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Monitoring & Diagnostics

How to Maximize Reliability

Interview with Michael Cunningham, COO at Camlin Group and Managing Director at Camlin Energy

Integrated Condition Monitoring: **Merging Data from Relays and Asset Monitors for a Fuller Evaluation**

Condition Monitoring Realities: Dealing with the Unexpected

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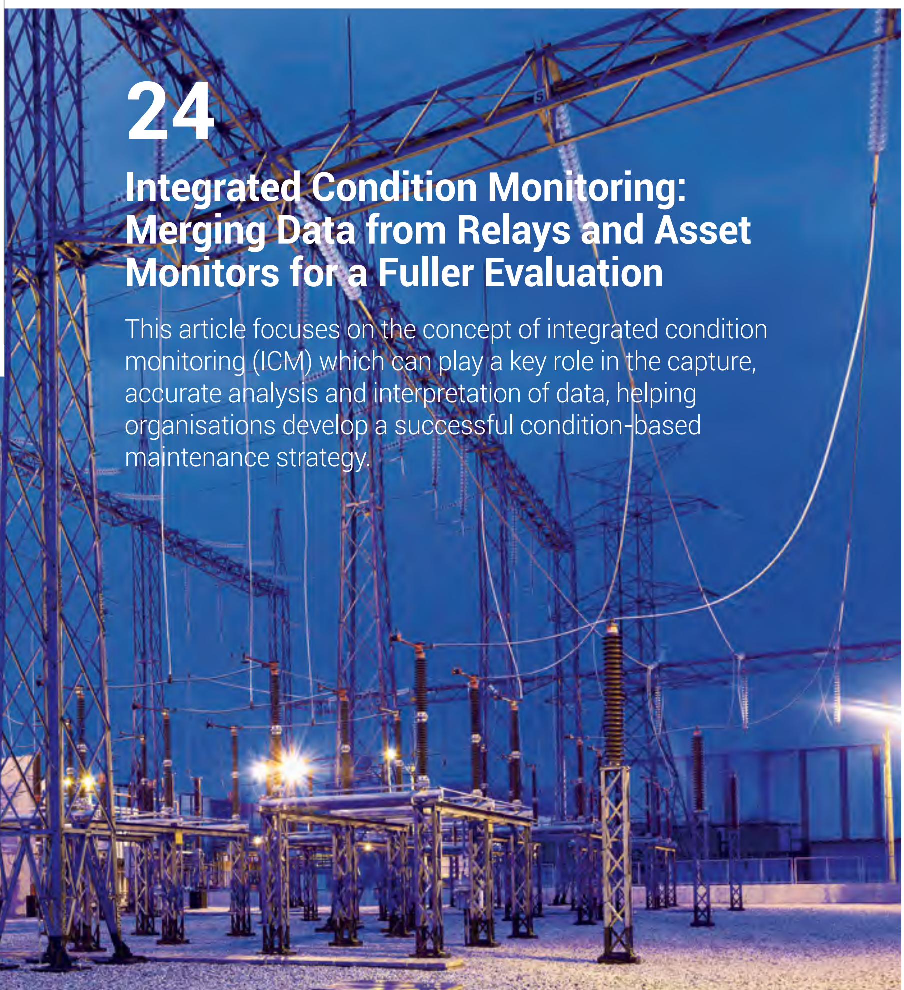

This article focuses on the concept of integrated condition monitoring (ICM) which can play a key role in the capture, accurate analysis and interpretation of data, helping organisations develop a successful condition-based maintenance strategy.

Asset managers and field operations staff are challenged every day with the reality of a continuously aging infrastructure and a rapidly growing loading process. The solution resides in a clear identification, acquisition, analysis, storage and management of test data obtained from offline as well as online monitoring and testing instruments.

Condition monitoring can provide valuable warnings about transformer health, including identification of deterioration, change in operational state, and impending failure. This article looks at two straightforward condition monitoring applications which resulted in expected results in one case and unexpected results in the other.

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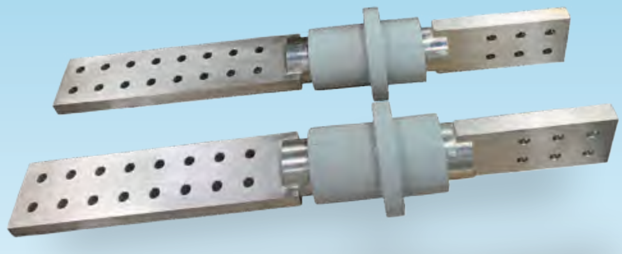

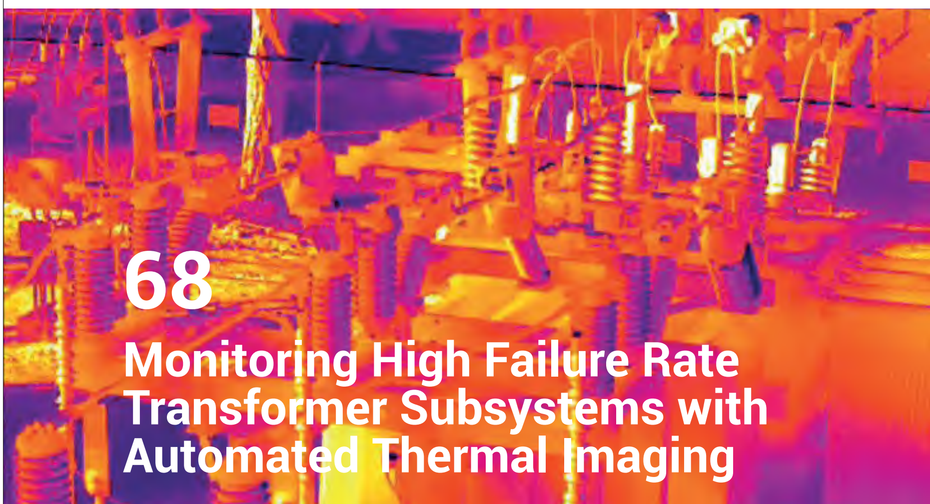

Automated thermal imaging technology can detect some of the most common problems in transformers before they become critical. This allows utilities to plan and schedule repairs, reduce outages and extend the life of their highest value assets.

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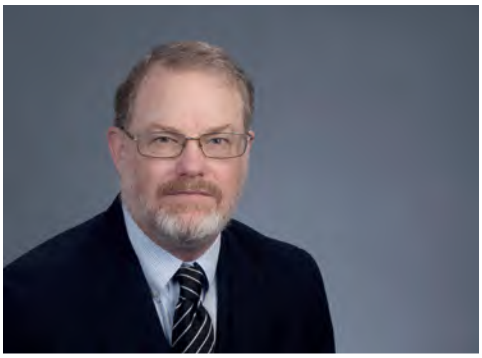

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Dear Readers,

I'll be honest. When we first decided to do an issue on the impact of digitalization and diagnostics on transformer monitoring, I was excited. Then I became skeptical: what kinds of articles and interviews would we get? It is potentially one of the segments that has seen most significant changes in transformer technology over the past few decades, yet I was not certain that it could carry an entire issue.

Transformer components, bushings, oils & fluids - our topics for the rest of the year, are pretty straight forward for the most part. We are familiar with the topics and know what to expect. With monitoring and diagnostics, not so much.

But to my great relief and to that of the TT team, our authors and experts came through for us. The overall result was more than I had anticipated and I believe you will enjoy the work of some of the best and brightest along with some new, next generation entrants as experts. I'll let the authors and interviewees speak for themselves, so I hope you enjoy this as much as I have enjoyed leading our editing team on your behalf.

I'd like to weigh in as well, but from a different perspective. I want to look to what the future might look like as a result of advances in digitalization, diagnostics and monitoring technology for power system overall, not just for transformers.

In 2018, pre-covid, when the world still met at conferences and expositions, I was at a reliability conference where I watched a presentation by Bentley Systems, a company heavily involved in the work of reliability and maintenance. It was a presentation on their work with Siemens on a Digital Twin substation. Since then, there has been much more information provided on the whole concept of digital twins, where a series of actual assets are mimicked through a digital twin, where simulations can be run showing the impact on a system or asset digitally, before it is experienced in real time.

Wikipedia defines a digital twin as "a virtual representation that serves as the real-time digital counterpart of a physical object or process. Though the concept originated earlier the first practical definition of digital twin originated from NASA in an attempt to improve physical model simulation of spacecraft in 2010."

When I saw the digital twin substation, I remarked to a colleague: "We are seeing the future... that is for those wealthy enough to make it happen." That might be a bit too skeptical, I realize, because most good ideas end up coming down in price as competition and advances in technology make it more cost effective. But in a very real sense, the creation of digital twins is really about simulating real time situations and seeing how a system or an asset reacts. Digitally "twinning" systems will become much more commonplace allowing us to determine what the impact will be on the whole system, when we make changes to one of the assets within that system.

I firmly believe this is becoming the way power systems, both large utility scale and industrial scale, are diagnosed. Monitors, of all types and complexity, will be deployed throughout these systems to send real time condition information back to the digital twin for determination of the impact on the system.

The advances in monitoring are still yet to be realized as we focus mostly on DGA monitoring, which is a lagging indicator of a problem. New solid state technology is coming online that will monitor leading indicators of failure potential. For me, that is the most exciting prospect I have seen during my time in the industry.

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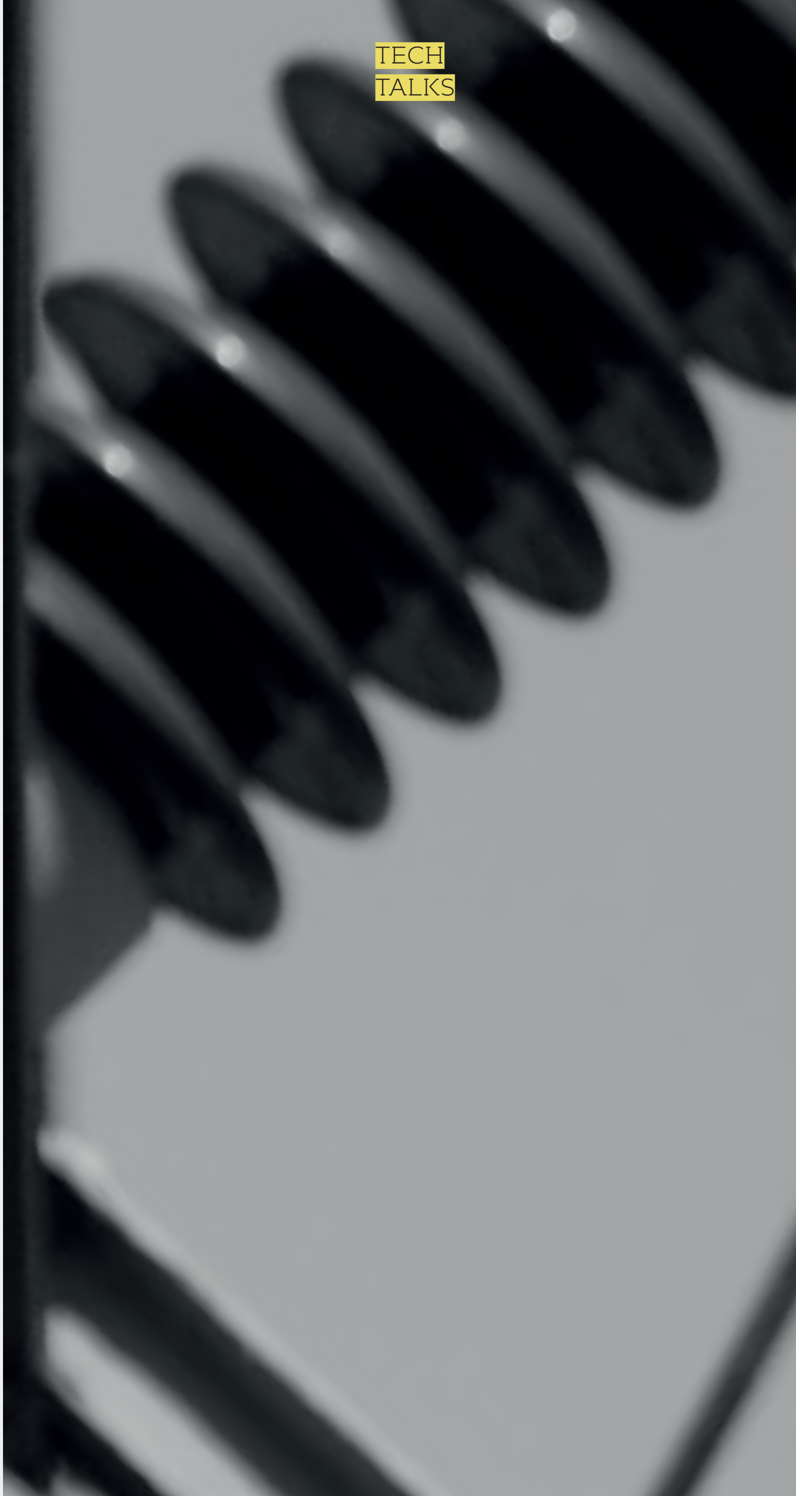
While the cost and array of monitoring availability grows, coupling that with digital twin concepts is going to make designing, operating and maintaining power systems much more exacting and bring a degree of certainty that we have not had before.

While the cost and array of monitoring availability grows, coupling that with digital twin concepts is going to make designing, operating and maintaining power systems much more exacting and bring a degree of certainty that we have not had before.

With that, I'll leave you to enjoy this digital issue of Transformer Technology, and as always, your feedback is greatly appreciated. We have created a TT Community hub with our TT website and producing these digital "digests" allows us to create audio and video content, which we share through the months and then along with the written content, we curate it all into this work.

I hope you enjoy reading it and forwarding it to your peers and fellow partitioners. Together we are building a Body of Knowledge unparalleled in our industry. Thank you for being part of our TT community.

Alan M Ross
CRL, CMRP
Editor in Chief
Transformer Technology
Curator of the Community
President of EPRA



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Michael Cunningham

COO at Camlin Group and **Managing Director** at Camlin Energy

“Renewables and sustainability bring with them challenges, and the industry needs to make significant changes in order to meet those needs.

We at Camlin believe that we have a significant role to play in that and we are very excited to do that.

Interview with **Michael Cunningham**

Photo: Camlin Energy

Camlin Group, based in Northen Ireland, is a major provider of monitoring products and services, with a focus on optimising railway and electrical power infrastructure. Camlin Power has recently undergone rebranding to become Camlin Energy as the company develops and refocuses to meet the demands of the sustainable energy future. In this interview, Camlin Energy Managing Director Michael Cunningham talks about the company's present efforts and its vision for the future.

Photo: Camlin Energy

Alan Ross: Michael, Camlin has gone through rebranding and I know that it is not just a marketing move. When I think of Camlin, I think of the double T - trains and transformers - because of your transformer monitoring program. Tell us a little bit about the rebranding of your power group.

Michael Cunningham: We recently went through a rebranding of the asset monitoring portion of the business, moving from Camlin Power to Camlin Energy, which might seem as a relatively minor change. However, we did that because the company is growing from one phase to the next: from a small or medium-sized company to a larger company. We recognized there was a need to restructure and refocus, and we asked ourselves where we are now, where we want to go and why we want to do that. We also recognize that there has been a lot of change happening in the industry. The challenges and the opportunities in the industry over the next decade are huge, probably the biggest challenges since the beginning of the industry in its early days of the design of electrical power as an asset to the society.

Renewables and sustainability, while essential for us all, bring with them challenges, and the industry needs to make significant changes in order to meet those needs. We at Camlin believe we have a significant role to play in that and we are very excited to do that.

I am the COO of the Camlin Group, but I also run the Camlin Energy space. Apart from 'trains and transformers', there were a lot of other areas that we were involved in, and we still are, but we carved out Camlin Energy into a separate entity to allow the dedicated focus on the energy sector. In addition to this refocusing, we recognize that to create that focus and to play our part more fully, we have to become more than just a supplier of boxes of monitoring devices; of DGA, partial discharge or circuit breaker monitors. We are creators and providers of solutions.

What really was involved here was going on a journey with customers. To be able to do that, we needed to be sure that we had all the right layers of expertise in place, and that those layers of expertise were aligned to provide value. This requires a very clear vision of what our customer's journey and the industry's journey is going to be like over the next decade. The restructuring and rebranding is all part of that.

AR Everything is changing, you are exactly right. In North America, we used to have a step-down grid, but according to the new FERC requirement No. 2222, utilities have to take the power generated anywhere within their grid, regardless of the cost. We have the electrification of transportation, batteries, a change in capacitance. What is not changing is the confusion of the engineers in the marketplace, especially the older ones like me. We wish good luck to the next generation and hope they figure it out. So, thank you for doing what you are doing and Camlin.

It sounds like starting the innovation process starts by questioning what you are trying to accomplish. Why are we trying to do it? I speak with a lot of different people in the industry, and I hear them say, I wish we knew how to get all of this to work together. How are you going to affect that at Camlin Energy?

MC You touched on something that I could completely agree with when you mentioned the reasons for change. Whenever we were going through the refocusing process, it would lead us right back to the beginning, and we would ask ourselves some very fundamental questions. We are very excited to create the company based on a very defined Purpose and Vision, along with a clear set of core values, and then build everything from that.

Our purpose is to 'engineer better futures'. And then our vision is to 'optimize the critical infrastructure all around us' - the very infrastructure on which society depends. So, we go back to the theme of transformers and trains (laughs). If we are to optimize that, what are our values? One of our values is that we don't accept the way it has always been done. That is at the core of the innovation that we have always been aiming at.

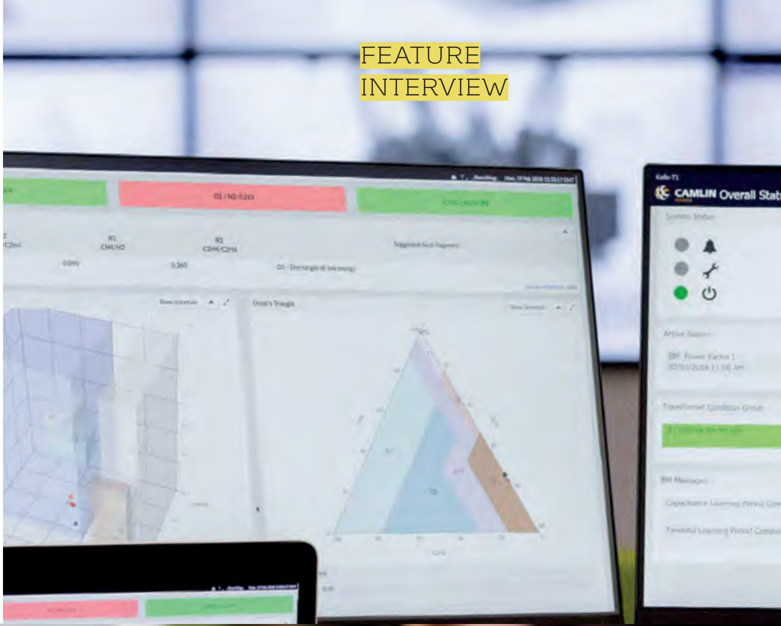
We recognize that the models, the methodologies, the diagnostics, the tools and the working practices that the industry is going to need in the next decade are not the ones that were created a decade ago.

The phrase that we use, which we didn't invent, but it resonates with us is: "What got us here, won't get us there." We recognize that the models, the methodologies, the diagnostics, the tools and the working practices that the industry is going to need in the next decade are not necessarily the ones that were created a decade ago. This is not a digital switch that can affect all the changes required, but a multidimensional journey over a significant period of time. But there isn't time to waste. The industry is going to need new technology, new ways of thinking, new analysis, new models and all of this in a collaborative feedback loop that is going to enable the industry to ultimately serve society's needs.

The reason I am proud to be part of this industry is that what we do makes everything else possible. All the changes that are happening and the sustainable future that we all require are impossible without the electricity industry being at the very core of that.

When my friends ask me, W*hat do you actually do?* and I try to describe it, their eyes just glaze over. *How do you think we get electricity?*

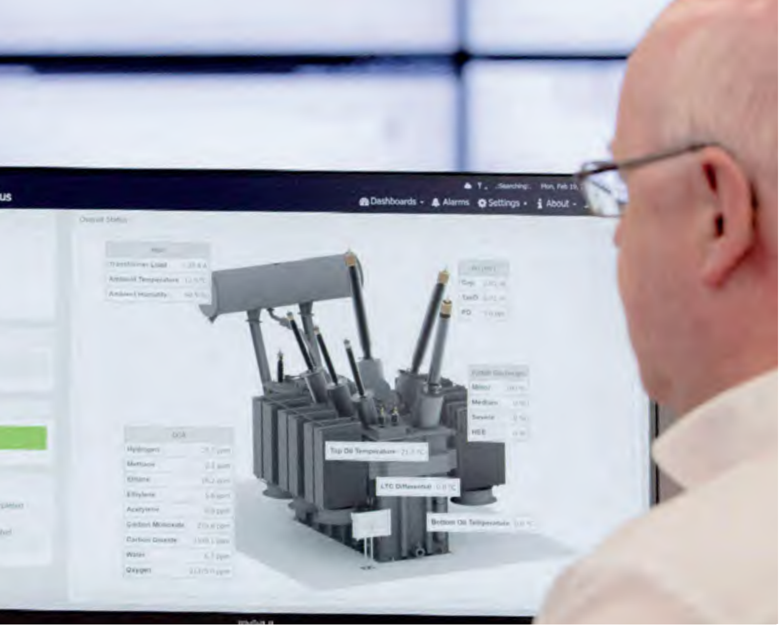
Do the kilowatt fairies just turn the lights on? There is a whole industry that I am extremely proud to be part of. It is propagated by well-intentioned, intelligent, hardworking people. I am talking about utilities and technology providers, even competitors of ours. The reason I am proud to be part of this is that what we do makes everything else possible. All the changes that are happening, and the sustainable future that we all require are impossible without the electricity industry being at the very core of that. With the electrification of heat and transportation, and the road to net zero, the burden is falling on a



relatively small number of people in the industry. For us to be part of that, is tremendously exciting. It is a privilege to be doing something important, even though most people don't understand it, and think perhaps that the kilowatt fairies still do their job (laughs).

That is the way I look at it, and that is what I try to describe to people. It is important to understand those big moving pieces and then to be able to hold that vision in your head; that 30,000-ft view of where we are going and why; then to be able to build our team and our layers of value to help that journey. There will be challenges down the line, but

Photo: Camlin Energy



we all are in this together. As the technology and the methodologies need to progress, we need to grow and progress as well. The Camlin rebranding and refocusing is part of that.

AR That is a powerful answer. I think that people in the industry are going to get the message that Camlin will meet them where they are and help them figure out where they are going. One of the situations that we have today is the electrification of transportation. Very few people understand what that's going to do to the world. Lithium mines are multiplying, green energy has its benefits, but there is also the issue of used batteries. Being in business with railway infrastructure, I would like to find out how Camlin Energy looks at the electrification of transportation from the energy perspective.

MC You are right, we are heavily involved in the electrification of transportation from a couple of different angles. On the Camlin Rail side, we are heavily involved in the railway industry. But if we focus primarily on the power side, there are two primary aspects - assets and networks. On the networks side we have also got a very large role, primarily in the U.K., with the distribution network operators.

The mass uptake of electric vehicles, to give just one example, is having a huge impact on the electric industry, and we are working to create network management systems that facilitate that. If it is not done correctly, the investment for network strengthening is beyond budget capability. We have got to work in ways that simply don't exist at the moment. That is something that our UK tram is working very heavily on and is tremendously exciting.

But there is one thing that is coming.
My experience in the industry has been that network management on one side and asset management on the other side are quite separate - it is almost 'never the twain shall meet. They have got different methodologies, different languages, they use different mathematical tools.

But they are going to increasingly crash together over the next years. There are new models and there is rethinking required, both in networks and in asset monitoring. It is going to require data

Networks and asset management are going to crash together over the next few years. It is going to require rethinking, data collection methods that are currently in their infancy, and data analysis using new tools such as machine learning.

creation and collation methods that are currently in their infancy, and data analysis using new tools such as machine learning. What is crucial is the expertise, the knowledge of the assets and the knowledge of the networks to know what this data is saying.

When we talk about different voltage levels, the mass onboarding of wind energy, both onshore and offshore, creates disturbances on the network that are significant and also largely unknown. The impact of those disturbances on assets is also significant and largely unknown. What that means is as the network parts of utility change, evolve and take these necessary steps, the asset management side of the business is going to have to change as well.

They have got models about probability analysis of risk and risk mitigation that they have evolved and improved over the last 20, 30 years. But does the maths stack up? I would hazard a guess that

it probably won't, and we don't know yet. In order to understand that over the next decade, we as an industry are going to have to create and deploy new models. The assets and the networks are either going to come together in a controlled fashion or they are going to come together in an uncontrolled fashion, but they are coming together.

We at Camlin Energy have a part to play; we can help because we have got the hardware creating he right data both in the networks and in the assets. We have got the data collation and diagnostics, the AI machine learning and crucially the expertise to understand these new insights. We also partner and work with others on this journey, refining and improving existing models, and creating new models and methodologies that are necessary.

That journey can be taken in a controlled fashion. It is back to the point of "What got us here won't get us there." The pace of change is accelerating to such a degree that the pace of the previous 50 years of change in the industry just won't work. That is what we are trying to do at Camlin with this reorganization. We need to be ready for this journey. We know what all the dots are, but the challenge is to get the right people together and connect those dots. That is one of the single most exciting and most challenging aspects of the next 10 years.

AR Michael, it has been an incredible opportunity for us to talk about the future. I love the fact that you used the word purpose when you talked about the rebranding at Camlin Energy. As the world changes rapidly around us and we change with it, it is important to remind ourselves of why we are doing what we are doing. "What got us here won't get us there", but it will be all the more exciting to follow you on your journey and see where and how Camlin Energy will go from here.

