ISSUE 22
October 2022
transformer-technology.com
ISSN 2642-2689

TRANSFORMER TECHNOLOGY MAG

TRANSFORMER TECHNOLOGY MAG

ADVANCES IN BUSHINGS TECHNOLOGY

SPECIAL SUPPLEMENT

PST POWER SYSTEMS TECHNOLOGY

When Bushings Go Bad: **Check Your Data**

Building Transformers. Building Quality. Interview with **Prabhat Jain**, CEO-CTO of Virginia Transformer Corp

Integrating Condition Monitoring into the Product: **Economical, Accurate and Hassle-free**

One product. One software. One world.

TRAX

Multifunction transformer and substation test system

A portable and compact system packed with features that maximise asset condition awareness:

- Easy to use, replaces the need for multiple test sets.
- A powerful, compact, and portable system for easy transport to the site.
- Accurate and reliable results using state-of-the-art measurement methods for advanced diagnostic testing.
- Configurable user-friendly interface reduces training and testing time.

www.megger.com

Scan this QR code to learn more about TRAX

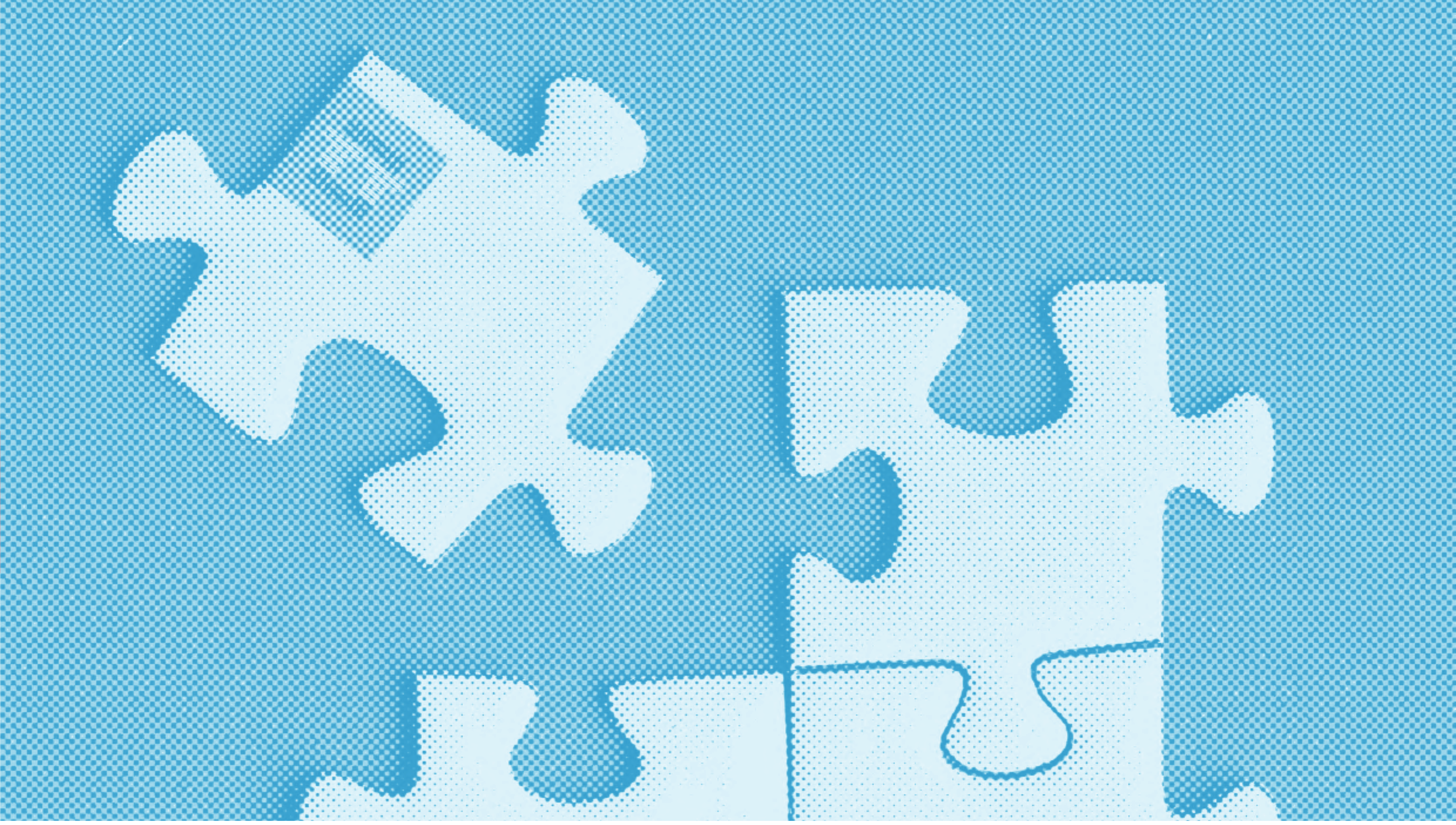
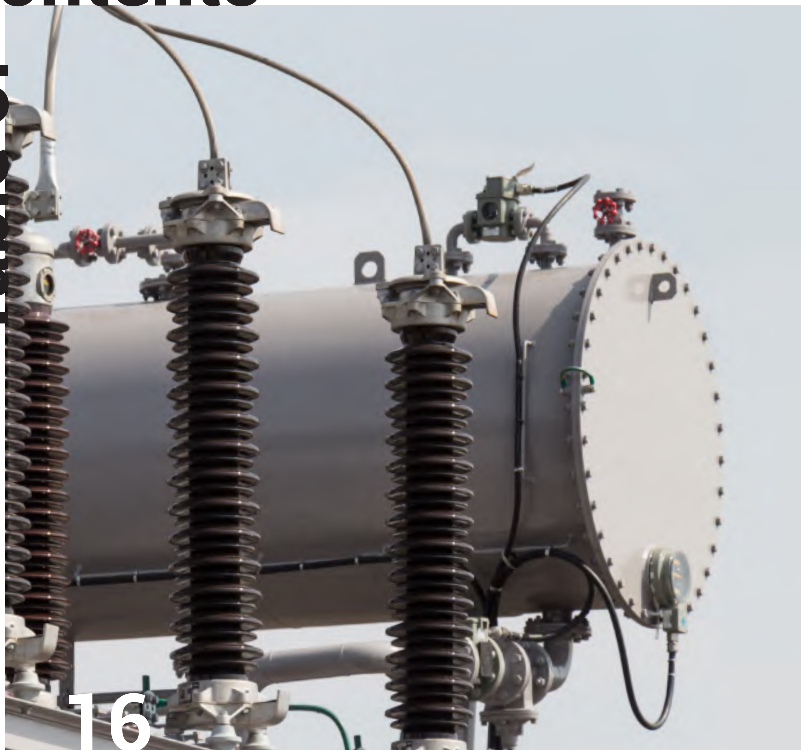
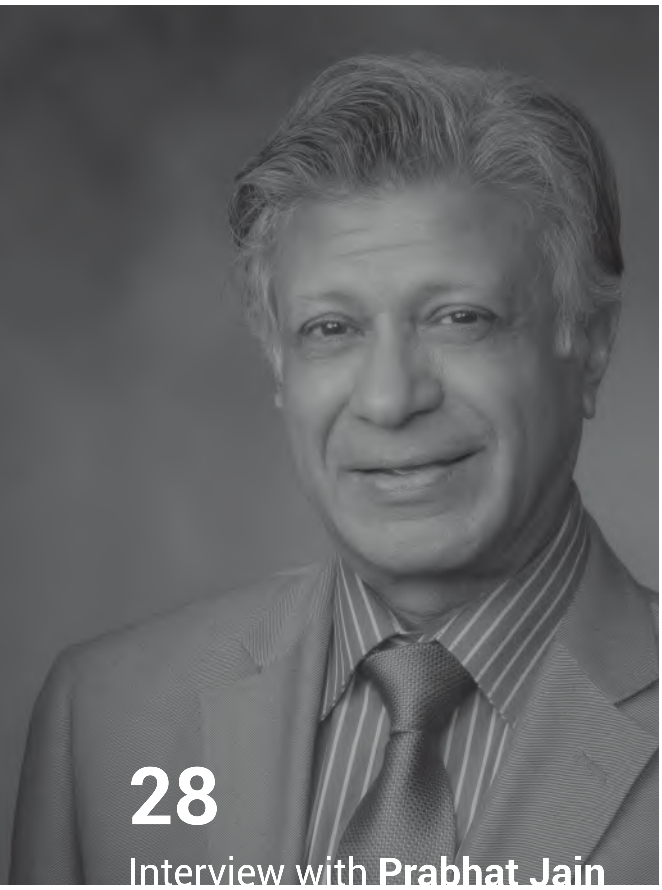


Photo: Mike van Schoonderwalt from Pexels

Index

Table of Contents



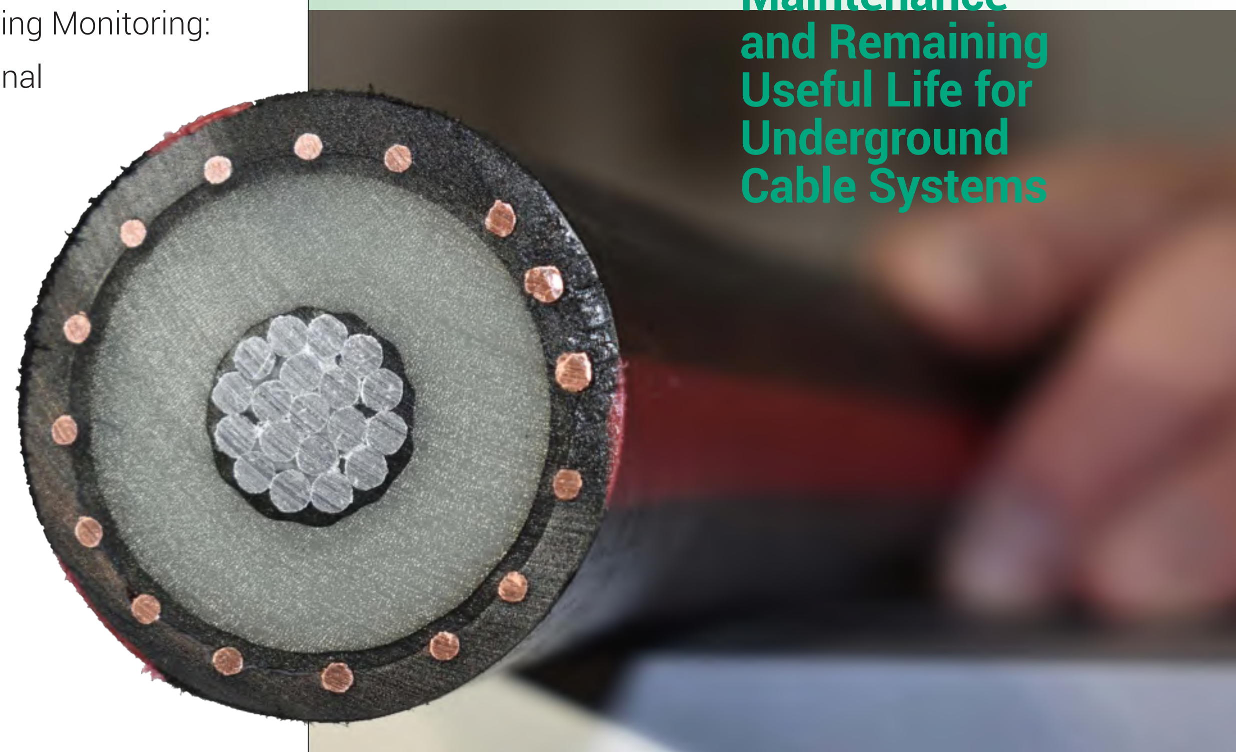


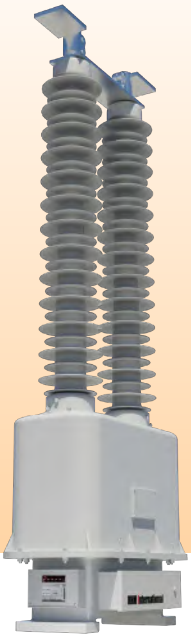
Index

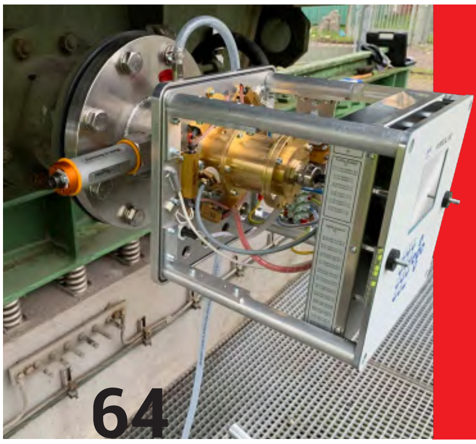
Table of Contents

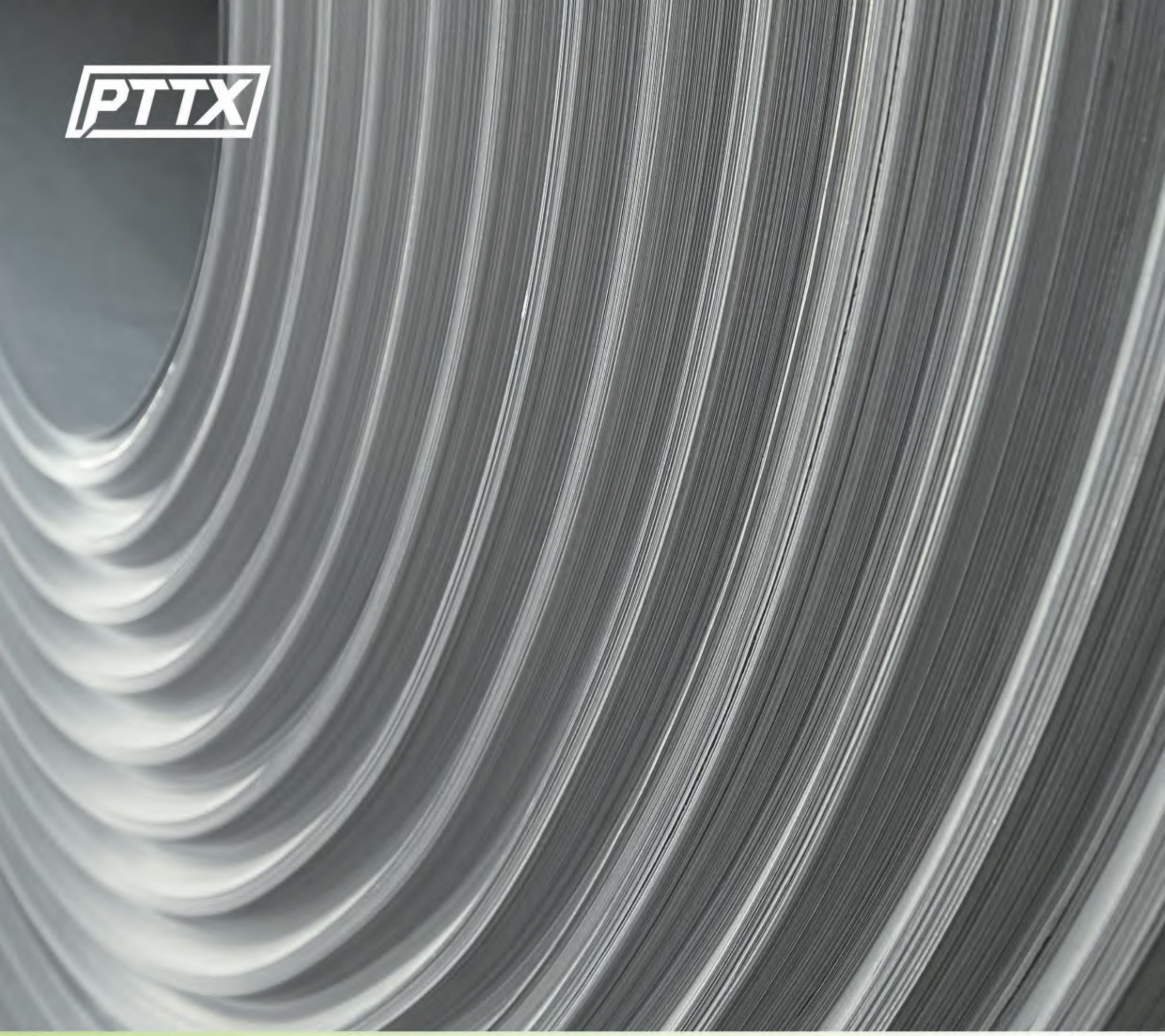
POWER SYSTEMS TECHNOLOGY

SPECIAL SUPPLEMENT









Impressum

TRANSFORMER TECHNOLOGY MAG

Technical Advisory Board (TAB)
Executive Advisors
Alan M. Ross, CRL, CMRP
The Chair and Editor in Chief
Corné Dames
Independent transformer consultant
Transfomer oils
Ben Lanz, IEEE PES Senior Member
Power system reliability, asset management
and diagnostics

Technical Advisory Board Members
Diego Robalino, PhD, PMP
IEEE Senior Member
Tony McGrail
Asset management & Condition monitoring
Edward Casserly, PhD
Senior Scientist, Transformer oils
Maria Lamorey
Industrial OEM manufacturing
Alan Sbravati, ME, MBA
Transformer insulating materials
Marco Tozzi, PhD
Diagnostics and asset monitoring
Curtus Duff
Power transformer design
Traci Hopkins, IEEE Member
Transformer Condition Assessment
Jon Trout, PE
Electric utility
Michael Riccio, CRL, IRT CAT-1
Reliability, Electrical safety
Alexander Doutrelepont
High voltage bushings & insulators
Ed Khan
Power Systems, Relay protection, Training

Graphic design
BE Koncept Communication Boutique

Photo Cover
Shutterstock

Sales & Marketing
Rachel Linke
rachel.linke@apc.media
Kevan Sears
kevan.sears@apc.media

Sales & Marketing Americas
Maria Salamanca
maria.salamanca@transformer-technology.com

Sales & Marketing Mexico
Fernando Campos
fernando.campos@transformer-technology.com

Sales **& Marketing Brazil**
Marcelo Braga
marcelo.braga@transformer-technology.com

Marketing Global
Marin Dugandzic
marin.dugandzic@apc.media

TAB Executive Advisor,
The Chair and Editor in Chief
Alan M. Ross, CRL, CMRP
Transformer maintenance
and reliability

TAB Executive Advisor
Corné Dames
Independent transformer
consultant Transformer oils

TAB Executive Advisor
Ben Lanz, IEEE PES Senior Member
Power system reliability,
asset management
and diagnostics

TAB Member
Diego Robalino PhD, PMP
IEEE Senior Member
Transformer condition
assessment and
diagnostics

TAB Member
Tony McGrail, PhD
Asset management &
Condition monitoring

TAB Member
Edward Casserly, PhD
Senior Scientist,
Transformer oils

TAB Member
Maria Lamorey
Industrial OEM
manufacturing

TAB Member
Alan Sbravati, ME, MBA
Transformer insulating
materials

Editors

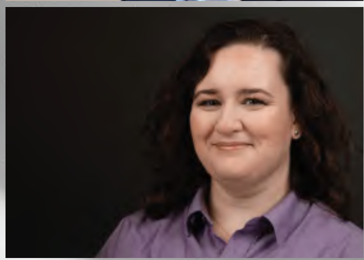
ISSN 2642-2689 (Print)
ISSN 2642-2697 (Online)

DIGITAL Membership
Free

Transformer Technology magazine is a quarterly magazine published by APC MEDIA LLC, 2152 Caper Dr., Marietta, GA 30064, USA. Published content does not represent official position of APC MEDIA LLC. Responsibility for the content rests upon the authors of the articles and advertisers, and not on APC MEDIA LLC. APC MEDIA LLC maintains the right to keep the textual and graphical documents submitted for publication.

Publisher:
APC MEDIA LLC
2152 Caper Dr.
Marietta, GA 30064, USA

transformer-technology.com



Dear Readers,

The two most downloaded and read issues of our digital magazine are Bushings and Oils & Fluids, both areas that are changing more dramatically than many other areas of transformer technology. Given the very name of the magazine it is no wonder. In November, you will see a departure from our Transformer Technology focus with more of a focus on Power System Technology, but first... **Bushings!**

I have had the opportunity to interview some thought leaders in the transformer market at the IEEE PES T&D Conference, and more recently via Zoom, and one of the major things I came away with is how change is taking place in bushings technology. Some of that change has been driven by supply chain issues, forcing manufacturers to rethink bushing material design. Another is the desire to decarbonize, digitalize and decentralize power. While those larger objectives will be part of our PST reporting, they also impact transformer manufacturing.

We will keep some of our thoughts on natural and synthetic esters for the December issue on Oils & Fluids, but the move to esters is also important in bushings manufacturing. One President of a major bushings manufacturer shared in an interview (that you will be able to access in the coming weeks) that their effort to decarbonize has led them to make a determined decision to replace mineral oil filled bushings with esters and move away from SF6 insulation to RIF where possible, or to gases with less harmful impacts on the planet.

> **Some of the change taking place in bushings technology has been driven by supply chain issues, forcing manufacturers to rethink bushing material design. Another is the desire to decarbonize, digitalize and decentralize power.**

In another interview with the CEO of Virginia Transformer and Georgia Transformer, Prabhat Jain, you will read about how their R&D and design teams are working with their own suppliers, internally and externally, to address issue of reliability, resilience, and reduced lead times. Bushings are part of those changes. With articles from our Technical Advisory Board members, Tony McGrail and Marco Tozzi, authors Emilio Morales and Robert Middleton, and a Perspective piece from Camden Spiller, we believe we have done another great job of representing the industry.

Now we turn our attention to November and December with Power System Technology front and center in November. What a tremendous lineup we have with interviews with several CEOs articles on battery safety and e-mobility, and a market review from Power Technology Research. While transformers are the heart of the power system, the power system is the heart of the economy, life as we know it, and part of the most dramatic shift in our lifetimes as we decarbonize, move to electric vehicles and deal with climate change.

From recorded interviews with over 30 people during the recent RE+ Conference in Anaheim, Netherlands, where 27,000 attendees gathered, it was clear that our global power system is undergoing dramatic and much needed change; change that will affect every one of us in ways we can only begin to imagine.

While transformers are the heart of the power system, the power system is the heart of the economy, life as we know it, and part of the most dramatic shift in our lifetimes as we decarbonize, move to electric vehicles and deal with climate change.

Our mission at APC Media as the Voice of the Power Industry is to bring you the best and most important news, information and thought leadership on Power System Technology. I hope you enjoy our current issue and look forward to end the year with two more great additions to the APC Technologies body of knowledge.

Alan M Ross
CRL, CMRP
Editor in Chief
APC Media
Technical Director

Alan M Ross


TRANSFORMER TECHNOLOGY
IS NOT (JUST) A MAGAZINE
IT'S A COMMUNITY
OF OVER 10,300 MEMBERS

Comprehensive Bushing Retrofit Solutions

for a long transformer service life

YASH HIGHVOLTAGE
www.yashhv.com

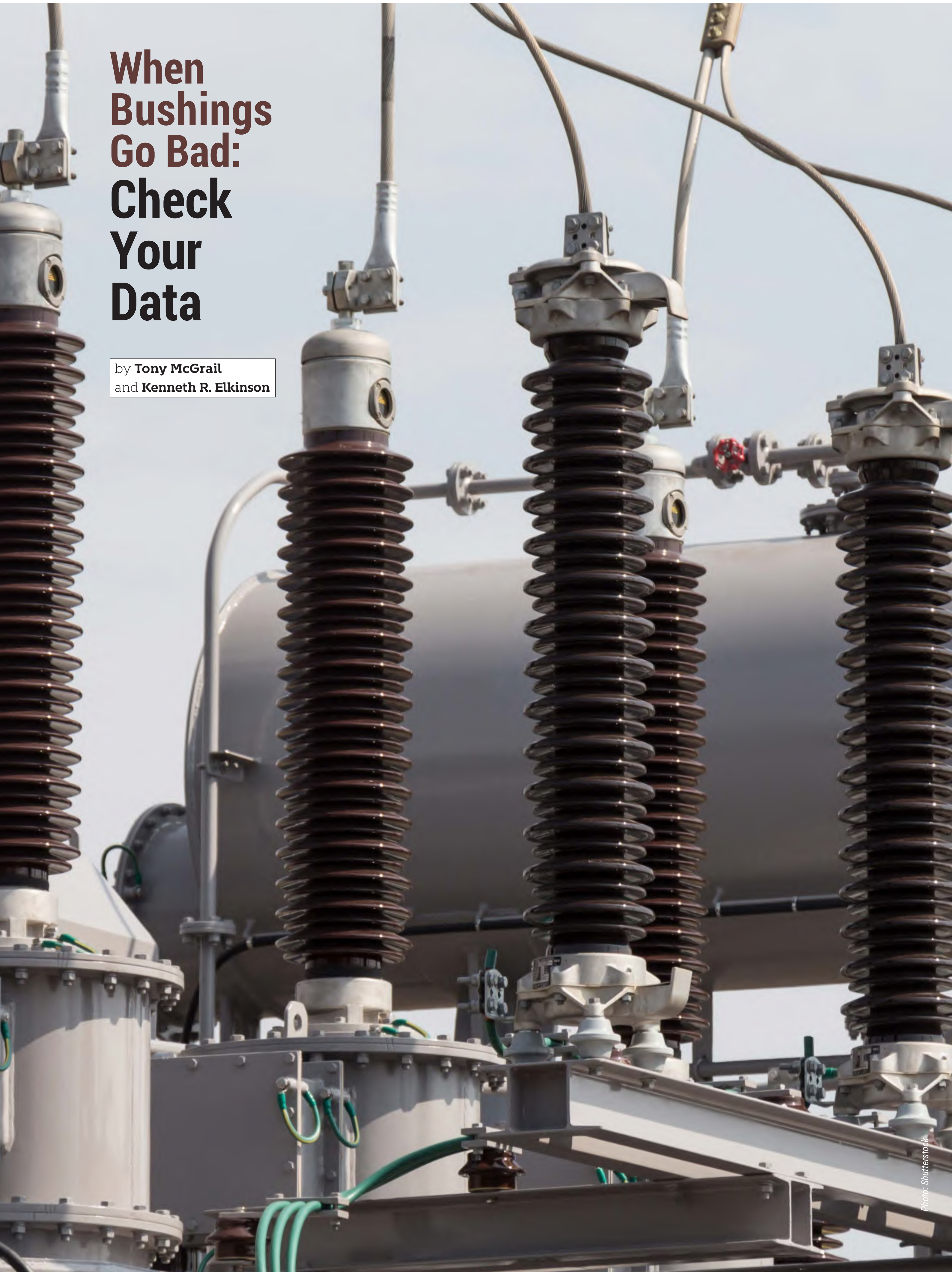
OIP Bushing installed on a transformer as a replacement to old SRBP technology bushing of 1962 make.

