes, the leads were retaped where the paper was significantly damaged and put back into service.

The four cases above show that On-line DGA provides the capabilities to track gradual increases in gases, facilitating predictive maintenance of an expensive and critical assets, and identify incremental changes in important gases in the presence of high accumulated PPMs of gases, which it is not possible with periodic lab DGA.

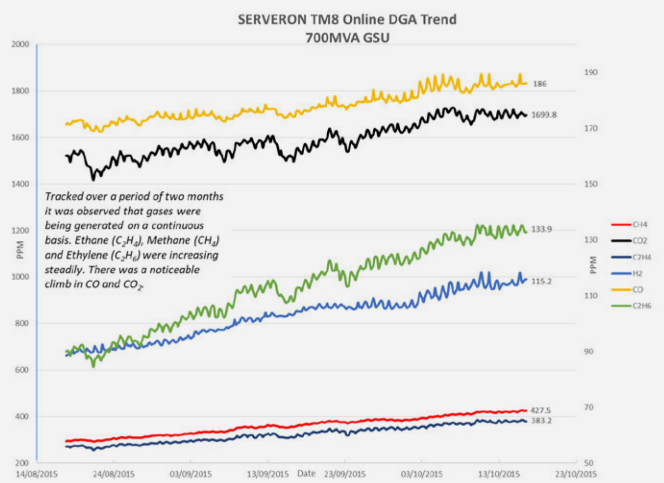


Figure 5. A gradual climb in 6 key gases was noted. There was no acetylene (C_2H_2), meaning this fault had not yet advanced to include any arching. The continuously increasing gas levels were a significant concern.

Figure 6: Overheated brazed connections at the bottom end of the LV winding lead.

Dates, times, and other details may have been changed to maintain the anonymity of the owner / operator in these case studies. All DGA data, timelines and technical specification are factually accurate.

Although multi-gas DGA monitors have become more reliable than they were 10 or 15 years ago, they are still complex machines that are installed outdoors in electric substations where they are subjected to all the elements weather forecasters have to offer.

Online Transformer Data Comes at a Price

In a data-driven world where transformer owners want to have as much data as possible from their transformers, they start by monitoring the top oil temperature, winding temperature, pressure relief device, liquid level, tank pressure, sudden pressure, and various load tap changer (LTC) data.

Leon White is Vice President of Transformer Sales and Business Development at H2scan. A 15-year industry veteran, White joined H2scan from Qualitrol and previously worked at General Electric. White began his career as a substation design engineer at Ameren, an electric utility. White has electrical engineering and MBA degrees from Southern Illinois University at Edwardsville and is a registered professional engineer (P.E).

When transformers fail without warning, they realize that more data is necessary. They then investigate single and multi-gas online dissolved gas analysis (DGA), partial discharge, bushing monitoring, acoustic vibration, etc. Then they build asset health centers and hire data scientists to manage the vast amount of data they didn't realize would be such a monumental task to manage.

There must be a better way.

Large utilities on the bleeding edge of technology have found that all of this data comes at a price. While many monitors do not interface directly with transformer fluids, the online DGA monitor must measure gases either directly in the fluid, or extract gases from the fluid for measurement after extraction.

Although multi-gas DGA monitors have become more reliable than they were 10 or 15 years ago, they are still complex machines that are installed outdoors in electric substations where they are subjected to all the elements weather forecasters have to offer.

by **Leon White** Vice President
Transformer Sales and Business Development
H2scan

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Utilities need affordable solutions that can be installed fleet-wide that can alert them to internal transformer faults prior to failure so potential failures can be managed during the regular workday rather than on overtime.

In addition, they must survive ground faults, corona, electro-magnetic flux, vibration, corrosive compounds in the oil, etc. Data scientists love data from multi-gas monitors because they get a better idea of the real-time health of the asset. Unfortunately, the reality is that most multi-gas monitors of any type are prone to some type of failure within 2-5 years after installation.