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Integrated Condition Monitoring: Merging Data from Relays and Asset Monitors for a Fuller Evaluation

by **Austin Byrne**

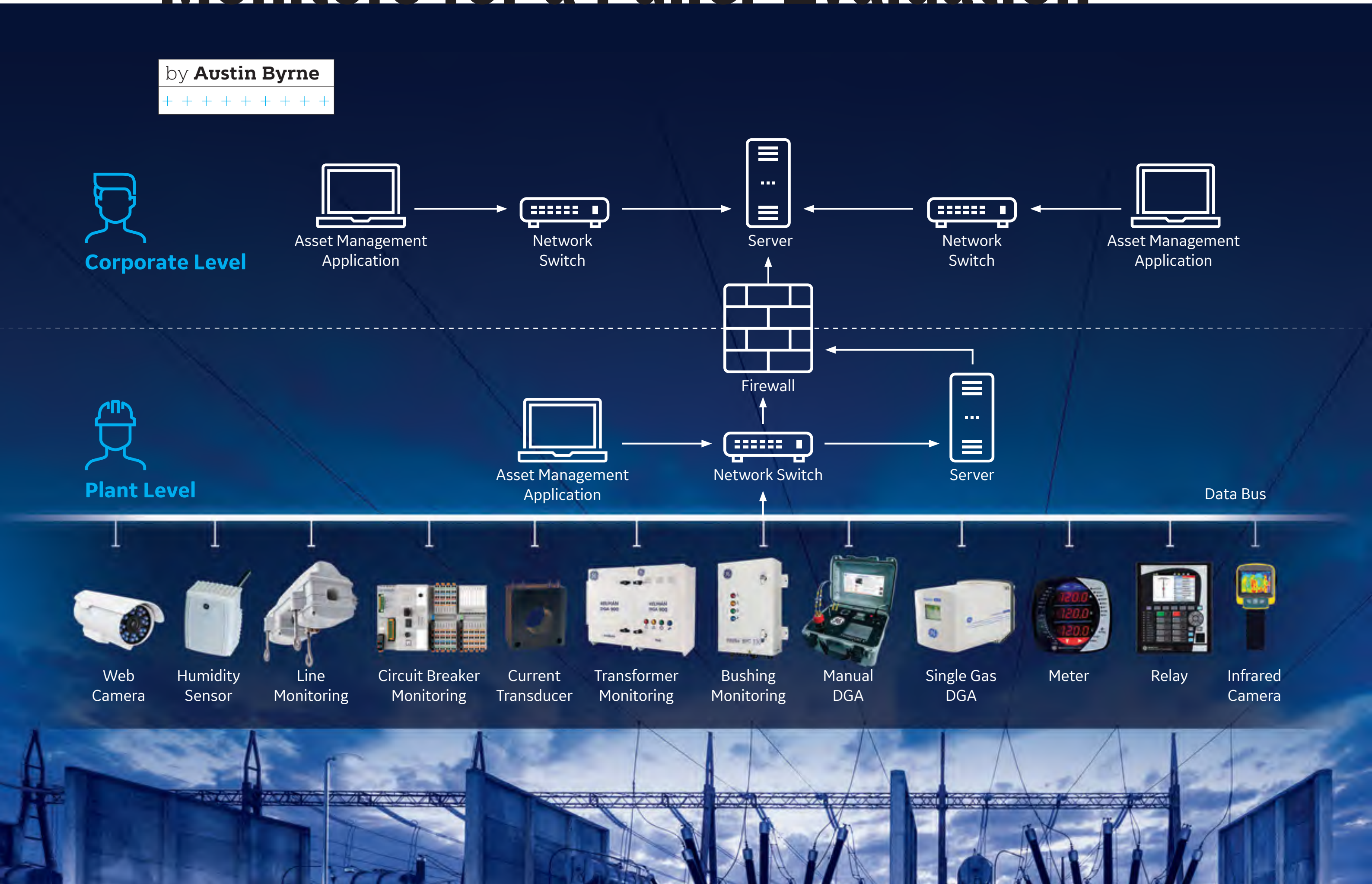


Figure 1. Example of ICM Topology

Austin Byrne leads the enhancement, promotion, development and delivery of GE's Monitoring & Diagnostics software solutions and applications. He is also responsible for operating transversely across Grid Automation product lines, focusing primarily on integrated condition monitoring within the electrical utility and industrial substations. He joined GE in July 2010 as the software quality manager for Monitoring & Diagnostics before moving into product management in 2013.

Introduction

All businesses share a common goal – implement operational efficiencies whilst maintaining a reliable service for their customers. Achieving this goal relies on information about the asset condition and in today's environment, this is increasingly challenging due to the abundance of aging assets across the globe and businesses focused heavily on reducing spend. Hence the common phrase: "do more with less".

Data drives the decisions businesses take to implement and achieve the expected efficiency and reliability results. Data derived from the critical components and assets is at the core of the service provided to their customers and is responsible for their operational process delivery. There has never been more data in the world than right now. It is estimated that 2.5 quintillion bytes of data is created each

Photo: GE

THERE HAS NEVER BEEN MORE DATA IN THE WORLD THAN RIGHT NOW. IT IS ESTIMATED THAT 2.5 QUINTILLION BYTES OF DATA IS CREATED EACH DAY, WITH THAT PACE ACCELERATING DUE TO CONNECTED DEVICES AND THE INTERNET OF THINGS.

day, with that pace accelerating due to connected devices and the Internet of Things [1].

However, this abundance of data must be derived and refined in to precise, strategic, and actionable information. Data is derived using communication networks and refinement comes in the form of its analysis and interpretation.

In this article, we will focus on the concept of integrated condition monitoring (ICM) which can play a key role in the capture, accurate analysis, and interpretation of data. ICM is the mechanism by which the data from multiple online and offline sources and assets is captured and analysed together to provide a holistic picture of an asset's condition at an individual and fleet level. ICM also focuses on situational information as part of the assessment to better understand the impact of operational fluctuations and external events. When deployed at a fleet level, ICM can provide a more accurate picture of the operational risk exposure of an organisation based on the potential of assets failing and the overall impact of the unexpected downtime as well as repair/ replacement costs. ICM can also help organisations develop a successful condition-based maintenance strategy.

ICM IS THE MECHANISM BY WHICH THE DATA FROM MULTIPLE ONLINE AND OFFLINE SOURCES AND ASSETS IS CAPTURED AND ANALYSED TOGETHER TO PROVIDE A HOLISTIC PICTURE OF AN ASSET'S CONDITION AT AN INDIVIDUAL AND FLEET LEVEL.

Data Analysis Challenge

Unfortunately, underutilisation of data continues to be an oversight in many organisations, hindering their ability to achieve their mission statements. There are a number of causes of this, with the most common and obvious cause coming from not connecting remote monitors to an IT (Information & Technology) infrastructure and being made available to applications where the data can be analysed in a timely manner by the right people.

When considering a new deployment of a remote online monitoring system, planning this connectivity will be an important step in that process. If the remote monitoring devices have already been deployed, fortunately, it is typically quite straightforward to retrospectively setup and establish communications with the remote monitoring devices.

However, in both instances, engagement between the organisation's IT suppliers, the end users of the data and the vendors is critical. Between the IT department and the end user, an architecture needs to be developed that shows where the data needs to travel from and reside at, and which zones or network substructures it must navigate to get to where it needs to be. Once that is understood, the IT department and the selected vendor or vendors can then develop a topology that can be used to provide the communication path as per Figure 1. This could be as simple as connecting an ethernet cable and opening specific network ports on an existing IT infrastructure. Or it could require a more comprehensive setup that requires deployment of dedicated wired/wireless communication devices and a network for transmitting the data along with application-to-application synchronisation servers.

Figure 1 exemplifies the several typical assets at an electrical substation and remote monitors and sensors that can be deployed. Some of the devices might be simple, like a weather station. However, an asset like a power transformer consists of various components: transformer tank with active part and oil-paper insulation, tap changer, bushings, cooling unit and conservator, to mention some. Advancements in sensing devices and analytics allow the implementation of solutions that go beyond the well-established Dissolved Gas Analysis (DGA) including on-load tap changer, cooling unit or bushing monitoring. An integrated monitor covering all components might help to simplify the data influx.

Another not so obvious cause of data underutilisation comes from a lack of awareness of the valuable data being generated by equipment classified as non-monitoring, such as relays and digital fault recorders along with other systems.

Types of Data

When it comes to ICM, there are different types of data being analysed, some of which are defined below:

- Symptomatic Data – This is data gathered on an asset which is a symptom of an issue rather than the result or cause of a problem.
- Fault Data – This is data captured when a fault occurs causing an event such as a trip; it can be the result or cause of a problem.
- Environmental Data – Data captured about the external environment in which the asset is operating, over which there is little or no control.
- Operational Data – This is data measured and captured on the operation of the asset such as load, energisation, tap changes, thermal, cooling control, etc.

Symptomatic and fault data can sometimes get confused. For example, when dissolved gases start to generate in an oil filled transformer, it is symptomatic of several issues, such as insulation breakdown, loose connections, overheating, damaged or worn components, etc. Whereas fault data would be considered data, such as over voltage which can cause damage to the equipment if it is not prevented.

Symptomatic data can often be a precursor to a serious fault and hence be detected well before fault data is generated and captured. However, symptomatic data can also be caused by benign changes in the operation of the asset, environmental variation or it can even be the expected behaviour of an asset.

Here in lies the challenge: without downtime and invasive internal examinations, how can you identify if the symptoms recorded are an indication of an issue? If so, how serious is the issue, the damage being done, what is the root cause and is the asset in danger of failing unexpectedly?

THE SUCCESS OF ANY ASSET MANAGEMENT STRATEGY RELIES HEAVILY ON HOW THE INFLUX OF DATA IS MANAGED AND EFFICIENTLY EVALUATED.


Photo: GE

Management of the Data

The good news is that by applying an ICM methodology and cross-corelating the multiple sets of data available, it is possible to better understand the asset condition.

Advancements in data science have enabled manufacturers to reuse existing parameters measured by a device to extract further information. Reapplication of existing sensors in equipment is becoming more and more prevalent as product vendors develop new techniques and firmware to extract and provide new data. The extra information that is extracted from the data generated by such equipment enables organisations to gain more insights into the connected critical assets.

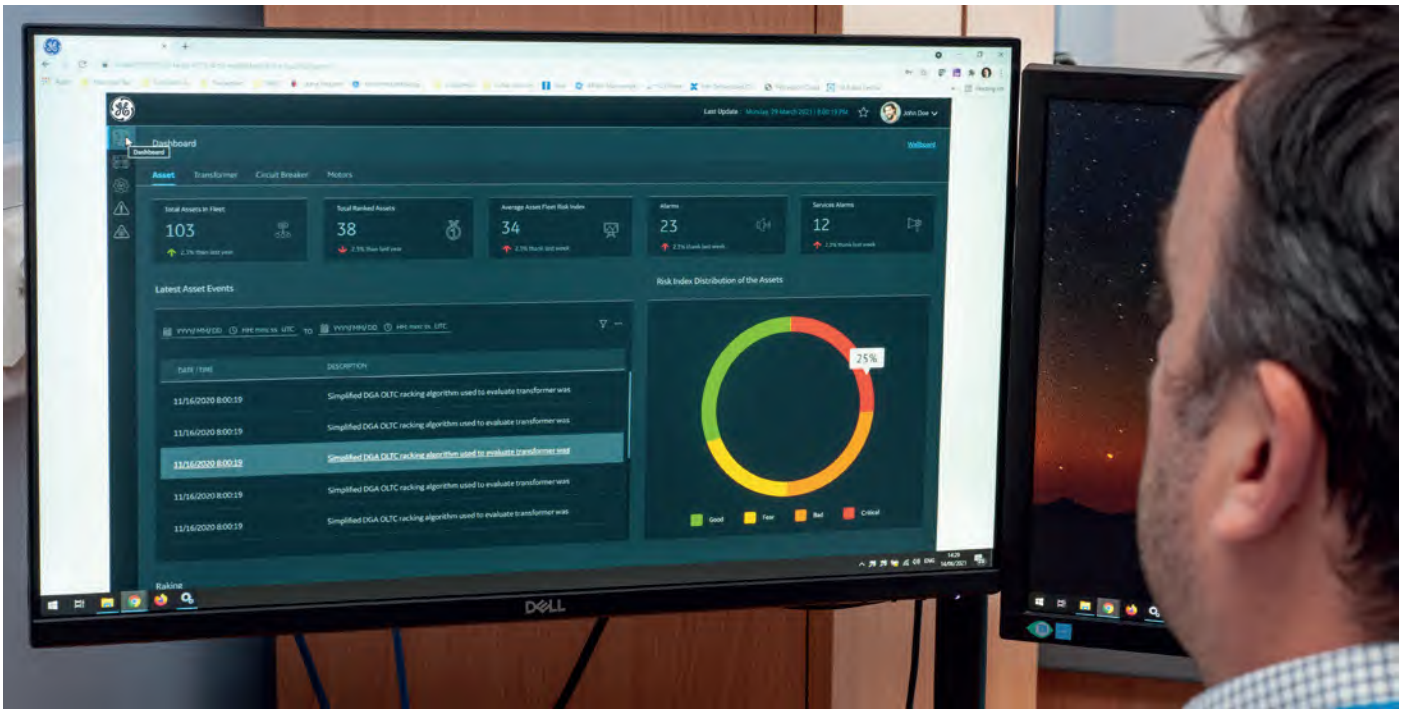
The success of any asset management strategy relies heavily on how the influx of data is managed and efficiently evaluated. More and more organizations are looking

THE KEY PREMISE OF INTEGRATED CONDITION MONITORING (ICM) IS THE COMBINATION AND ADVANCED ANALYSIS OF ALL THE RELEVANT DATA GENERATED. BY COMBINING THE DATA FROM MONITORING AND NON-MONITORING EQUIPMENT ALONG WITH EXTERNAL DATA SOURCES, A MORE COMPLETE PICTURE OF THE ASSETS SITUATION PAST AND PRESENT CAN BE CREATED.

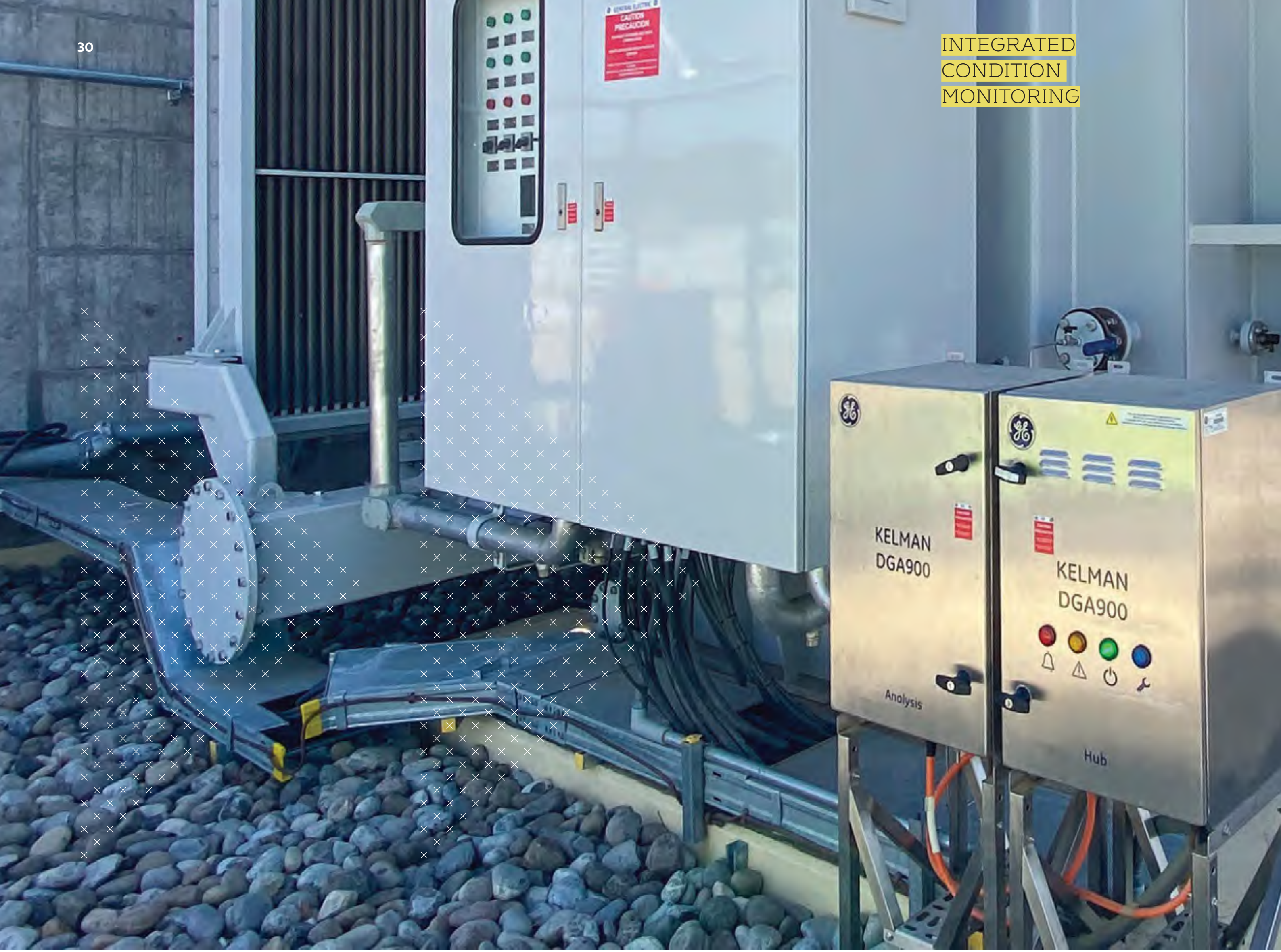
to software in the form of asset management applications, to enable business outcomes by managing the vast amounts of data and turning the valuable data into information and asset insights.

Understanding the differing types of data, how it is to be presented in an asset management application and how it will be analysed is critical. Using data analysis and diagnostics tools as detailed in standards such as IEEE C57.104 [2] helps with the interpretation of asset data. Asset management applications capable of performing automatic analysis of data to derive an assets health or risk of failure focus attention and streamline data analysis to assets in need.

Photo: GE



Dashboard
Asset
Transformer
Circuit Breaker
Motors
103
38
34
23
12
Latest Asset Events
Risk Index Distribution of the Assets
25%
DELL



Summary

As shown in Figure 1, there is a vast amount of data and information gathered for assets, captured by an array of equipment connected to the asset as well as external sources. By analysing the data sets separately, the subject matter expert's ability and opportunity to accurately diagnose the asset is vastly hampered.

The key premise of integrated condition monitoring (ICM) is the combination and advanced analysis of all the relevant data generated. By combining the data from monitoring and non-monitoring equipment along with external data sources, a more complete picture of the assets situation past and present can be created.

Advancements in interoperable data analysis software, equipment and sensors help organisations adopt ICM as it greatly simplifies the integration process and information extraction. By utilising data science and algorithms, software applications can automatically detect correlations in the data and further streamline data analysis, subsequently allowing the experts to focus more of their attention on the information that truly matters, freeing up more time for strategic planning.

When applied across an entire fleet of critical assets responsible for operational process delivery, for example, the transformers, circuit breakers and motors used in the day-to-day operation of utilities and industrial organisations, the results and information about each asset analysed can be combined to create a more comprehensive fleet overview. This ready to use information pool provides important details on the condition and health of the entire fleet, thus allowing organizations to understand their asset risk exposure, providing them with the information to pre-empt, plan and reduce downtime as well as deploy a successful condition-based maintenance strategy reducing future risk.

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[1] Data increase rate, retrieved from https://www.forbes.com/sites/bernardmarr/2018/05/21/how-much-data-do-we-create-every-day-the-mind-blowing-stats-everyone-should-read/?sh=6582117360ba

[2] IEEE C57.104-2019 – IEEE Guide for the Interpretation of Gases Generated in Mineral Oil-Immersed Transformers

Note:
The information from the article is based on the paper written and presented by Austin Byrne at the TechCon North America 2021: "Integrated Condition Monitoring, Merging Data from Relays and Asset Monitors for a Fuller Evaluation_Techcon_2021_Paper"

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A New Method for Detecting Transformer Air Leaks

A transformer's lifetime is determined in large part by the condition of its solid insulation. The presence of oxygen in transformer oil accelerates ageing of its solid insulation, most importantly the paper within its windings. With increased use of sealed transformer designs, the issue of air leaks as a source of oxygen has grown in importance.

Air leaks into the transformer are often caused by embrittlement of gaskets or the rubber bag. Therefore, monitoring and confirming proper sealing against ambient air ingress is crucial to maximizing your transformer's operational life.

SHORTCOMINGS OF TRADITIONAL METHODS

Traditionally air leaks have been detected by measuring oxygen and nitrogen from standard DGA oil samples. However, the challenge with sampling at the transformer site, followed by transportation and handling of the samples, is the risk of contamination from ambient air. Such contamination can be identified by observing nitrogen level fluctuations in DGA results over extended periods of time (Figure 1).

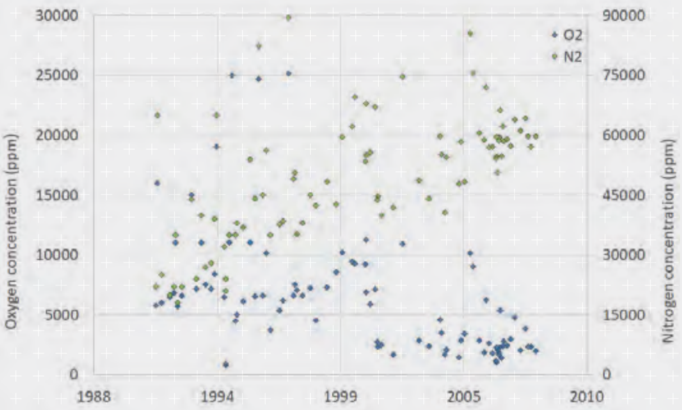


Figure 1.
Nitrogen and oxygen measured in a laboratory from DGA oil samples of a sealed transformer 1990-2008.

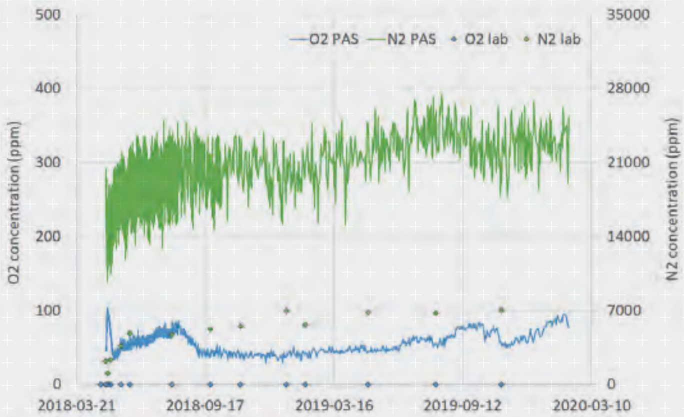


Figure 2.
Nitrogen and oxygen data from a PAS based DGA monitor compared against laboratory (lab) references.

Some online monitors have integrated oxygen measurement and nitrogen levels are calculated based on the oxygen values. However, these calculations assume that the oil is saturated to ambient air with a constant oxygen-nitrogen ratio. It is imperative to take into account that such calculated nitrogen values are valid for free breathing transformer only — but not at all valid for sealed transformers.

Figure 2 compares data from a photoacoustic (PAS) based DGA monitor against laboratory reference results. The data reveals that the calculated nitrogen values from the online monitor show significant bias compared to laboratory measured values. This is due to the transformer being sealed, that is, not exposed to ambient air. Worse still, the large fluctuation in data over 18 months makes determining possible diffusion of air into the transformer tank very hard.

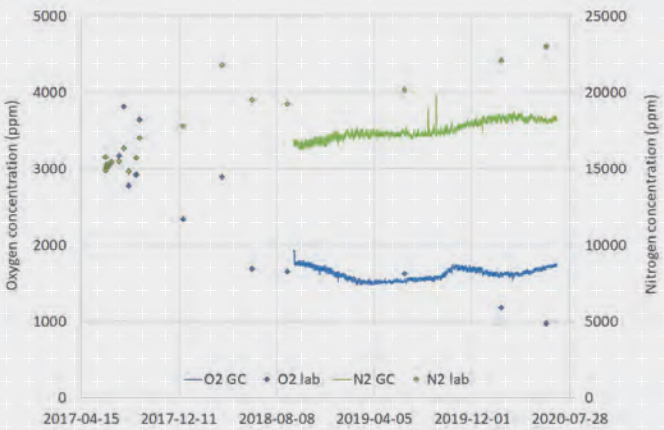


Figure 3.
Nitrogen and oxygen data by a GC based DGA monitor with laboratory (lab) references.

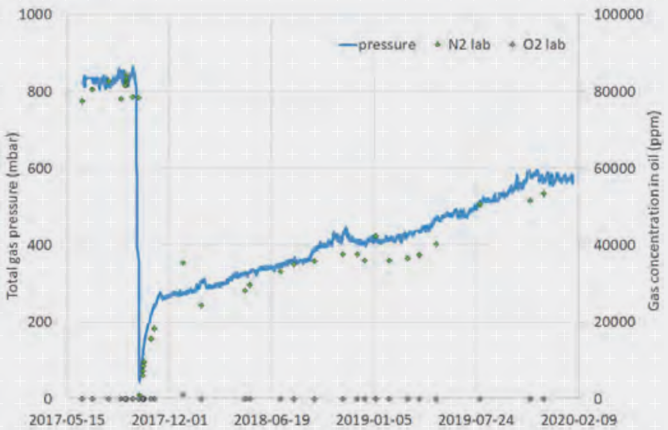
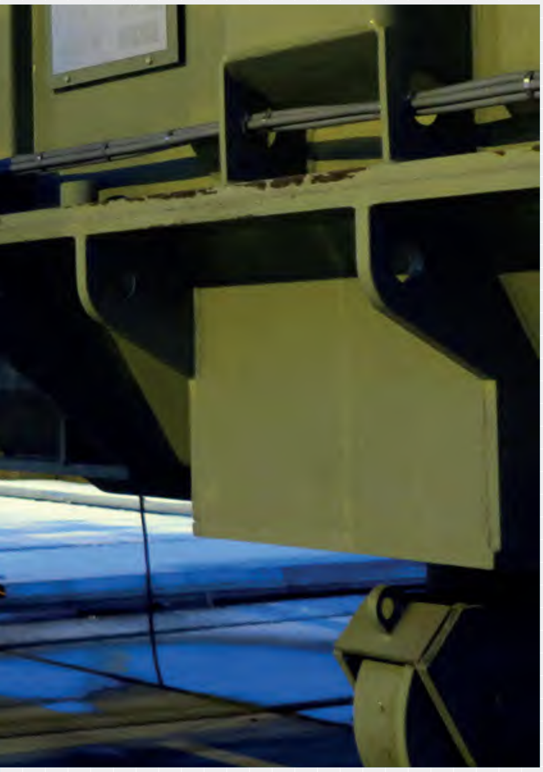


Figure 4.
Total pressure of gases measured with the Vaisala online DGA monitor OPT100 and laboratory (lab) defined nitrogen and oxygen.

The example in **Figure 3** compares an online gas chromatograph (GC) based DGA monitor against laboratory-measured references. Although the readings are closer to the reference values, a well-defined trend cannot be determined.

Figure 4 shows pressure data from a Vaisala OPT100 on a sealed transformer with a pre-identified air leak issue. Prior to degassing (October 2017), the oil was saturated to ambient air. The total pressure of dissolved gas was 800 mbar, equivalent to partial pressure of nitrogen in air. All oxygen entering the system was consumed simultaneously. As can be seen from the graph, the pressure value mirrors the laboratory-measured nitrogen concentration. The laboratory in question has exceptionally good reproducibility, which makes comparing the two parameters easy and reliable. Since degassing, air had leaked in again, resulting in 75% saturation to ambient air nitrogen in the oil.

Photo: Vaisala



A New Method

MEASURING TOTAL GAS PRESSURE

The Vaisala OPT100 DGA monitor uses partial vacuum to extract gases from the transformer oil. It also includes a pressure sensor, which makes it possible to determine the air leaks by measuring total gas pressure (TGP).