- Interchangeable Solutions possible for **SRBP to OIP** & **OIP to OIP** up to **245 kV**
- Customized solutions for **High Current Bushings** up to **25000 A**

Salient Features

- Excellent customization/retrofit potential for any globally reputed make bushing.
- Ability to interchange, to a large extent in terms of Mounting, BCT, Oil end length, Creepage, Terminations amongst other things.
- Whether the requirement is to procure a few or many bushings, we deliver.
- Swift development times for non-standard designs and parts.
- Highly competitive solutions.
- Ability to virtually guide or visit the site for measurements, if drawings are not available.
- Engineering consultation with customer's technical team, to arrive at interchangeable options.
- Full standard warranty offered on bushings supplied as a retrofit to the existing bushing.

24 kV 10000 A High Current *Bushings design retrofit solution*



When Bushings Go Bad: Check Your Data

by **Tony McGrail**
and **Kenneth R. Elkinson**

Photo: Shutterstock

In bushing monitoring it is very important to be aware of all available data – the raw phase angles and rms leakage currents for each individual bushing are often as useful as the derived power factors and capacitances in terms of deterioration detection, investigation and diagnosis.

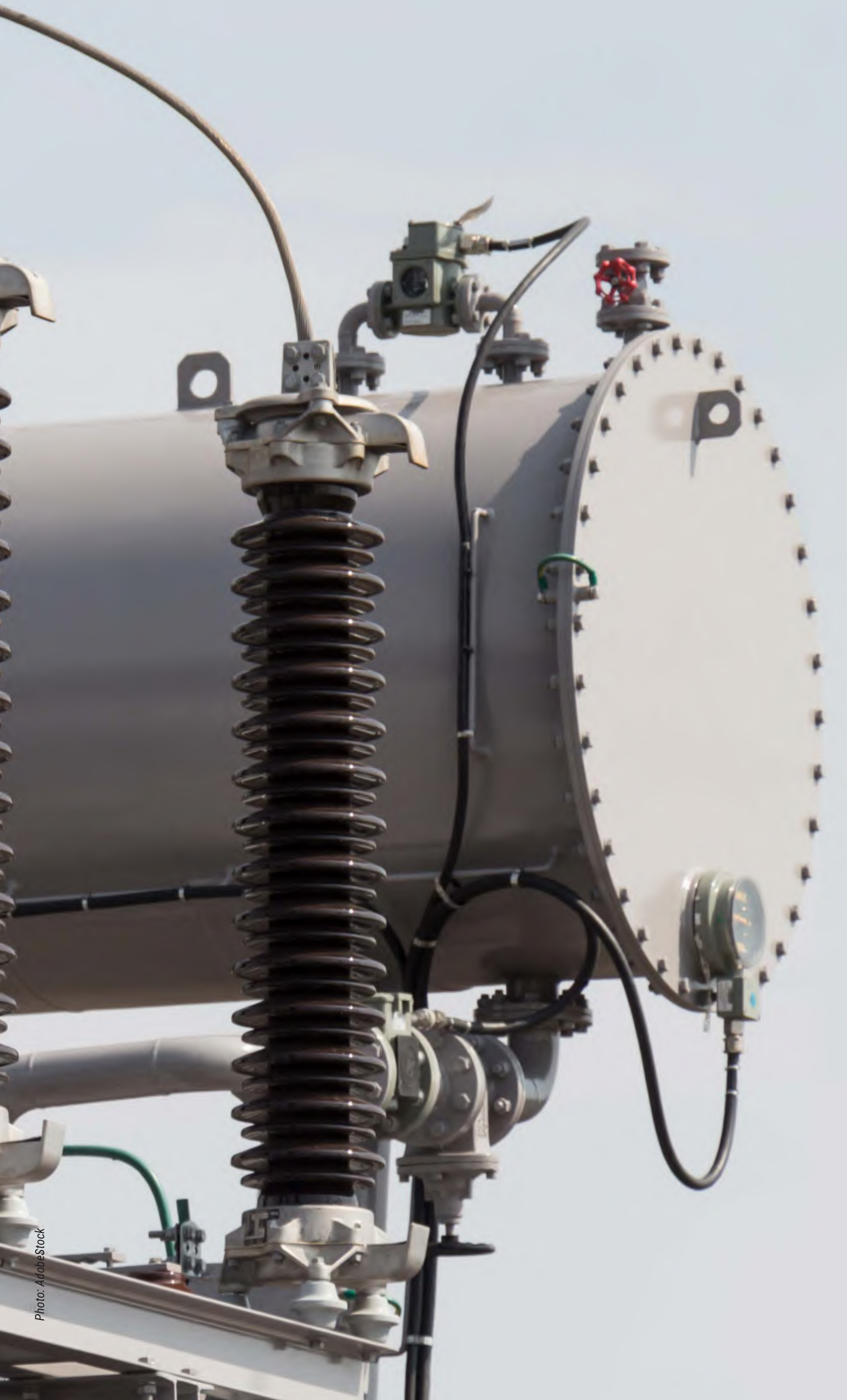


Photo: AdobeStock

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.

Kenneth Elkinson, P.E., received his Bachelor of Science in Electrical Engineering degree from the University of Massachusetts at Lowell. Kenneth has held a number of positions at Doble Engineering, as Field Engineer, Client Service Engineer, and now Apparatus Analytics Engineer. Previously, Kenneth worked with National Grid in the US as a Substation Engineer. Mr. Elkinson is a licensed Professional Engineer in the state of Massachusetts, and is an active member of IEEE, CIGRE, and the NSPE.

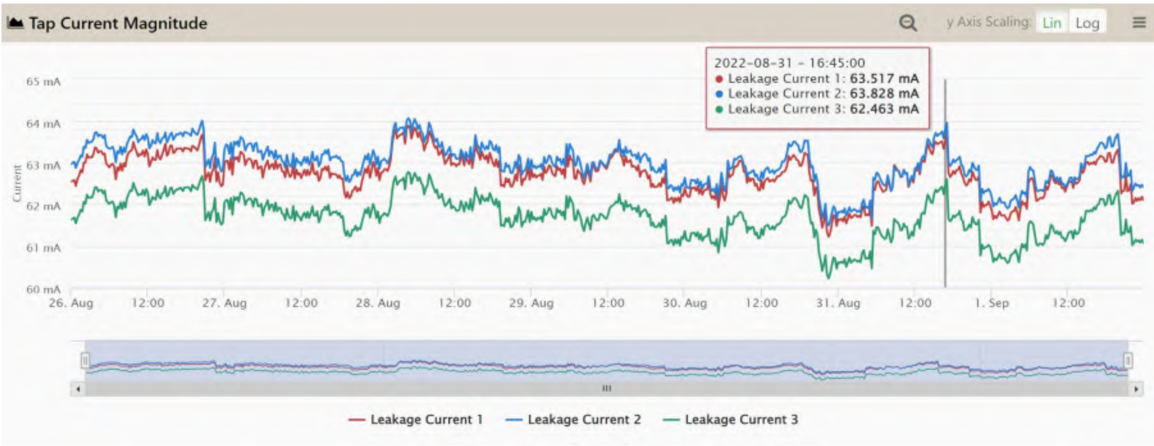


Figure 1. Showing the variation in leakage current magnitude for three GSU bushings over 7 days in 2022

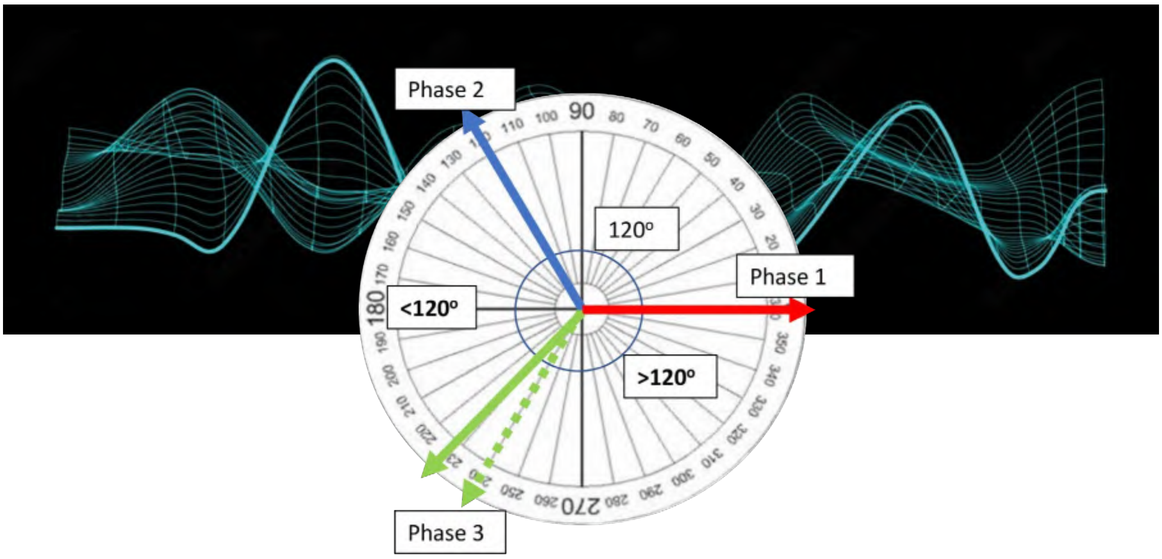


Figure 2. Exaggerated phase angle change for Phase 3 bushing showing Phase 1-to-2 staying unchanged

Bushings are usually reliable assets – a failure rate, per year, of no more than about 0.5% is usual [CIGRE]. Power factor and capacitance are good indicators of deterioration in offline bushing tests and are commonly used [Doble]. In addition, it is generally found that:

- it is not common for two bushings in a set of three to 'go bad' simultaneously;
- a rising power factor is a significant indicator of insulation deterioration.

These two findings are also useful in online measurements where raw current waveforms are recorded, from which we can calculate relative phase and rms magnitudes for the leakage current of each bushing; from these values we can calculate the individual bushing power factors and capacitances (TT). Leakage current varies with both bushing condition and system voltage providing a lot of 'noise' in the measurements, as shown in Figure 1.

As a result of the 'natural' variation in leakage current, it is usual to put some averaging into the resulting power factors to avoid false positives from sudden system variations: phase angle variation due to bushing deterioration start at ~0.1°, but system variation may be above 1° to 1.5° and vary minute by minute, making it difficult to detect the bushing deterioration. At Doble we calculate daily, weekly and monthly trends for power factor and capacitance, but also instantly respond to sudden changes if they exceed a user set threshold.

Power factor and capacitance have been used to detect and prevent failure in many bushings, of many different types, from Westinghouse, ABB, Trench, GE and others (Doble) using only the individual bushing leakage currents for diagnostic purposes. The addition of a voltage reference provides far greater capability and will be discussed in a separate article. For now, we have three bushings, with three leakage currents and an interest in diagnostics.

In Figure 2, we show the three phasors associated with the three leakage currents from a set of bushings which, in an ideal balanced system would all be 120°. We have added a very large change in the Phase 3 bushing – a change 100 times greater than expected from bushing deterioration – so we can easily see the effect on the relative phase angles:

- Phase 3-to-1 increases
- Phase 3-to-2 decreases by the same amount that 3-to-1 increased
- Phase 1-to-2 stays the same

Consequently, if we were to plot the data over time, Phase 1-to-2 should stay constant if just bushing 3 is deteriorating. Also note that the sum of the three phase angles is always 360°.

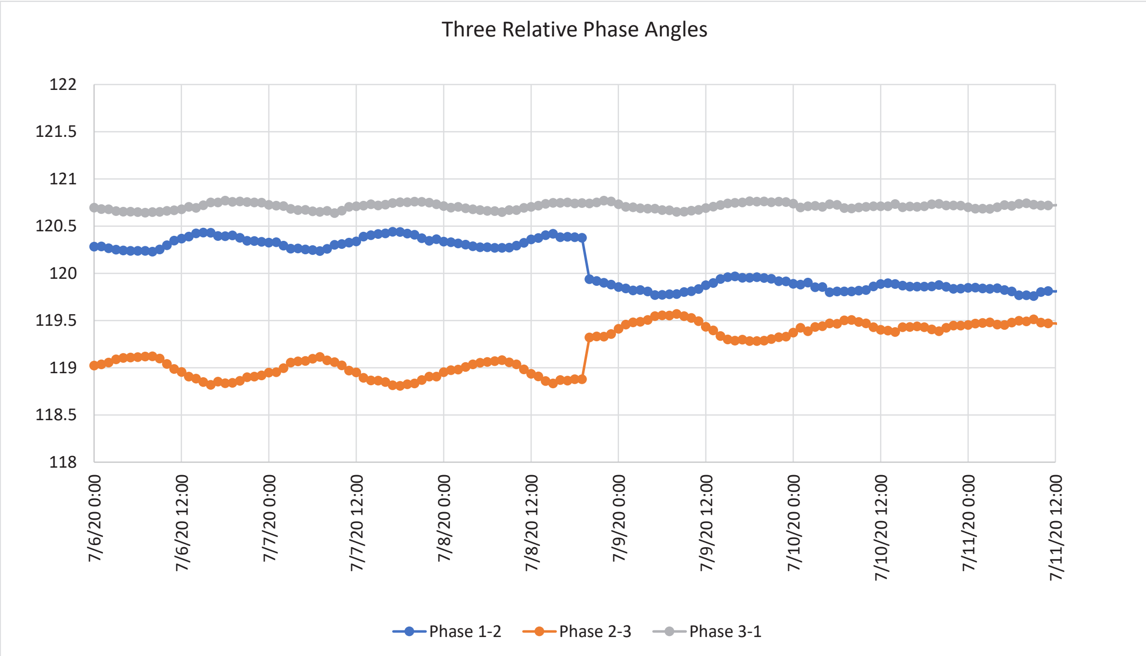


Figure 3. Step change in phase angle for Phase 2 bushing

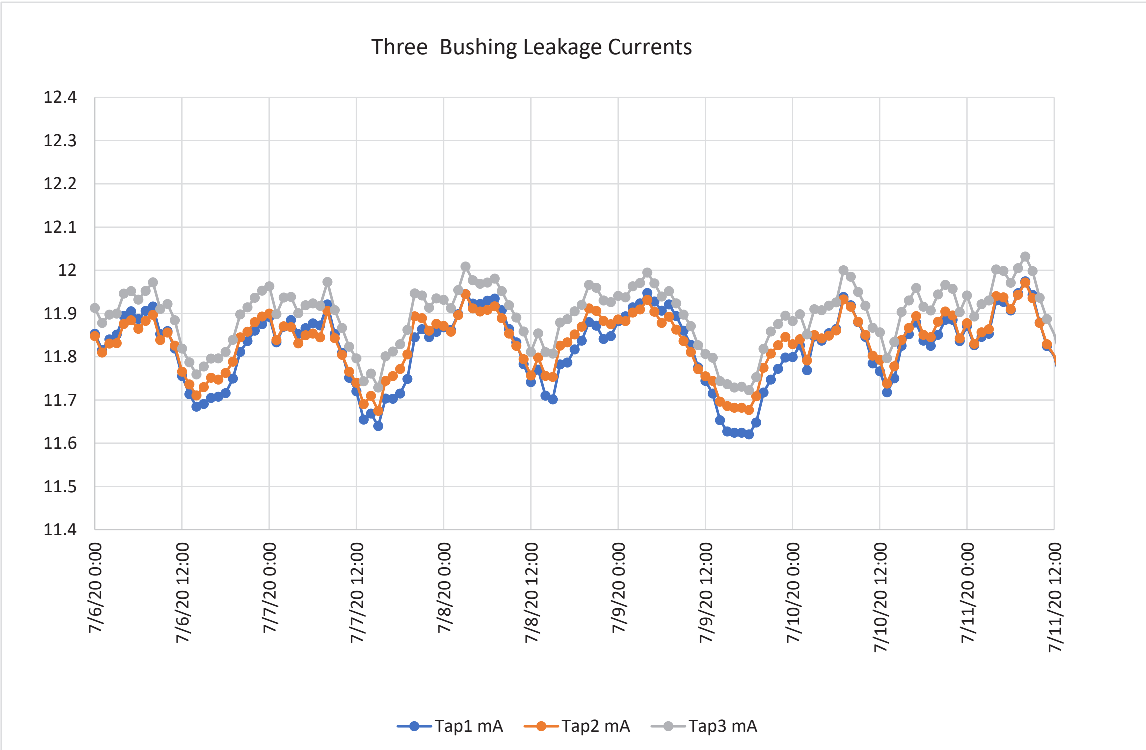


Figure 4. Leakage current magnitude for the three bushings

In Figure 3 we can see example results where both traces involving the phase 2 bushing show a sudden change in angle. Note that the remaining trace is relatively constant, indicating that it is just one bushing deteriorating. As expected in Figure 3, the sum of phase angles at any point is 360°, and the traces involving the deteriorating bushings show reflections of the variation, as expected: the increase in one is the same as the decrease in the other.

At the same time as recording the phase angles, we can also look at leakage current magnitude for the three bushings, shown in Figure 4. The natural variation in current magnitude, following a daily cycle shows no particular disturbance at the date/time of the anomaly in Figure 3.

In Figure 5 we can see the relative phase angles for three low voltage bushings recorded over several months. The changes recorded in Figure 3 were small, as expected, but in Figure 4 we are seeing changes of several degrees.

Power factor and capacitance have been used to detect and prevent failure in many bushings, of many different types, using only the individual bushing leakage currents for diagnostic purposes.

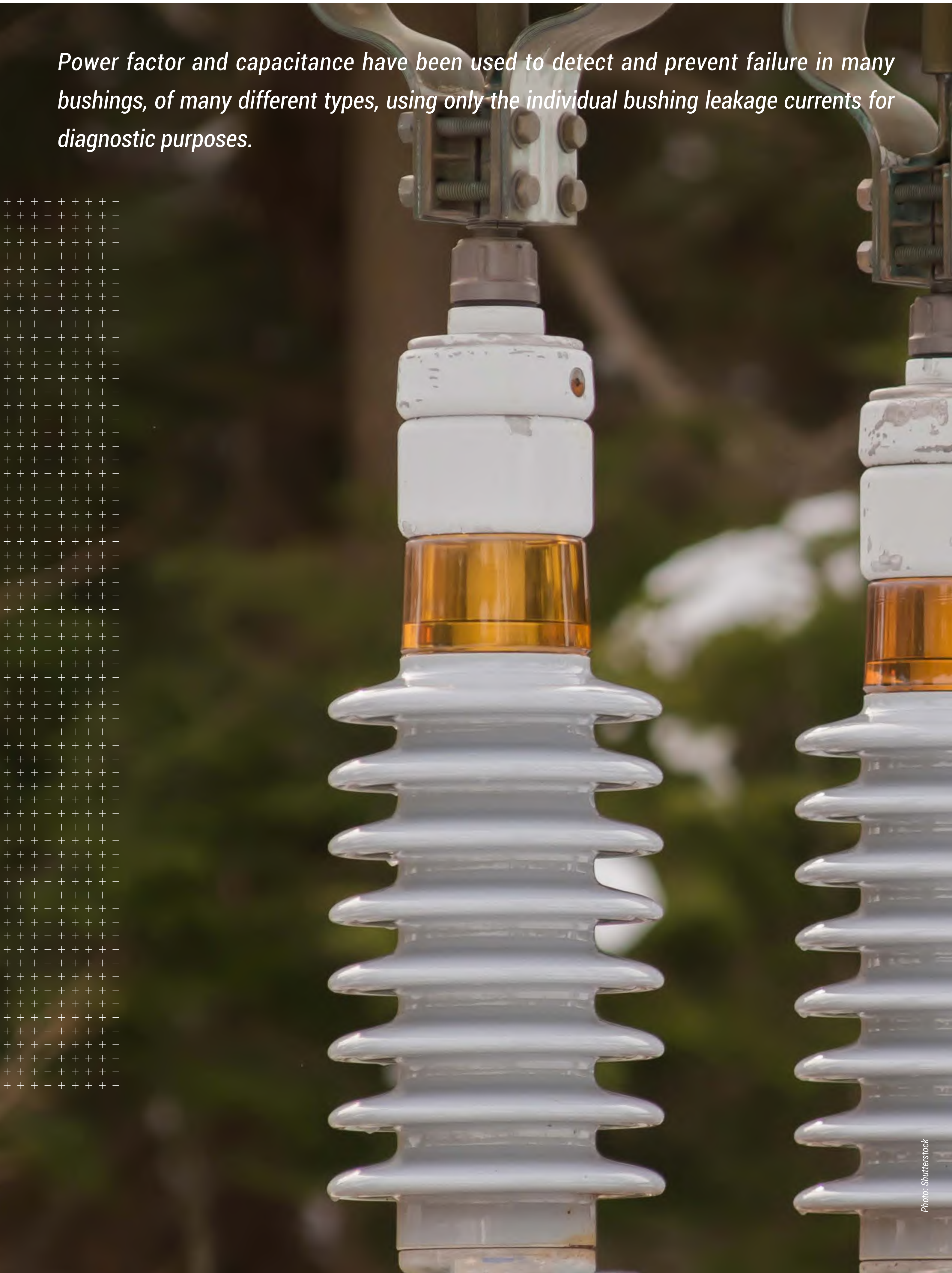


Photo: Shutterstock

The addition of a voltage reference provides far greater capability and will be discussed in a separate article.