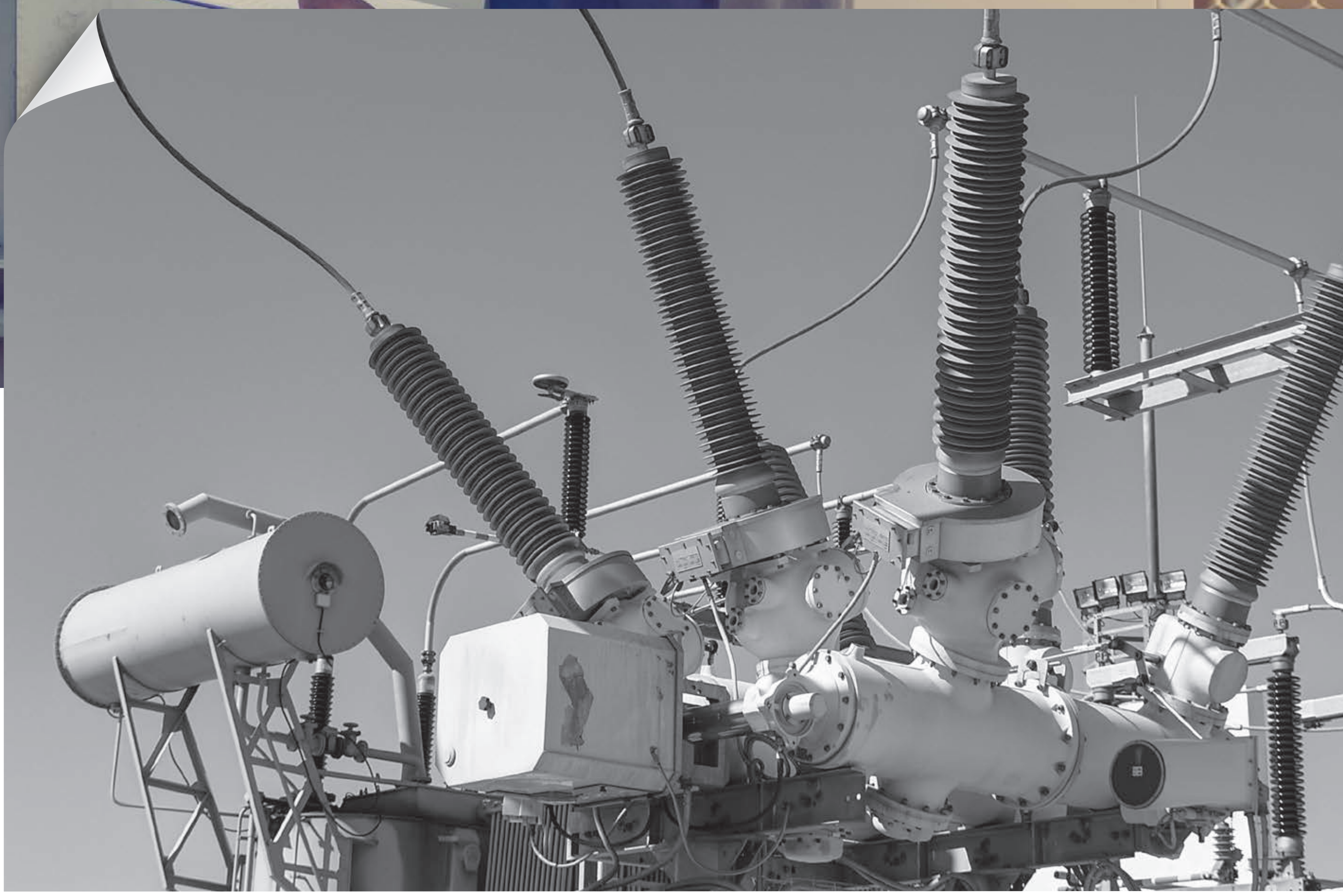
While a 5 year warranty sounds like a good plan, what happens after the warranty expires? Due to limited maintenance budgets, most utilities are unable to keep their multi-gas monitors running after the warranty expires. Therefore, after 10-20% of the transformer's life, the utility is back to relying on annual data from manual samples. Some utilities are now getting 10 year warranties on their monitors. While this extends the life of their monitors, does the cost of the monitor and warranty outweigh other options that could alert utilities to more transformer failures?

What Have Utilities Learned from Their Online Data?

Many utilities are frustrated because they spend more time installing, commissioning, and maintaining their multi-gas monitors than they spend actually fixing problems on their transformers. This means that they are starting to understand that using low-cost, reliable single-gas sensors that last 10+ years makes more sense than trying to equip every large transformer with a high-end monitoring solution.

Large monitoring systems may be justified for critical or sick transformers, but, today, most utilities spend too much time and effort getting their large monitoring systems installed, commissioned and maintained, when 90% of their fleet has no online monitoring. With an average transformer failure rate of roughly 1% annually, utilities need affordable solutions that can be installed fleet-wide that can alert them to internal transformer faults prior to failure so potential failures can be managed during the regular workday rather than on overtime.

In a world where people have less resources and more to get done every day, utilities need valuable, reliable and maintenance-free devices to alert them to problems with their transformers. It's time for utilities to take a step back and look at which data is most useful. They need to look at how they will get the most bang for their buck in the future.



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ADVANCED TRANSFORMER TESTING AND TECHNOLOGIES

From green steel in transformers to new ways of manufacturing transformers, and to the liquids we use for insulation, we are excited to bring you a combined April and May issue. With so much change taking place, it is exciting to see how even little changes will make a big difference in the long run.

We have had our issues, and still have, with supply chains for transformer components, but most manufacturers are addressing this issue in unique ways, not so much with revolutionary changes, but with evolutionary changes. While there are a good number of articles and interviews already committed, there is still time for you to add your voice. Contact me at alan.ross@apc.media to add your article or interview.

Alan Ross
Technical Director and Managing Editor, APC Media

COMING IN MAY ISSUE

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