Total Gas Pressure is the sum of the partial pressures of all gases dissolved in the oil. In case of an air leak into the transformer tank, the largest portion of gases would be nitrogen and oxygen. Both can be completely extracted from oil, because of their poor solubility. The proportion of fault gases in the total pressure value are negligible. Even if all oxygen had been consumed, the pressure value would give a reliable indication of a leak. A leak can be identified this way because the nitrogen value will both dominate and increase over time as it is neither formed nor consumed in the transformer.

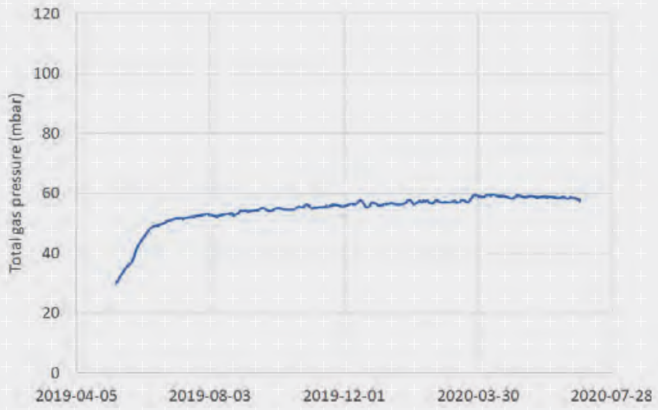
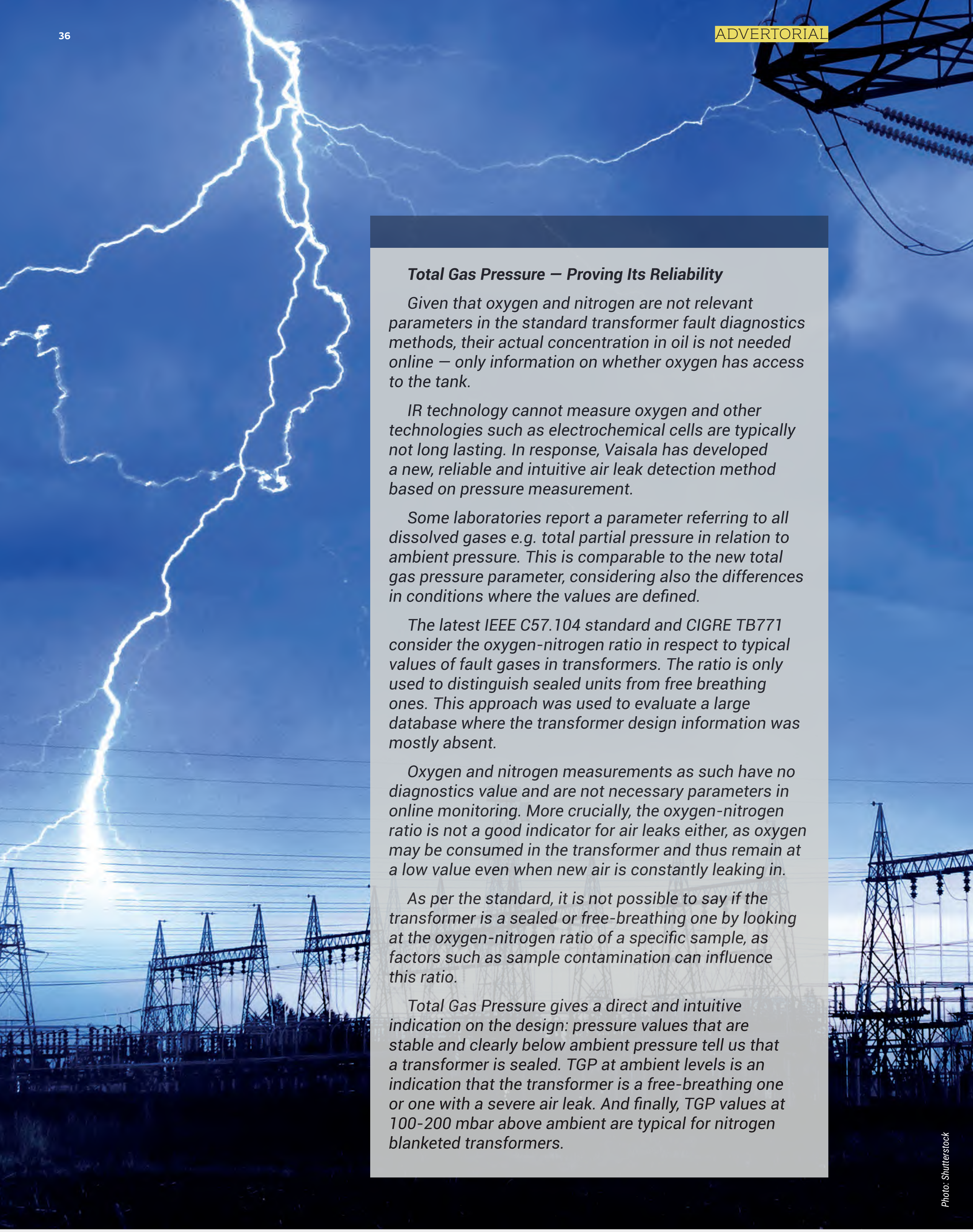


Figure 5.
Total pressure of gases in the insulation oil of a brand-new transformer as measured with the Vaisala OPT100 online DGA monitor.

Figure 6.
Nitrogen and oxygen data from a PAS based DGA monitor compared against laboratory (lab) references.

Figure 5 highlights a new, sealed transformer. The total pressure of dissolved gases forms a practical quality control measure. When commissioning a new transformer, its tank is filled with dry oil, degassed in a vacuum. This means that the gas pressure at the point of energizing the transformer will be very low (<100 mbar). If that is not the case, it can be assumed that there may be an issue either with the sealing or with the commissioning process itself. It is likely that in any case there will be a slight increase in gas pressure during the first few weeks after commissioning as gas, nitrogen, or dry air, trapped in solid insulation dissolves in the oil.

A well-sealed transformer will maintain low levels of gas pressure for a long period of time, up to the full lifetime of the transformer. This can be seen in the example in Figure 6, which shows data collected with a Vaisala OPT100 from a 29-year-old 100 MVA transmission transformer. Remarkably, the oil in this particular transformer had not been treated since its commissioning in 1989. The total gas pressure is low and remains stable at about 250 mbar, representing 25% ambient pressure.



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Total Gas Pressure — Proving Its Reliability

Given that oxygen and nitrogen are not relevant parameters in the standard transformer fault diagnostics methods, their actual concentration in oil is not needed online — only information on whether oxygen has access to the tank.

IR technology cannot measure oxygen and other technologies such as electrochemical cells are typically not long lasting. In response, Vaisala has developed a new, reliable and intuitive air leak detection method based on pressure measurement.

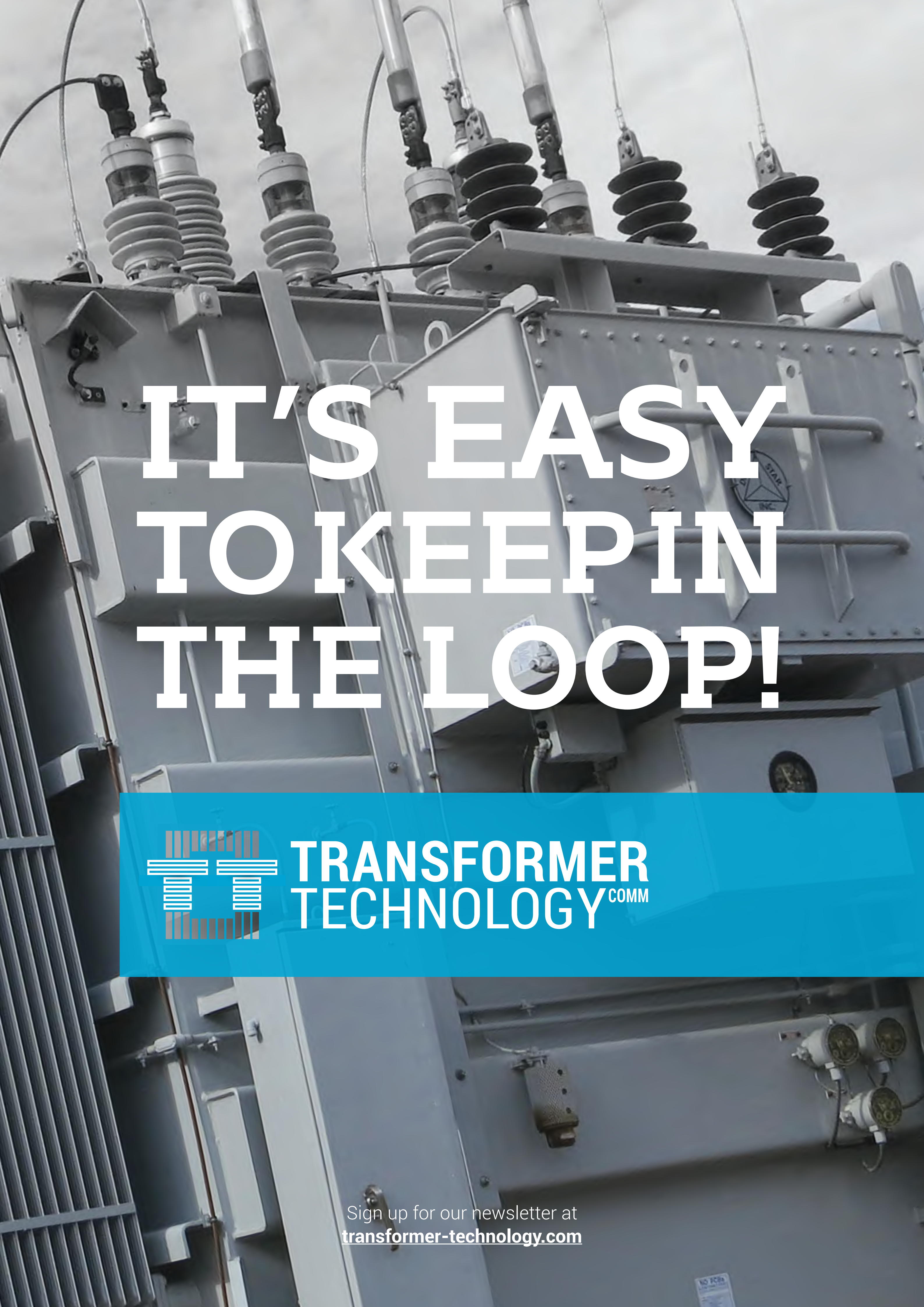
Some laboratories report a parameter referring to all dissolved gases e.g. total partial pressure in relation to ambient pressure. This is comparable to the new total gas pressure parameter, considering also the differences in conditions where the values are defined.

The latest IEEE C57.104 standard and CIGRE TB771 consider the oxygen-nitrogen ratio in respect to typical values of fault gases in transformers. The ratio is only used to distinguish sealed units from free breathing ones. This approach was used to evaluate a large database where the transformer design information was mostly absent.

Oxygen and nitrogen measurements as such have no diagnostics value and are not necessary parameters in online monitoring. More crucially, the oxygen-nitrogen ratio is not a good indicator for air leaks either, as oxygen may be consumed in the transformer and thus remain at a low value even when new air is constantly leaking in.

As per the standard, it is not possible to say if the transformer is a sealed or free-breathing one by looking at the oxygen-nitrogen ratio of a specific sample, as factors such as sample contamination can influence this ratio.

Total Gas Pressure gives a direct and intuitive indication on the design: pressure values that are stable and clearly below ambient pressure tell us that a transformer is sealed. TGP at ambient levels is an indication that the transformer is a free-breathing one or one with a severe air leak. And finally, TGP values at 100-200 mbar above ambient are typical for nitrogen blanketed transformers.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Condition Monitoring Realities:

Dealing with the Unexpected

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

We should have expectations when applying condition monitoring to transformers. If we know what to expect then we can identify measurements which are unexpected or anomalous and worthy of deeper investigation.

Photo: Doble Engineering

Introduction: Why are we here?

Condition monitoring can provide valuable warnings about transformer health, including identification of deterioration, change in operational state, and impending failure. To realize the potential of condition monitoring, we need to understand what it actually measured, how that measurement relates to failure modes which may apply and determine how to act on that information. This article looks at two straightforward condition monitoring applications which resulted in expected results in one case and unexpected results in the other.

A simple analogy for condition monitoring is a car tire pressure warning light: it can tell you that the pressure has fallen below a certain level and may even tell you what the pressure is, but it doesn't tell you *why* the pressure has fallen – so we are *detecting* a possible problem rather than *diagnosing* a problem. And we do need to remember that it is a *possible* problem, as the sensor itself may be at fault: if the tire pressure is indicated to be negative, say, we may suspect a problem with the sensor and monitor.

With a car tire, we have the tire specification and manufacturer's recommendations, so we know what the pressure should be: we have expectations. We should also have expectations when applying condition monitoring to transformers: what do we expect the top oil temperature to be under certain load/ambient conditions? What about dissolved gas analysis – how well does the online monitor match lab results? If we know what to expect then we can identify measurements which are unexpected or anomalous and worthy of deeper investigation. *(We could get into a whole discussion on false positives and false negatives at this point – but let's save that for another day.)*

CASE 1

All according to plan

This case is one where a rise in current was used as an indicator of bushing deterioration; a rise was detected, but the speed with which the deterioration developed was unexpected. In 2012, a monitor was making hourly measurements of leakage current magnitude and phase on two sets of three Trench bushings on a transmission transformer. Figure 1 shows the leakage current for all 6 bushings over a 24-hour period: HV bushing results overlaying well at about 24.5 mA and the LV set consistently at about 7 mA – in line with calculated values for the system voltage and the individual bushing C1 nameplate values.

There was a sudden rise in the leakage current over two hours, generating a high-level alert. The owners had a response plan which they acted upon, requiring the transformer to be de-energized within two minutes of receiving the alert for offline testing. The plan was followed, the bushing was tested, showing elevated power factor and capacitance, and replaced. The subsequent bushing tear-down confirmed advanced deterioration. The case is discussed with the original utility in a paper entitled "Condition Monitoring in the Real World" presented at the International Doble Client Conference of 2012 [1].

This case underlines the need for a response plan when applying monitoring, and also the need to learn about relevant failure modes. Unlike GE Type-U bushings which have a known failure mode where deterioration is usually reflected in power factor rise over several weeks to months, for the Trench bushing in this case, the owners thought a catastrophic failure was possible within 'about five more hours'. Consequently, for such bushings, we now usually recommend monitoring at the 1-5 minute interval level.

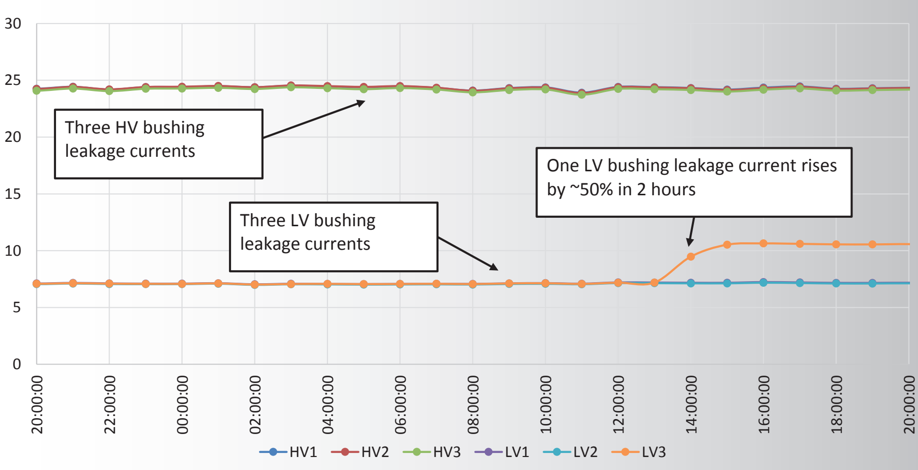


Figure 1.
Leakage current magnitude for two bushing sets on a transmission transformer

Photo: Doble Engineering

To realize the potential of condition monitoring, we need to understand what it actually measured, how that measurement relates to failure modes which may apply and determine how to act on that information.

When applying monitoring, there is the need for a response plan and also the need to learn about relevant failure modes.

CASE 2

All according to plan, then there is a change

In this case, a bushing shows a gentle rise in power factor over a period of several weeks, as shown in Figure 2. These results are from a relative power factor analysis of the currents from a set of three tertiary bushings. The rise is unexpected, with the other two bushings showing the expected form of almost constant power factor.

Relative power factor has been successful in detecting and diagnosing bushing issues for over 20 years, using the individual leakage currents from a set of three bushings. However, it is always useful to have a 'check' on the results, if possible. In this case a voltage reference was available for each phase, and 'true power factor' values were calculated based on the loss angle between the bushing leakage current and the instrument transformer voltage. Figure 3 shows the three relative power factor values, and the three true power factor values: the two gently rising values are from one bushing.

The bushing remained in service, and something unexpected happened: the power factor of the suspect bushing, from both relative and true values, started to fall, as shown in Figure 4, heading back to previous levels.

Although unlikely, we might ask whether the bushing has stopped the deterioration and put itself back together. Generally, once the insulation has deteriorated, it only deteriorates further over time – so we need to find a way to rationalize the results in terms of what could happen in practice.

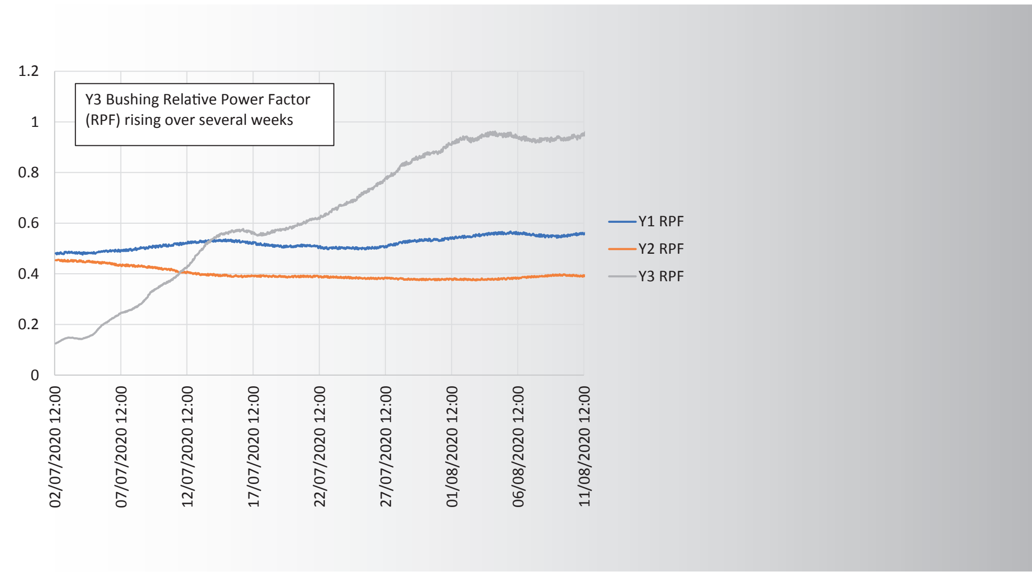


Figure 2.
Relative Power Factor for a set of three bushings

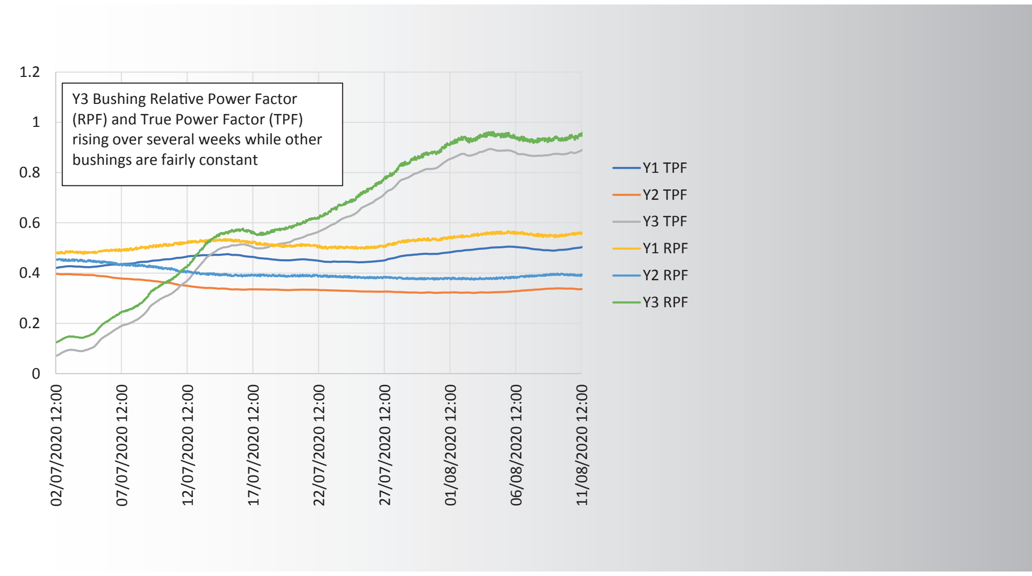


Figure 3.
Relative Power Factor and True Power Factor for a set of three bushings

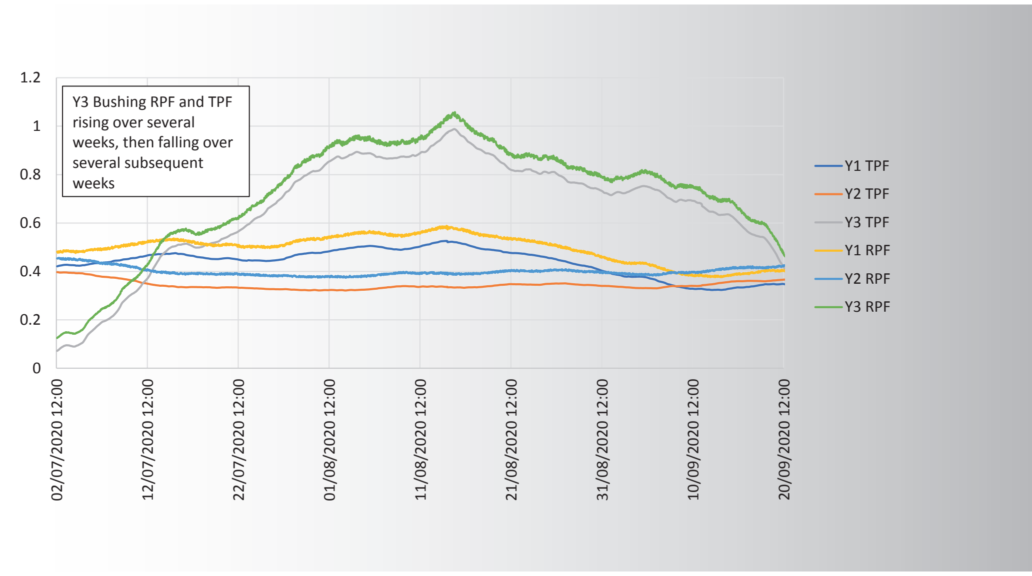
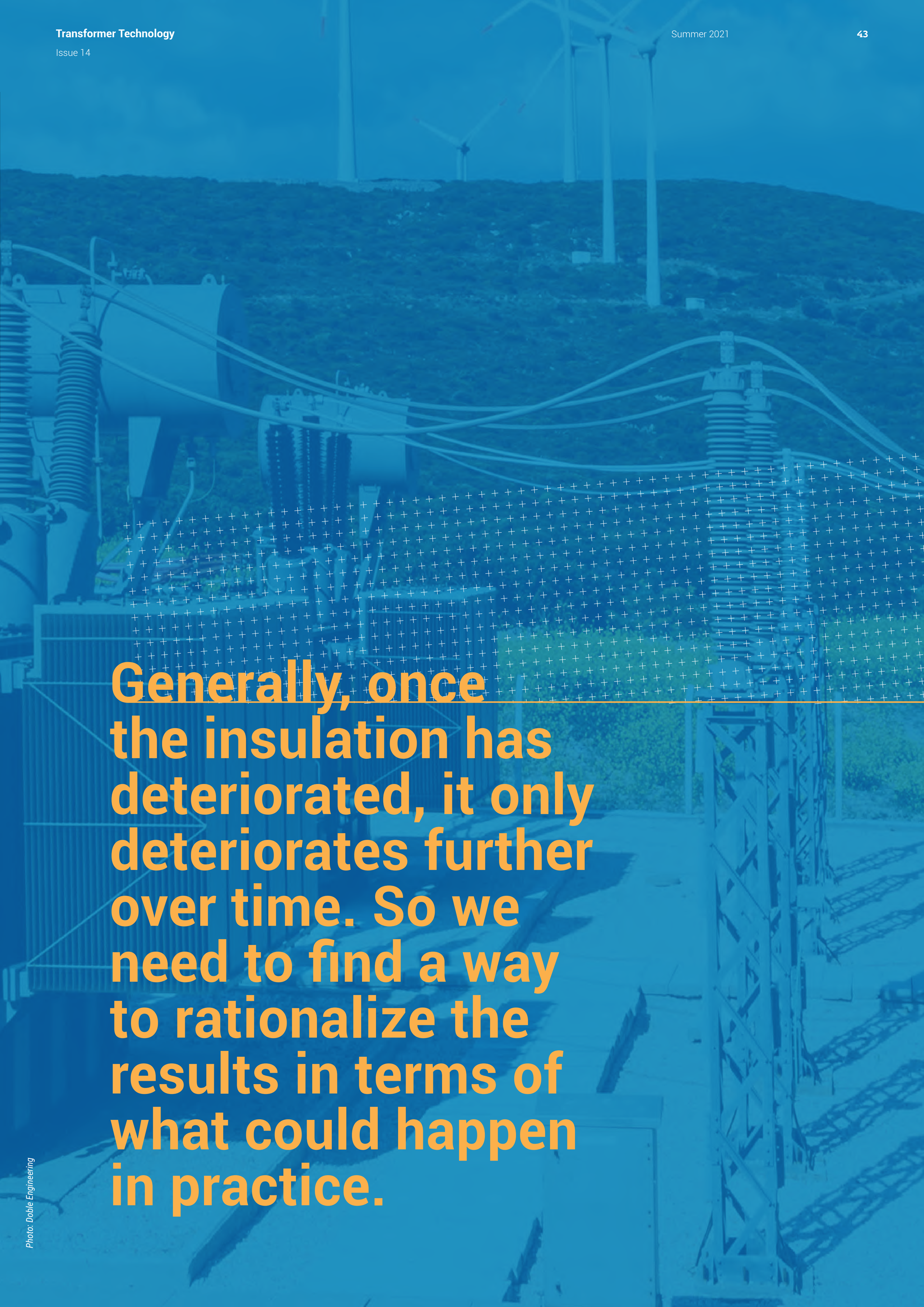


Figure 4.
Bushing Power Factor – unexpected results



Generally, once the insulation has deteriorated, it only deteriorates further over time. So we need to find a way to rationalize the results in terms of what could happen in practice.