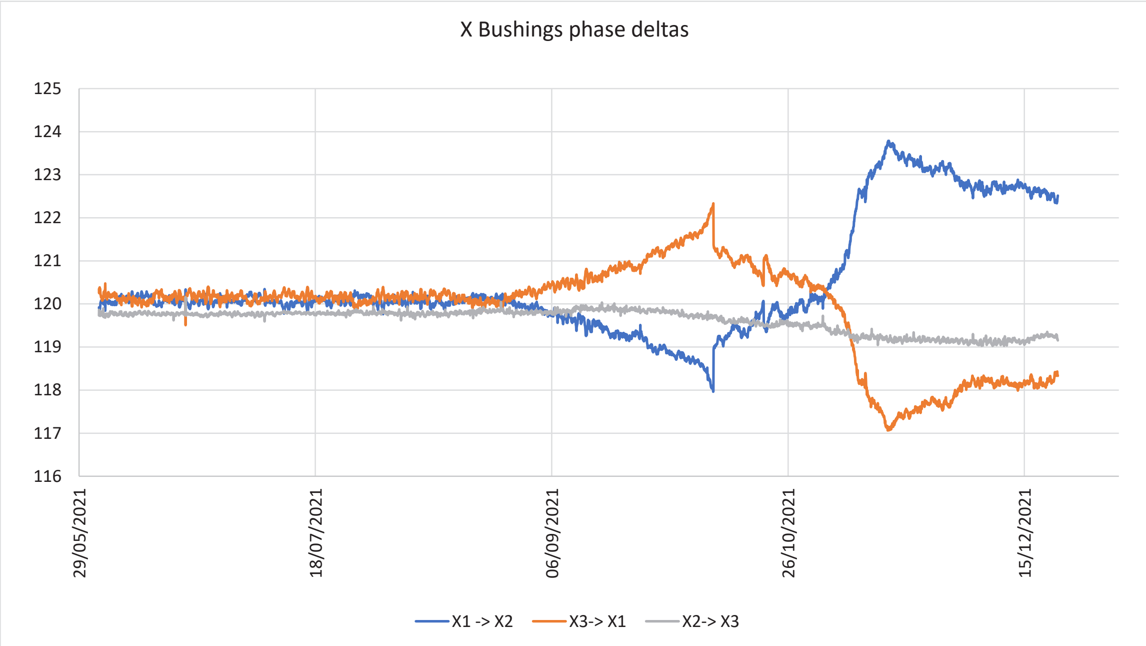


Figure 5. Relative phase for 3 bushings

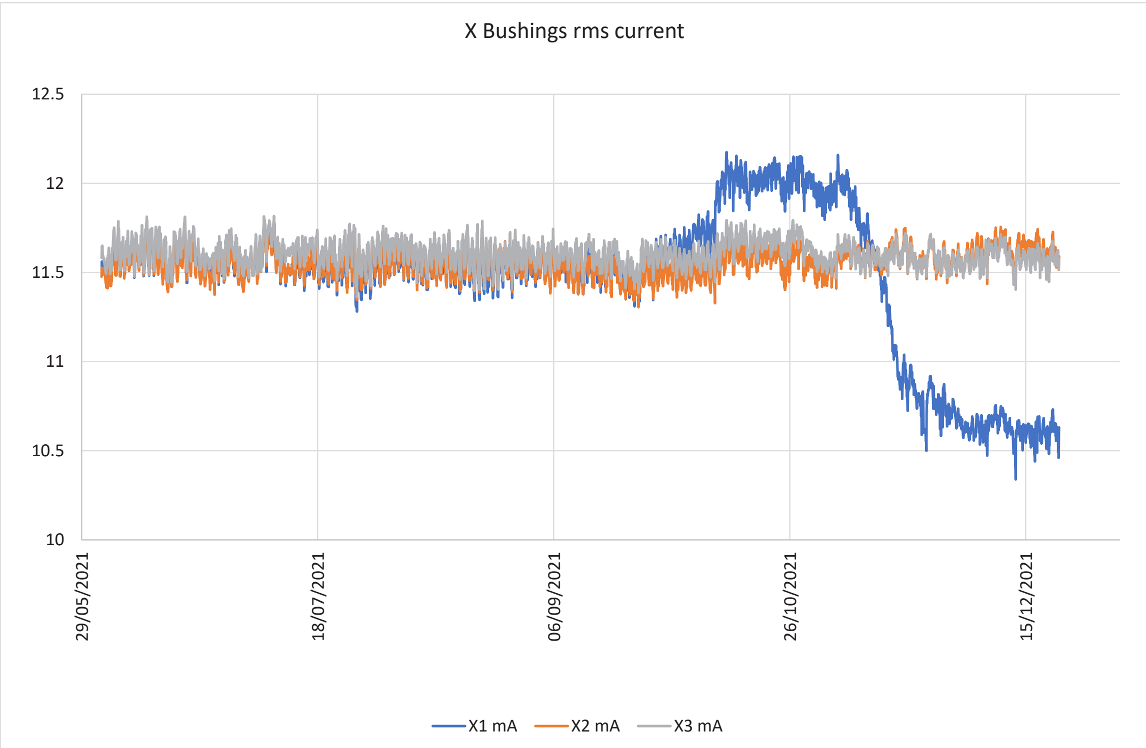


Figure 6. Leakage current magnitude for three bushings

In Figure 5, none of the traces show a constant value, indicating that more than one bushing is deteriorating. The two traces with large changes in phase angle both include the X1 bushing, which is thus the suspect bushing. In addition, the fact that for the X1 bushing the phase angle heads in one direction then reverses implies that the power factor has increased then decreased again. This is an uncommon effect where a bushing shows the effect of internal tracking within the bushing due to contamination or moisture ingress and can eventually lead to a negative power factor being recorded. The effect of tracking can also be seen in the leakage current magnitude over the same time period, as shown in Figure 6.

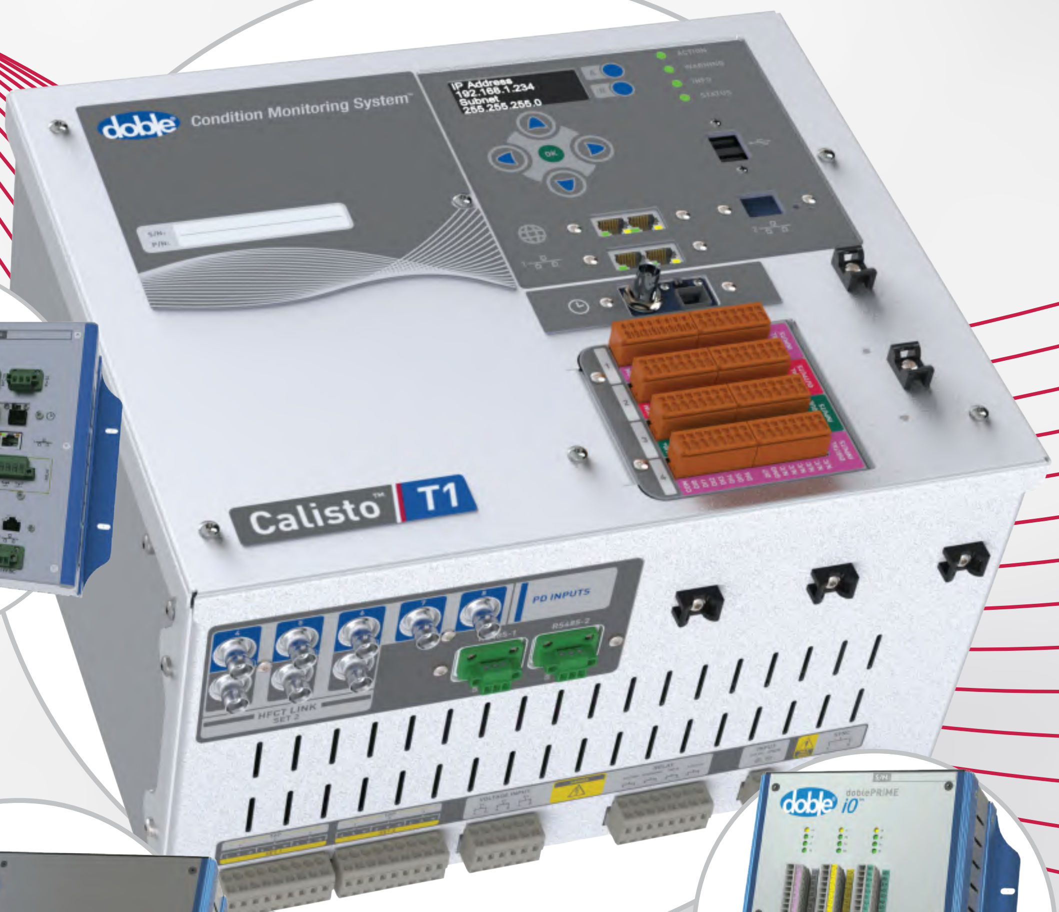
A rising current is typical of deteriorating bushing, but here the current rises, and then subsequently falls – again, an uncommon event, and one which relates to internal tracking within the bushing.

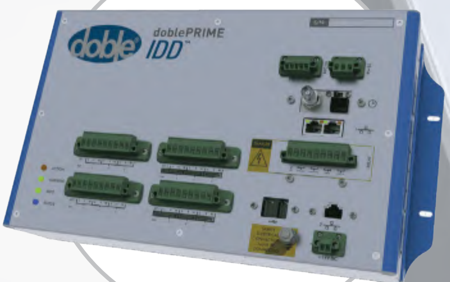
It is very important in bushing monitoring to be aware of all available data – the raw phase angles and rms leakage currents for each individual bushing are often as useful as the derived power factors and capacitances in terms of deterioration detection, investigation and diagnosis. A voltage reference is recommended when possible, as this helps to remove the effects of system variation and can focus investigation on to an individual bushing.

CALISTO® T1

A CONFIGURABLE, ALL-IN-ONE CONDITION MONITORING SYSTEM

UNLOCK THE POWER OF UP TO THREE OF DOBLE'S HIGH-PERFORMING MONITORS FOR A FRACTION OF THE COST





IDD™ BUSHING MONITOR

IO MULTI-FUNCTION DATA RECORDER

CLEAR USER INTERFACE THROUGH A BUILT-IN SERVER

PD-GUARD™ PARTIAL DISCHARGE MONITOR

WWW.DOBLE.COM/CALISTOT1

Should You Consider Online Bushing Monitoring?

Online monitoring enhances the safe, reliable operation of substation power equipment, measured performance, reduced failure rates, and provides more consistent and frequent information of the existing fleet. Online monitoring can be a key tool to help understand the condition of your bushings.

Photo: GE

As utilities move from traditional off-line, routine testing of power transformer towards on-line continuous monitoring, many benefits are realized. On-line monitoring enhances the safe, reliable operation of substation power equipment, measured performance, reduced failure rates, and provides more consistent and frequent information of the existing fleet. In addition to these benefits the end user realizes improved integration of relevant information so that Operations Managers are better positioned to make more informed decisions.

In this perspective we want to show you the benefits of on-line bushing monitoring, establish what properties you can see and demonstrate why on-line monitoring can be a key tool to help understand the condition of your bushings.

Cigre WG A2.37[1] established, via a survey of 964 major failures between 1996-2010, that approximately 14.4% of the failures were caused by bushings over all voltage ranges and 47% of those led to fire, explosion and leakages. While we understand off-line monitoring is the most widely applied program, we can demonstrate the benefits of an on-line monitoring system especially when the time taken for incipient faults to develop can be less than the measurement time between off-line inspections. Although we do not see online monitoring replacing off-line monitoring but complementing it – it is another tool in your diagnostic toolbox for early detection of faults that otherwise may go unnoticed until it is too late to correct.

When monitoring bushings there are two main measurements collected – Capacitance change of C1, and Power Factor enabling a customer to understand the mechanical integrity of the bushing core (C1) and assessing the condition of the bushing insulation (PF) respectively. Off-line monitoring can measure these directly. However, these measurements are not systematic and can be affected by change in operator and the presence of contaminants. Also, off-line measurements are not taken under operational conditions. Conversely on-line measurements are continuous, systematic and are taken under operational conditions enabling better trending of developing faults to mitigate surprise failures of these critical transformer components.

On-line bushing monitoring capturing a Conductive Layer failure

Figure 1 shows a relative change of C1 Trend Chart (left) of a set of three bushings where all three are in very close proximity of each other, as they should be in normal conditions; when C1% of bushing B suddenly increases by a significant step and then it maintains this deviation against the other two phases. The Polar Plot (right) offers a different view to the same data where the step change can be more easily observed, alerting the end user of an issue.

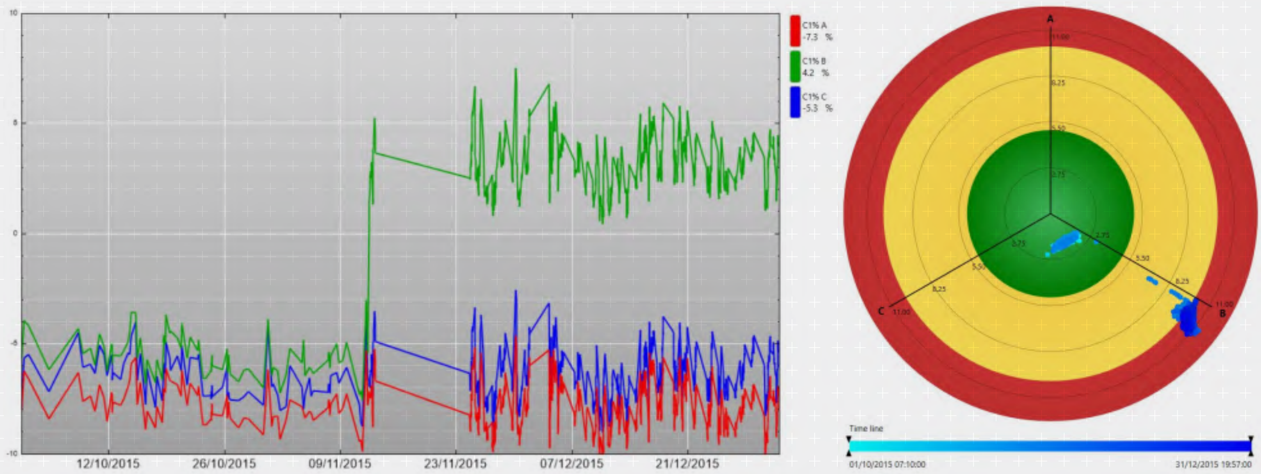


Figure 1. Relative change of capacitance C1: Trend Chart (left); Polar Plot (right)

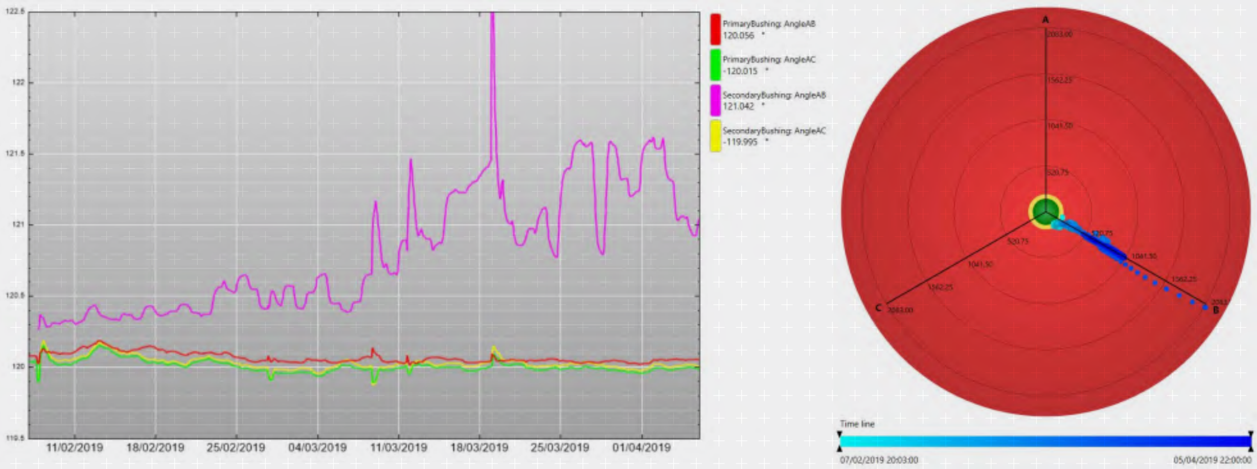


Figure 2. Inter-phase shift increase for LV phase B (indicative of a PF increase): Trend Chart (left); Polar Plot (right)

Through online monitoring, terminal bushing failures can become incipient bushing failures.

On-line bushing monitoring capturing an accelerated ageing of the insulation layers

Figure 2 shows an increasing inter-phase angle (as measured at the bushings' test tap) for the LV phase B (same data shown in Trend Chart -left-, and Polar Plot -right-). This behaviour alerted the user of a rapidly degrading insulation for this bushing.

Photo: GE

Benefits of on-line monitoring

The two events (Figure 1 and Figure 2) occurred irrespectively of the monitoring of the bushings. Neither of the respective utilities had planned off-line testing for more than a year when the bushing monitors triggered their respective alarms. However, because of the on-line monitor warnings these faults were detected at an early stage. Although there is no certainty that this would be the case, it is highly likely that either bushing would have failed before the next planned off-line test. Thus, the respective utilities had the time to plan the de-energisation of each transformer, and the bushings were replaced before a developing failure could affect the surrounding assets.

By on-line monitoring, **terminal bushing failures** became **incipient bushing failures** [2].

Figure 3. DGA 900 Plus

GE's BMT family continuously monitors the condition of bushings in real-time and provides end users with the information they are used to receiving from off-line tests, namely changes in capacitance and power factor (tan delta), to assess the bushing dielectric efficiency and insulation integrity.

GE's BMT family continuously monitors the condition of bushings in real-time and provides end users with the information they are used to receiving from off-line tests, namely changes in capacitance and power factor (tan delta), to assess the bushing dielectric efficiency and insulation integrity. This is available as a stand-alone product or available as an integrated solution with our DGA Plus monitor.

References

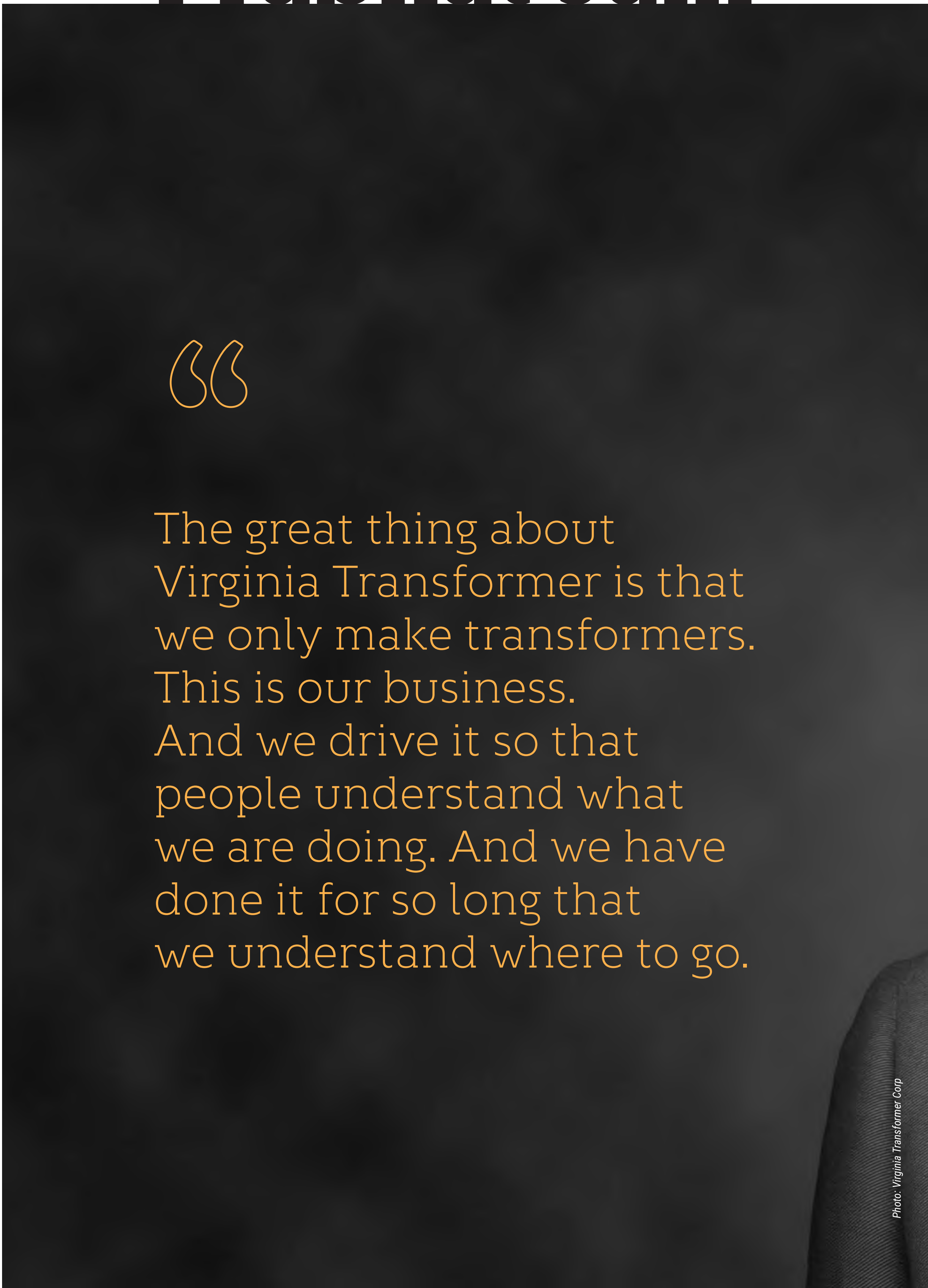
[1] CIGRE brochure 642, Transformer Reliability Survey, WG A2-37, 2015, ISBN: 978-2-85873-346-0

[2] CIGRE brochure 755, Transformer Bushing Reliability, WG A2-43, 2019, ISBN: 978-2-85873-457-3

Prabhat Jain

CEO-CTO of Virginia Transformer Corp

Interview with **Prabhat Jain**



> “The great thing about Virginia Transformer is that we only make transformers. This is our business. And we drive it so that people understand what we are doing. And we have done it for so long that we understand where to go.

Photo: Virginia Transformer Corp

Transformer Technology talked to Prabhat Jain, CEO-CTO of Virginia Transformer Corp, a leader with a fascinating biography, a mechanical engineer with an MBA who originally worked in the company and had nothing to do with transformers but then turned into a *transformer guru* as Virginia Transformer and Georgia Transformer, formerly Efacec, became arguably one of the very largest power transformer manufacturers in the world and the largest US-owned manufacturer in North America.

Photo: Virginia Transformer Corp

Alan Ross: In this interview I am hosting a frequent guest, or at least he's been a guest more than some other people. Prabhat Jain, the CEO and President of Virginia Transformer and Georgia Transformer, as well as a new plant coming online in Chihuahua, Mexico, and then another new plant that will come online near their existing plant in Virginia. Prabhat, it's so good to have you here.

Prabhat Jain: You're quite welcome, Alan. I am very excited about the interview and the opportunity to tell your readership and the industry community gathered around Transformer Technology and Power Systems Technology about Virginia Transformer and what we are doing.

AR Normally, when we do the interviews, we try to keep them purely editorial. However, it is impossible to do that with you because you are a forward-thinking leader and you've done some amazing things within Virginia Transformer and Georgia Transformer, which used to be Efacec.

There are a couple of things I want to talk about. The first is, you have a very unique approach to quality and quality assurance. And since we are still in an industry where transformers are pretty much built by hand, uniquely, there is no mass production, can you talk a little bit about when you started to think about quality and quality assurance? How do you go about controlling quality and how do you make a difference doing quality?

The transformer is a handmade product. So, we have to get people to produce quality, think quality and build quality all the way across in every step.

PJ I would start by saying it's all about people. As you said, a transformer is a handmade product. So, we have to get the people to produce quality, think quality and build quality all the way across in every step. Another factor is that the transformer is a technological product, and technology is not obvious. You can't see the electrons and the field running around when you're building a transformer. So, I will start from the fact that it's down to the people.

That being said, over the last 50 years the work ethic of the people has changed. In fact, the norm has changed. People used to work in a plant for ten, 20 or 30 years. But not anymore. Now it's like five years. That produces a huge challenge in terms of how we maintain the skill level that it takes to produce a custom manufactured product and custom designed product. We don't have as much of an issue with the designers. They see the opportunities of the technology and the development we do in the company. So, they attach value to that and stay with us longer. However, our hourly worker typically does not have what you call a broader view of the industry. They just look at it from their own perspective, basically speaking, and they realize the challenge of manufacturing. So, this is how I have approached it over the last seven to nine years, when we became a major force in the transformer production scene in our country, and we took steps to overcome the short tenure of trained, skilled employees.

There are several avenues we have pursued. One is training. That has given us some edge, but not really as much as it takes to maintain the high level of quality.

The second thing we did was installing technicians who are actually subject matter experts - 20-year-knowledge people, and we have taken them offline, so to speak, to monitor what is being done on the floor. Therefore we assured the processes are being followed because there is someone who understands them.

The technicians must be trained. They are as good as our designers in understanding insulation, dielectric spacing clearance and the tying down of the cable so the cable won't fly away when the short circuit hits it, etc. All these things are known to them. Some five years ago, we made an addition to that as I realized that everything we do in transformer manufacturing is mechanical. The diameter of the coil is mechanical. The strength and the tension on the wire is mechanical. The clearance between the coil and the inner diameter ID and the core outer diameter iOD is mechanical. The 2-mm gap that we have to maintain on the core corners is mechanical. No waviness in the three-meter long core legs is mechanical. Everything is mechanical. So, for years and years we had electrical inspectors on the floor because a transformer is an electrical product.

But when it comes to mechanical issues, what tools to use, how to calibrate, and then think mechanically in terms of forces, friction and handling; how to lift a 20,000 pound coil and bring it down straight onto the court so it doesn't scrape the sides and damage the insulation, how to make sure the coating coil assembly is vertical if it leans one degree, et cetera - these things are very easily understood by mechanical engineers and mechanical inspectors. I also sent our mechanical inspectors to American Quality Association courses to get them certified for mechanical inspection. So, these are examples of very simple ground changing initiatives. Just by realizing that the transformer making is mechanical, I started building up to the higher level of leadership, also mechanical.

To ensure quality, you need people. There are 250 engineers in the company today, and we are going to add more. They are the ones who are our assurance that we will continue to deliver and build a quality product. This takes a lot of drive from the CEO because it takes a lot of money. But if I am going to add 100 people, I know that's the right thing to do.

Another important area when we speak about quality is, of course, that we need more quality assurance people. Quality control is inspection. Quality assurance means that already at the

Photo: Virginia Transformer Corp

design and then the production stage we ensure the product is made so that it doesn't need much inspection in the first place. So, we are continuously adding more people.

If you want to have a better product consistency and a reliable product, as we are continuing to grow, we need a lot more people in the layers of technical and engineering knowledge. So, we have 250 engineers in the company today, and we're going to continue to add more engineers. My direction to all my leaders is hire any engineer that you can find to come and work in our company, because we have so much going on, and they are the ones who are our, what you call, assurance that we will continue to deliver and build a quality product. It's very simple. However, it takes a lot of drive from the CEO because it takes a lot of money. If I'm going to add 100 people, I know that's the right thing to do.

I don't need to go to Sweden and get permission to add 100 engineers. I don't have to go to GE Prolec headquarters saying I need to add 100 people. I just add them. And that's the great part about Virginia Transformer - we only make transformers. This is our business. And we drive it so that people understand what we are doing. And we have done it for so long that we understand where to go.

AR It's very interesting what you just explained. Yes, the transformer is part of the electrical system, but it's mechanically built, and some mechanical engineers think differently than electrical engineers. So, the idea that we can get mechanical engineers into production is an interesting approach.

The second thing I want to talk about is the history of transformers that is going back to pre-Westinghouse days, but the technology has not really changed that much. One of the things that has changed is that we used to design them using slide rules. We did it with our eyes. Today, we have better ways of doing design and we are much more exact. We build to specification. We don't overbuild anymore.

You talked about some changes that are happening in the technology of building transformers. What do you see are the current and future technology changes in transformer design and manufacturing?

PJ Design is a very vast field, and in designing, electrical engineers are kings. They are the ones who see, who understand the forces and the maximal equation, the electromagnetic, etc.

In any system, there are many safety factors, or margins, as we call them. So, there is a margin in force, there is a margin on field strength, there is a margin on thickness of insulation, there is a margin on the tolerances of the conductor, there are margins everywhere. And sometimes the margin in the system can vary from 1.5 safety factor to something like ten safety factors, just by nature and by practices that have occurred. So, what we have done at Virginia Transformer over the last seven or eight years is having a development department that consists of very analytically oriented, highly skilled engineers, who try to bring that safety factor to more nominal numbers, raise the one and a half, and lower the ten. The system is only as strong as the weakest link.

So we try to optimize and we have done a lot of work in that area in terms of the hot spot, the directive margin, the stresses, insulation, top oil rise, the velocity of the oil, the number of oil driving washers, how many we need to place to optimize them so we don't impede the flow, etc. Every time you have the oil making 180-degree turn, you lose some head and thus you lose velocity. We have done a lot of fundamental analysis using CFD, and using, of course, just very simple temperature gradient calculations with finite element analysis. So, we have improved that and this is one area of technological development that we have furthered in the last seven to ten years. And we are continuing to work on that.

The other technology area is materials. Materials are becoming more and more expensive. Millstone used to cost thirty cents a pound, now it costs sixty cents a pound. So, there were times when it was okay to use half an inch wall thickness, but now we are saying, instead of using 36,000 PSI, we would like to use 80,000 PSI steel which is available for a small premium. However, it saves a lot of cost. But then other issues emerge, and we have to manage those. The deflection goes up. We can manage deflection by putting it where it doesn't hurt. For instance, if bushings deflect, then they are going to come closer and that's not good. So, we want to design accordingly, and this is about materials, the dialectic design, and the temperature design.

Sound reduction is another very important area where we have made progress, which, believe it or not, gives you longer life because sound comes from vibrations. Vibration means that there is something that is rubbing against something else and the rubbing is going to eventually lead to abrasion and failure. So, these are the areas that we have improved in terms of technology.

Looking down the road, there is much coming at us and we have to evolve beyond just the mechanical and electrical spheres. There is EV charging and data centers, which are becoming important very exponentially, rising faster and faster. And, of course, solar and wind that has given rise to battery storage.

Battery storage uses a lot of computers, and harmonics. So, all of these together are pushing us in an area of what I would call solid-state electronics. Certainly, the solid-state transformer is the next step, if you will, from just normal inversion and conversion. Essentially, EV charging is about taking AC and taking DC out of that. We are going to need a lot of that. And then the electrical vehicle is another area where we're going to use a lot of solid-state electronics in order to drive the motors in the wheels, to drive the wheel directly, and eliminate a lot of mechanical systems from there.

This shift towards solid state electronics will apply to transformers in various aspects of its application. The transformer will exist as an electromagnetic device like we have today. However, it will be combined with a lot of solid-state electronics in order to make the transformer continue to serve the application. Our knowledge of harmonics is very deep. Virginia Transformer's foundation is in variable speed drive isolation transformers.

Photo: Virginia Transformer Corp

So that is growing nicely. There are so many other areas that we are working on as an engineering company to reduce the weight of the transformer, and then by using different materials and smoothening the fields. Very far-reaching developments are underway right now.

Here I would like to mention ester fluids and vegetable oil, which has been around for a long time. Now we are able to take the technology to 200 MVA, so we can supply transformers for data centers, particularly very large transformers for data centers, which are mostly located in urban areas. We want to keep them safe and ester is very powerful for that. And we're going to take this technology to 230 KV now. We are planning to do that. We have many PhDs on our staff who are chemistry and electrical engineering specialists in order to combine the knowledge and then see how we can take that technology forward.

Another area is the dry type transformer, which is again a safe device in terms that it has no oil and of course, no leaks. We can make dry type transformers up to 35 kV, 150 bil, 15 MVA, which is a fairly good size transformer to serve most of the industries.

AR Prabhat, you always leave me with so many questions to ask that we have to do another one of these interviews. And I have to comment on this. Most of the people that I have talked to who are leading transformer companies, don't know much about transformers. They know a lot about business. You happen to know a lot about business but, boy, do you know a lot about transformers, too! I really appreciate that, because you can tell that transformer is in your blood, and that's good to see, because I think that's what brings things forward.

So thank you from the industry, because I appreciate it very much.

PJ Thank you, Alan. And I always like to finish by saying one has to have passion. And passion brings excellence, and excellence will serve the industry better. Absolutely.

AR That's what we're going to end with. Passion. Thank you so much, Prabhat, and we will talk again.

PJ Thank you.

Are you focusing on the RIGHT box?

Accuracy and sensitivity are a MUST for online monitors. However, balance is needed while seeking for perfection without compromising the bigger picture. The focus ultimately needs to be your transformer.

I've been asked so many times "How many pico-Coulomb can your monitor detect?" or "What is the minimum pF change you can detect in a bushing?" or "Can your monitor match my laboratory readings?".

Although it is indisputable that we need reliable and accurate monitors, too many times we are focused on small details and we miss the larger scope of the analysis, which is: what is the condition of my transformer; and what potentially needs to be done? Sometimes the link to these core questions can be lost in the details.

Can a single absolute value from just one reading tell you what you are going to do next? Sometimes yes, more often not.

Searching for the pico-Coulomb

A 345 kV bushing was monitored online and, after about one year, a Partial Discharge (PD) event of 8 pulses per seconds was detected [1]. It occurred only at that time, never before and never after. At the same time the monitor detected a small

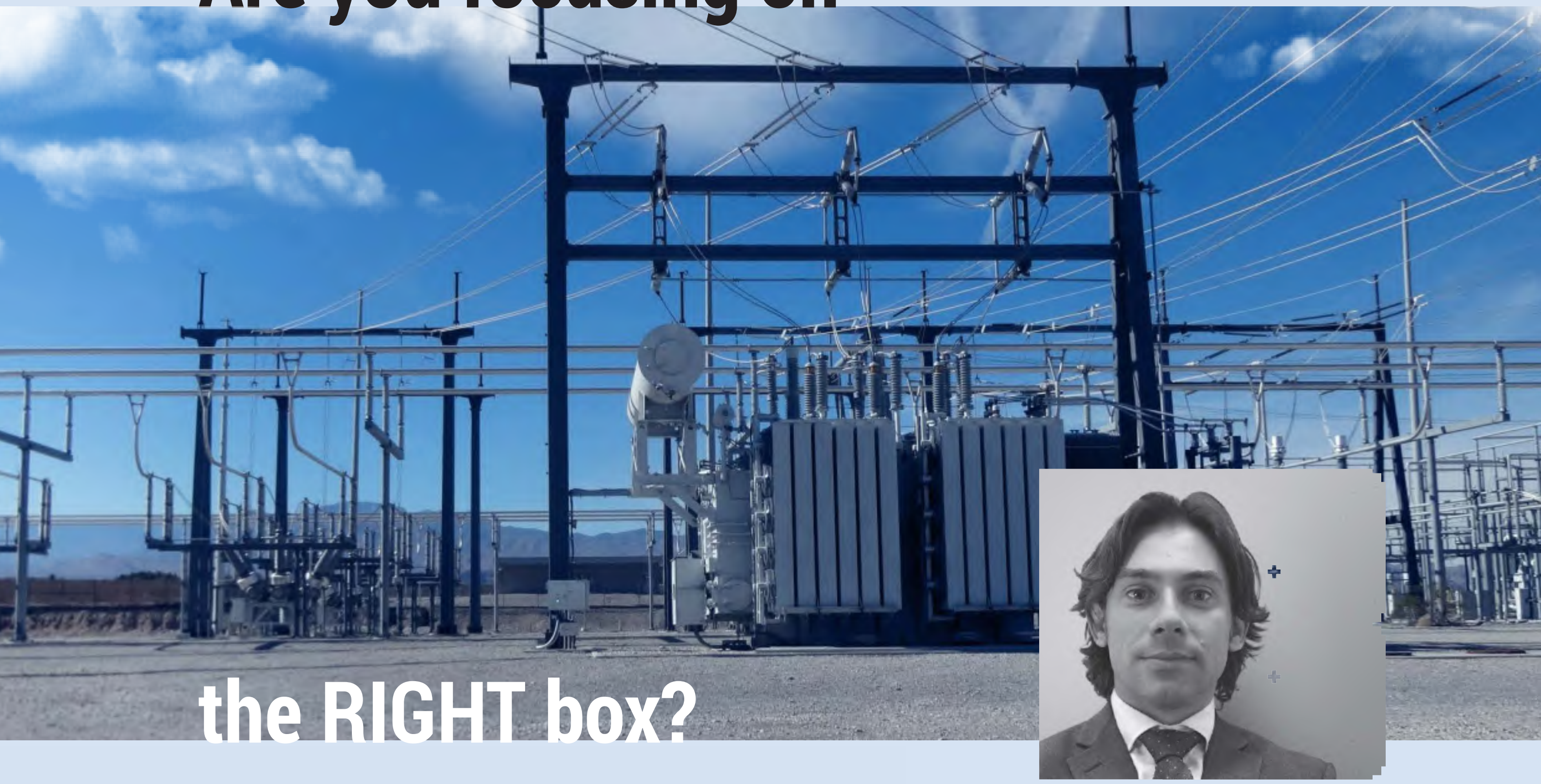


Photo: Shutterstock

While the 'little box' - your monitor - is important, it is vital to remember that its sole purpose is to give an insight into the 'big box' - your transformer.

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

increase of capacitance in the same bushings, less than 2%. No one would take an action based on just one of the two pieces of data, but the simultaneous occurrence of the two events suggested a correlation. A DGA test of the oil was done, which confirmed that the bushing had experienced an internal arcing (76 ppm C_2H_2), likely due to a short circuit between two layers.

Would have this action been different if the PD was 1, 100 or 1000 pC? My contention is that it wouldn't. The correlation of data led to the right test and right actions, not the value of the specifics of the data itself. Confidently knowing if there are PDs, in which winding, bushing, or phase, and whether they are stable over time or not, provides much more information than knowing how many pico-Coulombs.

Inaccuracies in DGA accuracy

Table 1 shows the comparison of readings from an online DGA monitor by two labs. One oil sample was analysed in lab #1, and two samples were analysed in lab #2. The lab data are apparently inconsistent showing variations in both inter-laboratory reproducibility (lab 1 vs. lab 2) and intra-laboratory repeatability (in lab 2).

Although we need reliable and accurate monitors, too many times we are focused on small details and we miss the larger scope of the analysis, which is: what is the condition of my transformer; and what potentially needs to be done? Sometimes the link to these core questions can be lost in the details.

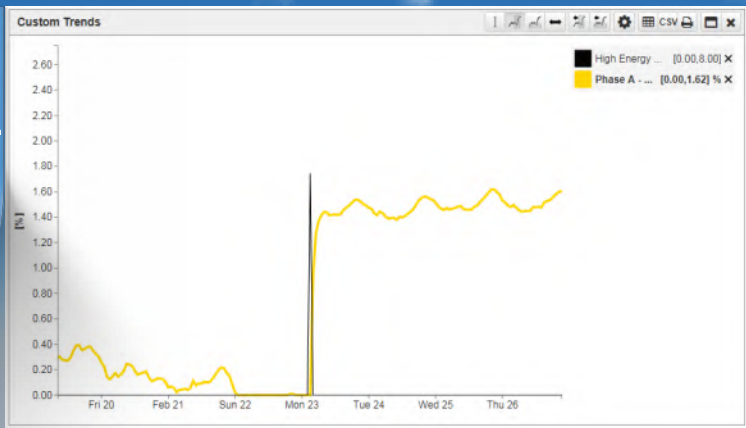


Figure 1. Simultaneous variation of bushing capacitance an PD occurrence

Gas	Online Monitor	Lab 1	Lab 2 Sample #1	Lab 2 Sample #2
H_2	116	96	140	117
CH_4	37.6	46.3	47	39
C_2H_6	57.8	76.1	70	56
C_2H_4	1	1.9	1	2
C_2H_2	0	0	<1	<1
CO	268.3	322.2	330	231
CO_2	2872	3165.1	1802	2067

Table 1. Gas concentrations in ppm. Comparison of DGA monitor readings by two labs

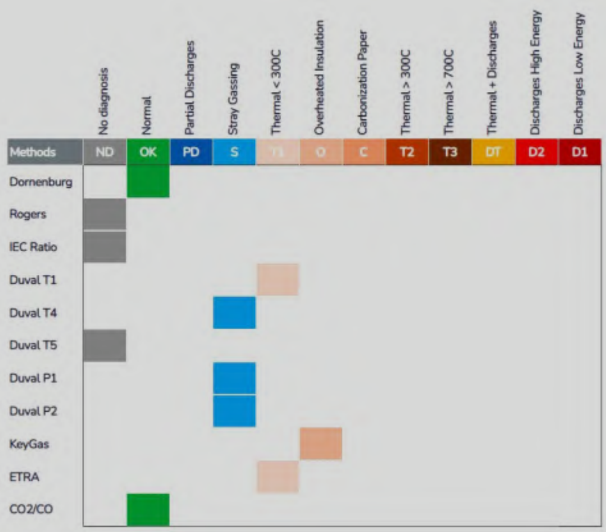


Figure 2. DGA diagnostics using DGA Matrix

Where is the truth? Which lab and which sample shall I use to validate my monitor? The interesting thing is that if you process the data of each column through all the standard diagnostic methods (Figure 2) you will see that all the readings provide the same, identical diagnostic results [2].

Comparing online DGA results with those of a laboratory can be done, but it must be done in a sapient manner, as described in IEC60567 [3] and CIGRE TB783 [4], which can be expensive in terms of time and money. The alternative way of comparing just one single value with a single sample in a single lab will often provide inaccurate results, due to the inaccuracy of the method rather than the data. In the end, what matters is that the different data sets provide the same diagnostic information.

Online data could not match offline, but it might be correct

How many times have you switched off the transformer, taken an offline bushing test and realised that the results are different from those in the online monitor? Is that because the monitor is inaccurate? It might happen, but most likely, it is because the increase of bushing losses is a complex dynamic process; it can be slow and can be fast, can be permanent or can be intermittent, can be small and can be big. The online monitoring system gives you a real picture of what is happening at real operating conditions. The offline test is an instantaneous snapshot at fixed and

Inaccurate results will usually occur due to the inaccuracy of the method rather than the data. What matters is that the different data sets provide the same diagnostic information.

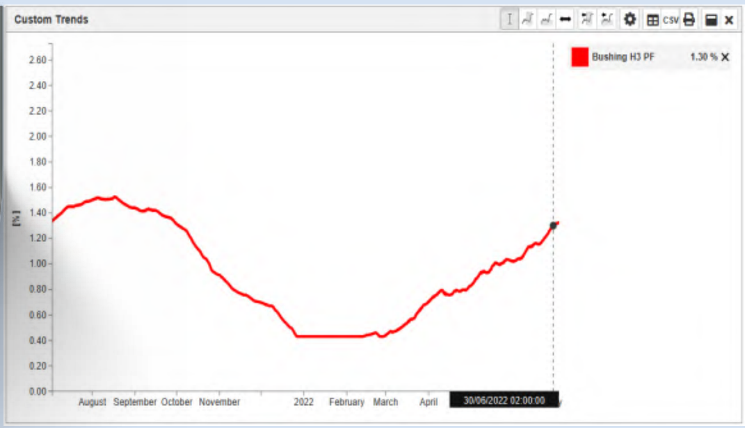


Figure 3. Bushing Power Factor seasonal variation

controlled conditions, and crucially, those may not be the same conditions that are causing the bushing to lose its properties. Figure 3 shows the relative power factor monitored online that is apparently ok in cold season, while it is higher in the hot season. If you test the bushing offline without taking into consideration the oil temperature, you might not see any deviation. But the monitor tells the truth here, which is that there is a faulty process in the insulation which increases the dielectric losses with temperature. In this case, as expected, the offline test done at ambient temperature showed a value twice the nameplate (0.6%), while the monitor at operating temperature was about four times the nameplate (1.3%). Which one is right? Both are right. And, despite the difference in the absolute values, there is no doubt that the bushing must be replaced.

While some can still get attracted by the debate on the 1-to-1 comparison of online to offline data, online vs. laboratory data, millivolt versus pico-Coulomb etc., it is key to focus on the right information and not get "lost in the weeds". Very often the most important thing is not the data itself, but the information given by the correlation of the data, enabling a proactive maintenance program.

So, the 'little box' is important, but it is vital to remember that its sole purpose is insight into the 'big box' – your transformer.

Photo: Shutterstock

While some can still get attracted by the debate on the 1-to-1 comparison of online to offline data, online vs. laboratory data, millivolt versus pico-Coulomb etc., it is key to focus on the right information and not get "lost in the weeds". Very often the most important thing is not the data itself, but the information given by the correlation of the data, enabling a proactive maintenance program.

References

[1] M. Tozzi, "Risk Management Requires Actionable Insight: Adding Value with Truly Integrated Transformer Monitoring," *Transformer Technology*, Issue 3, Sept 2019, pp 88-96
[2] https://camlingroup.com/en-us/dissolved-gas-analysis-dga-matrix
[3] IEC 60567:2011, Oil-filled electrical equipment – Sampling of gases and analysis of free and dissolved gases – Guidance
[4] CIGRE TB783, Technical Brochures – DGA monitoring systems

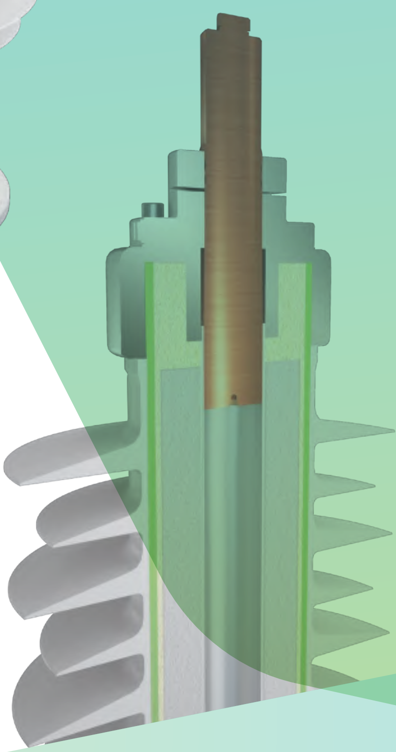
TRENCH
Sense the Power

HSP
Pioneering high voltage.

TOGETHER FOR A GREENER WORLD

ESTER IMPREGNATED TRANSFORMER BUSHINGS

RESIN IMPREGNATED TRANSFORMER BUSHINGS



SUSTAINABLE AND RELIABLE BUSHING SOLUTIONS FOR AN ECO-FRIENDLY LIFE CYCLE

- Ester fluid is 100% biodegradable, SF6-free foam for dry-type bushings
- Applicable in harsh operation and service conditions such as highest ambient and operating temperatures, high seismic, high altitude, heavy pollution
- Usage of non-hazardous materials, reliable and safe operation due to partial discharge free performance and overload capabilities
- No fire risk in case of failure/electrical breakdown
- Resin Impregnated Synthetic bushings and Ester Impregnated bushings are not sensitive to moisture exposure, easy for storage and installation

ENHANCED SAFETY AND RECYCLING OF ESTER INSULATED BUSHINGS

- High fire point, significantly increasing the fire safety of the equipment
- In case of major failure, no generation of toxic smokes
- Advanced recycling capabilities at the end of life

REGENERA™

REGENERA™ IS THE INNOVATIVE HOLISTIC CONCEPT BY TRENCH AND HSP

to preserve our environment and to create a more sustainable society, by providing the most advanced and competitive **GREEN PORTFOLIO** designed and manufactured to reduce CO_2 and polluting materials within transmission products.

POWER VOLTAGE TRANSFORMERS

INSULATION WITH "CLEAN AIR"

- With approx. 20% Oxygen and 80% Nitrogen, like the air we breathe
- For industrial purpose, cleaned from impurity and moisture
- Clean Air insulation is used in many other industrial applications besides High Voltage applications

ENVIRONMENTAL BENEFITS

- The only available HV insulation worldwide with a GWP of Zero
- No soil pollution in case of leakage

TECHNICAL/FINANCIAL BENEFITS

- Suitable for low and ultra low ambient temperatures without using mixture gases
- Maintenance free design
- Lifetime more than 30 years

SAFETY BENEFITS

- Explosion proof design
- Fire-hazard free

DISCOVER MORE

trench-group.com

hspkoeln.de

weareregenera.com

How Remanufactured Transformers Are Helping Companies Navigate Supply Chain Disruptions

by **Camden Spiller**

PERSPECTIVES

In the transformer industry, new factory-built units are encountering unprecedented lead times due to material shortages with electrical grade steel and various other components.

Camden Spiller began his career as a software engineer, attended Missouri State University and completed the Owner/ President Management Program at Harvard Business School. Away from work, Camden has served on the boards of various civic and business organizations and is very engaged with his local church and community. Camden and his wife Sarah reside with their kids near their family's farm in the Pacific Northwest.

Photo: Maddox Industrial Transformer

PERSPECTIVES

As supply chain disruptions continue to eat away at the global economy, companies are left searching for ways to navigate this crisis. The COVID-19 Pandemic of 2020 with its concurrent leash of restrictions and the growing labor shortage in the US have left the market in a bad way [1]. Near the end of 2021, *The Economist* concluded that a return to the "pre-covid years" was unlikely anytime soon as the world settled into an "era of predictable unpredictability" [2]. As this prevailing climate of uncertainty continues to shape and change the way companies operate, the desire for certainty and reliability in the procurement of goods and services remains as steady as it ever has, perhaps even more so in the face of such challenges.

In the transformer industry, new factory-built units are encountering unprecedented lead times due to material shortages with electrical grade steel and various other components. The relative scarcity of electrical grade steel is a problem further exacerbated by the new subsidies and incentives in the Inflation Reduction Act which will the innovative utilization of existing equipment is opening a wider berth for remanufactured transformers.

Transformer remanufacturing has existed as a niche industry since the early days of the technology's invention. The process has been performed by many groups over the years from small localized repair shops to large OEMs. Though the availability of remanufactured transformers is nothing new to the market, it provides four distinct advantages to help companies steer through the current supply chain dilemma.

The most obvious advantages to remanufactured transformers are their faster delivery times and lower upfront costs. With new factory transformer lead times out eighty plus weeks, in-stock, remanufactured transformers can be made available in as little as one to three weeks. Against the inflated cost of new factory-built units, remanufactured transformers offer a cost reduction between 10% and 40%.

Another benefit, equally worth noting is the reliability of remanufactured remanufactured transformers is often longer than new factory-built units.

From a fourth and broader perspective, purchasing remanufactured transformers helps alleviate an already bogged down supply chain. While recycling an electrically healthy transformer increases the availability of recycled materials for new products, it also increases the demand for the same product taken out of service, which now must be replaced. This cyclical manufacturing method cannot make room for the current industry demand. Utilizing remanufactured transformers reduces the overall product demand, which in turn brings relief to factories for the manufacture of new units. Remanufactured transformers also lower the high energy consumption and greenhouse gas emissions associated with new material manufacturing.

For many would-be purchasers of new transformers, the remanufactured option represents a new way of thinking. Remanufactured transformers are providing a reliable product, while outmaneuvering and reducing the disruptions within the supply chain.