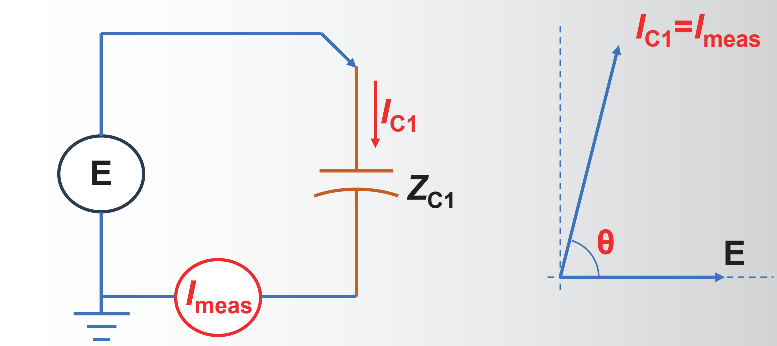
Photo: Doble Engineering

The phenomenon of reduced or negative power factor has been known and discussed for decades [2]. An excellent detailed discussion presented by Long Pong [3] showed negative power factor results obtained through standard offline tests in a number of different applications. He gives a simple model of a test object, in this case a bushing, as shown in Figure 5. The applied voltage, V, produces a current in the test object I_{C1}, with the bushing capacitance being Z_{C1}. If the C1 was purely capacitive, the phase angle θ would be 90°; in practice there is a small resistive component so θ is very slightly below 90° and the variation is exaggarated in the figure.

The measured current is given by Equation 1.

This simple model can be extended by adding a resistive path to ground within the test object – such as may be introduced by moisture or contamination, as shown in Figure 6. The Z_{C1} value for the bushing is now split into two parts, Z_1 and Z_2.

The measured current in this case is given by Equation 2.



With a very small resistive component the angle is just below 90°

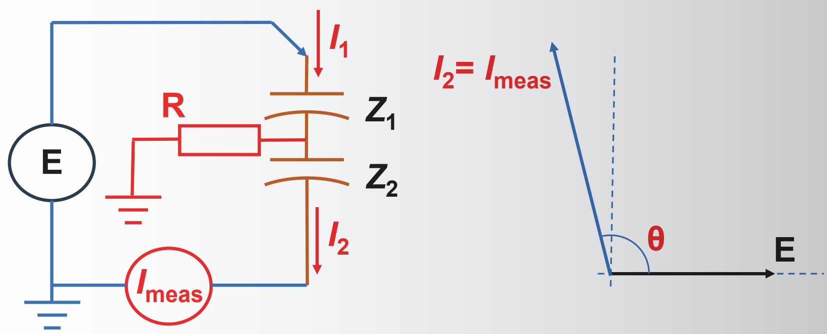
$I_{meas} = E/Z_{C1} = E/|Z_{C1}|e^{-j\theta} = |I_{meas}|e^{j\theta}$
So: measured power factor = cos(θ) >0

Figure 5.
Simplified Bushing Measurement Circuit

$$\vec{I}_{meas} = \vec{I}_{C1} = \vec{V} / \vec{Z}_{C1}$$

Equation 1. Basic equation for measured current in a bushing test

The C1 impedance is split into two parts, Z_1 and Z_2, which allow a resistive path to ground, R



The leakage current provides a voltage drop, V_R, which increases θ. Remember that θ is very close to 90° to begin with.

$I_{meas} = E/((Z_1 \cdot Z_2)/R + (Z_1+Z_2)) = |I_{meas}|e^{j\theta}$
So: with θ> 90° measured power factor = cos(θ) <0

Figure 6.
Bushing model with additional resistive path to ground

$$\vec{I}_{meas} = \vec{I}_2 = \vec{V} / \left(\frac{\vec{Z}_1 \cdot \vec{Z}_2}{R} + \vec{Z}_1 + \vec{Z}_2 \right)$$

Equation 2. Measured current in bushing test with resistive path to ground in place

The additional resistive path adds the complex product $Z_1 \cdot Z_2/R$ to the calculation of measured current. This product has the effect of adding an impedance accounting for the impact the current diverted through R has on the measured current. It shifts the measured current phase angle, θ, to be slightly above 90°, with the power factor now being negative.

How does this help in our case? We have had a rising power factor, then a falling power factor: one possible explanation for this set of events would be based on the oil fill cap for the bushing being damaged. Moisture and contamination would get into the bushing in small amounts, which would raise the power factor of the oil and thus the C_1 bushing power factor – reflected in a rise in power factor value provided by the monitor. As more moisture/contamination enters, a resistive path to ground develops and grows, reflecting the situation in Figure 6, and the power factor of the bushing drops as that effect becomes dominant. Given time, the power factor would become negative.

It was noted during the subsequent bushing forensic tear down that the oil fill plug gasket was cracked and significantly deteriorated and the oil in the bushing contained visual sediment, particulates, and free water. It would seem that slow ingress of moisture was not only a possible cause for the effect seen, but had in fact occurred, and would explain the resulting unexpected variation in power factor measurements.

Photo: Doble Engineering

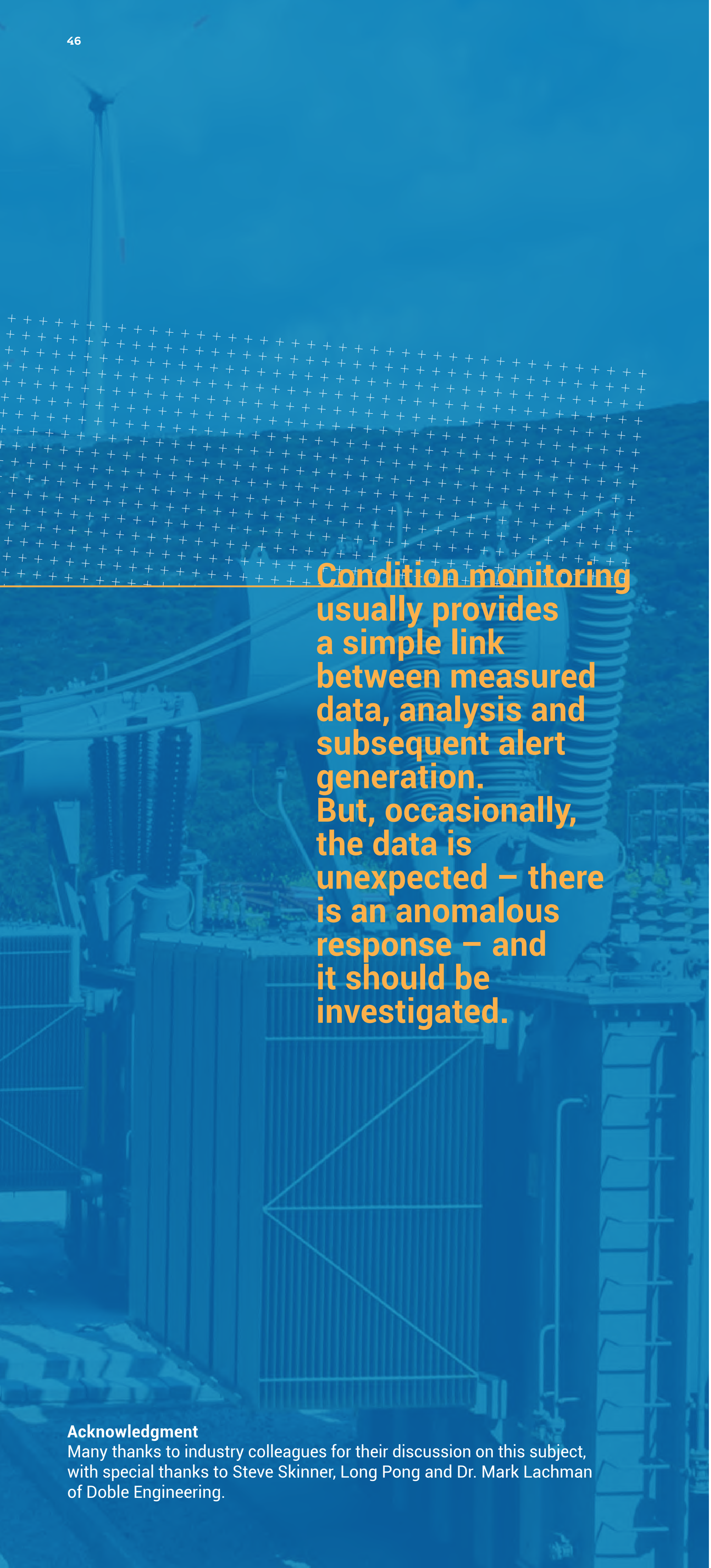


Photo: Doble Engineering

Discussion

Condition monitoring usually provides a simple link between measured data, analysis and subsequent alert generation. When monitoring data changes, it may be a simple case of linking the values to deterioration and on to a failure mode, allowing for planned intervention. But, occasionally, the data is unexpected – there is an anomalous response – and it should be investigated.

Condition monitoring usually provides a simple link between measured data, analysis and subsequent alert generation. But, occasionally, the data is unexpected – there is an anomalous response – and it should be investigated.

Such investigation should focus on finding an explanation for the data, and should include:

- Verifying that the data makes sense – ensuring there is no sensor or data acquisition issue.
- Consideration of what is actually measured and what is subsequently derived – and how the process can be disrupted.
- What could be a possible physical explanation for the results seen? Does the explanation make sense?
- What are we missing? Something small may have big consequences.

The second case discussed here is just one example of unexpected data and the subsequent attempts to identify a possible cause for what is seen, based on offline test analyses in prior technical papers, with the possible cause subsequently confirmed during the forensic teardown.

Acknowledgment
Many thanks to industry colleagues for their discussion on this subject, with special thanks to Steve Skinner, Long Pong and Dr. Mark Lachman of Doble Engineering.

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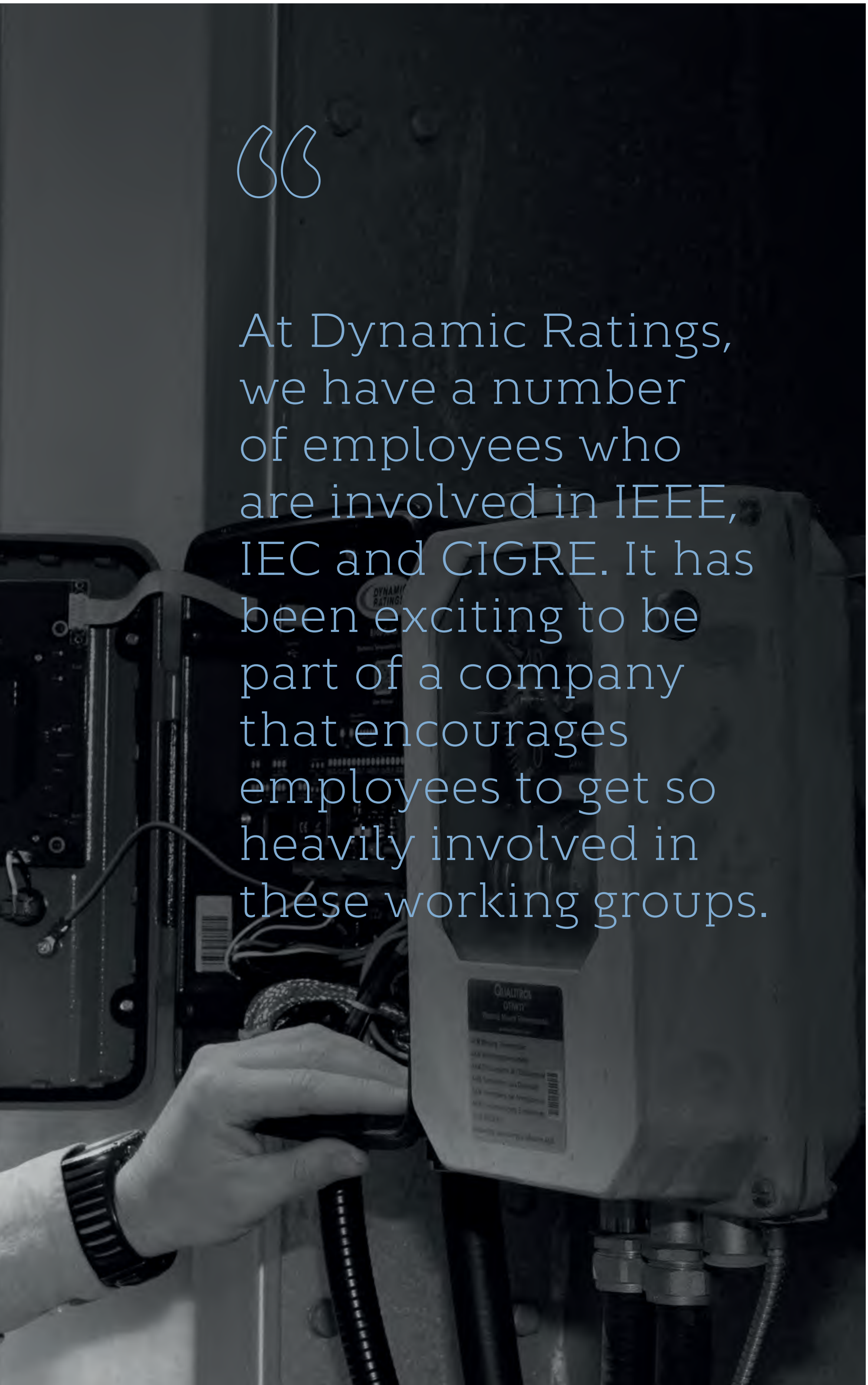
Seamus Allan

Interview with **Seamus Allan**

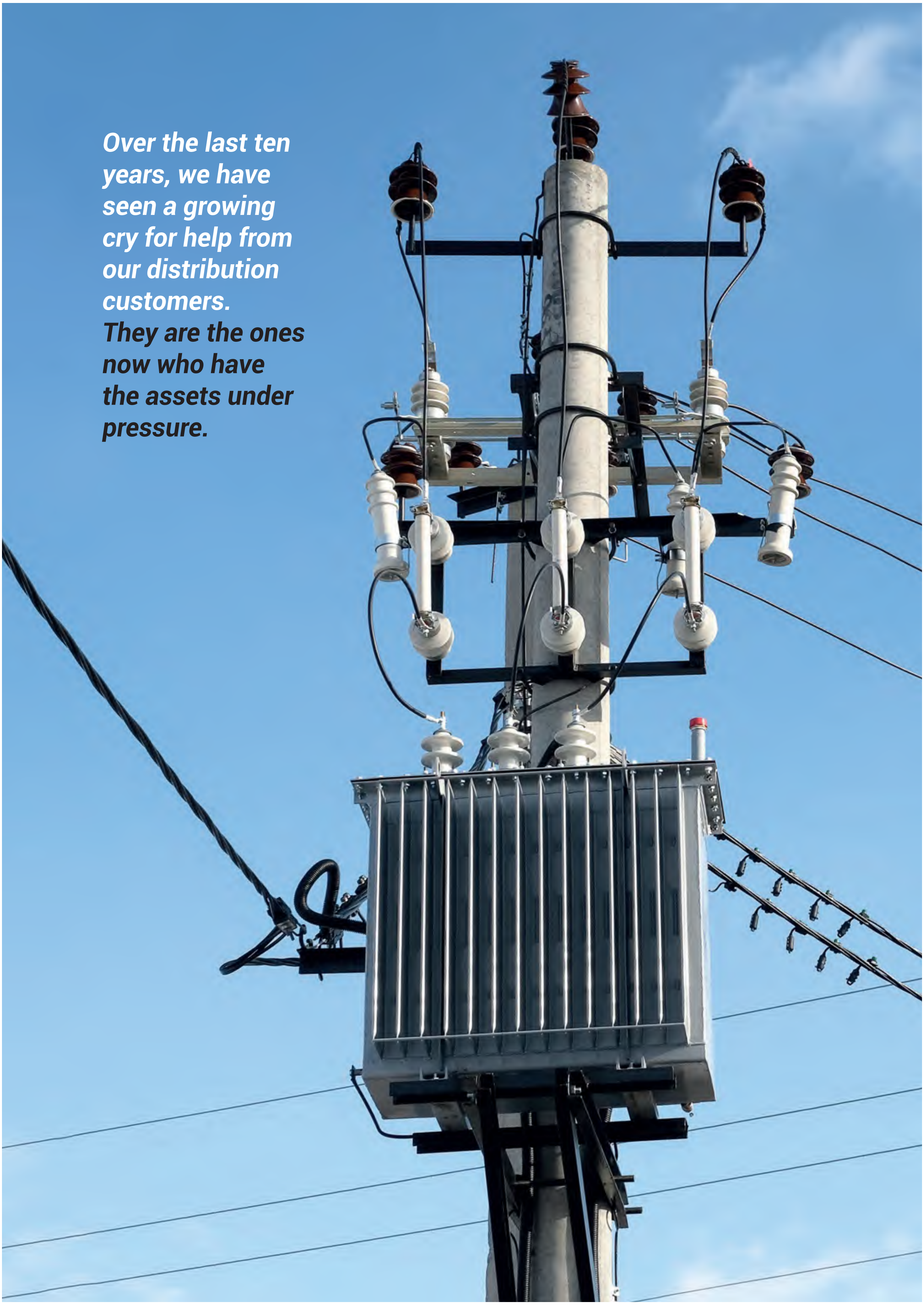
LV & Distributed Monitoring Product Manager at Dynamic Ratings

Photo: Dynamic Ratings



> At Dynamic Ratings, we have a number of employees who are involved in IEEE, IEC and CIGRE. It has been exciting to be part of a company that encourages employees to get so heavily involved in these working groups.

Seamus Allan is the Product Manager for LV & Distributed Monitoring at Dynamic Ratings' Australian headquarters in Melbourne.



Over the last ten years, we have seen a growing cry for help from our distribution customers. They are the ones now who have the assets under pressure.

Seamus Allan is the Product Manager for LV & Distributed Monitoring at Dynamic Ratings' Australian headquarters in Melbourne. In this interview, our editor in chief touched on different hot topics in the industry with Seamus, who is a recognized subject matter expert in many areas, including transformer and electrical apparatus monitoring and control technologies.

Alan Ross: I am delighted to welcome Seamus Allan from Dynamic Ratings. Seamus, I would like to go a little bit into your background. We know Tony Pink, General Manager at Dynamic Ratings, has done great things with the company and how Wilson [Transformer Company] has taken it to the global level. You have been in the US, in the UK and now you are in Australia. Can you tell us a little bit about the time you spent in the UK?

Seamus Allan: Thank you, Alan. Yes, that was a crossover role between WTC and Dynamic Ratings, providing support on both sides. Living in the UK was a really exciting time because the networks there are similar to North America – in that they have been around for a long time.

AR You have a lot of experience in the low-voltage area of the world. You have seen how the grid is changing and how utilities are having to adapt to the changing requirements of the grid. What are some of the big changes that are taking place and are causing professionals in the utility industry to change the way they do what they do?

SA It is an interesting time for our industry globally, I think. As a two-second background of Dynamic Ratings, our main focus has been on substations and substation assets, transformers and breakers. That is where my background comes from – looking at large power transformers and the substation assets. Over the last ten years, we have seen a growing cry for help from our distribution customers. They are the ones now who have the assets that are under pressure. That seems to be happening in certain areas in the world more than in others.

Those changes are coming from the very large increase in distributed generation in the network – solar photovoltaics and similar resources. The changing technology mix with battery storage going into the network is a huge aspect of it. Another aspect, depending on which country we are in, is the switching off of the large synchronous generation: fossil fuel generation, coal burning plants, etc. That massive shift in energy landscape has now put the distribution networks as a horizontal energy transfer mechanism rather than the traditional top-down energy transfer that came from the traditional networks.

AR We used to have the step-down system, as you said, and now we have an inverter-based system. With all of that happening, what do you think are the caveats for the engineering and the procurement, maintenance and management of utilities, especially the distribution utilities and the people in distributed energy resources (DER)? What are the main challenges they are going to be faced with?

Photo: Shutterstock

SA A large part of the challenge that we are seeing in these emerging markets is the loss of synchronous generation, which is a huge issue now in Australia. As of 2020, Australia has the most solar capacity installed per capita. It is a small country in terms of population, with around 25 million people, but are leading in that respect. 22% of residential houses have solar [PV] systems on the roof. There are a lot of commercial solar operations happening in the countryside.

The loss of synchronous generation here in Australia has driven a huge growth of the Frequency Control Ancillary Services (FCAS) market, because trying to prop up the frequency when there is a system event has become extremely difficult. Probably one of the major challenges are a lack of grid support services. Another aspect is in terms of loadings. The diversity factor for most LV connections - and this varies by country - is approximately 2.5 kW, which is what a residential house is expected to be drawing on average.

The entire distribution network was built around this diversity factor. Now we are dropping electric vehicles (EV) and other large batteries into the network, and they might draw 32 Amps, each one by themselves. That is just the distribution transformers, the connecting circuits. All of that was not designed for the intense loads we are seeing at the moment. When you hear talk in the UK of going fully electric in their transport space by 2030, and other countries having very strong incentives to go in the same direction, the transformer asset managers and people working in line ratings are starting to panic, because they are suddenly going to be putting huge loads onto the network. And this wasn't expected before. Load management is one of the pretty serious areas.

AR Load management is changing the specifications for transformers. If you are purchasing transformers, the specifications should be different. You can't simply replace the one that was there because the loads are going to be different.

22% of residential houses in Australia have solar systems on the roof.

Due to the massive shift in energy landscape, the distribution networks have now become a horizontal energy transfer mechanism, rather than the traditional top-down energy transfer that was the case in the traditional networks.

The electrification of transportation creates its own problems, and I would like to see that from your perspective. What is Dynamic Ratings doing about that and what it means for your company as it relates to opportunity?

SA I will speak from the work that we have been doing in the UK, in Australia, and a little bit in New Zealand. Admittedly, in Australia the government incentives haven't been there, so the uptake of electric vehicles here is a little bit behind other countries. On the flip side, some of the countries in Europe have had phenomenal uptake.

Probably the biggest challenge is plonking really large chargers into people's homes. Everybody wants to come home from work, plug in their car and have it ready for the morning. While the traditional load that happened in the evening came from everyone switching their ovens or their kettles on, now people are bringing home enormous loads, 16 or 32-Amp chargers, which, if they all get on the same time, have significantly greater draw than what the network was designed to provide; both from the top-down level, and also in the distribution network.

The biggest challenge that we are seeing is how to have equitable sharing of the network resources across the different users. There have been a lot of different trials to try and maximize the use of the available capacity of the LV network, the transformers and the feeding circuits, so that all

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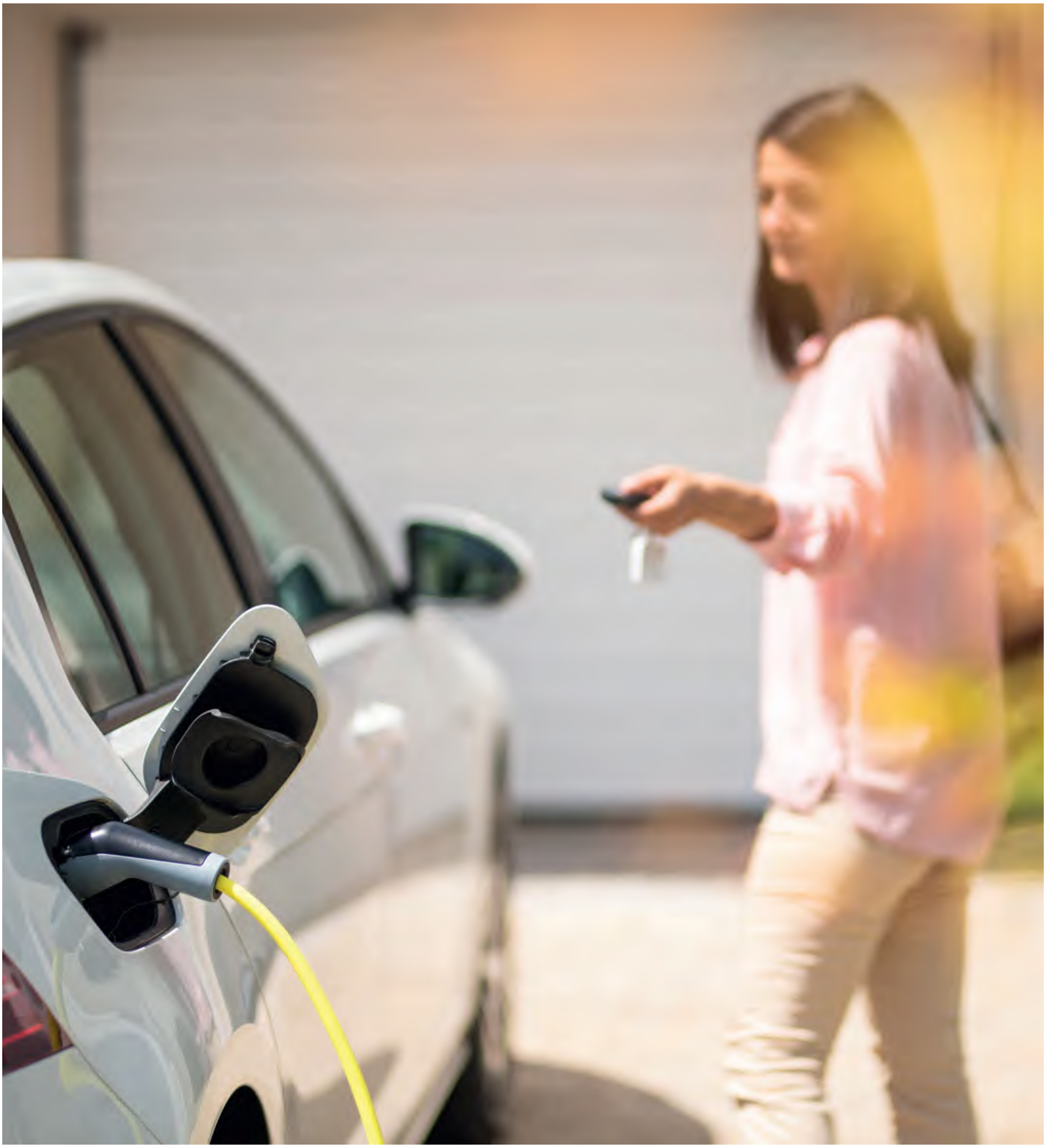
users are able to charge their cars when they want as much as they can, without turning their neighbors off and without tripping out a whole street. It becomes very unpopular when you plug your car in and everyone's lights turn off! We are trying to do that in a fair way and without having a significantly bad impact on the network assets.

When you hear talk in the UK of going fully electric in their transport space by 2030, and other countries having very strong incentives to go in the same direction, the transformer asset managers and people working in line ratings are starting to panic, because they are suddenly going to be putting huge loads onto the network that was not designed for that.

Photo: Shutterstock

A small side aspect of that is that many of these inverter-based generation and power electronics control devices are putting quite significant harmonics back into the network that are having an impact on the distribution transformers, which weren't designed for the K-factors coming from the levels of harmonics that are going back into the network. In a lot of cases, if you are talking kVA or kilowatts of charging, that is not even factored into the discussion.

That is a massive challenge as well. In reality, the projects that we are involved in today have been largely focused on demand management of those particular EV chargers. We are involved in projects globally where we provide measurements of the LV network based on measurements done on transformers and at the ends of feeders and circuits, working with utilities that are developing operating envelopes or state estimations for the networks. These estimations suggest what the impact on the network is going to be if we were to switch on a particular charger at certain rates, and how hard we can switch them on before the network starts to sag badly, and then sending out those commands to the charges and having active control over them. That has been really interesting - communicating with customers about whether they want to do the social good and allow us to turn the charger off or if we have to pay them to turn their charger off. There are many social challenges that are involved there.