> For many would-be purchasers of new transformers, the remanufactured option represents a new way of thinking. Remanufactured transformers are providing a reliable product, while outmaneuvering and reducing the disruptions within the supply chain.

result in increasing amounts of the steel formerly available for transformer manufacturing now being allocated to electrical vehicle charging applications. These factors have put considerable pressure on the new transformer market. Utilities, electrical distributors, contractors, and project managers who have ordinarily been able to operate with a build-to-order mentality are having to rethink their sourcing strategy. Now, the procurement plumb line is shifting to an emphasis on the ability to adapt and think resourcefully, leading to a greater focus on readily available equipment that can be quickly fitted into a project's particular needs. This growing focus toward transformers. According to a study done by The Hartford Steam Boiler Inspection & Insurance Co. [3] the second leading cause of transformer failure stems from design & manufacturing issues. Such failures can be detrimental to project deadlines and incur a significant loss in revenue. Many such failures occur at initial energization. Purchasing a unit with a proven track record in the field provides an additional level of assurance for future reliability. In the same vein, the remanufacturing process includes identifying any previous design flaws and correcting and improving any defects for a longer service life. For this same reason, the warranty period for

References

[1] Ron Hetrick et al., "The Demographic Drought," accessed at https://fs.hubspotusercontent00.net/hubfs/4906807/Demographic%20Drought%20V18.pdf

[2] "The new normal is already here. Get used to it," *The Economist*, accessed at https://www.economist.com/leaders/2021/12/18/the-new-normal-is-already-here-get-used-to-it

[3] William H. Bartley P.E, "Analysis of Transformer Failures," IMIA 2003, accessed at https://www.imia.com/wp-content/uploads/2013/05/wgp3303.pdf

TRANCO CORE

STILL THE BEST SOLUTION AFTER ALMOST 50 YEARS!

TRANCO BUILDS FAST, RELIABLE CORE WINDING PRODUCTION MACHINES

Wound magnetic cores are commonly used in the manufacturing process of distribution and instrument transformers around the world. Thanks to automation and continuous feeding, the wound core process offers greater production capacity and efficiency than the cut & stack option. The core winding process needs to be very accurate and consistent for the end product to be performing as expected. The machines used in the winding process need to be highly reliable and flexible so that a variety of gap patterns (Distributed, Flare, Zig-ZAG, Concentric) are available with ease of set up.

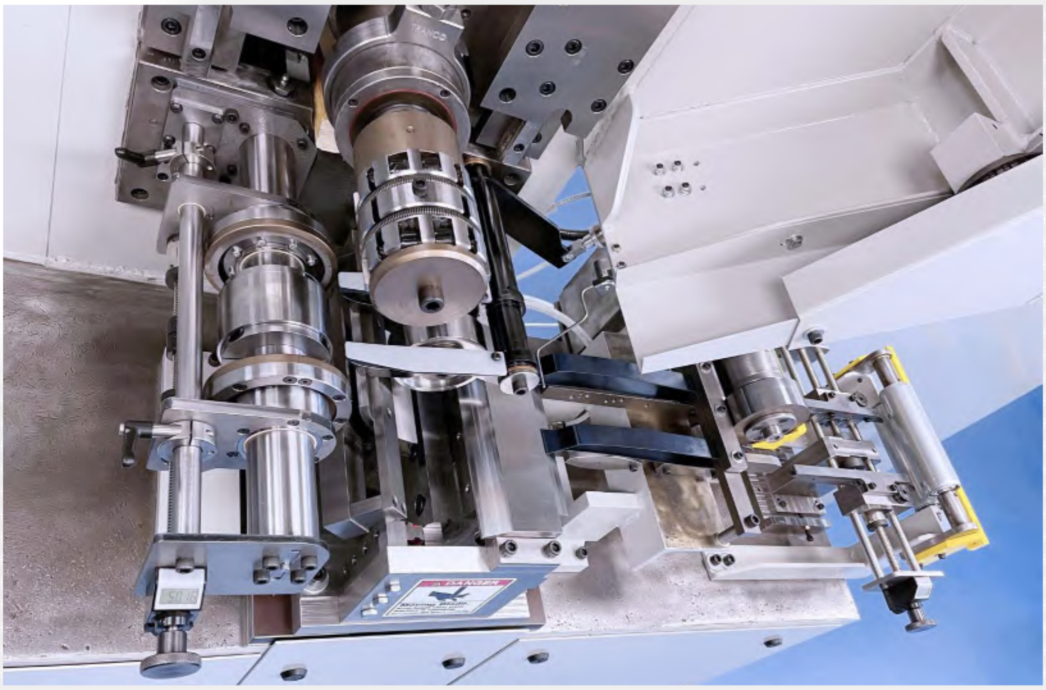


Photo: TRANCO

Key to profitability is also the possibility to operate the core winding machines without the need of a lot of manpower and space. High degree of automation and small footprint design are therefore important factors to consider during the selection and procurement process of a core winding machine. Of course, the up time and speed of process execution are also key in order to maximize the production rate and meet the highest possible output required to keep production costs down. Safety considerations which apply to equipment with moving parts and sharp tools also need to be included in the design and operation procedures in order to protect the physical integrity of the operators and maintenance crew.

> **CUSTOMERS TELL US THAT THEY HAVE BEEN USING EXCLUSIVELY TRANCO CORE WINDING MACHINES IN DISTRIBUTED GAP (DG) CORE PRODUCTION FOR MANY YEARS AND WOULD NOT CONSIDER ANY OTHER MANUFACTURING METHOD FOR HIGH VOLUME DG CORE PRODUCTION.** - Grattan Schutte – Tranco President

THE TRANCO CORE TECHNOLOGY

Transformer core manufacturing is normally done either in-house by the transformer manufacturer or is outsourced to specialized manufacturers which have in-depth expertise and dedicated processes. This second type of arrangement is widely popular for smaller, mostly distribution type, transformers as it allows economies of scale. Historically, transformer core production has been a manual and labor-intensive operation but things changed in the mid 1970's when the Original Automatic Core Winding machine was invented by Alfred S. Cooper who went on to establish **TRANCO Production Machines** Ltd, a company based in Canada and from where they have been designing, producing and supplying their high quality core winding machines to the transformer industry around the world for almost 50 years. TRANCO Machines have been sold in over 20 countries and the count keeps growing. Tranco has grown to be so recognized in the industry that **Tranco core** has became synonymous for the wound core technology in general.

The TRANCO Production Machines work from a continuous feed of magnetic steel that enables the most efficient process. Thanks to their adjustable settings, Tranco machines allow for the production of a wide variety of core diameters with consistent gap patterns featuring exact specifications.

TECHNOLOGICAL ADVANCEMENTS

In order to meet the high expectations of our customers, TRANCO has been, since inception, developing and implementing innovations on a continuous basis. We also support our customers with the training and after sales service that they expect. Over the years, continuous improvement has been integrated to the TRANCO machines, including electronically-controlled patterns, improved set-up speed and broader versatility, all of which allows the customers to address a wide range of transformer types while lowering total core production cost.

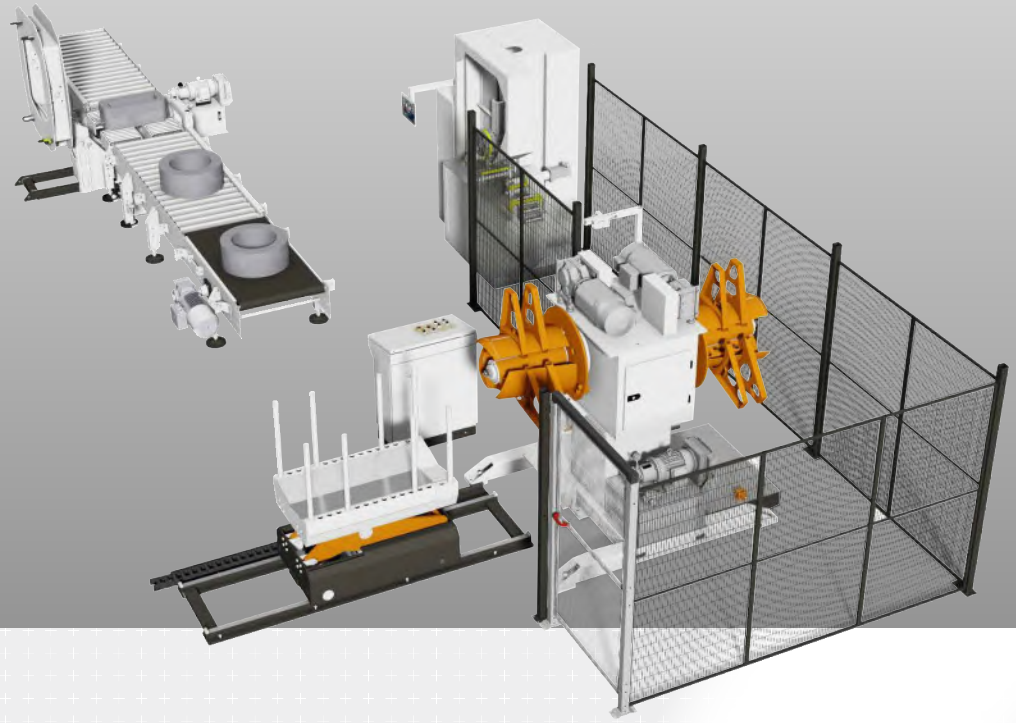
Automation has been a significant part of the innovations integrated in the TRANCO machine in recent years. The machines are now controlled by their integrated PLC (Programmable Logic Controller) and have a very user-friendly HMI (Human Machine Interface) digital display with which the operator can easily control all operations. They can also easily be integrated with the user's in-house SCADA (Supervisory Control and Data Acquisition) system for remote input of production specification and adjustments as well as production performance monitoring. Utilizing the newest versions of PLC and proprietary computer programming, TRANCO can configure the equipment to operate under many different computer languages. TRANCO Machines are able to have scan times in the sub second range which is imperative for cut accuracy at high speeds.

TRANCO MACHINES ARE RELATIVELY SIMPLE AND EASY TO MAINTAIN, AND THEY OFFER PLENTY OF FLEXIBILITY IN THE RANGE OF CORE SIZES, FROM THE SMALLEST OF CORES ONLY A FEW INCHES IN DIAMETER TO VERY LARGE CORES OF A FEW FEET IN DIAMETER.

TRANCO also has integrated numerous additional improvements. The newest and most critical innovation is the Tranco servo driven shear which now enables run speed of 400 ft/min (122 m/min) with improved cut gap accuracy and much quicker cut engagement (50% faster).

The revised design of the linear rails of the Tranco Machine improves the square of the mandrel relative to the machine to maintain alignment, improves gap cut consistency, extends the life span of the bearings and therefore reduce maintenance time and cost. Upgraded electronic pneumatics controlled by the PLC have allowed improvements in the pressure accuracy and consistency. They have also been relocated, as did the PLC console, to reduce any interference which may be associated with vibration. Other recent improvements deserving a mention include the adjustable winding cheeks and horizontal guide. The new design reduces the down time for change overs and eliminates the need to replace or carry the spacers. This improvement facilitates the work when the operator wants to align the steel into the machine. This system always keeps the steel centered and can be adjusted in 0,000 increments.

Photo: TRANCO



TRANCO DOES NOT GET OUT OF STYLE

Some older TRANCO machines which have been in service for many years can benefit from the latest technology improvements that have been introduced. In such cases, TRANCO offers its retrofitting process of which the extend can vary depending on the age of the existing machine, and how heavily it has been used. But the end result is always a machine that looks and operates like a brand new one. This means that companies whose budget might not accommodate a new machine purchase can still enjoy the recognized high quality of a TRANCO core winding machine and all its associated benefits. Typical turn around time for refurbishing can be as quick as three months compared to completely new models which take around 5 months to produce.

TRANCO machines are customized to meet each customer's specific requirements. They come in right or left handed design, require only a small footprint installation, and do not require any special services to operate. TRANCO production experts collaborate with each end user to clearly establish their unique production parameters and ensure that their TRANCO core winding machine is equipped and programmed to meet the specific targeted production requirements and objectives.TRANCO Machines are able to have scan times in the sub second range which is imperative for cut accuracy at high speeds.

TRANCO MACHINES ALLOW MANUFACTURING STRIP WOUND DISTRIBUTED GAP CORES AND THEY READILY ACCEPT ALL COMMON THICKNESS RANGES FOR THIN GAUGE, GRAIN ORIENTED AND NON-ORIENTED STEELS WITHOUT HAVING TO CHANGE ANYTHING.

Photo: Shutterstock

pst

POWER SYSTEMS TECHNOLOGY

SPECIAL SUPPLEMENT

How Canada and JFE are pushing beyond 2050

In June of 2021, the government of Canada adopted the *Canadian Net-Zero Emissions Accountability Act* to achieve net-zero emissions by 2050.

At JFE Shoji Power Canada (JFE), we're committed to helping Canada and the world reach this goal. However, our commitment to the environment goes well beyond that. Our mission is to support our clients and society as a whole in building a stronger, more efficient and expansive electrical grid to lessen the burdens on our environment.

JFE

Achieving net-zero emissions means our economy will emit no greenhouse gases OR we will offset emissions through actions such as tree planting or implementing technologies that can capture carbon before it is released.

Photo: JFE

Every day, now and into the future, we're working to develop a stronger, renewable energy source. For over a century, we have relied on burning fossil fuels to create energy and gas-powered vehicles to take us from A to B. There *must* be a shift to clean electrical, renewable energy sources to make a positive environmental impact. How do we do this? By providing customers with the services, products and expertise that will help us through this transformation.

We've been inspired to work with our clients and suppliers to find more sustainable energy solutions. Still, for many companies, taking a first step toward the climate goals for 2050 can feel somewhat daunting. To begin, let's discuss how companies can get started in a positive, productive way.

Making "environmental protection" a true priority at a company level

Easing the strain on Mother Earth is a discussion that's coming up more and more at the corporate level. As Canada is one nation on the growing list of countries that have pledged to achieve net zero in carbon emissions, many companies are asking what they can do to take up the cause. Still, throwing the phrases "net zero" or "renewable energy" around at a board meeting or a town hall is the easy part. The reality is that Canada cannot achieve its environmental goals without a collaboration between businesses, government groups and non-governmental organizations.

Overall, businesses need to have an understanding of how they're currently impacting the environment and how they can actively create climate-minded initiatives to share with their partners and clients.

As a start, here are some tangible steps that a business can take:

1. Create a carbon reduction budget. This is a clear first step for all companies, but specifically those in the energy sector. Though Canada as a country uses emission targets rather than a carbon budget, budgets can be scalable, and are great tools to help you measure progress to see where you stand.

2. Prioritize early adoption. The time for waiting is far gone. For companies, now is the time to seize opportunities for cleaner, more renewable energy sources while looking at new technology, new products and services and, frankly, new ways of thinking.

3. Stay on top of policy makers. Business leaders have the leverage to inform and positively impact climate change strategy. We need to ensure that the economic changes made to reach 2050 goals result in good-paying jobs and strong business communities. We cannot wait for mandates or policy initiatives to regulate these improvements – now's the time to act and lead. Business leaders must provide the vision and the resources to deliver creative solutions to make these changes.

A global leader in sustainability

Originally known as Cogent Power, JFE Shoji Power Canada came into existence when it was acquired by JFE Shoji Trade Corporation (JFE Group) in September 2019. Based in Tokyo, the JFE Group is one of the world's largest steel producers, but places climate change as a critical business concern. As a whole, the steel business emits 99.9% of JFE Group's total CO_2 emissions, so developing new technologies for renewable energy is more imperative than ever. When looking ahead, the JFE Group has made a number of pledges to help reach our goals for energy conservation. These include:

- To develop and maintain a variety of eco-friendly products and technologies to aid in renewable energy power generation;
- To seek business opportunities that allow JFE to enhance its contributions to decarbonization throughout society; and
- To prioritize JFE's offshore wind-power business by uniting the strengths of each. individual group within the organization.

JFE

"Our team is very excited about the work we're doing to improve our electrical efficiency, the sustainability of our grid and providing lower-carbon solutions for many of our clients."

Ron Harper, CEO, JFE Shoji Power Canada

Photo: JFE

JFE's three-part strategy for sustainability in Canada

So, what are we doing here at home? It's easy to make claims that we're working toward lessening the impact on our environment, but where's the evidence? Our CEO Ron Harper has outlined three critical initiatives that our Canadian business is working on to show its dedication to the cause.

1. **Increasing the capacity and efficiency of our electrical grid.** We have worked for decades to provide cost-effective, higher-efficiency materials and parts to the transformer industry that supports our electrical grid. As society increases its demand for electrical energy, we are strengthening and renewing that commitment. We are expanding our North American electrical grid's capacity by replacing aged equipment and finding more renewable generation sources. Sustainability of our electrical energy sources is of paramount importance to our modern society. Our path to get there must be an efficient one.

2. **Carbon reduction.** JFE is currently working very closely with all its suppliers, particularly raw material suppliers, on carbon awareness and reduction. In fact, we are in an advanced partnership with one of our European suppliers and a North American OEM client to start using a carbon-reduced electrical steel product for a Canadian Utility Transformer. As Ron elaborated, "This initiative, working through our supply chain with our business partners and clients, is an important part of our carbon-reduction strategy and our support of the 2050 net-zero initiative." We seek to expand and strengthen our carbon reduction strategy through our supply chain, and our internal processes. We will be formalizing our strategy through the balance of 2022, along with efforts to deepen awareness and understanding of our initiatives.

3. **Electrification of the transportation grid.** It is of critical importance that we reduce the number of gas-powered vehicles currently on the road and replace them with cleaner alternatives. Most transportation OEMs have announced bold strategies in this direction, and we seek to support and strengthen the capacity for this transformation. Again, this task is driven not by economic reasons, but by environmental ones. Though there continues to be a strong growth in the number of Plug-in Electric Vehicles (PEVs) on the road, as of 2021, PEVs accounted for only 5.2% of new vehicle registrations in Canada. Our work is ongoing to ensure Canadians feel compelled to see them as a viable option. This includes working with our utility clients to ensure consumers have a full understanding of the positive impacts electric mobility will have (i.e., where will charge outputs be available, and what will the cost be?). As Ron outlined, "We're working very hard with automotive OEMs (Original Equipment Manufacturers) to make sure we're providing energy-efficient solutions for the growth and demand of electrically efficient vehicles." In 2021, we announced our strategic collaboration with Enedym Inc., a Canadian-based inventor and designer of paradigm-shifting motor technologies. Along with our sister companies within the JFE Shoji Group, including JFE Steel, we intend to be a major force in enabling this transition to allow Canada to be a leader in clean energy technologies. It is our commitment to work with these OEMs and industry partners within our supply chain along with governments and government partners to achieve these objectives.

With eyes toward the future, there's a lot less road ahead than expected. Nevertheless, JFE has a number of additional strategies in the works for 2023 and beyond. We are working with governments, industry partners, clients and advocacy groups to advise and create the needed policies to protect future generations. As Ron puts it, "We're fortunate that we're working with some very progressive companies to build strategies, and we will have a positive impact in the future."

JFE

Company contact details:
JFE Shoji Power Canada Inc.
845 Laurentian Drive, Burlington, ON L7N 3W7
Local: **(905) 637-3033**
Toll-Free: **1 (800) 296-1103**

The first of three articles by IMCORP presenting a new technology that will redefine underground cable life-cycle management.

PREDICTIVE MAINTENANCE AND REMAINING USEFUL LIFE FOR UNDERGROUND CABLE SYSTEMS

When it comes to electric power distribution, the fundamental goals of today's electric utilities have not changed much in fifty years. They comprise a safer distribution system that poses minimal risks to the public and to utility workers, the reliable and stable delivery of power to critical, commercial, and residential customers, and economically sound business operations that meet both shareholder and ratepayer expectations.

The challenges to these goals, however, have grown significantly over the past decade. Increasingly intense and frequent weather events raise the threat of outages and environmental risks; the process of shifting from a centralized to decentralized grid to meet decarbonization mandates creates complexities; and the integration of renewable energy sources and the proliferation of electric vehicles are escalating the demands on an aging distribution grid. The resulting economic impacts to utilities range from high O&M costs to loss of revenue, the need for new investments in infrastructure, and, sometimes, class action lawsuits.

The replacement of overhead lines with underground power cable inherently mitigates some of these challenges by increasing the reliability, stability, safety, and, ultimately, resiliency of the grid. Underground power cable systems are less susceptible to windstorms, lightning, wildfires, ice and snowstorms, vehicle collisions, and other environmental hazards. This results in lower life cycle costs compared to overhead lines, where costly O&M restorations and preventive maintenance programs, such as pole inspections and vegetation management, drive long-term costs. Overall, an investment in underground systems pays off in improved safety, reliability, and economic return.

Although underground cable systems are much more reliable, they do occasionally fail. When they do, they can be more expensive than overhead lines to repair, as the failures can be more difficult to pinpoint and to remediate. Replacing failed underground cables can cost even more, as it can be time consuming. The replacement of direct buried cables, for example, can involve directional boring, a slow process that comes with costly risks of hitting other underground infrastructure. Underground cable replacement can take months or even years, depending on circuit mileage, design, and construction work. Hence, the potential for cable defects can certainly not be ignored. Left undetected, they will lead to power outages, and to health and safety risks to the public.

Photo: IMCORP

Predictive tools combine innovative data analytics and IoT technologies to significantly improve maintenance efficiency, asset availability, reliability and lifetime value.

Cross-section of a typical solid dielectric cable

The Problem

The essential problem is that there is no visual inspection of underground cables. Although manufacturers' quality control standards for cable and accessory performance assume a life expectancy of approximately 40 years, that presumed reliability diminishes from factory to installation through shipping and handling and installation workmanship. Of the new cable systems IMCORP has commissioned, only around 60 percent met the manufacturers' quality standards. Approximately 23 percent had deficiencies primarily due to workmanship-related issues that were easy to remediate before the cables were put into service, while 17 percent had deficiencies involving underground issues, such as damaged cable or splices, that required additional rework to meet standards. As we look further down the life cycle at the aged cable systems (30+ years old) that IMCORP has tested, 43 percent on average met the factory-grade quality standards. Again, approximately 23 percent had deficiencies that were easily remediated, leaving 34 percent involving cable or splice rework. The testing and subsequent repair effectively reset the "life cycle clock," demonstrating that cables can last well beyond the 40-year life expectancy.

In sum, these results mean that a large percentage of cables—new and old—are perfectly fine. An additional percentage do not meet standards, but they may not all be at risk of failure anytime soon. In the millions of miles of cable already present in an evolving power grid, how do we know which cables meet manufacturers' specifications—or come close to meeting them—and can be safely left alone? How do we identify the cables not meeting the standards that can be locally repaired or, in some cases, require replacement? How do we ascertain what defects they have developed or how much longer they may last?

Underground cable system components are highly engineered and adhere to significant quality control standards during manufacturing. After shipping and installation, approximately only 60% of cable systems meet those quality control standards.

Although underground power cable systems are less susceptible to windstorms, lightning, wildfires, ice and snowstorms, vehicle collisions, and other environmental hazards, the ongoing health assessment is completely different than overhead lines.

The replacement of underground cable just because it is old is an expensive undertaking, costing as much as hundreds of dollars per foot and taking perhaps a day or more for a single cable to be replaced. Testing a foot of cable to find out whether it really needs to be replaced, on the other hand, carries a small fraction of that cost and can reach five to seven times the amount of cable that wholesale replacement does in the same amount of time. But repeating cable diagnostics or resetting the "life cycle clock" every so many years is not always economically or operationally efficient.

So, with only these options available to them—wholesale replacement or recurrent testing—how can utilities prioritize risks, establish budgets and financial forecasts, and maintain the safety and reliability of their underground systems? The answer is a technology that makes it possible to locate defects, diagnose them, and predict the remaining useful life in the relatively small percentage of cable that does not meet the manufacturers' quality control requirements.

To that end, IMCORP's objective has been to develop a proactive and predictive maintenance model for underground cable systems that provides visibility for future reliability and, ultimately, lower life cycle costs—a technology that costs less, takes less time, and is more accurate than training and using human analysts to analyze and interpret results from measurements taken in the field.

The Problem of Partial Discharge

According to the Institute of Electrical and Electronics Engineers (IEEE), over 90 percent of failures in underground cable systems are associated with partial discharge (PD), a phenomenon in which an electrical discharge does not completely bridge the gap between two electrodes. Underground cable and accessory manufacturers go to great lengths, from design to manufacturing and quality control, to eliminate any potential for PD in their products. Once these products get installed, however, PD inevitably is introduced into these cable systems. In these cases, PD slowly erodes the insulating material at the point of the defect until the cable eventually fails. The challenge to the utility is to find the instances in which PD is occurring and to determine the severity of the PD and the potential time to failure.