AR There is going to be another challenge in the United States. Recently, a number of cities such as San Francisco and New York have been looking at making it illegal to build a house that uses natural gas. Safety is one aspect of it, and another is moving away from fossil fuels. Everything is going electric.

SA Yes, and vehicles-to-grid is going to be a very big part of this. People are already putting residential batteries in, and utilities are putting grid-scale batteries in. Here, at the zone substation or the local substation, we are seeing 10 or 20 MW batteries going in. There are a lot of trials of much smaller, 30 kW batteries going up poles in the neighborhoods.

Then there is also Tesla Powerwall and all the other associated residential batteries. The automobile is becoming one of those large battery assets in the network that will be able to be controlled. And, yes, it will be interesting. A lot of these scenarios are partly state or power company-owned, and then in other cases, they are privately owned. And that does tag along onto the Federal Energy Regulatory Commission's (FERC)

Photo: Dynamic Ratings

No matter which country you're in, no matter what language you speak, we are all moving electrons around the network.

Order No. 2222 in terms of the virtual private power plants, in terms of aggregators of (residential) electricity (generation), or it might be (dispatchable demand, such as) electric vehicle chargers.

Here in Australia, there are a couple of companies that do private EV chargers, and they are basically talking to utilities about how they can work together on managing their customer base in terms of charging and vehicle-to-grid connection as a business model in its own right. It will be very fascinating to see how that pans out.

AR You mentioned the FERC Order No. 2222, which enables distributed energy resource aggregators to compete in all regional organized wholesale electric markets. What do you think the impact of that order is going to be on the load management issue?

SA It is hard to say at this point. There is the idea of virtual power plants, VPPs as they are being called here, and it is essentially what is referred to in FERC 2222. There are a lot of organizations in Australia that have been doing this. They have been talking to residential solar owners, telling them that we can pool our purchasing power and buy electricity off the wholesale market, and then sell on the wholesale market at a better rate, and get them better feed-in dollars for their kilowatt-hours. The government regulator for the electricity networks ran a lot of trials across the networks here. They found that, because the networks here need it most, these VPPs are being used as a method not so much for demand control, but more for those frequency control ancillary services. Basically, VPPS are being used as grid support services because they are able to accurately forecast how much residential solar energy will be available. It is very diversified. There is a very large number of generators pooled into one, so it has got a high reliability factor. Battery-based loads have really good visibility as to how much energy is going to be coming in.

AR That is excellent work. Seamus, one of the things that interests me greatly about you is your commitment with CIGRE and IEEE. How long have you been involved, and what does it mean to you to be part of that part of the industry?

SA It is super exciting to be involved in this industry in general. The electrical industry globally is quite small, which makes a nice community to be involved in. Coming into Dynamic Ratings, there were a lot of people involved in IEEE, IEC and CIGRE that drew me in as well. It has been pretty exciting to be part of a company that encourages employees to get so heavily involved in these workgroups. My statement is that no matter which country you're in, no matter what language you speak, we are all moving electrons around the network, around the same transformers and the same wires. It is amazing how many times the wheel has been reinvented in every country. Every power utility has the same problem with voltage management or demand management or transformer oil testing, and they go and reinvent the wheel. It is super exciting to be involved in these global workgroups with like-minded people who are all passionate about the same things, who can share their experiences, the great successes and failures, which can then be used to build the body of knowledge and make advancements.

The more that happens, the more exciting things we get to see. I am currently in the Dynamic Thermal Modeling of Power Transformers workgroup, and I see models that are currently used by most people, which are not that great. But there are so many more technologies available now with machine learning, neural networks, etc. for us to make it better. It is quite thrilling to see how we can use this to improve the utilization of transformers and to be involved in these organizations.

AR That is what collaboration and getting everybody involved does. We want to connect people from around the world and start to share collaboratively.

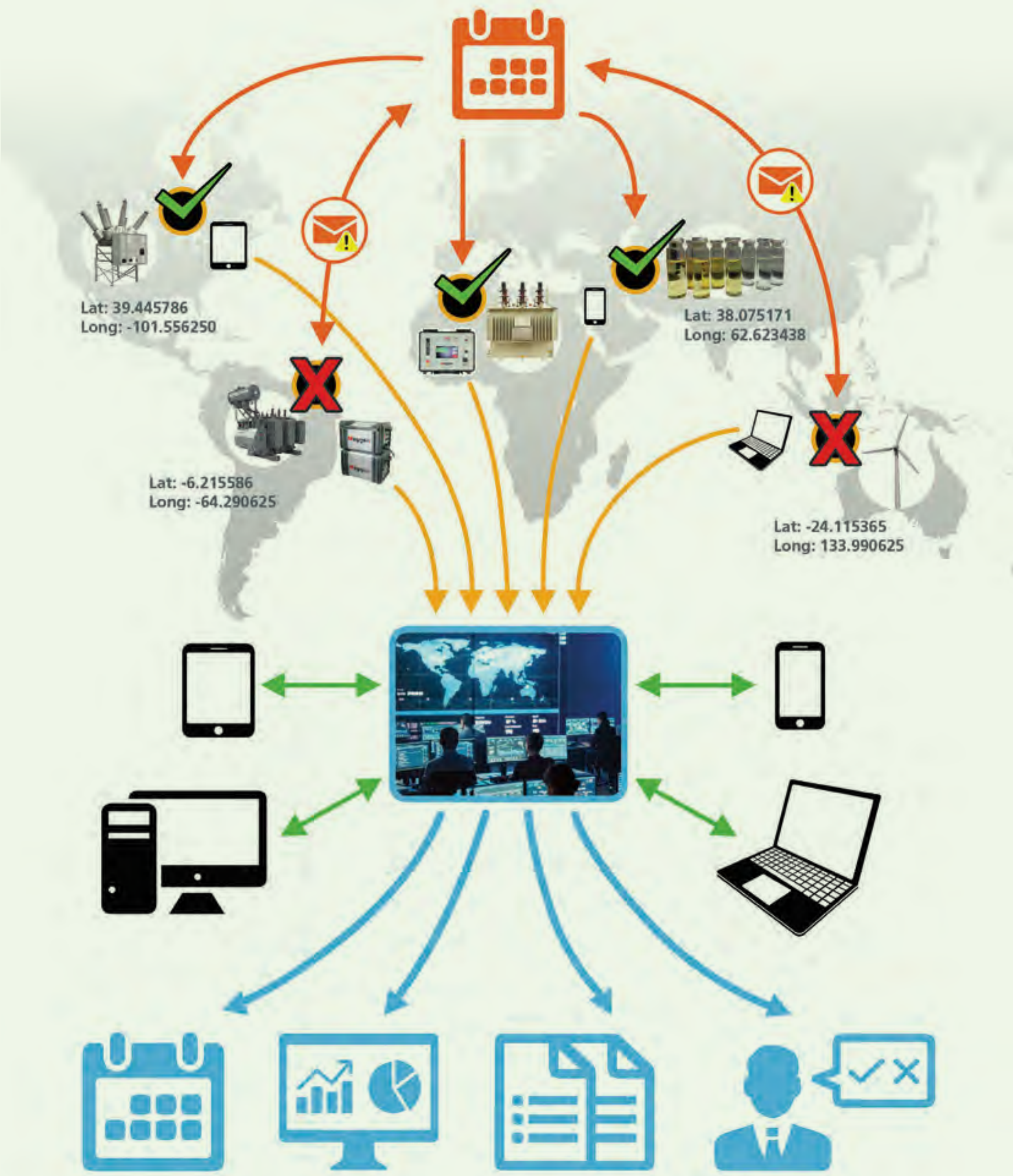
Thank you so much, Seamus, for being part of that great change.

SA Thank you very much, Alan.

Monitoring, Diagnostics and Condition Assessment

What Is the Data Telling Us?

by **Doug Sawyer**
Mark Meyer
and **Brad Perry**



Doug Sawyer is a computer engineering graduate from Texas A&M. He has over 20 years of experience working in the electrical testing software industry with PowerDB Inc. He is currently the Software Development Manager at PowerDB.

Mark Meyer is currently Product Manager for PowerDB Pro Software, where he has provided support for product development, sales, marketing, and customer service for the past 10+ years. He earned his engineering degree from Kansas State University and has over 30 years of experience in the electric power industry. Mark started his career as a utility substation maintenance engineer at NIPSCO Industries, responsible for testing all high voltage substation apparatus. He has been an active member of IEEE, NETA, and ASTM.

Brad Perry is currently National Sales Manager for PowerDB Pro Software, where he has provided support for product sales and marketing for the past four years. He has 20+ years of experience in the electric power industry. Brad has been responsible for the testing and commissioning of various low to high voltage substation assets including transformer dress-outs and repairs. He has managed technical sales of testing equipment as well as rental services.

Photo: Megger

Reliability of the system correlates with monitoring, diagnostics and maintenance of its assets. A chain is only as strong as its weakest link.

Monitoring, diagnostics and condition assessment of power and distribution transformers is a rather broad topic of discussion. Asset managers and field operations staff are challenged every day with the reality of a continuously aging infrastructure and growing loading profiles. Effective asset management solutions are rooted in the clear identification, acquisition, analysis, storage, and management of test data obtained from offline, as well as online, monitoring and testing instruments.

Most field assets are not candidates for online monitoring. Therefore, a systematic approach to monitor and assess the condition of critical devices based on a secure data management system is paramount to the entire electrical industry.

In this article, the authors describe the methods for consistent, reliable, and efficient monitoring and diagnostics of critical electrical equipment including power, distribution, and instrument transformers, based on continuous data acquisition and expert engineering analysis. These methods culminate in notable technical and economic benefits for utility operators and service companies.

High-investment assets must be monitored even before they start their service life.

Monitoring: A Good Starting Point

Asset management and operations & maintenance groups are intrinsically governed by an edict to maximize assets' ROI (returns on investment). Pressure to control OPEX money and extend the service life of assets has moved the gears from Time Based to the Condition Based Maintenance (CBM) process. Modern technology including power electronics, computer science, data processing, and high-speed data transfer, enable a much more efficient and cost-effective approach for monitoring, diagnostics, and maintenance programs than possible before. Today's modern technology allows monitoring, diagnostics, and CBM of almost every substation asset type, diverting unplanned shutdowns and emergency calls.

Every substation asset is critical and performs specific functions in a continuous mode or under transient conditions. All these assets range from high voltage and high power to low voltage and low power, and they are part of the energy transfer, protection, control, or metrology schemes in a well-engineered network. Not all assets have the same high reliability or 40-year life expectancy as a power transformer. As reported by CIGRE TB 642 "Transformer Reliability Survey", the cause of failure of power transformers may not only reside inside the power transformer, but might be an effect derived from the failure of one of its accessories (bushings, tap changes, cooling system) or the failure of external assets such as instrument transformers, cables or grounding connections.

High-investment assets, such as transformers, are and must be monitored even before they start their service life. Manufacturing processes are monitored with rigorous Quality Assurance / Quality Control (QA/QC) procedures. The lives of critical network assets start from sound professional designs that consider the application, environment, and stressors that will be actively speeding up the asset's aging processes. Factory Acceptance Test (FAT) records are the intersection of the Equator and the Prime Meridian (zero latitude and zero longitude). All offline testing is recorded and accepted by the buyer. At that point, monitoring has already started.

Asset management is a strategic science based on 'information'. Data management that renders the behavior and condition of network assets makes a better-informed operations team, now capable of making wiser decisions.

Photo: Megger

The 'Battlefield'

If you do not have the right tool and do not have a clear view of the 'battlefield', chances of winning this war are very slim. It is quite interesting to hear Alan Ross and his EPRA (Electric Power Reliability Alliance) friends discussing 'reliability'; an important topic often not well understood. Do asset managers look at the reliability of specific assets or do they scrutinize the reliability of the entire system? Of course, they prioritize the system. However, "a chain is only as strong as its weakest link."

If one decides to spend all available resources (time, technical, financial) on a single asset, good luck. Asset management is a strategic science based on 'information'. Data management that renders the behavior and condition of all network assets makes a better-informed operations team, now capable of making wiser decisions.

Remember: "no one else runs an operation like yours". Loading factors, environment, accessories, protection systems, etc. are uniquely yours. Consequently, knowing more about the condition of the overall network and how each component presents risk to the reliable operation of the entire system is paramount. Reliability of the system correlates with monitoring, diagnostics, and maintenance of its assets.

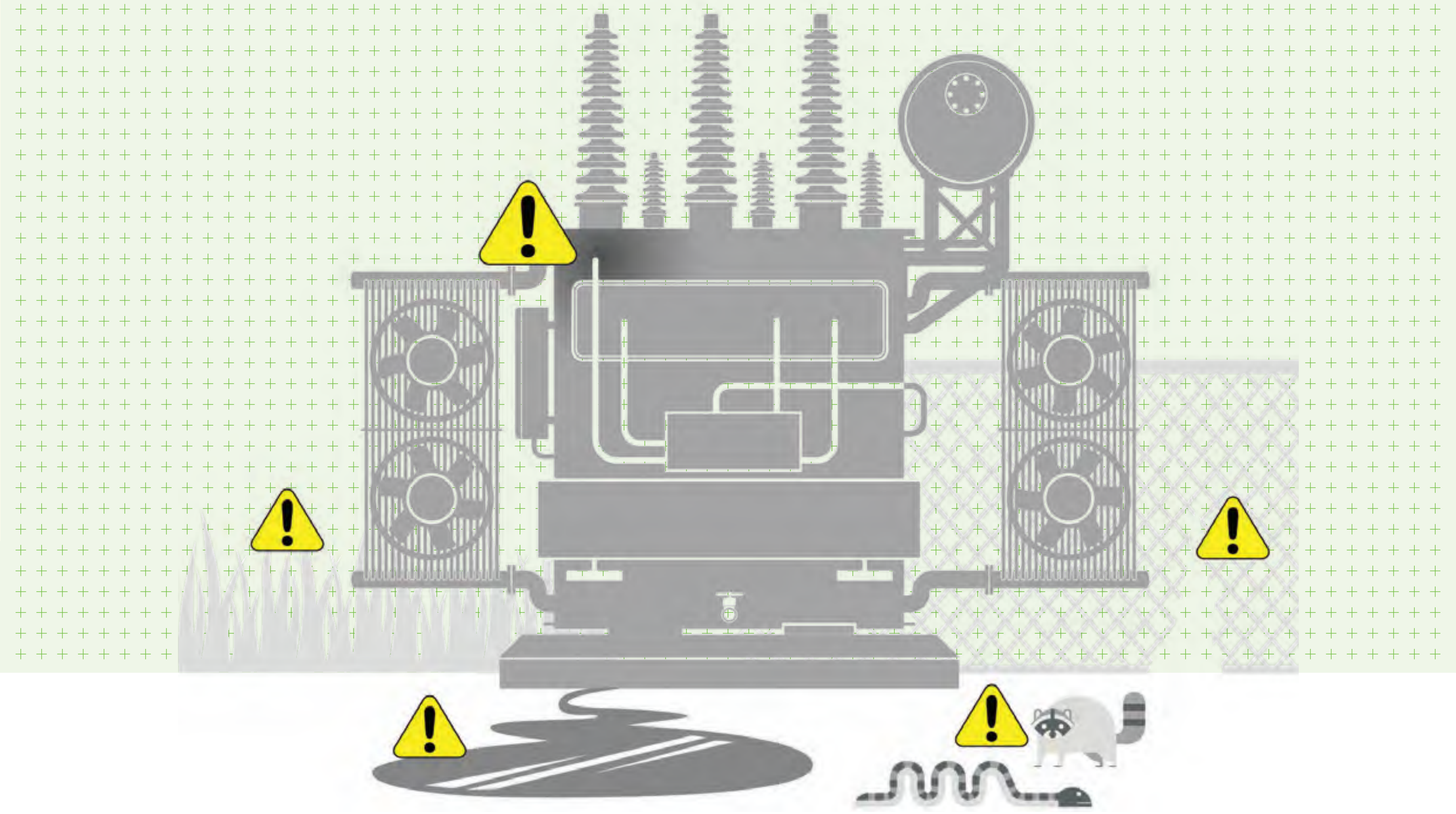
> The lives of critical network assets start from sound professional designs that consider the application, environment, and stressors that will be actively speeding up the assets' aging processes.

Now the question is, how is monitoring carried out on all the network assets? A simple answer is through offline and online measures. High investment assets are very good candidates for online monitoring; others are not. Therefore, the best way to monitor the system altogether is by using a combination of both — offline and online — techniques so that all assets are considered in the reliability analysis.

Offline and Online Monitoring: The Ideal Combo

In the transformer industry, it is well-known that one single test may not be able to pinpoint fault conditions affecting the service life and reliability of the asset. A well-structured and properly supervised monitoring system involving a variety of offline and online (if available) test data is the ideal combo to better assess the condition of individual assets and the reliability of the entire system.

It is not a secret that many utilities operating in the electric industry will implement monitoring systems that will be later validated with offline testing procedures.



As mentioned previously, monitoring starts with a good set of FAT results. From the factory, the unit must be transported to its final destination, e.g., a substation. Therefore, the transformer has already been subjected to mechanical stress. Before start-up, must go through a commissioning and field acceptance process. This testing is fundamental to validate that FAT results have not changed during the transportation process, field assembly has not affected the integrity of the internal components, and contamination was avoided in this process. Testing also confirms that accessories have been assembled according to the manufacturer's and engineering specifications. Commissioning and field acceptance testing generate a baseline record, defining the 'state' of the transformer, before facing network load for the next forty years.

One of the most important, condition-indicating parameters to monitor throughout a transformer's service life is liquid insulation. Whether mineral oil or alternative insulating fluids are used inside a power or distribution transformer, liquid insulation serves many purposes including electrical insulation, cooling of windings and solid insulation, and, not least, a trustworthy source of information. Conveniently, there is no need to de-energize the transformer. An oil sample is taken following the best ASTM or IEC recommendations, and is either tested on-site or sent to a lab for analysis. The most common testing practices carried out in the field are dielectric breakdown and dissipation factor testing. A complete analysis of the oil performed in the utility lab, or a lab of preference, will generate a trend covering physical and, chemical characteristics, as well as diagnostics metrics based on gasses dissolved in oil or other methods, including Furanic compounds quantification, and degree of polymerization estimation.

A well-structured and properly supervised monitoring system involving a variety of offline and online test data is the ideal combo to better assess the condition of individual assets and the reliability of the entire system.

Data Management: We Know the Symptoms – Let's Run Some Diagnostics

There are two offline data acquisition approaches: rely on internal resources to perform testing or contract testing out.

In either situation, offline testing might be carried out with a variety of testing instruments of different brands and data capturing capabilities. One might imagine the inefficiencies of managing several reports in different formats, being manually added to a bigger database wherein human transcription error becomes a factor. Thankfully, modern technology allows the transfer and conversion of offline test data into a single template that will allow the next important step in the process – Diagnostics.

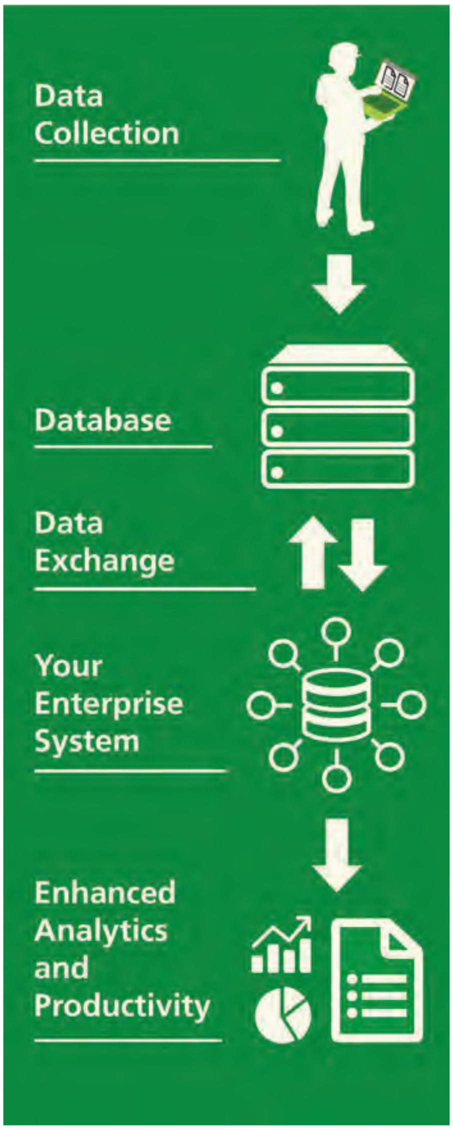
Now we step into the diagnostics section. Multiple tests carried out on a specific asset are far more revealing than a single test alone is. Each test examines a unique facet of an asset's health and, when thoughtfully grouped, provide a comprehensive view of the asset's present-day condition. In the next step, trending of critical information determines characteristic changes in the operation or the condition of a monitored asset.

Insulation data trending analysis, including line-frequency power factor, oil physico-chemical, dissolved gasses in oil, and insulation resistance testing, among the most relevant, has been a preamble for instantaneous condition assessment, additional investigation, and forecasting of maintenance activities. The testing program will be designed to ensure that, as far as possible, incipient faults are detected before they progress to failures and that assets are replaced when they have genuinely reached the end of their useful service lives, whether or not this coincides with the end of their nominal service lives. As well as the type of asset under consideration, the formulation of the testing program will acknowledge the criticality of the asset, the criticality of its function, and its operating conditions. Critical assets operating in severe conditions will, for example, be scheduled for the most frequent testing.

Once captured, test data is stored in a database, and the databases from multiple devices running should be synchronized into a single, central database for added security and to ensure wider accessibility. It is even possible to merge data imports from other sources — such as external databases — to aid analysis and trending.

The capabilities of advanced data management, however, go far beyond

Well-designed monitoring, diagnostics and maintenance programs must provide the tools to incorporate scheduling of activities and to correlate those with specific compliance state or federal regulations.



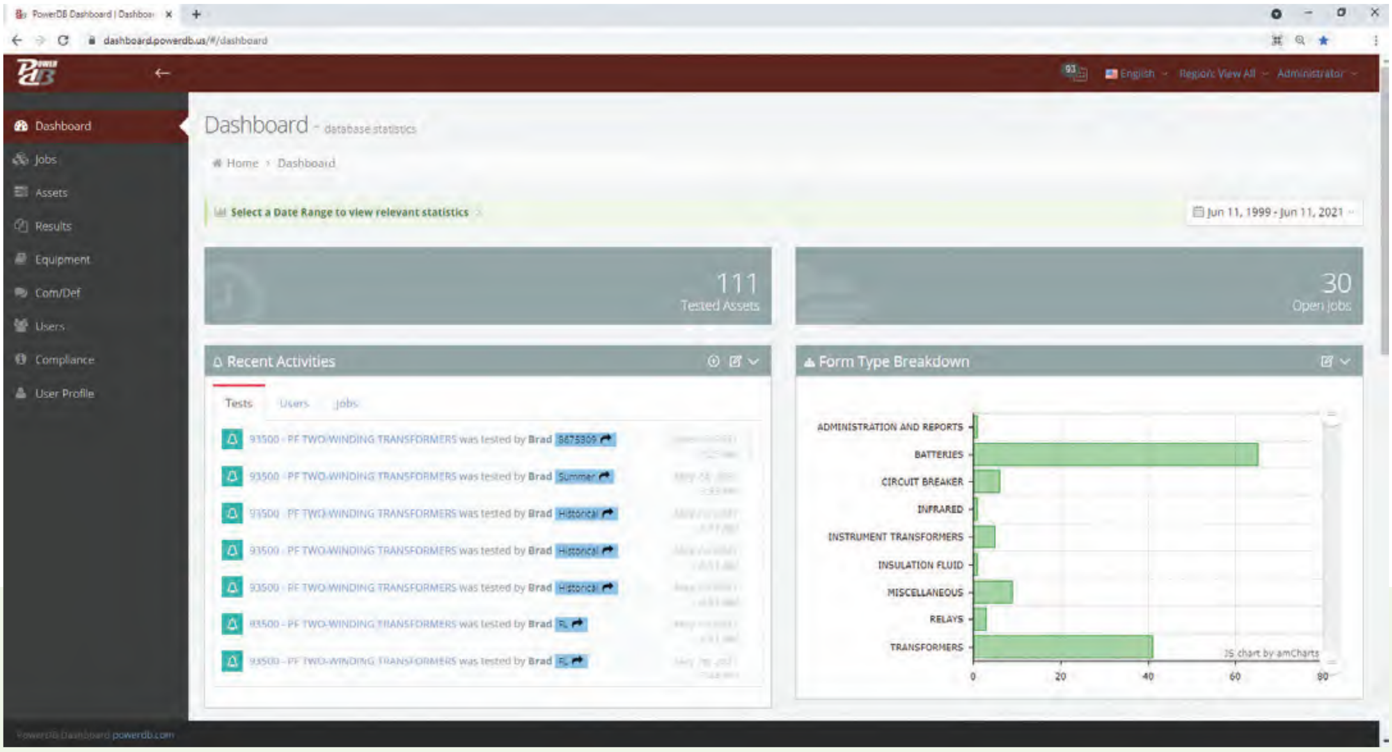
simply collecting, organizing, and storing data; although, these are the central elements of its functionality. Ultimately, the goal should be to create a system that allows for data analytics. The testing life cycle for these systems spans years. Therefore, to prepare data for analytical dashboard tools like PowerDB, Dashboard, or Tableau, several steps need to be taken to begin to create and maintain a quality data store.

Three key requirements for an effective program of regular testing are scheduling, consistency, and documentation.

To help ensure consistency in work practices and reports, and to provide an intuitive user interface, the database must provide dedicated forms for data entry, instantaneous and trending data display, and printed reports. As mentioned before, the battlefield is wide and many assets play an important role. It is not only important to have a good reference of a specific power transformer, but also fundamental to know the condition of its metering and protection devices, such as current or voltage transformers; other accessories mounted on the transformer, such as bushings and on-load tap changers (OLTC); and even better, if in the entire database there is information about circuit breakers, cables, battery banks, generators, motors, grounding system, capacitor banks and other substation components, which overall reliability of the substation is dependent.

Moreover, once these dedicated forms are chosen, a system must be in place to ensure they are used exclusively going forward. This is a common challenge when an asset owner uses a mix of internal technicians and one or more contractors to complete offline testing, but this can be accomplished by using a common testing database across all users. Little changes—like a variation in serial number entry or a change of units of a test result—do little to affect the outcome of a single test report. However, this can cause major headaches when mining the data for trending or other analytic purposes.

Photo: Megger



An added benefit of a centralized testing database is that it can be configured to integrate with computerized maintenance management systems (CMMS). Enterprise-wide CMMS strengths are typically organizing all assets and scheduling maintenance activity. However, they fall short in facilitating the collection of granular test data. Integration between the two allows the CMMS system to focus on what it does best, without having to sacrifice the collection of the detailed test data. An ideal integration would have the work orders created in the CMMS system, flow into the Testing Database, and as the testing is completed, that CMMS would be updated with the key testing metadata. The Testing Data would then keep all detailed testing data for future trending and analysis.

The ultimate payoff of this system is the ability to use analytic tools for assessing asset health, trending like assets, auditing compliance and future scheduling.

Time for Action: Maintenance, Technical and Financial Decisions

As the symptoms are detected, a diagnosis is elaborated based on a variety of sources, and, of course, actions are expected from maintenance managers.

The decisions might be quite different: no immediate action required; maintain components as per CBM; prepare for major shutdown and a potential replace of components; or remove from service.

Maintenance activities are better when there is a process to plan them. Having enough time allows for a more convenient technical and financial solution, proper scheduling of specialists to perform the work, ordering of spare parts and tools, etc. Well-designed monitoring, diagnostics and maintenance programs must provide the tools to incorporate scheduling of activities and to correlate those with specific compliance state or federal regulations. In North America, an optional compliance view makes it easy to monitor compliance with NERC-mandated testing schedules or simply to track regular testing of assets or groups of assets. Users can create compliance categories and sub-categories and assign these to individual assets or groups. Powerful filtering capabilities then make it a simple task to determine the compliance or maintenance status of these assets or groups.

A modest investment in software unlocks big gains in asset reliability. This, in turn, saves money and eliminates disruption.

A wide range of analytical functions is available for processing test results. These include the generation of an asset 'health index' based on information acquired from multiple tests and failure studies that can provide revealing insights into the failure rates for a population of assets.

Carefully planned testing is undoubtedly the surest route to maximizing asset reliability, but it is only effective if the tests are carried out on schedule using prescribed procedures, and the results are properly organized, stored, analyzed, and reported. These requirements might seem onerous, but there are powerful software packages designed specifically to meet the needs of the electrical power sector, providing a complete and cost-effective solution. Simply put, a modest investment in software unlocks big gains in asset reliability. This, in turn, saves money and eliminates disruption!

PARTNERSHIP AND PLANNING

THE BENEFITS OF A PARTNERSHIP PROGRAM WITH YOUR TRANSFORMER BUSHING MANUFACTURER

Since the beginning of the COVID-19 pandemic, the global supply chain has faced unprecedented and complex challenges. For manufacturers, these supply chain challenges have caused considerable disruption, exposed risk, and have driven many to reconsider their existing methods of reshoring and moving manufacturing. As companies continue to navigate the issues in the evolving global supply chain, and as industries that invested heavily in outsourcing, offshoring and lean manufacturing continue to experience dramatic increases in risk, the need to protect against serious and costly supply chain disruptions is paramount.

This is especially true for transformer manufacturers. For many transformer manufacturers, finding materials to build their products used to be a fairly straightforward task of calling suppliers and placing orders. But, with the disruptions caused by the pandemic negatively impacting supply, and with demand being driven by natural disasters, such as the forest fires currently plaguing many parts of North America, manufacturers are finding it more difficult than ever to deliver for their customers.

So, how can transformer manufacturers insulate themselves against supply chain disruption, mitigate risk, and even grow their business during uncertain times? It often takes a change in mindset. Companies that are proactive and agile, and that are open to new options, practices and procedures are better equipped to respond to unforeseen events, take corrective action, reduce negative impact on their business, and ensure their future sustainability. In a word: planning.

Photo: Shutterstock, CrossLink Technology Inc.

The importance of planning

Many transformer manufacturers are feeling the pinch right now, but the ones that are feeling it the most are those that have not made it a priority to determine and plan their future materials needs. While it's impossible to plan for every contingency, by reviewing past sales data, current market trends, as well as making reasonable forecasts for upcoming potential business, transformer manufacturers can mitigate their risk, maintain the flow of material resources, and protect themselves against market and supply chain volatility.

Through its partner program, Crosslink works closely with its multi-national transformer OEM customers to help them plan their inventory and material requirements, and ensure crucial products are delivered on time, every time.

The importance of partnering

There are many benefits of partnering with a supplier who understands how to help you plan your inventory. Planning your inventory helps you increase your chances of having on hand the necessary resources you need to meet the required lead-times and avoid long material queues. This, in turn, can help result in considerable cost savings, greatly mitigate the risk of your product sitting on the dock waiting for parts, and avoid costly penalties for not delivering on time. The key is finding and working with a supplier who understands the value of forecasting and inventory planning, has the experience and resources to help you plan effectively, and crucially, is willing to warehouse the added inventory.

Crosslink Technology

Crosslink Technology is a vertically integrated company that formulates and manufactures epoxies, a key material in the creation of cast components. Crosslink's business model allows for greater direct control of manufacturing and supply chain processes, mitigating supply chain risks and issues for its customers. Through its partner program, Crosslink works closely with its multi-national transformer OEM customers to help them plan their inventory and material requirements, and ensure crucial products are delivered on time, every time.

Crosslink's partner program delivers on short-notice 500% order increase

The ability for Crosslink to deliver in this crucial situation stems from the foundational approach of spending the time upfront to develop a planned release system with a back-up supply of key raw materials. This type of planning is highly effective for ensuring the continuous delivery of material to maintain day-to-day operations, and serves as a strong infrastructure for delivering greater quantities of materials in emergency situations and during demand spikes.

Mike Groves is Crosslink's national sales director. He says working with customers to develop custom inventory plans and scheduled deliveries has greatly helped customers predict their inventory needs, maintain the flow of business, and created a strong sense of trust and teamwork between Crosslink and its customers.

"We keep two releases ready for this particular customer to ensure we keep a two-week lead time for their releases, and beyond that, to help in critical situations where we have an unexpected demand-spike," says Groves. "Our dedicated account team intimately knows our customer's business, which allows us to understand their requirements and work with them as a partner rather than as just another supplier."

Crosslink's partner program is founded on four key pillars of success, including lead time and delivery, capabilities and expertise, communication, and quality.

Key components of a supplier-customer partnership program

Partnering with suppliers to develop strong and beneficial relationships over the long-term can mitigate risk and contribute to business continuity and growth. Crosslink's partner program is founded on four key pillars of success, including lead time and delivery, capabilities and expertise, communication, and quality.

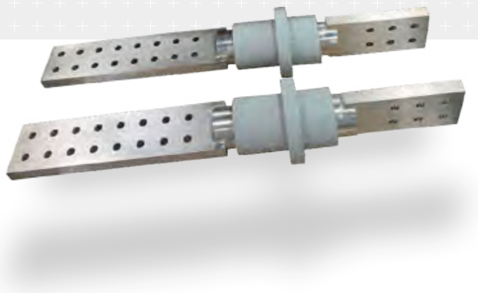
Lead time and delivery

Crosslink's partner program emphasizes working closely with partners to understand their businesses, including their challenges, strategic goals, and other important factors, and then develops custom inventory and delivery plans to meet client needs. Crosslink regularly works with customers to develop customized plans including scheduled monthly deliveries, quick turnaround requirements, long-term delivery agreements, stocking programs, direct-to-end-user shipping and labelling programs, raw material volatility procurement plans, and inventory management plans. Crosslink's close relationship with clients ensures important information is communicated both ways, so amendments to existing plans can be easily made as customers' businesses grow and evolve.

Capabilities and expertise

Crosslink offers in-house expertise on all fronts, including a variety of skill sets: engineers, designers, tooling specialists, manufacturing teams, as well as designated account and product managers. This combination of expertise helps keep all parties aligned and ensures an efficient process from start to finish, as well as the consistent delivery of high-quality products. In addition to expertise, Crosslink is equipped with a range of specialty equipment, resources, and manufacturing facilities to manufacture products and scale production to meet the needs of any customer.

Crosslink has collaborative multi-functional specialists with a variety of expertise to ensure all technical and business aspects of its customers' supply needs are addressed and accounted for.



Communication

Effective communication is critical for the success of any relationship, and especially so when choosing suppliers. A supplier may provide exceptional quality products, but if they are not adept communicators, it could lead to serious disruption for your business. To ensure that your product vision is executed according to plan and communicated at every stage of the design and manufacturing process, you need a partner that speaks your language – literally and figuratively. Crosslink emphasizes effective communication as part of its company culture, and incorporates communication strategy and tactics throughout its processes. Crosslink has collaborative multi-functional specialists with a variety of expertise to ensure all technical and business aspects of its customers' supply needs are addressed and accounted for. For each customer, Crosslink designates a single team member to act as a point person to manage the customer's account and ensure efficient project management. Crosslink's specialists are easy to contact and provide partners with quick and accurate responses. In addition, Crosslink's diverse workforce allows the company to communicate in a number of languages.

"Crosslink is capable of efficiently and cost effectively transforming an original idea into a unique end-product, handling every step of that process."

Mike Groves
Crosslink's National Sales Director

Quality

When choosing a supplier, it's important to ask them about their processes and certifications, and do your due diligence to make sure the supplier places emphasis on the quality of what they produce. Crosslink follows best-in-class manufacturing techniques, adheres to the highest safety and quality assurance standards and practices in the industry, and is backed by stringent ISO certification.

About Crosslink

Since 1981, Crosslink Technology has earned a reputation in the industry for consistently delivering high-quality products.

Crosslink primarily works with OEMs and ODMs, and has a research and development team dedicated to continually improving the company's transformer bushings and parts offering. As an OEM partner, Crosslink creates products, parts, and pieces of equipment used in the manufacturing of other end products. Crosslink also partners with OEMs to create specialty cast parts based on their designs. As an ODM, Crosslink can work with its partners to both design and produce custom products.

"With our product design, electrical engineering, tooling, testing and manufacturing capabilities, we can provide customized products from first article inspection through to high volume production," said Groves. "Crosslink is capable of efficiently and cost effectively transforming an original idea into a unique end-product and handling every step of that process."

As the world continues to manage the difficulties of the current supply chain disruption, transformer manufacturers can benefit from partnering with companies that understand their issues, and are proactive in developing solutions that ensure the profitable continuity of business.

"Companies that want to stay ahead and maintain an efficient supply chain process would be well advised to focus on planning and partnership," said Groves. "Working in partnership with suppliers like Crosslink Technology can help you reduce price volatility, mitigate risk, and provide supply chain predictability."

Crosslink follows best-in-class manufacturing techniques, adheres to the highest safety and quality assurance standards and practices in the industry, and is backed by stringent ISO certification.

Monitoring High Failure Rate Transformer Subsystems with Automated Thermal Imaging

by **Richard Harada**

Richard Harada has more than 20 years of experience in industrial networking communications and applications. Prior to joining Systems With Intelligence, Richard worked at RUGGEDCOM and Siemens Canada, where he focused on industrial communications in the electric power market. Richard is an electronic engineering technologist and has a Bachelor of Science degree in computer science from York University in Toronto.

Dual thermal and visual sensor monitoring of a transformer

Photo: Systems With Intelligence Inc.

Monitoring

Introduction

Some of the most common failures on transformers are in the subsystems that are physically located outside the main enclosure or tank of the transformer, making them suitable targets to monitor with infrared sensors. The operation of the transformer is only as good as its worst performing subsystem, therefore monitoring and maintaining the performance of each subsystem is equally important.

Some of the most common failures on transformers are in the subsystems that are physically located outside the main enclosure or tank of the transformer.

The transformer subsystems that are the leading causes of unplanned outages in substations are bushings at 21.6%, on-load tap changers at 29% and the cooling system at 8.7% [1]. From the Canadian Electricity Association report on Forced Outages, these subsystems and components together make up the majority of substation outages.

This article will look at how these subsystems can be better monitored to provide health data and advanced warning of failures to reduce the number of unplanned outages that utilities must deal with. With this data, utilities can begin to deploy Transformer Intelligent Condition Monitoring (TICM) to strive for "optimal preventive maintenance planning, reduced equipment unavailability and increases in reliability" [2] with their available resources.

Background on Thermal Imaging

Thermal imaging is able to measure the infrared radiation from an object and convert it into a temperature value. An important feature of thermal imaging is that it is 'non-invasive'. It uses a sensor that can measure temperature values without physically touching the object, therefore it is not required to power down equipment to install the sensor or to make the measurements.

Infrared measurements are affected by many environmental factors including temperature, humidity, wind, distance, and emissivity of the target object. With these factors in mind, it is difficult to obtain an accurate temperature measurement in an outdoor environment. It is often more meaningful to use comparative measurement; comparing the temperature differences between like components instead of trying to measure an absolute temperature value. A comparative measurement will effectively cancel out the environmental variables.

An advantage in the electric power industry is that the power system runs on three phases, so in many cases inside a substation, it is possible to measure like components on different phases, such as measuring the temperature difference between the A, B and C phase transformer bushings [3]. In this case, instead of trying to calculate what an absolute temperature value should be, it is simpler and more meaningful to compare temperatures between phases. Typically, the temperature of like components should be within 1°C of each other; if not, there could be a load problem or a component problem in the system. The International Electrical Testing Association (NETA) has established a guideline of comparative measurements and relative comparisons to ambient temperature. As outlined in Table 1, NETA has recommendations for actions to take when comparative readings reach defined levels.

Portable infrared cameras have typically been used by thermographers to periodically inspect substations and other key areas of the grid. While periodic scanning is useful, automated, and continuous thermal monitoring has many advantages such as being able to provide measurements during changing environmental and load conditions, as well as being able to provide the data directly to operators, SCADA, and asset management systems.

Transformer subsystems that are the leading causes of unplanned outages in substations are bushings at 21.6%, on-load tap changers at 29% and the cooling system at 8.7%.

Table 1. Recommended temperature thresholds and actions for monitoring electrical components. Source: NETA World – Infrared Inspections and Applications

Temperature difference (ΔT) based on comparisons between similar components under similar loading	Temperature difference (ΔT) based upon comparisons between component and ambient air temperatures	Recommended Action
1°C - 3°C	1°C - 10°C	Possible deficiency; warrants investigation.
4°C - 15°C	11°C - 20°C	Indicates probable deficiency; repair as time permits.
- - - - - -	21°C - 40°C	Monitor until corrective measures can be accomplished.
>15°C	>40°C	Major discrepancy; repair immediately.

Monitoring the On-load Load Tap Changer with Infrared Sensors

Since the on-load tap changer (OLTC) is one of the highest failure-rate subsystems of the transformer, it is a key subsystem to monitor to ensure it is operating optimally. Some of the more common failure modes in the OLTC produce heat that can be detected by an infrared sensor. These failure modes are mostly due to the defects in the contacts including alignment problems, wear, pitting and coking. The effect of these defects is to create reduced surface area between contacts which will cause an increase in temperature due to the I^2R factor. Since the infrared sensor is reading the temperature of the OLTC enclosure, an absolute temperature reading would have little value. A temperature threshold may never be reached on a very cold and windy day, or a false alarm may be generated on a very hot day. To overcome the environmental variables, a comparative measurement should be made between the OLTC enclosure and the main tank of the transformer. If the OLTC enclosure ever exceeds the temperature of the main tank, then there is some localized heating taking place. If the defect is only in one phase, then the localized heating may be evident in that section of the OLTC enclosure.

The problem may exist at only one OLTC setting if only one set of contacts is defective. Possibly an overload condition caused current to flow beyond the rated capacity of the contacts and caused pitting on that set of contacts. This means excessive heat will be generated only when the OLTC is in that position. It can then be determined which contacts are damaged by correlating the rise in temperature delta with the switch position.

> **While periodic scanning is useful, automated and continuous thermal monitoring is able to provide measurements during changing environmental and load conditions, as well as to provide the data directly to operators, SCADA, and asset management systems.**

It may also be the case that heat problems are detected at a particular time of the day. This could indicate a problem with the contacts that only shows up under heavy load. The I^2R factor will produce more heat in the contacts when there is high current flow, a problem that may not be revealed by periodic thermal scanning.

Depending on the conditions, the overheating problems in the OLTC may be transient, only occurring under specific conditions or on a particular set of contact points. Due to the transient nature, periodic infrared inspection may miss the problem where an automated, full-time monitoring system will find it. Additionally, an automated system will collect and store temperature data, allowing it to be trended and correlated with weather and load current to further narrow down the problem. OLTC temperature data can also be correlated with the tap position to help isolate which contact points require maintenance.

The Cooling System

Proper operation of the cooling system is critical for optimal operation of the transformer and

Monitoring

A single thermal and visual sensor can be used to monitor hundreds of points in a substation when set to automatically patrol a site

Monitoring

preservation of its life expectancy. An overheating transformer can damage the winding insulation, causing shorts and possible catastrophic failure.

Infrared sensors can monitor bushing temperatures without a physical connection making it an easier and more economical method to continuously monitor many points without the high cost of installation.

Monitoring of the cooling system ensures that all its components are correctly functioning and the transformer is operating within its designed temperature ratings.

Using infrared temperature monitoring allows several cooling system components to be monitored using a single sensor. The infrared sensor detects the heated oil as it enters the top of the radiators and cooling oil as it flows down. This pattern will show the oil being cooled as it moves through the system when it is operating correctly. Deviations between radiators can indicate several issues such as failing pumps, blocked radiators, coolant level problems, or leaks. Comparative thermal measurement can be done between like radiators to determine that they are operating correctly. Comparative measurement can also be done between the top and bottom of the radiator to determine the cooling delta that is being provided. Coolant level in the conservator can also be monitored.

Cooling fans are an integral part of the system and are required to provide air flow through the radiators to dissipate heat from the coolant. As the fans operate, the motors will generate a heat pattern that can be monitored by the infrared sensor. Comparative measurements can be made between cooling fans to ensure they are operating at the same temperature. Fan motor temperature measurements should also be correlated with the fan control signals to ensure they are operating when they are supposed to be and are not overheating due to worn bearings, etc.

Automated thermal systems collect data continuously, providing a wealth of information to the utility.

Transformer Bushings

Bushings are among the most common subsystems on the transformer that fail. Many bushing tests, measurement or monitoring techniques require an outage to perform the test or to install the test equipment. Infrared sensors can monitor bushing temperatures without a physical connection making it an easier and more economical method to continuously monitor many points without the high cost of installation.

Before failure, it is likely that the bushing will develop excessive heat that can be detected using an infrared sensor. The most common deficiencies that are detected with infrared sensors are due to insulation degradation causing arcing or a mechanical connection problem with an I^2R fault. As with most situations it is recommended to use comparative measurement between the bushings

Snapshot from a thermal sensor shows a visual representation of asset temperatures

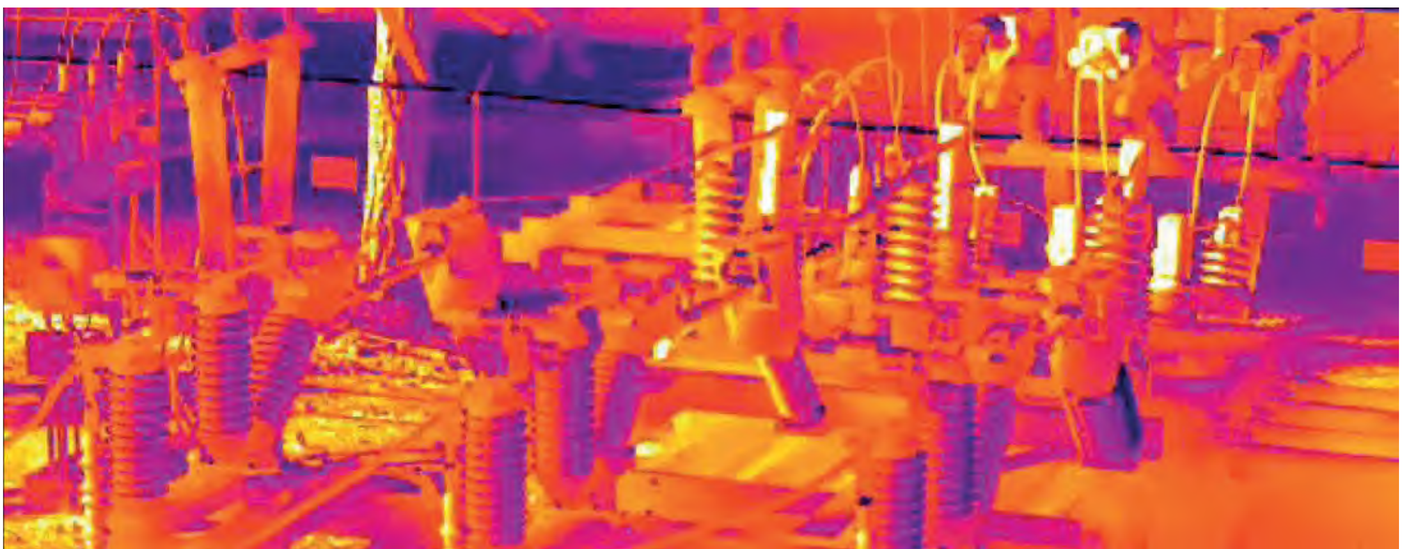
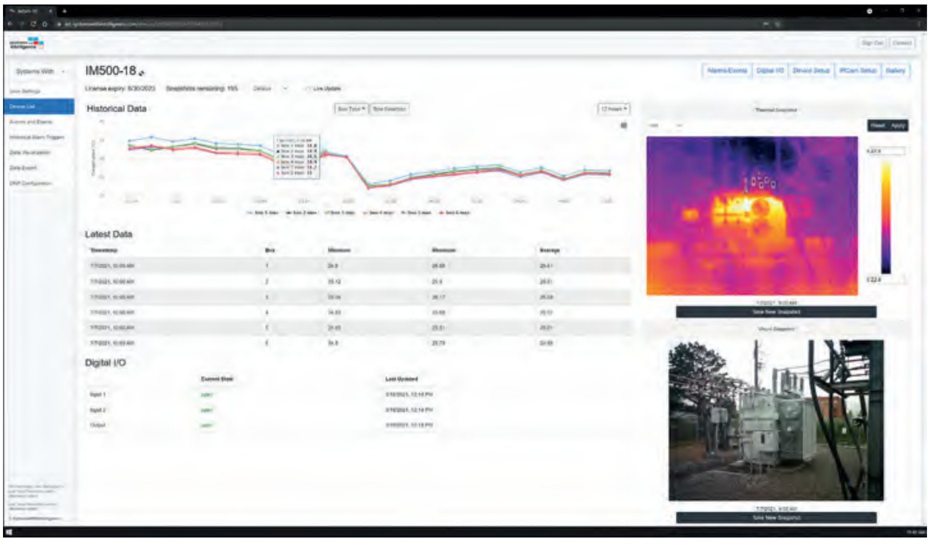


Photo: Systems With Intelligence Inc.



Thermal monitoring dashboard

to eliminate the environmental effects on the temperature reading. Any temperature difference of more than 4°C is an indication of a problem that requires repair [3]. Alarms should be set in the monitoring system to alert operators of the condition so maintenance can be scheduled.

Monitoring the Main Tank

The infrared sensor will only be capable of monitoring the outer wall of the main tank; however, there is still valuable information that can be obtained, especially when correlated with other data. As it has been stated, an accurate absolute temperature is difficult to obtain in an outdoor environment; however, the temperature pattern and rate of change can be an indication of problems in the transformer windings. If temperatures of the transformer tank are increasing under the same weather and load conditions, it may be an indication of internal arcing. This may also be indicated by a hot spot in localized area of the tank since arcing occurs at a very high temperature.

Other Equipment

There are many other pieces of equipment around the transformer that should also be monitored with thermal imaging including arrestors, CTs, VTs, breakers, disconnect switches, etc., as these devices have insulation and connection points that can degrade and become an issue in the substation.

Processing the Data

Automated thermal systems collect data continuously, providing a wealth of information to the utility. Systems with built-in analytics can raise alarms as soon as an out of tolerance condition is reached, providing the utility an opportunity to correct the problem before a failure occurs. Additionally, the data can be stored and exported to other systems such as SCADA or asset management. Machine learning systems can analyze and detect anomalies from thermal data and images, correlated with other data such as weather, time of day and electrical load. Machine learning can go into much further detail and enable more accurate detection of faults in transformer components than manual data interpretation.

Summary

Advancements in infrared technology and the communications around it make thermal monitoring more widely available through reduced cost, ease of use and accessibility to the data. Automated thermal inspections can be used for more than just finding hotspots in the electrical system. With advanced analytics correlated with external information such as load and environmental conditions, thermal sensors can isolate and help utilities pinpoint the most common transformer problems before failures occur. An automated, online monitoring system improves the safety of utility operations by reducing operator exposure to hazardous environments while reducing maintenance costs and unplanned outages through deployment of Condition Based Maintenance (CBM) [4], or the more focussed Transformer Intelligent Condition Monitoring.

Advancements in infrared technology and the communications around it make thermal monitoring more widely available through reduced cost, ease of use and accessibility to the data.

References

[1] Canadian Electricity Association, Forced Outages Report
[2] Cigre Working Group A2.44 – Guide on Transformer Intelligent Condition Monitoring (TICM) Systems
[3] Don A. Genutis, Netaworld, Infrared Inspections and Applications, 2006
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SWI Cloud Dashboard

Senja Leivo

Interview with **Senja Leivo**

Senior Industry Expert
at Vaisala Oyj

"Power industry is very fascinating. We have new technologies coming in, but we still have very old assets combined with those new technologies. That offers a lot of different and interesting opportunities.

Photo: Vaisala

In an interview for Transformer Technology magazine, Senior Industry Expert at Vaisala Oyi Senja Leivo talks about her professional journey in the power industry, her role in developing Vaisala's breakthrough solutions for transformer gas monitoring, and reminds us of the importance of hearing the voice of the customer.

Photo: Vaisala

Alan Ross: Senja, you are deeply involved in Vaisala's global efforts to provide innovative measurement solutions. Could you tell us a little bit about your background and your journey into the power industry?

Senja Leivo: I think I have had quite a long journey. I definitely had not planned to enter the power industry. I started as a research scientists working on biomaterials with medical professionals. Then in 1999 I came to Vaisala and that is how I ended up in the technology industry. One of the first products I was involved with were moisture probes that were already used at that time for monitoring moisture in transformer oils. That's how it all started.

AR Moisture probes are still a very big industry in the transformer world. With over twenty-one years in that world, you must have witnessed a generation shift. What would you share with the next generation about coming into this industry?

SL I see power industry as very fascinating. It offers a lot of different opportunities. What I value a lot is that we have a variety of people working in the industry, all very experienced. Some of them have been working for decades and still continue to work within the industry, even though they have retired. We have new technologies coming in, especially in the IT world, but we still have very old assets combined with the new technologies. That offers a lot of different, interesting opportunities.

where I belong organizationally. At the time when I started, the instruments were mostly generic products used in a wide range of industries. Many still are, but over the last few years we have focused on certain industries. The power industry is one of them and we have developed power-specific products.

AR With the US government planning to spend $43 billion on the transmission of wind and solar energy in the next decade, we can see that this is an amazing time for change, and Vaisala will definitely be part of that. I am particularly interested in your transformer monitoring. You are working on something completely different than the classic DGA and monitoring solutions. What is it specifically that you have worked on for Vaisala?