IMCORP™
Power Cable Reliability

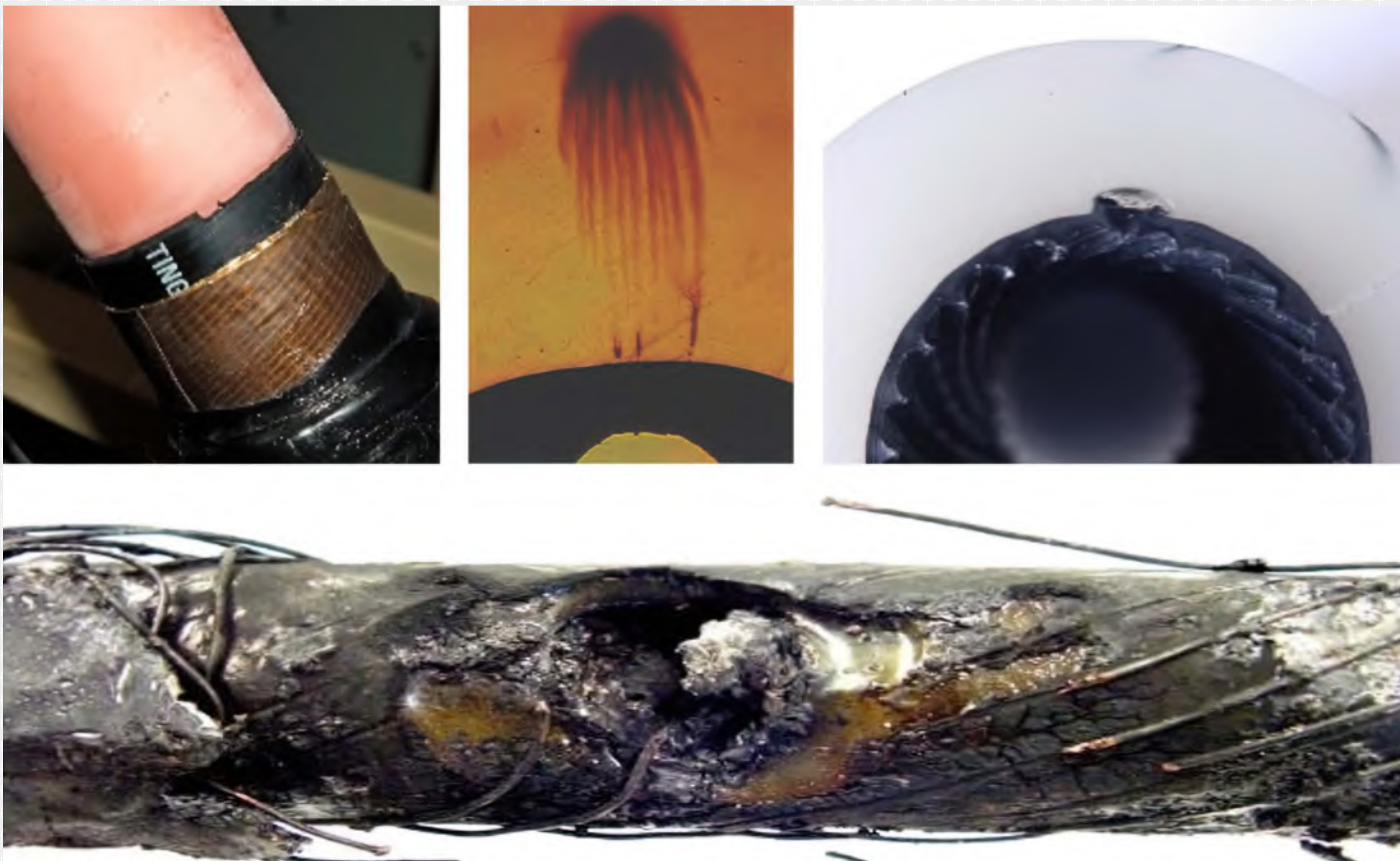
Photo: IMCORP

When activated, PD produces high-frequency signals that are symptomatic of dielectric deterioration and, eventually, fault. At the factory, manufacturers are able to test cables and accessories for PD to high standards because they typically perform their measurements in multimillion-dollar electrically shielded rooms with metallic walls that block all electromagnetic interference from radio waves and other high-frequency signals that can obscure PD defect signals. These tests are performed on all new components at the manufacturing plant prior to shipping and installation, with results that must meet Insulated Cable Engineers Association (ICEA) standards for power cable and IEEE standards for separable connectors, joints, and terminations.

Detecting PD becomes more complicated once the cable is installed and then assembled with other cable system components. The only way to achieve a factory-comparable result in the field is to use a factory-grade technology, using 50/60Hz excitation voltage, high-efficiency sensors, and advanced digital signal processing capable of achieving a measuring sensitivity of at least 5 pico Coulomb. This allows identification of potential PD signals by human analysts, who "characterize" the signals—that is, they assign labels to the PD signals, including location, magnitude, and PD type, and determine how far they deviate from the manufacturers' standards and, therefore, how likely they are to lead to cable failure and how soon.

IMCORP's objective has been to develop a proactive and predictive maintenance model for underground cable systems that provides visibility for future reliability and, ultimately, lower life cycle costs.

The interpretation of PD signals by human analysts is subjective and can vary from person to person, which makes the process time consuming, expensive, and difficult to scale. With the tremendous expansion of underground transmission and distribution cable systems in recent years, automation of this task has become of paramount necessity. To accomplish it, IMCORP has set out to develop a technology that uses deep learning to do what the human analysts do, faster, more reliably, and on a much larger scale.



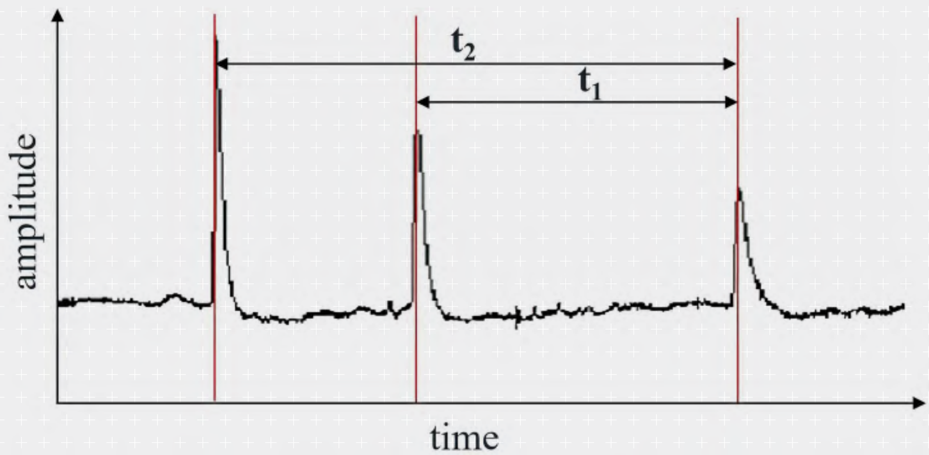
Typical PD-producing defects in underground power cables.
Top row: nonradial cut (left), electrical tree (center), and insulation void (right).
Bottom: cable failure (Photo courtesy of General Cable)

Deep Learning and PD Diagnosis

Machine learning is a branch of artificial intelligence (AI). It involves developing algorithms that allow computers to identify and learn from patterns in sample (training) data, based on which they can make predictions whose accuracy increases as they learn. The larger the base of training data, the greater the potential for the computer to find patterns and successfully learn from them. Two general types of machine learning exist: supervised and unsupervised learning. Supervised learning means the training data fed into the machine learning algorithms are supplemented by the correct outputs—called "labels"—from the analysis of those data. In IMCORP's case, the inputted data are the PD signals, and the labels are those that have been generated by the human experts analyzing them. With deep learning—a subset of machine learning—neural networks are created by IMCORP that simulate the behavior of the human brain doing PD characterization.

The end goal is to be able to predict faults before they occur, rank all defects by severity and the risk they present, and determine what this means in terms of the remaining useful life of the cable.

Over the past 25 years, IMCORP has tested over 250,000 cable systems and more than 300 million miles of underground cable, amassing a database comprising tens of millions of instances of PD labelled by human analysts. Using this database as sample data, the deep learning networks we are developing are learning to identify and characterize signals by "partial discharge" or "nonpartial discharge," PD location of origin, and PD defect type with ever greater precision and accuracy. Already, they are providing results that rival the accuracy of the human analysts in finding and diagnosing defects in underground cable systems—to date, an accuracy rate of 97 percent. They also provide a more consistent level of quality and a time savings of up to 500 percent in the analysis and interpretation of complex data sets.



Signal waveform of a positively identified PD

A Proactive, Predictive Maintenance Model

Locating and characterizing PD signals through automation is helpful for preventing cable failure, but it is only a first step toward developing a predictive maintenance system for underground asset management. Already, the neural network has learned so much about finding and assessing defects that we can rank them according to how severe they are and how likely they are to lead to cable failure. Eventually, it will be able to indicate how soon failure will happen—that is, it will predict the cable's remaining useful life. With this information, utilities will be able to prioritize preventive maintenance, cable repair, and cable replacement and will know exactly where, along the millions of miles of cables in their systems, to make available the materials, equipment, and human resources needed to carry out the work.

Ultimately, we want our deep learning networks to perform classifications in near-real-time so that technicians in the field can see the results soon after data are captured, with the benefit that cables already very close to failing may not get switched back into service. The end goal is to be able to predict faults before they occur, rank all defects by severity and the risk they present, and determine what this means in terms of the remaining useful life of the cable.

IMCORP™ Power Cable Reliability

Part 2 of the series will describe the underlying data IMCORP is using and how deep learning is being applied to develop its predictive models.

Power System Technology:
The Solid-State Revolution

Protection systems, relays, switchgear, batteries, and solid-state technology, oh my!

We are tremendously excited to announce our **special November Issue!** We will get to report on the groundbreaking changes from an electromechanical approach to a truly digital approach, discussing the topics of protection systems, relays, switchgear, batteries, and solid-state technology.

In fact, we will feature articles that we believe will showcase the next great leap in solid-state technology for the battery market. It will be electrifying!

While a large part of our content is already assigned, there is always room for a few new pieces of content.

Would you like to present your company's expert knowledge and technological solutions in our November issue?

Reach out to Dorotea Filipan

Coming in November Issue

Integrating Condition Monitoring into the Product: Economical, Accurate and Hassle-free

by **Robert L. Middleton**

A recent generation of dry type insulation technologies has changed the economics for real-time insulation condition monitoring. This article discusses integrated condition monitoring solutions that can be built into the primary condenser cores of transformer bushings, current transformers and cable accessories (terminations and joints). These solutions include monitoring of capacitive current in the primary condenser core to detect changes in the condenser core C1 capacitance, a new approach for capturing and processing high frequency PD pulse signals in power transformers [1] and HV cable circuits and monitoring accuracy "drift" in revenue-metering current transformers. These factory-installed sensing solutions provide the customer with low-cost real-time condition monitoring options in place of expensive maintenance and field testing programs [1].

Condition monitoring of electrical power equipment has evolved into a significant growth industry offering a wide variety of very sophisticated, multi-parameter solutions. However, with these solutions come the significant costs of managing the large volume of data that is generated from these systems and the ongoing maintenance of the monitoring devices.

This article will describe integrated monitoring systems that can be built in during the manufacture of the equipment and/or components. With this type of system accurate monitoring is ensured due to a high interference shielding design and insensitivity to changes in temperature or frequency. These integrated monitoring systems require no external power source as they are powered directly from the grid connection. Integrated monitoring systems have been developed for

Robert L. Middleton received his degree in electrical engineering from the University of Manitoba, Canada in 1971. He is a registered professional engineer in the Province of British Columbia. He has an extensive background in generation and transmission engineering including quality assurance. He has served on several CSA, CIGRE and IEC working groups and co-authored numerous technical papers. He is presently the Chief of Technology and Engineering for RHM International, a manufacturer of high voltage dry type current transformers, transformer bushings and cable terminations. Prior to joining RHM International he worked over 40 years at two western Canadian provincial electrical utilities.

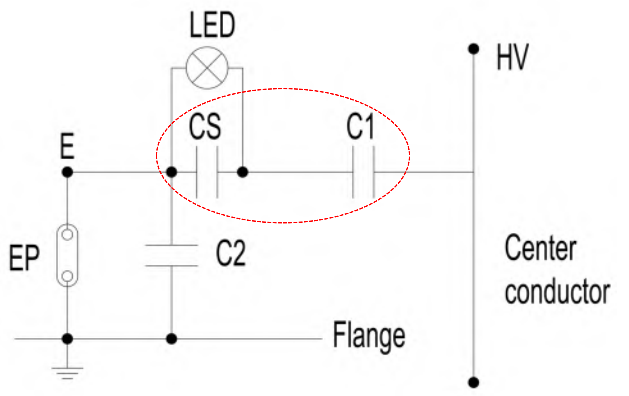
the real-time monitoring of the condition of the primary insulation for transformer bushings, current transformers and HV cable terminals, the detection of partial discharge activity in transformers and HV cable circuits and the monitoring of accuracy "drift" in revenue-metering current transformers over their service life.

Integrated monitoring systems that can be built in during the manufacture of the equipment and/or components ensure accurate monitoring due to a high interference shielding design and insensitivity to changes in temperature or frequency.

The Smart RIF® Bushing

The smart RIF® bushing provides a simple and economic alternative for insulation condition monitoring of the bushing. Condenser-graded insulation can be modelled as a series of capacitors separating the conductor and ground. During the process of insulation breakdown screens fail sequentially eventually leading to total breakdown of the insulation. As subsequent screens breakdown the capacitance and capacitance current gradually increases [2]. The smart RIF® bushing is manufactured with a large Cs capacitance (Cs>>C1) integrated into the condenser core to create a capacitive voltage divider for accurately measuring these changes (see Figure 1). The two ends of Cs are brought out to a smart measurement terminal installed on the bushing mounting flange where a factory calibrated LED sensor can be plugged in to collect and process the signal (see Figure 2). The LED lights "Green" for normal condition and turns "Red" should a change of capacitance be detected in the condenser core. The LED "Red" indication is only a pre-alarm of a deteriorating condition and allows the utility time to schedule future options for the affected equipment. There is no risk of an imminent failure as lab testing has shown that subsequent failures of capacitive screens will be very slow progressing.

Figure 1.
Smart RIF® Bushing Schematic Representation



HV – HV terminal connected to grid, E – earth terminal, EP – equipotential plate, C1 – main core insulation capacitance, Cs – signaling capacitance (Cs>>C1), C2 – test tap to bushing flange insulation capacitance

Figure 2.
Smart RIF® Bushing LED Sensor

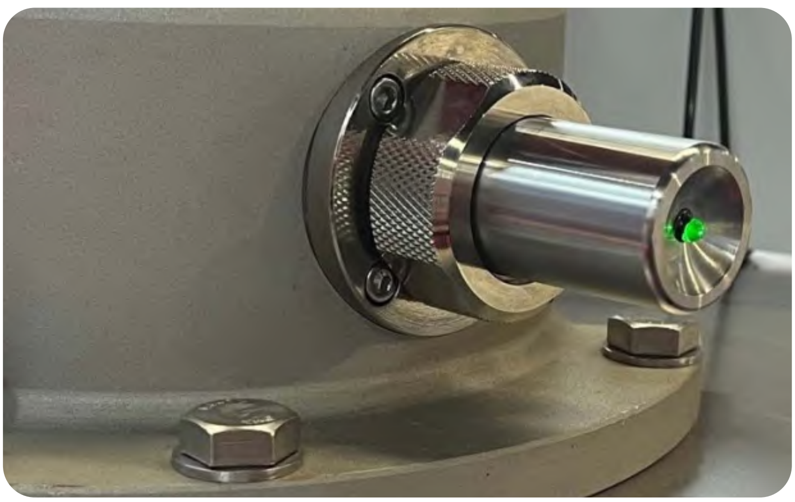


Photo: RHM International

Integrated monitoring schemes provide economical but accurate real-time monitoring of key condition parameters without having to manage the large volume of data generated by conventional monitoring systems.

Scheme for Detecting PD Activity in a Transformer Using the Smart RIF® Bushing as the Sensor

Field testing for partial discharge in transformers is costly requiring specialized equipment and highly skilled technicians to perform the testing and interpret the data. A more economical solution for detecting PD activity can now be realized by using RIF® bushings equipped with a smart measurement terminal and plug-in PD sensor to couple the discharge pulse current signals coming from the transformer (see Figures 3a and 3b). Depending on the number of RIF® bushings installed on the transformer the scheme can be configured to simultaneously monitor transformer PD signals from up to 9 locations [1] thereby ensuring a very accurate locating of the PD source. The coupled signals from each RIF® bushing are transmitted by a signal cable to a PD monitor installed on the transformer tank wall for data acquisition and processing (see Figure 4). Data for the PD analysis system can be downloaded from the PD monitor, transmitted with optical fibers to a computer in a central control room or transmitted wirelessly.

With this scheme the transformer's entire insulation condition is monitored; it simultaneously monitors the transformer PD condition and the bushings insulation condition.

Figure 3a.
3-Ph View Showing RIF® Bushing PD Sensors and Tank Mounted PD Monitor

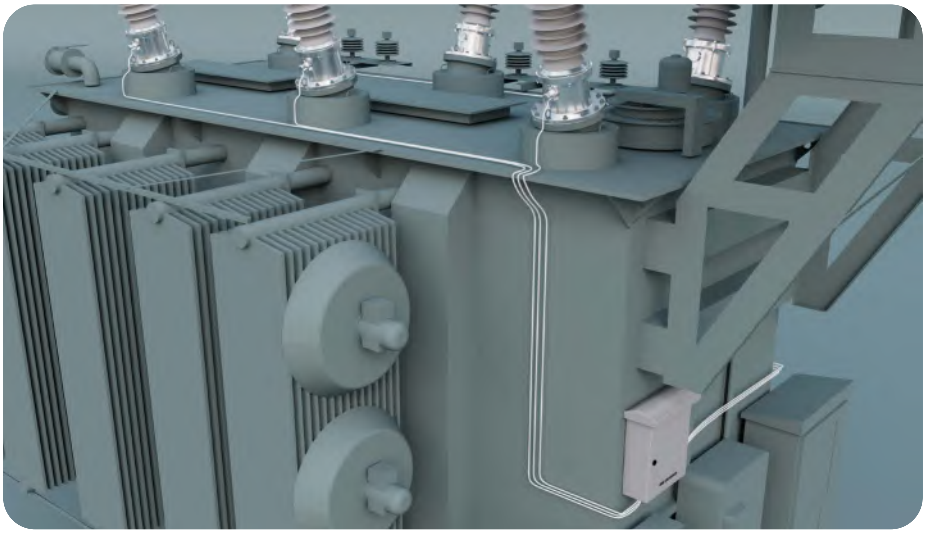
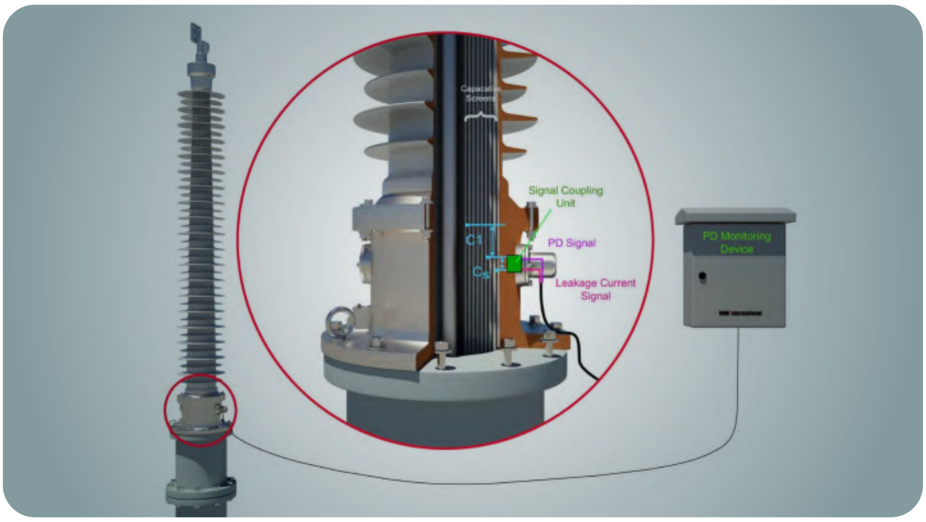


Figure 3b.
1-Ph View Showing RIF® Bushing PD Sensor Details



Monitoring PD Activity in HV Cable Circuits Using Smart RIF® Cable Accessories

RIF® cable accessories (terminals, joints) can also be provided with smart measurement terminals and plug-in PD sensors for detecting PD activity in the terminations and cable circuit (see Figure 5). Partial discharge detection uses the pulse current method and direct coupling provides positive anti-interference performance and high detection sensitivity. With the smart RIF® cable accessories the insulation condition of the terminations and cable circuit can be monitored 24/7. The working principle is consistent with IEC 60270 and requires no additional sensor installation [3].

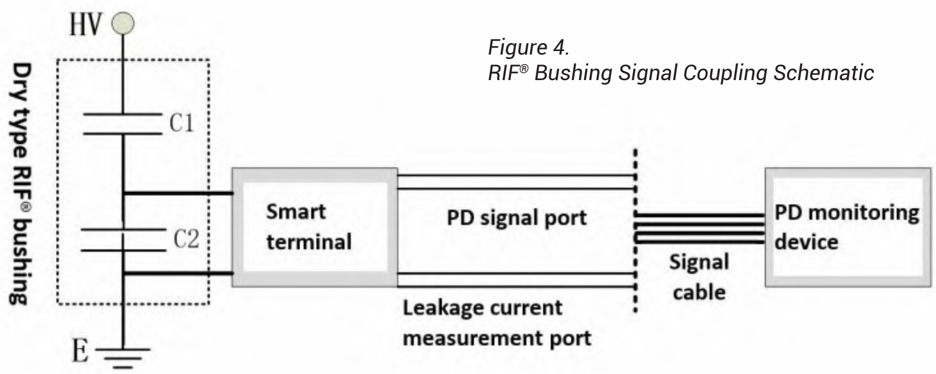


Figure 4.
RIF® Bushing Signal Coupling Schematic

Dry Type CT with Real-Time Insulation Condition and Error Monitoring

The current transformer comes equipped with a built-in monitoring device that provides real-time monitoring of the CT's primary insulation condition and the ratio and angle errors for each of the CT's secondary coils (see Figure 6). This is achieved by built-in information collector technology and benchmark coils that are guaranteed not to drift over the CT's service life. This built-in monitoring device needs no external power as its power source comes from the CT itself and is isolated from the HV primary so as not to affect the CT's performance. Finally, standardized data interfaces according to IEC 61850 communication protocol are provided. This monitoring will help to prevent outages due to failing insulation and discover accuracy errors in real-time caused by secondary remanence and inter-turn short circuits. It is well known that revenue-metering current transformers once installed usually do not get checked for accuracy "drift" over their service life. This can result in a significant loss of revenue for the utility. Using a current transformer equipped with this monitoring allows the utility to regularly check the accuracies without having to do expensive off-line testing.

> Integrated monitoring systems come factory calibrated and provide a lower cost plug and play installation.

Conclusion

The integrated monitoring schemes discussed in this article provide economical but highly accurate real-time monitoring of key condition parameters without having to manage the large volume of data generated by conventional monitoring systems. These systems come factory calibrated and provide a lower cost plug and play installation.