SL Roughly four years ago, we launched the online DGA monitor. We worked a lot with our customers, discussing questions such as what gases need to be measured - obviously, the seven fault gases that are used for diagnostics. But then there was a question of oxygen and nitrogen, which were often in the specifications. I tried to understand why they are there, because neither of them is a fault gas. After some research I learned that oxygen is the one accelerating the ageing of the transformer insulation. You don't really need to know the exact concentration, but you need to know whether your sealed transformer is exposed to air ingress, air being the source of oxygen. I started to think about how that could be done in an easier, simpler way.

At Vaisala, we have a different way of controlling the operating processes in the DGA monitor. Once we extract all gases from a drawn oil sample under vacuum, it is easy to measure the pressure of those gases in a controlled environment. If we have a sealed transformer and we see that the total gas pressure is starting to increase, that is always an indication of air ingress into that sealed transformer.

AR I agree. Many people see the power industry as old, but it is fascinating and very dynamic right now. Vaisala has been present in the industry since the 1930s. It is a global company with great reputation. You are currently doing some new things in the market. Tell us about some of the changes at Vaisala overall, especially those that relate to the technologies in the markets we serve.

SL When I started with the company, it had two main business areas, which are still here today. One is the Weather Observations - which is the origin of the company and is still a big part of it. The other is Industrial Measurements,

I looked at the data of one of our first prototypes. We had the sensors and the needed operational processes in place already. This means that we could measure the pressure of all extracted gases. That earlier prototype version was in a transformer that was free-breathing, but it was degassed after the repair of a thermal fault. When I looked at the data from different sensors, I realized that the pressure was increasing over the months after the degassing, and that was a clear indication of air coming in.

That was when I got the idea, which I discussed with my colleague scientists, that that could be a useful parameter - instead of measuring oxygen and nitrogen where you don't need the numbers, you just need to know if there is any air ingress. That is where we started, and it is now implemented into the monitor.

AR Being very familiar with DGA gas monitors, I am interested in what you do differently. How would you describe the difference in the way Vaisala's monitoring technology functions?

SL One main difference is in the way we operate the monitor and measure the gases. We have a metal cylinder where we extract the gases from the drawn oil sample under vacuum. Oxygen and nitrogen have very poor solubility in oil so they also tend to come out easily. When we do the extraction, we get all of the oxygen and nitrogen from the oil. Once we have extracted the gases, it is easy to measure the pressure of those in a controlled environment. The fault gases always represent a negligible part of the pressure. If we have a sealed transformer and we see that the total pressure of the gases is starting to increase, this is always an indication of air ingress into the sealed transformer.

AR That is a completely different way of looking at it. If I owned a transformer fleet and I used your monitor, where does the data go once you detect the air ingress from the pressure, and how do I interpret it?

SL We also measure the fault gases – hydrogen, methane, acetylene, ethylene, ethane, carbon monoxide and carbon dioxide – the seven gases that are used for diagnostics purposes. In addition to those, we have the total gas pressure. The use of data usually depends on the utility and their existing systems. The data usually goes into the utility's centralized monitoring system. If it is an older utility, they may even take that data into their supervisory control and data acquisition system (SCADA). But most modern utilities have a separate asset monitoring system because they use the SCADA as an operational system, and they don't want the overflow of data coming into the SCADA.

This data is part of the information on the transformer condition, indicating if it is supposed to be sealed from ambient air. If the data shows

Photo: Vaisala

Within our organization, I am the one bringing the customer's voice into our development. I have the privilege of knowing a lot of people within the industry, so it is rather easy to check ideas with different people.

a recent ingress of air through the total gas pressure increase, then the technicians can decide if there is something they need to check during the next service break, for example, look at the sealing or gaskets, check for a broken membrane, etc.

AR I love that your solution shows that the air leak is part of the overall data. Everybody is trying to say their one product should tell you everything they need to do, and it never works that way. The whole data set and the trending analysis is the answer. Does Vaisala do the trending analysis of the pressure that allows you to detect the type of leak?

SL Yes, in the user interface, there is a graph for the gas pressure, so you can see whether it is increasing or it is stable. Especially with new transformers, the gas pressure should

An idea that I got from a customer is that total gas pressure could be used as a quality control tool in the commissioning of a new transformer. The total gas pressure should remain low during and after the transformer commissioning. If it is increasing, then this is an indication of a problem either with sealing or with the workmanship during the process.

be very low because the tank and the oil are degassed during the commissioning of a new transformer. If it is a sealed transformer, then the pressure will remain low. But in case it starts to increase, it is an indication that something is wrong. This is actually an idea that I got from one of our customers when I was testing the idea of the total gas pressure. He said that this is a very informative parameter because it could be used as a quality control tool in the commissioning of the new transformer. The pressure should remain low during and after transformer commissioning, and if it is increasing, it is either an indication of an issue with sealing, or with the workmanship during the process. That was an additional idea on benefits of the total gas pressure that came from a customer.

SL I am part of the international community. I am working with CIGRE and IEC. Some people may consider it as a position of influence. While this might be true, I see it more as an opportunity to learn more because that is the place to meet the most experienced people, and through the discussions, you get a lot of ideas. You also need to learn the new needs of the industry.

Within our own organization, back at home turf, I am the one bringing the customer's voice into our development. Whether it is a software development, a sensor development, a mechanical feature or something else, I am the one who will receive the questions and then discuss them with our customers. I have the opportunity and privilege of knowing a lot of people within the industry, so it is rather easy to check ideas with different people.

I see my work with CIGRE and IEC as an opportunity to learn more because that is the place to meet the most experienced people.

AR That is excellent for quality control on new and degassed transformers. I am a reliability person and I believe that, in reliability data, there is the leading-edge indicator of a problem, and DGA is a lagging indicator. It sounds like you at Vaisala have got a leading indicator for the reliability of an asset, which is brilliant.

Senja, what is your role now as it relates to this new way of looking at the reliability of transformers?

AR I would like to invite you to be part of the Electric Power Reliability Alliance (EPRA) forums, where we put smart people together and they talk about a problem and the solution, as well as the IEEE Smart Grid forums where we discuss a problem with experts from the supplier, the operator and the asset owner's perspective. Thank you for sharing your brilliant insights with us, Senja. We look forward to following Vaisala's innovative solutions and seeing how it will shape the way we take care of our transformers.

Photo: Vaisala

Brenda Méndez

As the Industrial Applications Director for Oil & Gas at Siemens Energy for Mexico, Central America and the Caribbean, **Brenda Méndez** is a next generation leader who inspires by her example and advocates for equity in the workplace.

Brenda studied industrial engineering at the Monterrey Institute of Technology and Higher Education in Mexico (Tecnológico de Monterrey), graduating in 2008. She later specialized in strategic sales and management, completing her studies and professional training in 2019. Early on her professional journey she was a consultant on a logistics project for Macropol; from there she continued to the Clorox Company, where she showed exceptional organizational and analytical skills and went from Maintenance Trainee to Progressive Maintenance Leader & Analyst in less than two years. Brenda made the most significant move of her career by joining Siemens in 2010. Starting in Service Sales for the automotive sector and having completed her Management Leadership Training, over the next ten years she successfully progressed from Service & Maintenance Contract Manager in the mining sector with one of the largest global customers, to the leading positions at the departments of Customer Services in Energy Management and Sales & Marketing in Power Generation Services (Oil & Gas), rising to the role of Business Unit Director for Transmission Solutions. In 2016, she was recognized as one of the 30 young promises of Mexico by the business markets magazine Expansión. Today, Brenda leads the Industrial applications division (Oil & Gas) of Siemens Energy for Mexico, Central America and the Caribbean. She is the first woman to lead a vertical business in this region. As a successful and socially responsible leader, she uses her voice to support organizations for equity in leadership positions and promote gender diversity. She is one of the sponsors of the #EnergíaSinLímites program based on diversity and inclusion within Siemens Energy.

Source: **LinkedIn (Brenda Méndez)**

Photo: Brenda Méndez, rawpixel.com

EC Technology is Robust, Quiet and Efficient

COOLING POWER TRANSFORMERS

WITH COMMUNITY ENVIRONMENT IN MIND

Photo: ebm-papst Inc.

Power transformers are essential in power networks. They convert AC voltage between different voltage levels, and thus play an important role in power plants, industrial operations, and electrical substations. As a result of urbanization, a lot of towns are growing closer and closer to transformer stations that once stood on open greenfield land sites. This poses new challenges in terms of noise emissions. It is not just the transformer that has to be quiet, but it's the cooling system as well. That is why manufacturers need to rely on efficient and quiet fans from ebm-papst.

During the voltage conversion process, a great amount of waste heat is generated – which heats up the oil inside the transformer. In order for the cooling process to work, cooling fins are attached to the transformer, through which the oil circulates. In the case of smaller transformers, the cooling ambient air is enough to prevent the oil temperature from reaching a critical level. However, in the case of larger transformers, additional measures need to be put in place for the cooling process. A simple and efficient solution is to use highly efficient fans – attached to either the sides or below the cooling fins (Figure 1).

Figure 1. EC fans built by ebm-papst can be attached either to the side of or below the cooling fins.

Focus on: Noise and Efficiency

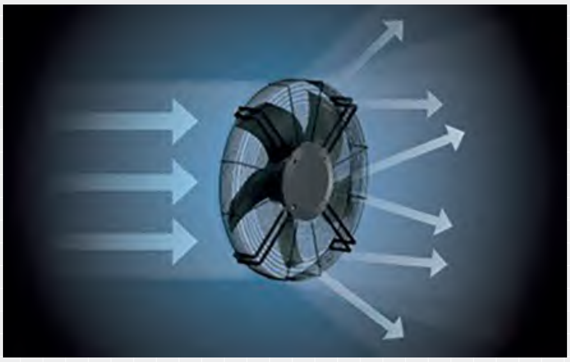
Transformer manufacturers have been in the business for decades and are constantly expanding their portfolios – to include larger and more complex transformers (Figure 2). Manufacturers should have high requirements in terms of the fans used for the cooling process, with a focus on low noise emissions. Due to the fact that towns are continually expanding, a lot of transformers that not long ago stood on open and empty greenfield sites are now situated near new housing developments. Residents and strict legal provisions demand a quiet cooling process and community friendly noise emissions. As most power transformers are positioned in the open air, they also have to be wind-proof and weather-resistant, including being able to function under hot, extremely cold, humid, and salt-spray conditions. On top of everything, fans built into transformers have to comply with specific regulations (for example: EU's Energy-Related Products Directive), which is why the efficiency level of the fans is also becoming more and more important.

Figure 2. The complexity of cooling transformers has increased over recent decades resulting in higher efficiency and less noise emissions.

ebm-papst's fans satisfy all the DIN requirements for the sophisticated cooling of large transformers (EN 50216-12 "Power transformer and reactor fittings – Part 12: Fans"; and come in sizes 500 mm to 1,250 mm with air performance of up to 27,500 cfm. Their development is based on decades of experience and intense research supported by extensive simulations and tests. The range also has a long service life and resistance to salt spray (corrosion protection class C5M as per DIN EN ISO 12944 / UL) – the fan is therefore also suitable for use in coastal areas.

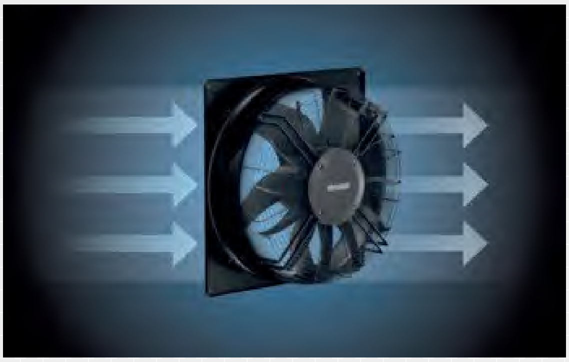
Perfectly Matched Components

All the components of the plug-&-play-compatible modules – the fan housing, HyBlade® impeller, EC motor with integrated electronics and intake-side guard grill (OSHA-compliant) – are perfectly matched. For example, aerodynamic optimization reduces air turbulence and operating noise. The impeller has an aerodynamically ideal shape based on combining an aluminum frame with a covering of glass-fiber reinforced plastic. Compared with traditional blades, this significantly reduces noise and improves efficiency and, at the same time, reduces overall weight. This is good news for the transformer operators, who thus can comply with strict legal provisions, and also for the people who live near the transformer stations. All of the motor types meet the requirements of the current Ecodesign Directive and, thanks to their integrated electronics, also reduce the wiring work and number of components needed compared to conventional systems with AC fans.



Old technology without wall ring / venturi

- + Erratic air flow
- + Turbulences creating noise
- + Very low aerodynamic efficiency



State of the Art Technology

- + Reduction in power consumption
- + Best aerodynamic efficiency
- + Maximum reduced turbulences lead to low noise level
- + Housing significantly increases the air performance

As per IEEE Std. C57.120-2017, there are auxiliary losses (AL) on power transformers, which account for the watts used when auxiliary cooling equipment (fans and/or pumps) is applied. Auxiliary losses are dependent on hours of operation and the power consumed during operation of these devices.

EC fans result in a better option in terms of better efficiency and lower losses since AL must be considered in the transformer Total Owning Cost (TOC), especially if two or more separate cooling stages are used; these stages should be expressed in separate parts because the individual stages will be used at full speed for different amounts of time. When a cooling stage start to cool the transformer, it typically does not need full speed to begin the cooling process. With EC fans, stage can begin cooling at a reduced speed that could be further reduced or increased depending on the rate of increase of the transformer temperature. With this method, reduction of the number of cooling stages or cooling fans may be considered, or the kVA rating may be increased.

Photo: ebm-papst Inc.

The motor mount of the fans is positioned on the intake side and provides protection against accidental contact. On the outlet side, guard grills are available as an accessory. Both the guard grills and the fan housing are made of hot-dip galvanized sheet steel with an extra coating for additional protection. The outlet side also has an integrated circumferential flange for direct attachment to the radiator. Especially when the fans function with free air (as is usual in the case of oil-cooled transformers), the positive effect of this type of fan housing is excellent (see above characteristics showing benefits of using a fan housing). It significantly reduces air turbulence, increases the airflow rate and, ultimately, the efficiency of the fan.

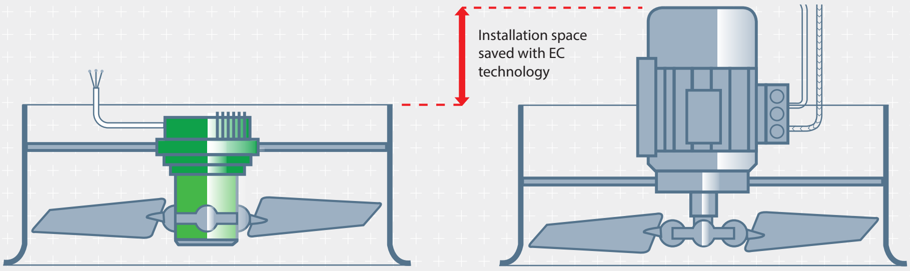


Figure 3. Low profile EC motor design vs. conventional AC motor design

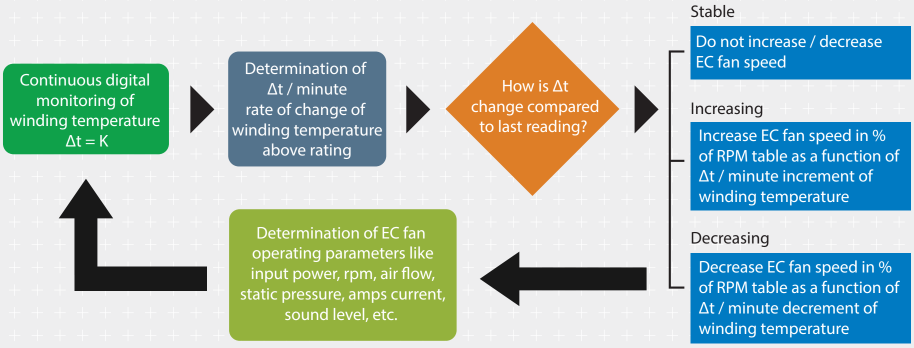


Figure 4. This algorithm is only possible using EC fans to reduce the range of variation of the winding temperature for more efficient cooling. It shows how a large transformer cooling can be digitally controlled.

EC Technology in Transformer Cooling

Our EC products (Electronically Commutated motor) use an external rotor motor with integrated electronics which can be connected directly to an AC mains supply, and will operate at 50 and 60Hz without any change in performance. In addition to performing the commutation, the electronics convert AC to DC and control the fan speed by regulating the power of the motor.

According to IEEE Std. C57.136-2000, a practical technique for sound level abatement is installing low-sound fans, where EC motor plays a significant role, especially if the user specifies a sound level below the value in the NEMA TR1 sound level table.

This means you get high performance, silent speed controllability, and long-life expectancy, all in a compact package that is proven to be more efficient, quieter, and overtime, less costly than the AC products it replaces (user no longer needs to incorporate a VFD, filtering, and extensive labor in order to speed control their conventional AC product), see Figure 5.

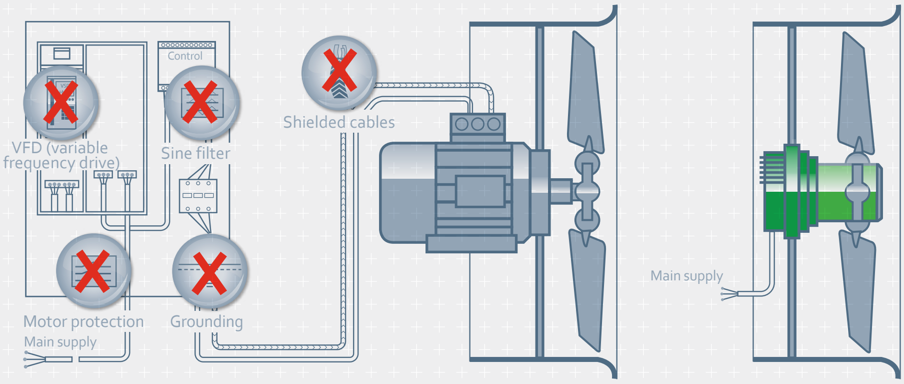


Figure 5. EC technology with unsurpassed compactness

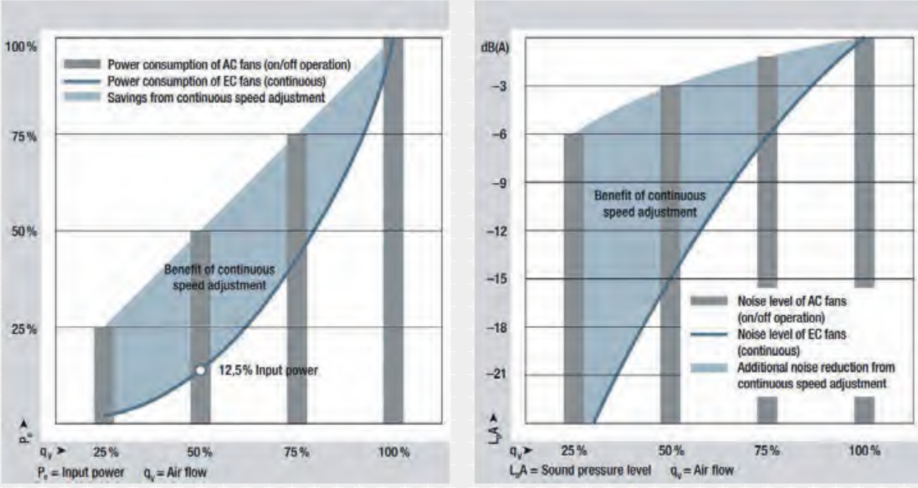
Reliable All Over the World

The continuous control characteristics of the EC fans is another significant advantage. They enable the fans to adapt to the load and climatic conditions, which helps them to work in an energy-efficient manner. They can be used with a range of power supplies – between 200-240 V and 380-480 V (in 50 or 60 Hz operation) – and fulfill all of the relevant standards (CE, UL, CSA, EAC, CCC). Due to their practical design, the transformer fans are also easy to put into operation. For example, it is possible to install and mount the fan directly on the transformer with a horizontal or vertical installation position as required. The motor terminal box for the supply connection and control is easily accessible and isolated from the motor electronics. Great value was placed on the quality of the terminals.

Figure 6. Transformer fans from ebm-papst stand out from the competition in particular through their energy efficiency, low noise emissions, and robustness.

Photo: ebm-papst Inc.

Figure 7. Possible energy savings and noise reduction with continuous speed adjustment in part load operation



Reduced energy consumption
The bars show the power consumption of fans that are switched on stepwise as needed. Air performance is reduced by 50% when half of the fans are switched off. The blue line shows the power consumption of all fans with smooth speed adjustment at the required air flow (50% air flow = only 12.5 % input power).

Lower noise generation
While switching off half the fans (50% decrease in air flow) only reduces noise generation by approx. 3 dB, a speed reduction resulting in 50% less air flow achieves an improvement of 15 dB.

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Feed the Machine: Five Ways to Queue Up Automated Transformer Management

by **Wesley Suplit**

Photo: SDMyers

Just a short decade ago, the notion of using machine learning to solve everyday problems felt like the stuff of science fiction films. However, technology develops at far faster speeds than we can necessarily anticipate. This is why, only a heartbeat after IMB's 1997 introduction of a machine that could beat the world chess champion, we find ourselves interfacing with machine learning every day. Netflix recommendations. Email spam filters. Alexa.

The rate of adoption moves at similarly warped speeds. It took 75 years for 50 million people globally to have access to the telephone, but only 19 days to achieve 50 million downloads of the mobile app, Pokémon Go [1]. That speed is striking; the potential for change, immense.

Electric power reliability has been forced to evolve to meet the demands of this digitally transforming world, now characterized by an increasing connectedness between humans and machines. In terms of transformer management, a core aim is reaching the point where we can let the machines make the maintenance and reliability decisions for us — data-driven asset management powered by machine learning.

Wesley Suplit is a senior product manager at SDMyers, a transformer testing and maintenance company with 55+ years in the electric power reliability space. He is responsible for transforming ideas into extraordinary products, services, and customer experiences related to improving the reliability of electrical equipment and decreasing failure modes.

If You Build It, They Will Come

Of course, the term "digital transformation" implies a change, shifting your facility from one operating reality to another. The technology available to our industry isn't sophisticated enough to completely remove the human element. Yet. However, by definition, machine learning improves the more you use it. Accruing a rich knowledge base of verified condition data, whether or not you currently have predictive analytics in place, will help refine machine-led transformer reliability. In other words, start building now, and automated transformer management will come.

So, how should you attack this dataset issue? Honestly, the best and most basic thing you can do is to keep gathering transformer data — visual inspections, DGA analysis, moisture testing, infrared scans, all of it — even if you're not sure exactly how or when you'll use it. Additionally, here are five areas of the transformer maintenance and reliability process where digitalization efforts can help move the needle toward automated transformer management.

Accruing a rich knowledge base of verified condition data, whether or not you currently have predictive analytics in place, will help refine machine-led transformer reliability.

1. Digitize Transformer Data Collection

Here's a wake-up call: research shows that 44 percent of facilities still rely on paper records [2]. This represents an enormous loss of accessible data. Machine learning algorithms can't analyze data sitting in file cabinets or in the back of a technician's van. Implementing digital inspection and monitoring tools is critical. There is a range of tablet-based inspection apps that aid in digital data collection during routine transformer inspection and sampling. These tools go beyond simply digitizing your condition data. They add value by improving the accuracy and quality of that data with step-by-step workflows, barcode scanning, data verification steps that flag erroneous data (e.g. data fields that won't accept four digits as a temperature), and image uploading to improve visual checks and aid in corrective action plans. Most inspection apps also include built-in safety features, such as PPE requirements and SOP checks. The most advanced inspection software allows embedded remote tech support via video chat, voice recognition, efficiency improvements based on history, and augmented reality to assist with specifying and quoting repairs.

Remote monitoring is another lynchpin in ensuring that you collect the level of data needed to properly utilize predictive analytics. By attaching an online monitor to your transformer, you can collect condition data around the clock, enabling real-time fault detection. Monitoring devices can detect and measure the presence of up to nine gases for a full DGA report. In addition to the real-time oil data, remote monitoring also collects electrical or thermal parameters for a comprehensive look at a transformer's health.

2. Automate the Liquid Testing and Analysis Process

Collecting data is just the first step. Your routine transformer fluid samples and remote monitoring reports are sent to a dielectric fluid testing laboratory for expert analysis. However, note that not all dielectric liquid analysis labs are created equal. It's important to select a testing lab that utilizes best-in-class digital solutions in order to not only capture the wealth of data contained in your sample containers—but also to ensure accuracy and visibility.

Laboratories that employ a digital-first strategy rely on a robust laboratory information management system (LIMS) that interfaces directly with samples (via bar-code tracking, Figure 1), instruments (automatic direct data transfer), and a customer portal for real-time sample tracking and reporting throughout the entire analytical process. These platforms allow for computer-assigned diagnostics with an expert final review, utilizing the best of both humans and machines.

3. Incorporate Data Visualization

When selecting a fluid testing laboratory, or when adopting an in-house asset management platform, consider placing data visualization at the top of your features/functionality priority list. Why? For starters, the human brain processes images 60,000 times faster than words with four times the recall. With that in mind, the ability to receive and review data in a visual format as opposed to rows of information in Excel sheets seems almost like a superpower.

With specific regard to transformer management, data visualization is key to exercising fast and efficient data-driven decision-making. Viewing data in color-coded, clickable charts and graphs allows you to quickly digest asset health information with the ability to drill deep into a single asset or view

Machine learning algorithms can't analyze data sitting in file cabinets or in the back of a technician's van. Implementing digital inspection and monitoring tools is critical.

Photo: SDMyers

Figure 1. Lab technicians using barcode tracking for sample check-in.

The human brain processes images 60,000 times faster than words with four times the recall. With that in mind, the ability to receive and review data in a visual format as opposed to rows of information in Excel sheets seems almost like a superpower.

fleet-level information with GPS mapping capability (Figure 2).

This level of insight empowers you to:

- Audit the specific level of risk for any of the transformers in your fleet
- Prioritize your maintenance allocations with greater judgment
- Ensure your most critical transformers are receiving the attention they deserve
- Economize on the amount of time that is associated with interpreting your data

The power of data visualization comes to life when you consider health indexing (Figure 3). A visual data dashboard can assign your transformer a health score based on whatever parameters you set. The more data you accrue, the more confidence you can have in that score. In this example, the score is a four-level rating system that informs reliability engineers of the transformer's overall condition, enabling better resource allocation and action toward reliability.

The condition score aids the recipient in decision-making and greatly simplifies the review of each diagnostic test with four basic categories:

- Satisfactory — Requires normal monitoring
- Watch — Needs more frequent testing and continued observation
- Service — Needs service or further evaluation
- At Risk — Requires immediate attention

4. Define Your Alarm Management Philosophy

Modern automated control systems are very effective at improving the efficiency of industrial processes. However, these systems make it very simple to set up alarms and notifications—sometimes too simple. This results in unnecessary alarms, confusing alarms, and alarm flooding conditions – annoying conditions that lack insight.

Whether you're looking at transformer liquid sampling data or remote monitoring reports, I'm going to assume that you don't want to be pinged by "at risk" health scores or similar alarms when the issues don't necessarily mean that catastrophe is nigh. Defining a clear and strategic alarm management philosophy ensures that your alarms are meaningful to your unique operation (Figure 3).

When developing an alarm management philosophy, it's best to consider:

- Any known assumptions regarding equipment and processes

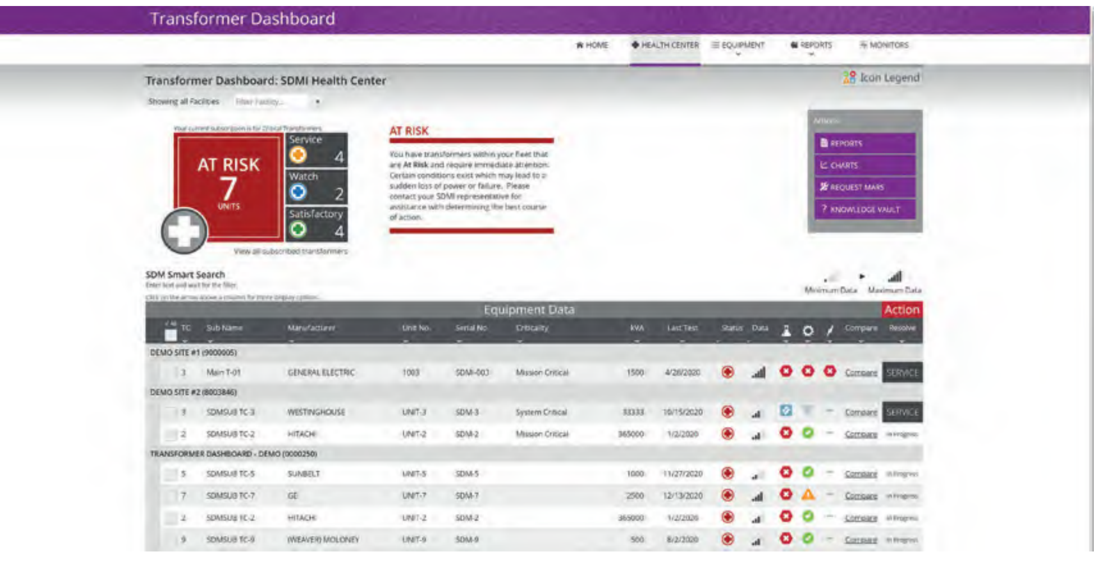

Figure 2. Data presentation dashboard (demo only) showing health indexing.

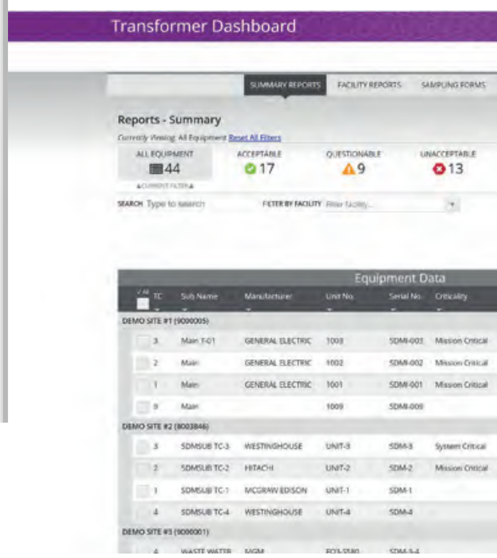

Figure 3. Dashboard (demo only) with manageable, actionable equipment alarms.

Modern automated control systems are very effective at improving the efficiency of industrial processes. However, these systems make it very simple to set up alarms and notifications—sometimes too simple.

- Regulatory standards such as ANSI/ISA 18.2-2016, OSHA requirements, etc.
- Condition triggers, such as IEEE standards, provider limits, or machine learning-based parameters
- Alarm design and prioritization rules
- Alarm lifecycle and reassessment

Who receives alarms and what do they do with that information? These are internal workflows you should also clearly define before you're ready to take the full plunge into machine-led transformer management.

5. Leverage Business Intelligence Tools

Clearly, a rising theme in this article is that reliability engineers and asset managers have access to more data at a higher quality than ever before. This is a good thing, yes. However, it's only a great thing if you have a system set up for maximizing the value of your historical and trending data. Based on a sample of customers, 91 percent say they use comparative data to make equipment decisions. Because we have 55+ years of transformer condition data, we're in a unique position of making that data available for comparative analysis (Figure 5) with a benchmarking tool that allows customer to compare the condition of their asset with all of the like assets we have in our system.

This is just one example. With the software capabilities in existence today, you have an arsenal of analysis options that can take your historical data out of retirement and put it to work with machine learning.

The Fast Track Forward

When you're in the midst of building a digitally focused reliability strategy, it can feel like you're behind and your progress is slow. The bad news is that you very well may be behind in terms of machine learning and its wealth of capabilities. But, the good news is that progress in this arena tends to happen very quickly once the right puzzle pieces are all in place. Just ask Alexa.

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Figure 4. Benchmarking tool (demo only) showing how a customer's transformer fleet compares to industry averages.

Moisture Monitoring and Continuous Filtration: A Way to Avoid Damaging Consequences of Moisture in Power Transformers

by **Jean-Baptiste Frain**

Jean-Baptiste Frain obtained his master's degree in engineering, electrical and automation from the National Institute of Applied Sciences (INSA) in Toulouse, France in 2009. He then joined SOCOMEC as the marketing manager first in India and then in North America. In 2013, Jean-Baptiste joined Streamer Electric AG, Switzerland, a company expert in medium and high voltage overhead lines lightning protection. In 2018, he was appointed Head of Product Marketing and he expanded the Streamer Electric product portfolio by adding the online moisture monitoring and drying solution for oil filled transformers.

Photo: Streamer Electric

Moisture is one of the major causes of failures in power transformers and one of the main degradation factors in the insulation paper. It increases the risks of operational failures and shortens the life expectancy of this valuable asset. Moisture in a transformer can occur from several external or internal sources and it creates a complex dynamics between the oil and the paper inside the transformer. The use of silica gel breathers, sealed tanks, or nitrogen blankets allows us to avoid ingress of all or at least the majority of moisture from the atmosphere into the transformer. When the transformer is energized, creation of water inside the unit is a natural and inevitable occurrence which develops over time due to the depolymerization of the cellulose paper. This article looks at the consequences and the mitigation of moisture issues in order to manage this challenge.

Effects of Moisture in a Transformer

Moisture is one of the major causes of failures in power transformers, yet it is a natural and inevitable occurrence in an energized transformer which develops over time due to the depolymerization of the cellulose paper.

Transformer Safety: Breakdown Voltage

One of the critical transformer characteristics is that the higher the relative water saturation in the transformer oil, the lower the breakdown voltage (BDV) of the oil, as shown in Figure 1. This property is therefore directly linked to the relative moisture saturation in the oil.

As water migrates between the solid and liquid insulation in a transformer with changes in load, and therefore in temperature, it changes the relative water saturation in the oil since the speed of water exchange from the paper to the oil is different than from the oil to the paper. The peaks of relative saturation are usually observed when there are changes in the transformer's state (from high to low temperature or vice versa).

Consequently, the breakdown voltage tends to decrease during temperature changes, as observed in Figure 2. The figure also clearly shows that the negative effect on the breakdown voltage is stronger when the water content in the paper is higher, i.e. when there is more water in the transformer. In this example, the breakdown voltage decreases by an average of only 10% in a transformer with 0.5% or 2% of water content during temperature change; however, in a transformer with 3.5% water content, the breakdown voltage can drop by more than 30%.

Water content levels in transformers have been standardized by CIGRE and IEEE standards (see Figure 3 for CIGRE). The percentages represent the mass of water in the cellulose versus the mass of the entire insulation paper. While it is expected to have less than 1% water content in paper when the transformer is new, this water content will rise with time and should be maintained below 2%. Above this level, the transformer is considered to be too wet, leading to breakdown voltage volatility and paper degradation.

Figure 1. Dependency between breakdown voltage and water content in the insulating liquid [1]

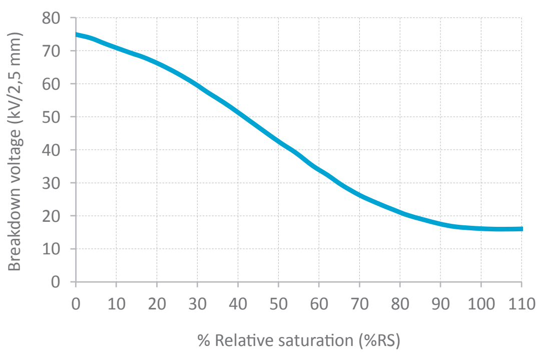


Figure 2. Temperature and breakdown voltage in oil for different temperature gradients [2]

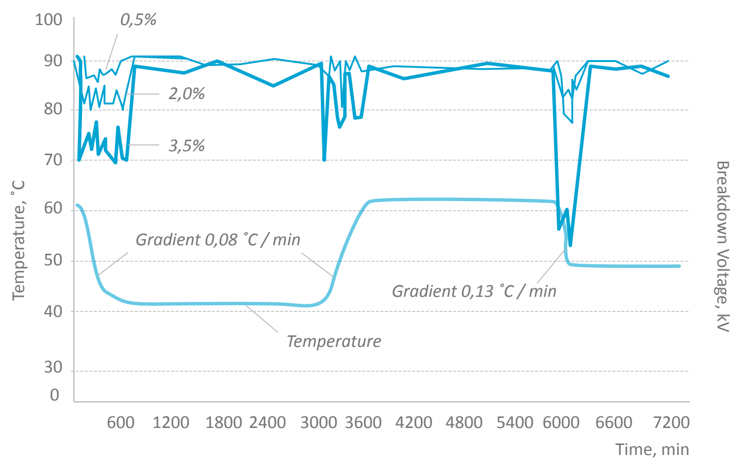


Figure 3. Water content levels as defined by CIGRE [3]

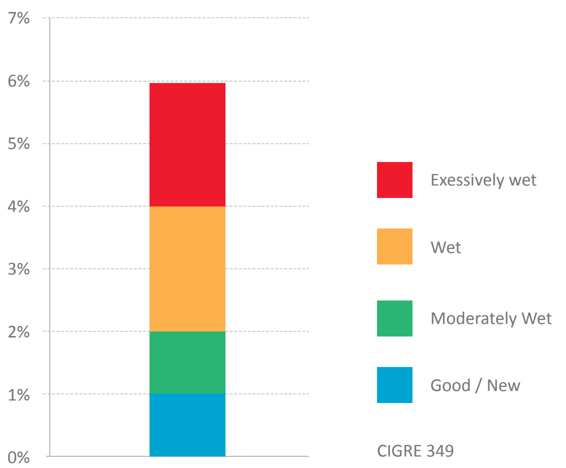
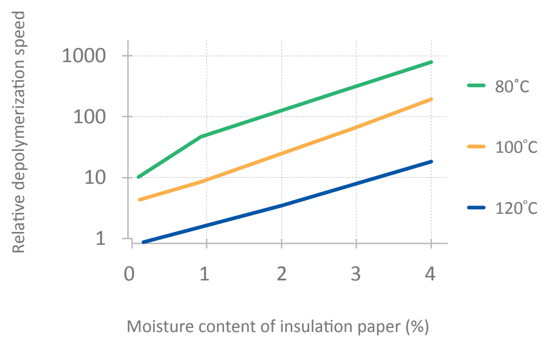


Figure 4. Dependence of cellulose depolymerization rate on the paper moisture content at different temperatures [1]



We know that high water content in a transformer can endanger the asset as the breakdown voltage decreases with a change of state (temperature). Moisture reduction is therefore a key effort to increase safety, especially for transformers with short and frequent load changes.

Transformer Life Expectancy: Degree of Polymerization

The mechanical strength of the insulation paper is defined by the degree of polymerization, also called DP, which represents the average length of cellulose chains in the insulation paper. A DP in a new transformer is typically between 1,200 and 1,000. When the transformer reaches a DP of about 200, this point is considered the end of its operating life. While paper degradation cannot be stopped, its rate will depend, among other factors like temperature or acidity, on the water content in paper, as shown in Figure 4.

In CIGRE brochure D1.01.10 (2007), Fallou showed that the rate of paper degradation with the initial water content value at 4% was 20 times higher than at 0.5% water content. Additionally, when the cellulose paper is degrading, i.e. when the cellulose chains start to break down, water molecules are created as a result of this chemical reaction [5]. Thus, the degradation of the cellulose increases the rate of degradation.

It has been observed that moisture has a major effect on the rate of paper degradation and therefore on its life expectancy, which is counted in years. Considering the high cost of transformers, the economic impact of moisture in a power transformer, on top of the safety impact discussed in the previous paragraph, is something we must be aware of and mitigate.

Photo: Streamer Electric

Assessing the Moisture Content of a Transformer

Following from the discussion above, water content in a transformer should be assessed in order to understand if it is safe to operate it and to establish whether the rate of paper depolymerization is too high. Over 98% of the total volume of water in the transformer is concentrated in the paper, while less than 2% is dissolved in the oil [1]. Accessing the insulation paper to take a sample is impossible without a costly offline procedure. But the oil is easily accessible. An oil sample can be taken while the transformer is energized and the amount of water can be assessed in this sample to then estimate the water content in the paper.

However, when taking an oil sample, it is crucial to know the oil temperature, since the water solubility in oil is higher at high temperature, as shown in Figure 5. It is therefore normal to find a higher PPM value in an oil sample that has been taken on a transformer operating at high temperature.

Some equilibrium curves have been developed to correlate the concentration of water in oil, in PPM, and the percentage of water content in paper at different oil temperatures, as illustrated in Figure 6.

Knowing the PPM value and the oil sample temperature allows us to estimate the transformer water content, and therefore evaluate if the transformer is wet or not.

These curves are only valid if there is an equilibrium between the insulation paper and oil at the time of taking the sample. Unfortunately, on an operating transformer this equilibrium is basically never reached. Even the outside temperature variations will have an influence on this equilibrium.

Figure 7 shows the evolution of the moisture content in PPM over time (hysteresis) and the relative saturation in oil depending on the temperature. It is clear from the chart that there are several PPM values, or relative saturations for a given temperature depending on when the

Figure 5. Water solubility (S) vs. temperature according to the results from literature and CIGRE round robin test [1]

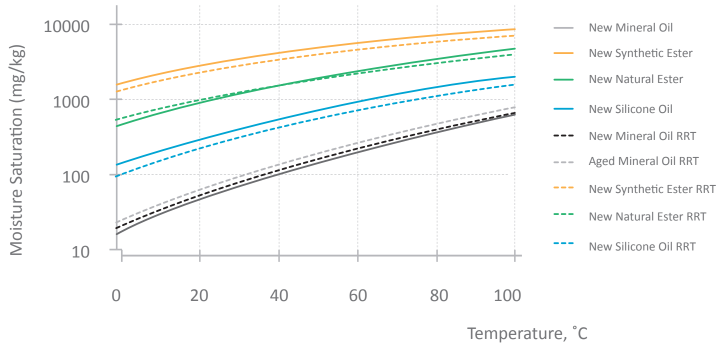
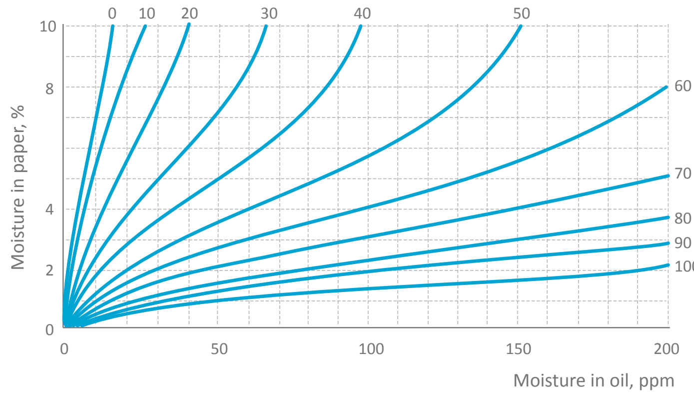


Figure 6. Moisture equilibrium curves [1]



Moisture can have several negative effects on the safety and life expectancy of a transformer, so it is important to monitor its level accurately. The common methods of oil sampling may not provide sufficient information to draw conclusions on the transformer water content.

Figure 7. Hysteresis loops %RS and calculated water content vs. temperature in a 40 MVA refurbished transformer during a special loading test [1]

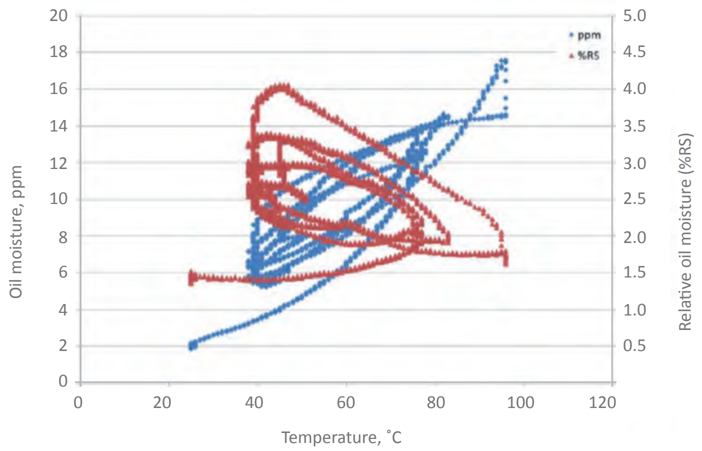
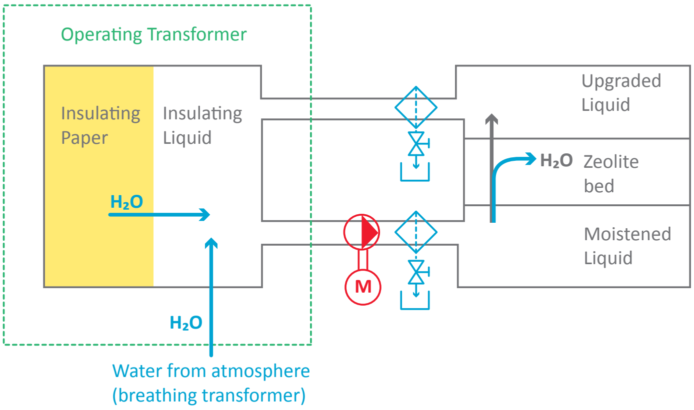


Photo: Streamer Electric

Figure 8. Schematic representation of the drying process through diffusion and zeolite adsorption [4]



With online drying process using molecular sieves, a continuously dried oil should maintain a high level of breakdown voltage; and the continuous extraction of moisture created in the paper will slow down the degradation process, and therefore increase the life expectancy of the transformer.

sample was taken. In this example, at 60°C, the oil moisture ranged between 6 and 13 PPM, while the oil relative moisture saturation ranged from 1.5% to 3.5%. This is due to the fact that the oil temperature can vary faster than the moisture can diffuse from oil to paper, or from paper to oil. When the oil temperature decreases, the paper can only accept a certain amount of moisture at a time. During the period of oil cooling down, the water solubility in oil decreases while the amount of moisture does not decrease as fast, and therefore, the relative saturation increases with the negative consequences on the breakdown voltage, as shown previously.

Knowing this, it becomes obvious that trying to estimate the water content in a transformer, or even the moisture level in the oil, is not possible by doing punctual sampling. Taking an oil sample once a year will have a high probability of providing a false water content value, particularly on an older transformer, or with a high variation in temperature.

That moisture can have several negative effects on the safety and life expectancy of a transformer, so it is important to monitor its level accurately. The common methods of oil sampling may not provide sufficient information to draw conclusions on the transformer water content.

A Proposed Solution: Continuous Drying and Moisture Monitoring

Online Drying Devices Based on Molecular Sieves

This technology, developed in South Africa some 20 years ago, allows continuous drying of a transformer while the unit is online. The principle is fairly simple: The oil is pumped from the transformer tank at a low flow rate (<100 liters per hour) passing through the bed of molecular sieves. These sieves extract the water molecules dissolved in the oil.

The sieves used in most of the available solutions are zeolites type 3A. This is a porous material which has a very high affinity with water molecules and its pores are perfectly sized to catch the water molecules. This also means that these sieves will not extract other molecules of different sizes, and therefore will not disturb the gas levels within the transformer [4]. Next, the dried-out oil is pumped back into the tank. Figure 8 illustrates this process.

This simple process allows us to have the transformer oil continuously dried while avoiding issues created by moisture ingress from outside. Also, the moisture created due to the degradation of the cellulose paper is transferred to the dry oil and extracted. So, this method offers a solution to two problems mentioned in the first part of this paper: a continuously dried oil should maintain a high level of breakdown voltage; and the continuous extraction of moisture created in the paper will slow down the degradation process, and therefore increase the life expectancy of the transformer. This solution is very affordable to set up as it can be installed and operated without shutting down the transformer, and it does not require any operators to run it.

Continous Monitoring with Capacitive Sensors

Capacitive sensors have been used for decades to define moisture level in oil and solid insulation (provided an equilibrium is established). They have two main advantages:

1. The sensor is placed directly in the oil within the transformer, so there is no risk of external contamination, which might happen during sampling or handling at laboratories.
2. These sensors provide analog information remotely, so the moisture level can be monitored continuously.

These sensors generally combine the measurement of relative moisture saturation in oil and oil temperature. This allows us to plot the hysteresis in Figure 9 and then have a much better overview of the moisture level in the transformer than with time-based sampling. In the example depicted in Figure 9, we can see the hysteresis of five different transformers. There is a difference in the shape between a new or dried out transformer at the bottom of the graph, and a wet transformer at the top. It is considered that if the hysteresis passes the 20% level, a drying maintenance should be considered [1].

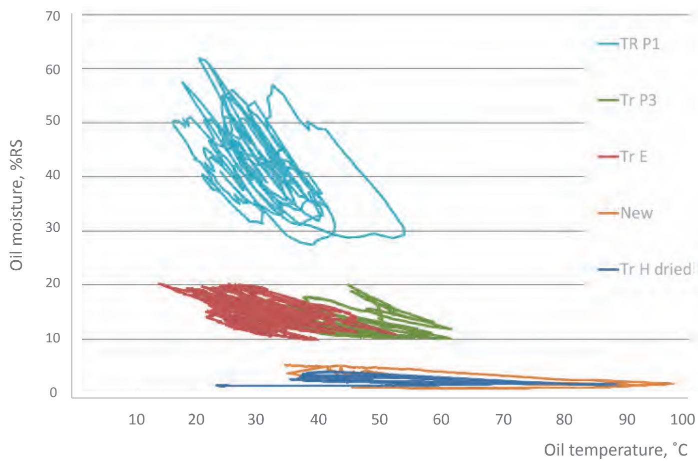
Online drying devices with molecular sieves can easily include capacitive sensors within their system since they require a continuous oil flow for their process, as do the capacitive sensors. Together they provide a solution for managing moisture.

A Real Case Application of Online Drying System

An online drying device with moisture monitoring was installed on a 40 MVA three-phase transformer in Saudi Arabia's Abqaiq region as a pilot project in November 2017. The installed online drying system is shown in Figure 10.

This 115 kV/13.2 kV sealed transformer from the 1970s had always been used at a relatively low load, which explained why moisture level in the oil never reached an

Figure 9. Hysteresis loops of %RS vs. temperature in transformers with different moisture [1]



Online drying systems offer a solution that will remove moisture from both the insulating oil and paper

Figure 10. Online drying device with moisture monitoring installed on a transformer in Saudi Arabia's Abqaiq region

Photo: Streamer Electric

Figure 11. PPM and temperature monitoring between April 2017 and November 2018 on the transformer T-602

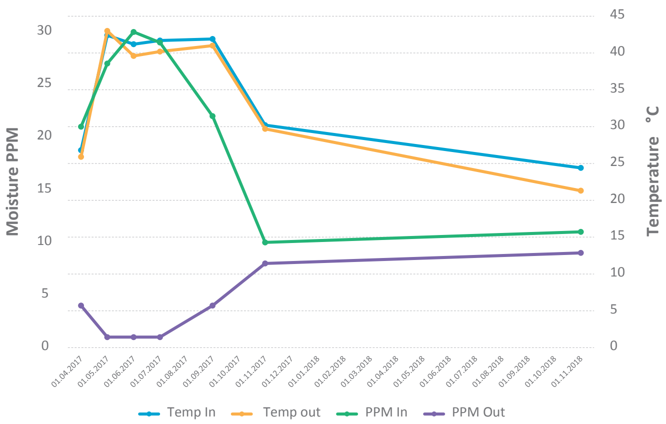
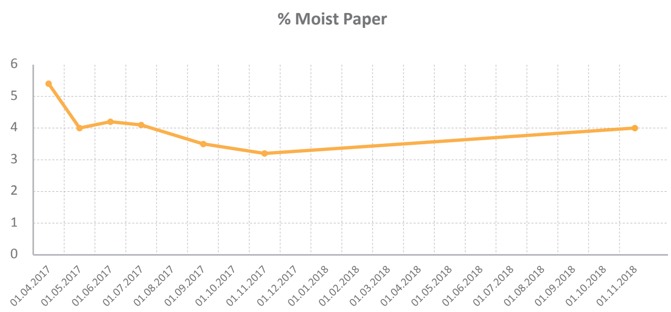


Figure 12. Calculated moisture content in the transformer T-602 between April 2017 and November 2018



alarming level. However, the level of moisture increased rapidly between 2015 and 2016 when a leakage appeared in the gasket. In February 2016, moisture levels in the oil reached 54 PPM; relative humidity in the oil was 45%; the estimated water content in the paper was 7%; and the breakdown voltage dropped to 22 kV. At this point, the transformer was immediately deenergized and a leak search was initiated. Once the leak was located and repaired, the increase of moisture in the transformer stopped; however, an enormous amount was already in the oil and paper had to be removed to operate the transformer safely. Using an offline solution like low frequency heating was not an option due to the risk of paper shrinkage during the removal of such a large volume of water. As a result, the end user decided to try an online drying device. Once installed, the unit started removing moisture from the oil immediately, which naturally provided a positive effect on the breakdown voltage value. In the second step, the water began to be extracted from the paper as moisture equilibrium was established.

With the moisture and temperature sensors installed within the online drying device, it was possible to follow the development of moisture over time. Over the first year, the PPM inflow, as shown in green in Figure 11, decreased. Also, within that year the calculated paper water content in the transformer dropped from 5% to about 3% (which is a much more acceptable level), as seen in Figure 12. If we consider that each additional percent of water content increases the rate of cellulose degradation by two, the reduction from 5% to 3% decreased the degradation rate of this transformer by four, and therefore, increased the remaining life expectancy by also a factor of four. It is clear from Figure 11 that during the second year of operation the PPM values of inflow and outflow were almost matching, which is the sign of water saturation in the online drying unit. This hypothesis was confirmed by the water content increasing again from 3% to 4% at the end of the second year. The saturated online drying device extraction cylinders were then replaced by new ones to restart the filtering process. Once emptied and cleaned in the factory, it was calculated that they had extracted about 12 liters of water from that transformer.

Conclusion

It is a known fact that moisture can have damaging effects on power transformers in terms of safety and life expectancy of the asset. Also, we know that moisture in a transformer is difficult to estimate without continuous monitoring. Online drying systems will remove moisture from both the transformer oil and paper solving both problems. This solution has been proved and successfully evaluated based on the pilot project results.

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