Figure 5.
Scheme for Detecting in HV Cable Circuits using Smart RIF® Cable Accessories

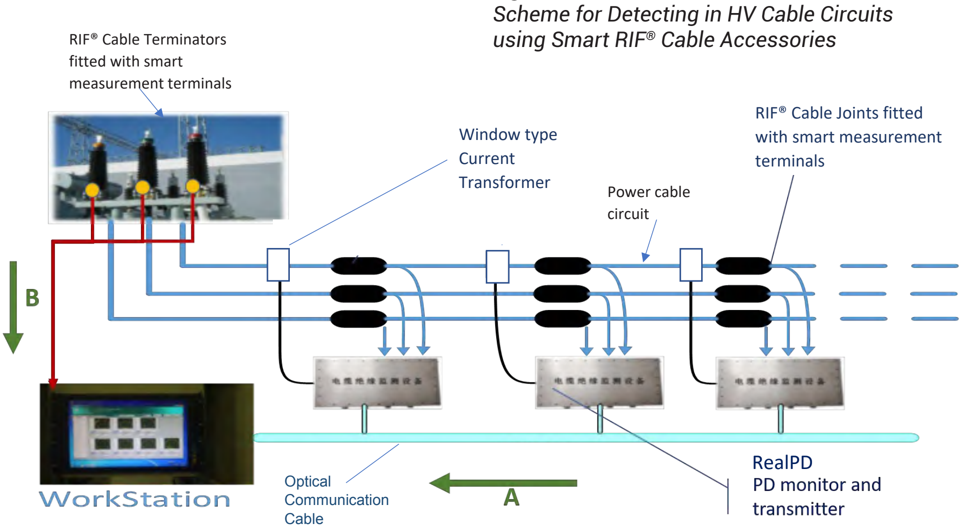


Figure 6.
Dry Type CT Equipped with Real-Time Accuracy Display Monitor

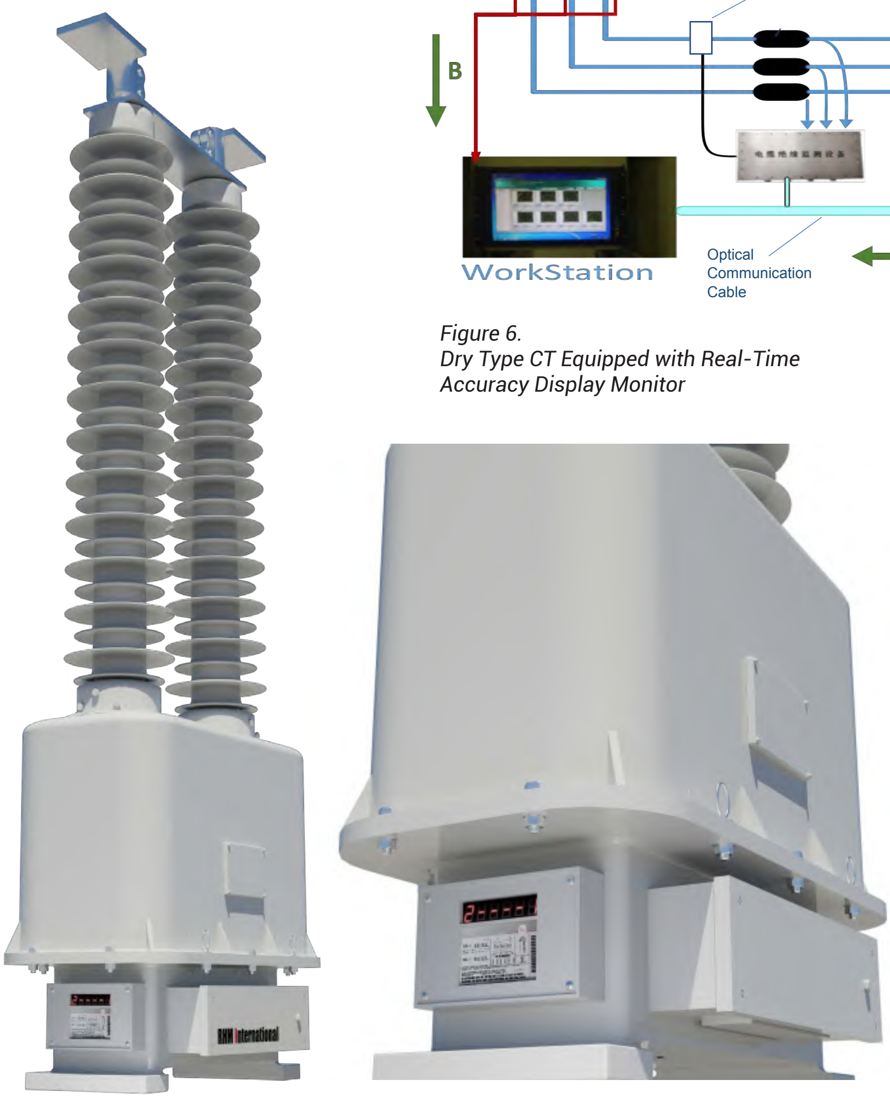


Photo: RHM International

References

[1] E. Euvrard, R. Middleton, H. Wang, X. Song, *Innovative Condition Monitoring Solutions Using Integrated Sensing Enabled by a New Generation of Dry Type Insulation Technologies*, IEEE PES T&D New Orleans USA, April 2022

[2] Tianshui Zhou, XiaoDong Zuo, HaiLiang Wang, Ruzhang Wang, Robert Middleton, Eric Euvrard, *The Development and Operation of Novel Built-in Insulation Monitoring Functions in the Management of HV Bushings*, INMR World Congress Munich Germany, October 2015

[3] R. Middleton, E. Euvrard, H. Wang, D. Song, Y. Zhao, *Development of a New High Voltage Dry Type Cable Terminator with Optional Integrated Partial Discharge Monitoring*, CIGRE Session 48 (Virtual), Paper B1-102, August/September 2020

How can modern monitoring methods upgrade laboratory testing practice?

Passerro

Transformer monitoring is the measurement, collection and careful analysis of all relevant data. If we measure the right data in real time and learn to interpret that data, we can get a good insight into the operating condition of a transformer. Constant monitoring then provides information about possible and necessary immediate maintenance or can result in a guarantee for maintenance-free and carefree availability.

Miroslaw Ch. Wrobel received the M.Sc. degree in applied physics from Silesian University of Technology, Gliwice, Poland, in 1993. He received his Ph.D. degree from the Institute of Fundamental Technological Research, Polish Academy of Sciences Warsaw, Poland. He pursued his Ph.D. research in the area of medical physics focusing on molecular acoustics. He worked on non-invasive medical diagnostic and imaging techniques as a visiting fellow at the Defence R&D Canada, Toronto (previously known as DCIEM) of the Canadian National Defence. Since 2005, parallel to his medical research, he has been working on the application of acoustic and optical sensing method in high-voltage technology. He holds several patents in the field of medical diagnostics and monitoring of industrial plants.

Photo: Passerro

The digital revolution has changed everything in our lives these days. Every day we face new opportunities and challenges. Internet search engines allow us to answer almost any question that comes to our mind. So-called social media give us the opportunity to connect with like-minded people all over the world, just like e-commerce gives us the opportunity to buy or sell products in a global marketplace. Information is freely accessible; people are instantly connected, and markets are available worldwide. The mankind has integrated digital technology into the "soul of its being". It is hard to imagine a day without a smartphone, WiFi or social networks, but then the question arises, why are our all-important but vulnerable high-voltage systems still being monitored with the "steam gauges" systems known from the last few centuries?

Electrical systems make a significant contribution to the stability of the global energy supply, but their aging and stress lead to irrevocable changes in the insulation material. These changes can inform the operator about the electrical insulation and cooling ability of the oil during the operation of the transformer and about its safety status. Therefore, monitoring these parameters is crucial.

Extensive repertoire of laboratory test procedures

Theoretically, this task is solved by regular sampling and testing according to the IEC regulations. Basic monitoring consists of recording the easily ascertainable main parameters of the system, e.g. of the transformer. These consist of mainly two methods – a dielectric-chemical analysis, which gives an insight into the oil quality; and the chromatographic methods, which allow a statement to be made about the "inner life" of the oil-insulated high-voltage system. The dielectric-chemical parameters are the breakdown voltage (IEC 60156 [1]) and the dielectric loss factor tgδ (IEC60247 [2]). Determining the breakdown voltage (BDV) and the dielectric loss factor tgδ (tan DELTA) offers the possibility of assessing the current insulation condition of the oil. An increased (Wc) water content (IEC 60814 [3]) drastically worsens the insulating properties of the oil.

Other oil properties such as the neutralization number (IEC 62021-1 [4]) are used to make a prognosis about the further operation of the transformer. The neutralization number or Total Acid Number (TAN) indicates the oxidation state of the insulating oil. If the neutralization number is too high the formation of organic acids is very advanced and there is a risk of sludge precipitation, which can result in serious consequential damage. An increased neutralization number is often reflected in a reduced surface tension of the oil (ISO 6295 [5]). The oxidized oil components act as surfactants and therefore influence the surface tension. This is measured as the interfacial tension (IFT) in the oil/water system and is a very sensitive measure for the expected further aging behavior of the insulating oil.

As a preventive measure against accelerated oxidation, the oil is usually treated with approx. 0.3% of the oxidation inhibitor DBPC (IEC 60666 [6]). Determining the decomposition gases dissolved (DGA) in the oil (IEC 60567 [7] and 60599 [8]) allow conclusions about impending faults in the transformer. Local thermal overloads of the insulation system or partial discharges within the solid insulation can be detected. The determination of the furans in the insulating oil (IEC 61198 [9]) has been used for some time as an additional information-source about the condition of the solid insulation. With abnormal thermal aging of solid insulation (cellulose), various furan derivatives are formed, which greatly accelerate the aging of the solid insulation.

Passerro has found the solution to integrate all the necessary sensors and mathematical processes into an online oil sensor.

Unfortunately, these types of measurements and analysis for the purpose of monitoring the correct operation of any given transformer are only being carried out by selective and sporadic laboratory analyzes of the oil far away from actual operation and with sometimes great delay. This means that no real-time and immediate action can be taken and a response to measured parameters is taking place, long after the circumstances have changed. Only a proactive approach based on real-time and online oil condition monitoring can extend the transformers life. The "gold standard" is the best study and laboratory test we could do right now – but the downsides are cost and delay. However, this is still necessary, e.g. because of insurance cover. The many standards and guidelines cover almost all aspects of good laboratory practice but cannot keep up with the changing times. Laboratory tests are extremely accurate when done well but are only performed sporadically.

How can we change it and what procedure can give a more power grid security and cheaper overall cost?

Figure 1. Typical connection and sampling field of a 40 MVA, 110 kV/15 kV transformer

Standard procedures are not enough to keep the grid safe and future-proof

Authorities agree that despite the current IEC 60567 regulation [7], incorrect and careless sampling and testing techniques are at the root of 99 percent of "poor" dielectric and DGA readings; showing once again that the human factor is the weakest "link in the chain".

According to IEC 60567 "Oil-filled electrical equipment – Sampling of gases and oil for analysis of free and dissolved gases" [7] and IEC 60475 "Method for sampling liquid dielectrics" [10], the sample should be taken from that part of the container where the insulating liquid is likely to be most contaminated. Two samples can usually be taken to assess the quality of a delivery (point 4.1.1). Furthermore, in the same standard, in point 4.1.2, the quantity of the sample to be taken is explained. It depends on the tests to be carried out and the methods used.

Typically, a 2-liter sample is taken. In addition, there is the clarification in point 4.1.4.1 Sampling from transformer tank: "the valve is opened and at least 10 liters of insulating liquid are allowed to flow slowly into a waste oil container; the sample bottles are rinsed with the insulating liquid; The sample bottles are filled". What does 10 liters mean for a medium-sized 110 kV/15 kV, 75 MVA transformer with approx. 30 m³ oil volume (Figure 1)?

When developing and testing the sensors, we paid special attention to the use of modern materials and energy-efficient components and assemblies.

When using the drain valve AA023 "Bottom" for oil sampling, we have approx. 0.5 liters of oil in the line (this is negligible). If we use the drain valve AA022 "Middle" for oil sampling, we will already have approx. 1.5 liters in the line (no longer negligible).

What is then the volume we can take for our sampling by running, say, 12 liters of oil through – then grabbing 2-liter sample of new oil for the lab test? Assuming that the new oil is tapped in a sphere around the connection, this results in a sphere with an effective radius of 13 to 15 cm around the tapping point. Let us compare this with the transformer LxWxH dimensions, which are 7,350 x 2,970 x 4,755 cm. We know that every oil-insulated high-voltage system is unique due to its aging, its design and its load history. The oil reflects this history. So, the question arises: Is it a representative sample of our oil? Does the single sample give an insight view into the "inner life" of this oil-insulated high-voltage system? The measurement practice that has been common up to now "only" provides us with a snapshot under laboratory conditions, the measurement done of the oil parameters under IEC guidelines – usually at 20°C – cannot provide any information on the behavior of the oil at operating temperatures which are greatly deviating from 20°C; also keeping in mind that an error due to falsifying oil samples by incorrect human handling is omnipresent.

Figure 2. A bypass cabinet with oil pump and sensors

Just image a cabinet created by Passerro containing a sensor connected to the transformer oil filler necks or to the top/bottom oil check valves as a bypass to a transformer to feed the oil, in a closed circuit with an average capacity of about approx. 1.4 m³/h, see (Figure 2) or other online systems such as online DGA (Figure 3).

Figure 3. Direct installation on the transformer oil connections – with DGA, moisture and break-down-voltage sensors

Such sensor, with full digital and true Internet of Things capability is able to make several measurements a second and depicture the fast changes in an inhomogeneous liquid insulation system. Some "gas flares" coming from PD or spontaneous environmental gas intrusions as it is O_2 can be detected and traced. This can be made only with direct-in-oil immersed gas sensors without using membranes to separate the liquid and gas sections.

The innovation includes the research, development and integration of a measurement method that also enables inspection and targeted monitoring of ester-based transformer fluids.

Photo: Passerro

Passerro was able to build an online sensor that can measure the following oil properties:

- ✖ Temperature [°C]
- ✖ Relative humidity (RS) [%]
- ✖ Water content [ppm]
- ✖ Dielectric strength (BDV) [kV]
- ✖ Color [N]
- ✖ Dissolved gas:
  - × Hydrogen – H_2 [ppm]
  - × Carbon Monoxide – CO [ppm]

Other parameters will follow shortly:

- ✖ Neutralization number (TAN) [mg/kg]
- ✖ Interfacial tension (IFT) [mN/m]
- ✖ Dissipation factor (tan_Delta) [deg]
  - × Ethylene – $C2H_2$ [ppm]
  - × Methane – CH_4 [ppm]
  - × Carbon Dioxide – CO_2 [ppm]

and as the parameters acquired with Passerro's system are completely in line with already established, well-known and implemented IEC procedures, this then becomes a real online "laboratory" allowing a constant and real time monitoring (Figure 4). Some very important readings nowadays are coming from laboratory methods knowns as titration (KF for water and KOH for TAN). Applying a stringent chemical titration in an online procedure is currently not possible without contaminating the oil with the titrant. In this case, some substitutes must be used for this procedure. The engineers at Passerro GmbH have solved already the KF-Water measurement Wc using the acoustical resonator and working very intensively on some online solutions to the TAN challenge.

The constant monitoring of oil parameters provides accurate and up-to-date values as well as trends over time and with this knowledge the electrical systems can be operated and loaded in a more targeted manner, so that the economic efficiency of the systems is optimized.

Passerro has found the solution to integrate all the necessary sensors and mathematical processes into an online oil sensor. One of the main challenges, besides estimating the Wc and BDV, is estimating the neutralization number (TAN). Other challenge is to find a high-performance gas sensor that could withstand the everyday environments of multi-megavolt-ampere power transformer for long periods of time. We build new platinum-palladium-doped MOX selective gas sensors specially designed for such missions.

When developing and testing the sensors, special attention was paid to the use of modern materials and energy-

Figure 4. Installation in OLTP top hatch

efficient components and assemblies. At the same time, the innovation includes the research, development and integration of a measurement method that should also enable the inspection and targeted monitoring of ester-based transformer fluids. Ester-based transformer fluids will, not only in our opinion, replace the current and long-used standard mineral oil in the future. From an ecological point of view, transformer oil based on mineral oil is not the optimal dielectric. Mineral oil spills can have devastating effects on the natural environment – including animals, plants, water, and humans – due to the polychlorinated biphenyls (PCB) and polychlorinated terphenyls (PCT) found in mineral oil. Unlike mineral oils, natural ester dielectrics (ester oil) are non-toxic in water and soil, non-hazardous, and quickly and thoroughly biodegradable. Recent installations of ester oil filled power and distribution transformers around the world, due to their natural dielectric properties, have shown the industry that this can be a path towards a cheaper, more resilient, better performing, and safer industry. However, the corresponding measuring and monitoring sensors must also work for this type of oil.

So, the constant monitoring of oil parameters provides accurate and up-to-date values as well as trends over time and with this knowledge the electrical systems can be operated and loaded in a more targeted manner, so that the economic efficiency of the systems is optimized.

Look out for more of our articles in the following editions of the magazine, where we will talk more about alternatives that use modern digital monitoring systems.

References

[1] IEC 60156 – Insulating liquids – Determination of the breakdown voltage at power frequency – Test method
[2] IEC 60247 – Insulating liquids – Measurement of relative permittivity, dielectric dissipation factor (tan d) and d.c. resistivity
[3] IEC 60814 – Insulating liquids – Oil-impregnated paper and pressboard – Determination of water by automatic coulometric Karl Fischer titration
[4] IEC 62021-1 – Insulating liquids – Determination of acidity – Part 1: Automatic potentiometric titration
[5] ISO 6295 – Petroleum products — Mineral oils — Determination of interfacial tension of oil against water — Ring method
[6] IEC 60666 – Detection and determination of specified additives in mineral insulating oils
[7] IEC 60567 – Oil-filled electrical equipment – Sampling of gases and analysis of free and dissolved gases – Guidance
[8] IEC 60599 – Mineral oil-filled electrical equipment in service – Guidance on the interpretation of dissolved and free gases analysis
[9] IEC 61198 – Mineral insulating oils – Methods for the determination of 2-furfural and related compounds
[10] IEC 60475 – Method of sampling insulating liquids

Nurul Noor

Nurul Noor is the Special Project leader for cybersecurity in Siemens Energy Malaysia. currently leading the Mid Management Control & Digitalization team. She is a marketing development and strategy enthusiast with more than 20 years of experience.

Right after graduating with a degree in Business Administration from Northumbria University in the UK, she pursued to further her studies and graduated with a Master's in Business Administration (International) from Nottingham University UK. Her track record of success with top multinational companies like Phillip Morris, Dell, and Shell has distinguished her as a driving force for transformational changes. **She handled multiple events and projects within local and global contexts where she delivered diverse matrix projects across multiple geographical locations, involving virtual stakeholders while overseeing operational tasks and maintaining the corporate brand name.** Recently she was one of the main committee members for the launch of a prestigious ceremony for a ground-breaking Cybersecurity Hub in Asia Pacific for Siemens Energy. **Nurul is a dedicated mom of three, a traveler at heart, and loves the beaches, mountains, and rivers.** She spends her weekends going out and spending time with her family, reading books and new exciting topics that could enhance her knowledge of human studies, empowerment, and technology.

Source:
Nurul Noor

Photo: Nurul Noor, rawpixel.com

Monitoring Technology of Dissolved Hydrogen in Transformer Oil

by **Julie Feng**

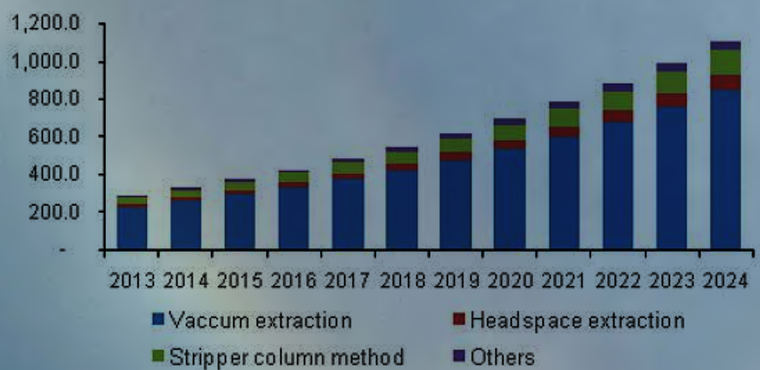


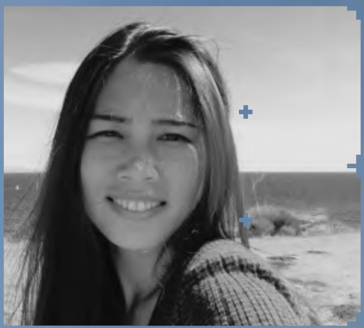
Figure 1.
Asia Pacific Dissolved Gas Analyzer Market by extraction type, 2013 - 2024 (USD Million) (Source: Grand View Research [1])

Photo: Shutterstock

Introduction

The Asia Pacific dissolved gas analyzers (DGA) market is expected to reach USD 1.11 billion by 2024, expanding at a CAGR (Compound Annual Growth Rate) exceeding 12.0% over the forecast period, according to Grand View Research [1]. This growth is based on mitigating faults in high-voltage transformers combined with the high cost of transformer replacement. Incorporating real time DGA analytics aids companies in detecting faults in power transformers at the onset instead of weeks or months later. Early diagnosis allows clients to develop proactive maintenance programs to avert faults and extend the life of power transformers. This is expected to propel global demand for online DGA systems significantly over the next few years. Figure 1 illustrates this trend specific to Asia Pacific.

DGA hydrogen monitoring in transformer oil has the advantages of small size, convenient installation, and rapid response to sudden failures.



Julie Feng obtained her degree in mechanical engineering from China Shanxi Technology University in 2008. Over the past ten years Julie has been engaged in industrial sales, working with the largest DGA OEMs in China, supporting the State Grid and other private entities. Julie is currently Business Development Director at H2Scan, China.

Background

China's electric power industry has rapidly developed with the accelerated development of China's economy and associated science & technology. This economic development has improved the quality of life by propelling forward increased requirements for the operation, reliability, and life of their power system equipment. To this end, analyzing dissolved gases in transformer oil is the most effective method of evaluating the operation of oil-filled transformers. Online monitoring devices that measure dissolved gas in transformer oil are vital tools for the power industry's operation and maintenance management of critical equipment. Hydrogen is one of the key gases reflecting the internal insulation defects of fluid-filled equipment. Monitoring hydrogen in transformer fluid has several advantages including small size, convenient installation, and rapid response to sudden failures. In recent years China's DGA programs have been standardized and applied in monitoring both in-service and newly installed large power transformers to mitigate the risk associated with loss of these important assets.

Hydrogen is one of the critical and characteristic gases reflecting internal insulation defects of oil-filled equipment.

Hydrogen Sensor Application

A Hydrogen sensor is a device that detects hydrogen and generates an electrical signal proportional to the Hydrogen concentration. Compared with traditional gas chromatograph or mass spectrometer detection, solid state Hydrogen sensors provide the advantages of low cost, small size, fast response, no maintenance, no cross-sensitivity, long life and online real-time monitoring.

Technical Principles of Transformer Oil Decomposition:

Transformer oil is a mixture of various hydrocarbon molecules of different molecular weights. Electrical or thermal failure can break certain C- H bonds and C- C bonds, accompanied by the generation of a small number of active Hydrogen atoms and unstable hydrocarbon radicals (China State Grid Research Center). These Hydrogen atoms or radicals rapidly recombine through complex chemical reactions to form hydrogen.

A hydrogen sensor is a device that detects hydrogen and generates an electrical signal proportional to the hydrogen concentration.

Technical Core Performance Indicators Include:

1. Detection range and measurement accuracy
2. Minimum detection concentration
3. Minimum sampling interval time
4. Measurement repeatability
5. Response Time (T90)
6. Cross sensitivity

Measurement accuracy performance is rated in Classes A, B, C: Table 2 for 750 kV and above sub-station device requirements; Table 3 for 500 kV Substation device requirements; Table 4 for Lower voltage device requirements.

The testing parameter	Measurement range (pL/L)	Measurement limits
Hydrogen	2~20[a]	±2 µL/L or ±30%
	20~1000	±30%
Acetylene	0.2~5[a]	±0.2 µL/L or ±30%
	5~10	±30%
	10~50	±20%
Methane, Ethane, Ethylene	0.5~10[a]	±0.5 µL/L or ±30%
	10~150	±30%
Carbon Monoxide	25~100[a]	±25 µL/L or ±30%
	100~1500	±30%
Carbon Dioxide	25~100[a]	±25 µL/L or ±30%
	100~7500	±30%
Total Hydrocarbons C_1+C_2	2~10[a]	±2 µL/L or ±30%
	10~150	±30%
	150~500	±20%
[a] whichever is greater		

Table 2. Measurement requirements for multi gas monitors in substations of 750 KV and above. Standard Q/GDW 10536-2021 (Source: China State Grid Research Center [3])

Hydrogen requirements/ Attention values	Transformers and reactors		Voltage/Current Transformer		Bushing	
Voltage level	330 kV and above	220 kV and below	330 kV and above	220 kV and below	330 kV and above	220 kV and below
Before Operation	ISO 2512	<30 PPM	<50 PPM	<100 PPM	<50 PPM	<150 PPM
In operation	150 PPM	150 PPM	150 PPM	150/300 PPM	500 PPM	500 PPM

Table 1. Technical Standards and the Application of Hydrogen Diagnosis in Oil (PPM Level) (Source: China State Grid Research Center [2])

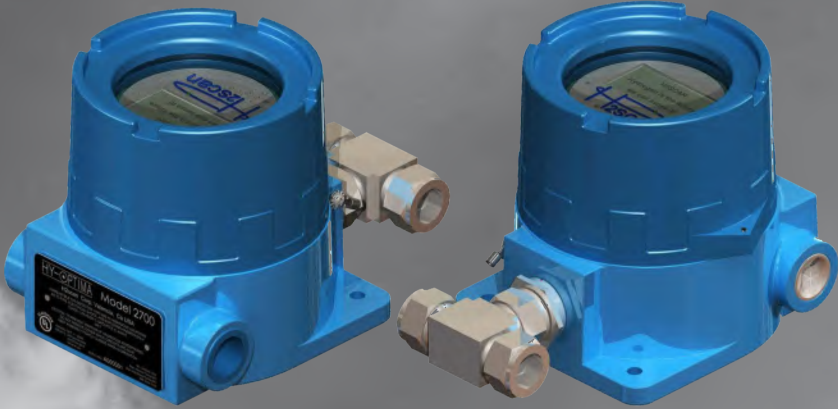
Per China State Grid Corporation Standard Q/GDW 10536-2021, the measurement range for monitors should meet the requirements outlined in Tables 2, 3 and 4.

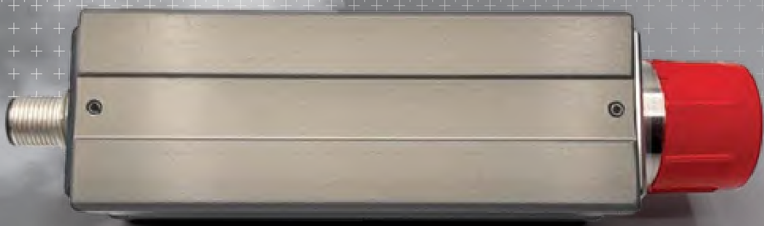
The testing parameter	Measurement range (pL/L)	Measurement limits Level A	Measurement limits Level B	Measurement limits Level C
Hydrogen	2~20[a]	±2 µL/L or ±30%	±3 µL/L or ±30%	±4 µL/L or ±30%
	20~2000	±30%	±35%	±40%
Acetylene	0.2~5[a]	±0.5 µL/L or ±30%	±1 µL /L or ±30%	±1.5 µL /L or ±30%
	5~10	±30%	±35%	±40%
	10~200	±20%	±30%	±40%
Methane, Ethane, Ethylene	0.5~10[a]	±0.5 µL/L or ±30%	±1 µL/L or ±30%	±2 µL/L or ±30%
	10~600	±30%	±35%	±40%
Carbon Monoxide	25~100[a]	±25 µL/L or ±30%	±30 µL/L	±40 µL/L
	100~3000	±30%	±30%	±40%
Carbon Dioxide	25~100[a]	±25 µL/L or ±30%	±30 µL/L	±40 µL/L
	100~15000	±30%	±35%	±40%
Total Hydrocarbons C_1+C_2	2~10[a]	±2 µL/L or ±30%	±3 µL/L	±4 µL/L
	10~150	±30%	±35%	±40%
	150~2000	±20%	±30%	±40%
[a] whichever is greater				

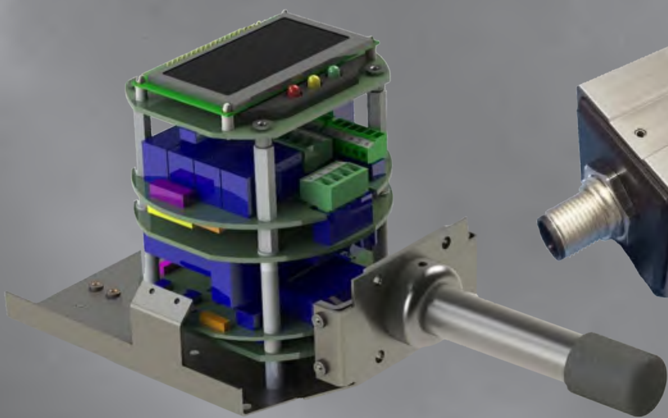
Table 3. Measurement requirements for multi gas monitors in substations of 500 KV and below. Standard Q/GDW 10536-2021 (Source: China State Grid Research Center [3])

The testing parameter	Measurement range (pL/L)	Measurement limits Level A	Measurement limits Level B	Measurement limits Level C
Hydrogen	2~20[a]	±5 µL/L or ±30%	±10 µL/L or ±30%	±15 µL/L or ±30%
	20~2000	±30%	±35%	±40%
Acetylene	0.2~5[a]	±0.5 µL/L or ±30%	±1µL/L or ±30%	±1.5µL/L or ±30%
	5~10	±30%	±35%	±40%
	10~200	±20%	±30%	±40%
Carbon Monoxide	25~100[a]	±25 µL/L or ±30%	±30 µL/L	±40 µL/L
	1100~15000	±30%	±35%	±40%
Composite gas (H_2,CO,C_2H_4,C_2H_2)	2~20[a]	±5 µL/L or ±30%	±10 µL/L or ±30%	±15 µL/L or ±30%
	20~2000	±30%	±35%	±40%
[a] whichever is greater				

Table 4. Measurement Requirements for few gas monitors Table 3. Standard Q/GDW 10536-2021 (Source: China State Grid Research Center [3])


HY-OPTIMA Model 2700





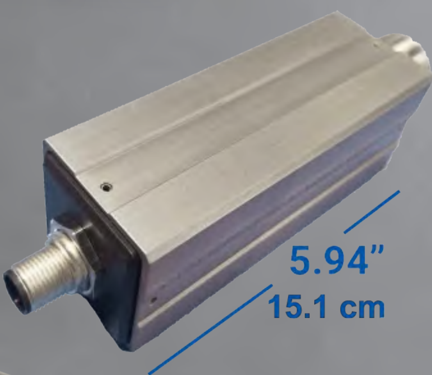

5.94"
15.1 cm

Photo: H2scan, Shutterstock

Commonly Used Devices

Monitoring devices for dissolved hydrogen in transformer oil include a dissolved hydrogen sensor, control and data acquisition equipment, communication and auxiliary modules, and an installation interface.

Compared with traditional hydrogen gas chromatograph or mass spectrometer detection, hydrogen gas sensor provides advantages of low cost, small size, fast response, no maintenance, no cross-sensitivity, and online real-time monitoring.

Installation Simulation Tests and Setup Examples include:

1. Gas relay gas collection alarm testing
2. 100°C oil temperature continuous power-on assessment
3. Simulation test for retrofitting a single hydrogen monitoring device
4. Joint pipe installation monitoring device vibration; vibration stress

In-plant Installation and Verification

Chinese Academy of Electrical Sciences has installed a hydrogen monitoring device on a large power transformer and ran feasibility analysis. Physical testing takes place once the performance verification and simulation operation tests have been carried out.

Conclusion

In summary, the application of online monitoring ensures the stability of the transformer, saves high labor costs, reduces the frequency of sampling and improves efficiency. Ongoing improvement in the industry requires suppliers, operators and technicians to conduct in-depth research and continuous improvement based on problems arising in the industry. The sector strives to provide the most reliable data for transformer monitoring to allow for the power grid's optimized function for everyone's benefit.

References

[1] "Dissolved Gas Analyzer Market Size, Share & Trends Analysis Report By Extraction Type (Vacuum Extraction, Headspace Extraction, Striper Column Method), By Power Rating (100-500 MVA, 501-800 MVA, 801-1200 MVA), By Analysis Type and Segment Forecasts To 2024," Grand View Research, accessed at https://www.grandviewresearch.com/industry-analysis/dissolved-gas-analyzer-dga-market

[2] "Monitoring Technology for Dissolved Hydrogen in Transformer Oil," China State Grid Research Center, accessed at https://edirc.repec.org/

[3] "Standard Q/GDW 10536-2021," China State Grid Corporation

YASH HIGHVOLTAGE

A True Solution Provider for Capacitive Transformer Bushings

YASH MAKE 145 KV OIP BUSHINGS RETEOFITTED ON A TRANSFORMER TO REPLACE OLD SRBP BUSHINGS

24/7 Reliable and affordable power in today's scenario is essential for everyone including households, industry, commercial businesses, public needs, agriculture and many more applications. Today, a nation's development can almost directly be equated to its electricity consumption and innovation in power infrastructure. In order to ensure continual progress and sustainable development, governments across the globe have formulated various strategies and policies with dedicated focus on effective and efficient power generation, transmission and distribution networks. YASH Highvoltage Ltd. through its niche and varied Condenser Graded High Voltage and High Current Transformer Bushings solutions has been playing a pivotal role across the globe for over 20 years in helping power utilities and transformer OEMs alike to help realize the goal of uninterrupted and sufficient power supply by ensuring minimal downtime of transformers due to unavailability of a highly critical component of transformers – Capacitive Bushings.

It is well known that capacitive transformer bushings are mission-critical devices for a power transformer/reactor/GIS and power substations to help conduct power from/to overhead transmission lines/IPBDs, etc. to/from the active part of the transformation equipment, which essentially requires passage of the power safely through an earthed barrier at extremely high voltages. Though the cost of a transformer bushing is negligible in comparison to that of the transformer or the substation equipment around it, the failures of these products can be catastrophic not only in terms of collateral equipment damage and life-risks, but also in terms of disruption of power supply to the grid and thereby to the users. The critical operational requirements for transformer bushings demand their own set of stringent qualification requirements and business maturation time along with dedicated investment in specialized processes, R&D, know-how, infrastructure, human resources and, above all, a slow gestation period for brand recognition and establishment of trust with customers, which is the primary reason that globally there are only a handful of recognized manufacturers for transformer bushings – with YASH being a part of this distinguished list.

There are several surveys and technical papers internationally on power transformer failures

Photo: YASH

(transformers catching fire and explosive failure leading to disruption of power availability), clearly indicating that transformer bushings contribute to an average >18 to 20% of power transformer failures, several of which are at times catastrophic in nature causing damage also to the surrounding equipment. If the transformers are repairable, the time to repair runs in several months thereby disrupting transmission/generation. In view of the above-mentioned consequences, several utilities around the world are now increasing vigilance on bushing condition monitoring as well as adopting strategies to timely replace/retrofit old transformer bushings which are either displaying unacceptable results or are nearing the end of their service life. There are several bushing designs even today which are operational in the field but for which spares are not available either due to legacy designs, at times unavailability of the original manufacturer, or change in technologies and capabilities.

guided by seasoned technical experts hailing from transformer bushing industry from Europe and India as well as utility stalwarts in field of HV/EHV power substation and engineering design – all of them having a combined experience of 120+ years between them.

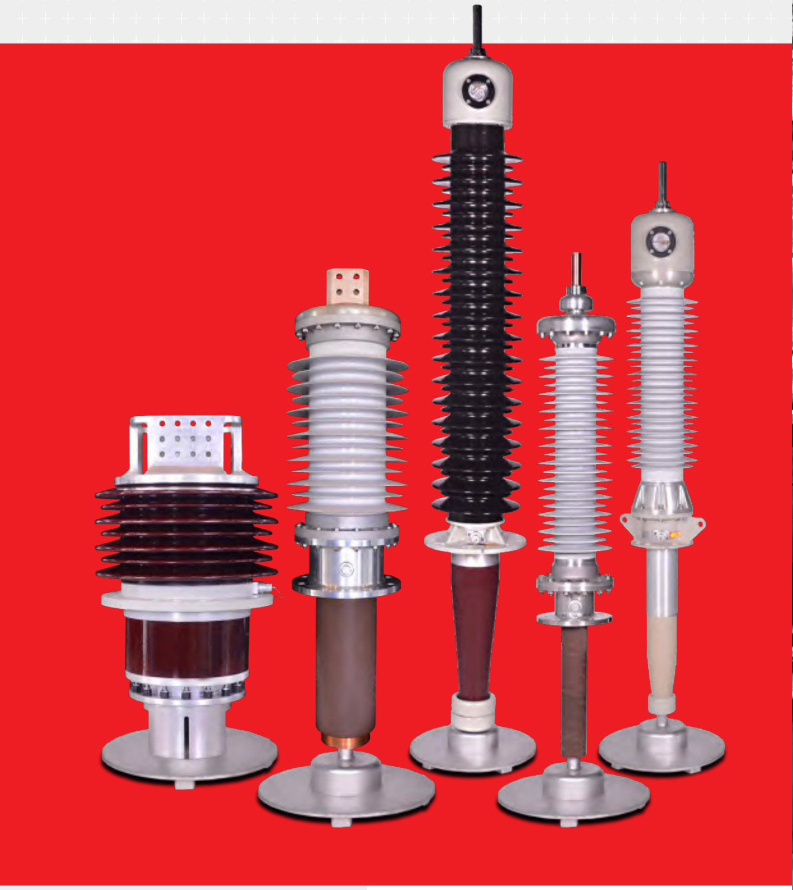
Possessing the ability to offer a combination of all bushing technologies under one roof and across applications, viz. retrofitting potential of SRBP to OIP, OIP to OIP, OIP to RIP/RIS are available from a single window along with engineering support for choice of the correct bushing and technicalities of application, gives relief to the customer. The presence of a dedicated PAN India Regional Services team of trained and knowledgeable engineers provide quick access and swift support to customers as an added advantage, whether it requires consulting or to simply take measurements of the existing bushings at site which are to be retrofitted.

36 KV 16 KA HIGH CURRENT BUSHING WITH 8 PALM TERMINATIONS, CUSTOM ENGINEERED FOR A GENERATION STATION

36 KV 16,000 A HC BUSHING SUPPLIED AS A RETROFIT SOLUTION TO US, TURKEY & OTHER MARKETS

Replacing them requires a lot of value engineering, involving considerable time, effort and risk purchasing. Being an independent manufacturer solely focused on transformer bushings, YASH possesses the ability to adapt and deliver made-to-order solutions whether the requirement is for a few bushings or for many, through a lean and responsive team which has a separate and dedicated focus for custom engineering, while maintaining industry best development times even for non-standard parts. The solutions are developed by an experienced and passionate in-house engineering team

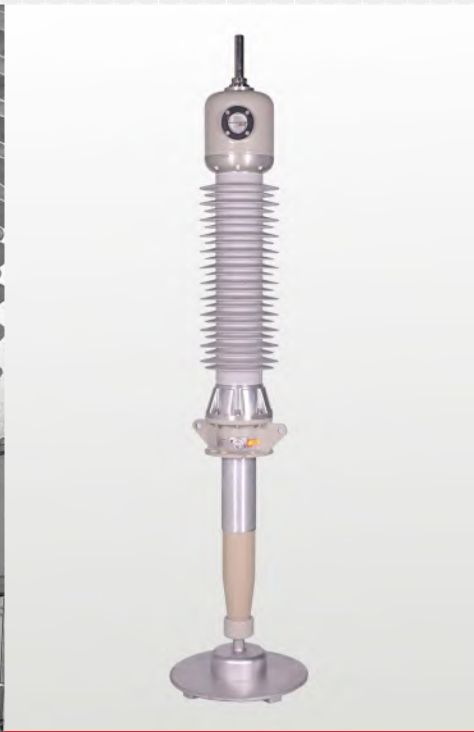
YASH being an independent manufacturer solely focused on transformer bushings with global supply experience of 27,000+ bushings across 50+ countries, has developed a unique identity of being more than an established bushing manufacturer, and as a one-stop solution provider to power industry (generation and transmission) for all combination of transformer bushings which has been appreciated alike by the end users and global MNCs such as Siemens, GE, Hitachi-ABB, Toshiba, CG, Schneider, Hyundai, BTW, and many more. In addition to a well-established and standardized product range, YASH possesses the ability to offer flexible and highly customizable retrofit bushings solutions to all customers alike for the comprehensive product basket of transformer bushings not only to transformer OEMs as well as transformer overhauling/repairing and servicing companies, but also directly to the end user sites with supply of interchangeable transformer bushings retrofitted to any reputed global bushing make hence justifying itself as a solution provider rather than merely a bushing supplier.



ONE STOP SHOP FOR HIGH CURRENT, HIGH VOLTAGE, OIP/RIP/RIS BUSHINGS, WALL BUSHINGS

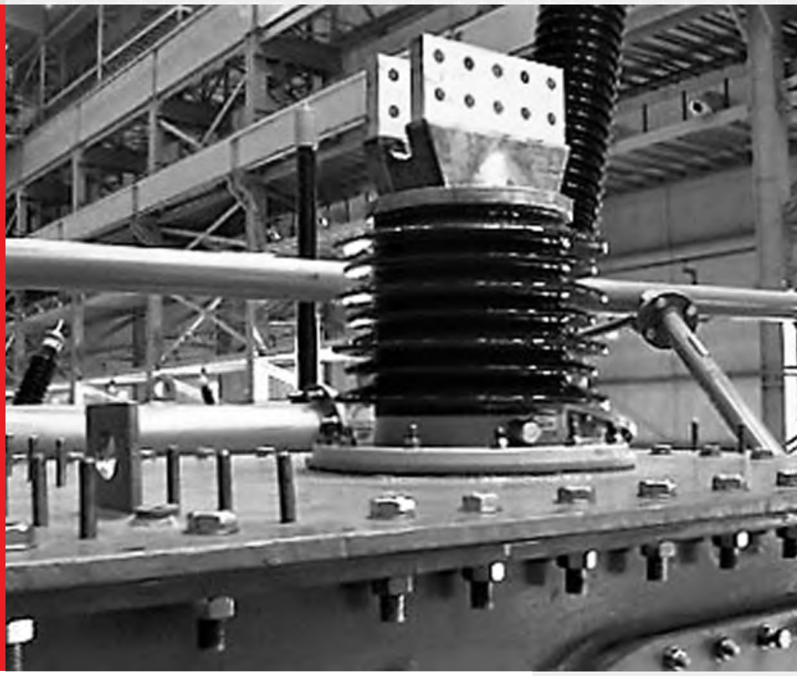
There have been plenty of situations wherein transformers have been under breakdown due to problems with the existing bushings and identical spares being non-available. This not only results in heavy losses to the end user but also forces them to replace the complete transformer driving the cost of maintenance in millions at times. A very similar situation was witnessed by a huge thermal power generating station in Turkey (2x660 MW) where power generation was hindered due to issues faced in LV high current bushings for seven generator step up transformers thereby crippling the entire plant's generation. The LV high current bushings of 36 kV 16,000 A had to be custom engineered and retrofitted. YASH successfully managed to develop this solution in record lead

145 KV OIL TO OIL BUSHING SUPPLIED AS RETROFIT SOLUTION



time overcoming the issues posed by the then ongoing COVID-19 pandemic. These special efforts by YASH were highly appreciated by the end user and helped restore power to a million households as well as industry and hospitals especially during COVID. Similar executions have been made for the power generating and transmission substations across the world including some noteworthy executions of 36 kV 16,000 A HC bushings and 34.5 kV 8,000A IEEE design high current bushings for multiple power generating stations of USA, 170 kV 1,250 A 860 CT OIP and 36 kV 10,000 A 0 CT high current bushings for Ecuador, to name a few.

Not limiting its capabilities of providing solutions for Oil-Air bushings, YASH has been pivotal in providing similar customized retrofit solutions for oil-oil and air to air bushings applications. There have been numerous other such instances where end users – both private and govt., whether they are industry,



RETROFIT SOLUTIONS TO DESIGNS OBSOLETED BY THE ORIGINAL BUSHING OEMS, WITH A VARIETY OF TERMINATION AND DIMENSIONAL CUSTOMIZATIONS

transmission application or generation applications, have been given respite by receiving the timely support and solutions through YASH retrofits value stream in the domestic as well as exports markets.

Globally there are several solution providers for power transformer repairs and overhauling, but YASH remains unrivaled in providing retrofit/repair solutions specific to transformer bushings, and this capability is well appreciated and welcomed by global utilities/power substations/EPCs and transformer repairing/overhauling enterprises.

Photo: YASH

600 KV EHV TEST LAB AT YASH

Superior infrastructure capabilities paving way for multifold growth

The critical operation requirements for transformer bushings also warrants an utmost attention to detail towards quality and testing. YASH factory consists of world class manufacturing and testing equipment sourced from reputed manufacturers in Germany, Switzerland, the USA, and other parts of Europe to enable a facility that is second to none for bushings manufacturing including automatic winding machines, SCADA controlled autoclave systems, industry best handling and storage systems, state of the art testing and evaluation equipment, including an in-house EHV test laboratory capable of all routine tests and several type tests in line with IEC 60137:2017 standard, enabling a 100% test capability of each and every product which departs from the factory.

The infrastructure is further strengthened by integrated ERP systems and world class 2D-3D designing software and modelling. YASH continues to invest in addition and upgradation of its infrastructure and CAPEX each passing year, with a view to cater the global bushing market and be the preferred transformer bushing solution provider to our discerning customers.

Photo: YASH

YASH CONSOLIDATED PRODUCT RANGE

About Yash Highvoltage Ltd.

Established in 2002, YASH Highvoltage Ltd, is an ISO 9001 certified independent and indigenous manufacturer of niche condenser graded transformer bushings. From a humble beginning as manufacturer of high current bushings, today YASH has grown steadily and has craved a niche for itself not only in terms of product range and business volumes of 27,000 products supplied globally but also in terms of the customers and 50+ markets served, as a true "one-stop solution provider" with a wide product basket comprising of OIP (Oil Impregnated Paper) Capacitive Bushings up to 245kV for Oil – Air, Oil – Oil and Air - Air application in power transmission, High Current Capacitive Bushings up to 25kA for generator step up transformers, Resin Impregnated Paper (RIP) Capacitive bushings up to 245 kV under technology and equity partnership with Moser Glaser – Switzerland, IEEE range of OIP condenser bushings and many more.

YASH
HIGHVOLTAGE

Yash Highvoltage Ltd.
sales@yashhv.com
www.yashhv.com

Transformer Bushing Monitoring:
The Reference Signal Method

by **Emilio Morales**

Photo: Shutterstock

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

Transformer bushings are one of the most critical components of a transformer. Up to 20% of major failures on high voltage transformers today can be related to bushings. Almost half of these failures result in catastrophic failures like explosions, fire or oil spillage. The cost of these damages and the lost opportunity to deliver energy could be several hundred times higher than the price of a bushing. Even a failing bushing which does not lead to a transformer catastrophic failure can harm people due to burst porcelain insulators, catapulted through the air by the force of the arc of the breakdown.

Experience has shown that there are two main periods when bushings fail. The first period of bushing failures has to do with production/quality related failures which occur once the bushings reach an age of 10 to 13 years. The second period occurs between 20 and 30 years of age, which is considered its normal lifetime. However, it is also true that bushings can fail before they reach 10 years of age, while at the same time there are bushings installed in transformers that are more than 50 years old.

In order to have a reliable monitoring system, the accuracy of the acquisition of the monitored parameters needs to be very high, so that the system can detect the slight changes of the lost angle that occur due to moisture contamination in the bushing core.

The two main health indicators for a bushing are the loss factor (tan δ/ Power Factor) and the capacitance. While the loss factor is sensitive to almost all bushing faults, the capacitance is an important factor to detect partial breakdowns between capacitive layers and to detect, in combination with the loss factor, contact problems inside the bushing.

Bushing monitoring is aiming to detect incipient faults and give an early warning as well as using the bushings till its real end of life. In order to have a reliable monitoring system, the accuracy of the acquisition of the monitored parameters needs to be very high, so it can detect the slight changes of the lost angle due to moisture contamination in the bushing core.

There are bushing monitoring systems today that are not able to capture these slight, but important changes. Voltage and angle differences between phases as well as different temperatures aging rates are not considered in the methods where the sister bushings are used as a reference source to assess the condition of a bushing (like the balanced current method). Methods using voltage sources as reference signals from the same phase of the monitored bushing provide the required accuracy. The phase shift between the leakage current signal from the bushing and the voltage from the voltage transformer is measured and corrected by the phase shift offset so the loss factor can be calculated directly. By using a voltage transformer (VT) as reference source, accuracies up to 0.1mrad in terms of measuring the phase shift can be achieved and small but relevant changes can be detected.

The two main health indicators for a bushing are the loss factor (tan δ/ Power Factor) and capacitance. While the loss factor is sensitive to almost all bushing faults, capacitance is an important factor to detect partial breakdowns between capacitive layers, and in combination with the loss factor, to detect contact problems inside the bushing.

Failure Statistic

Transformers are one of the most critical components within the electrical network and cannot, once one fails, be exchanged easily by a new one. Often transformer failures cause the inability to deliver energy, have high potential to harm people and can cause environmental disasters. Due to all of these, a high financial impact often is connected to transformer failures.

The old economies like Europe, North America and Japan are especially facing aged key network components. Continuous monitoring solutions were not used extensively in the past, due to n-1 availability of the main equipment. Furthermore, monitoring solutions were less reliable or not available 10 to 20 years ago. Nevertheless, the condition assessment in the utilities of the old economies was carried out under comprehensive periodic measurements and maintenance programs. Nowadays these utilities are seeking more solutions to operate their costly components till their real end of life. Furthermore, asset exchange programs will be based on the condition of the equipment. Condition monitoring and condition-based maintenance are seen as an important factor to achieve these goals.

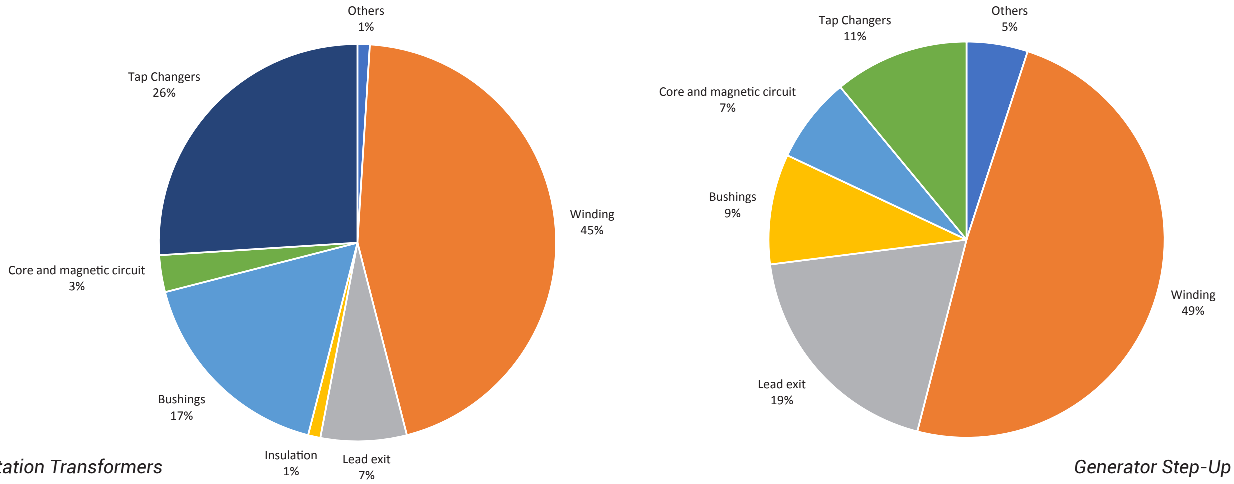
In 2012, the CIGRE WG A2.37 released an interim report [1] which shows the statistic on transformer failures (Table 1).

The results show that over all voltage classes, the failure rate is 0.44%, which means, out of approximately 230 transformers, one will fail per year. Besides the preventions of faults or early detection of upcoming faults, the assessment of the remaining life and the health of the equipment is of immense interest, especially for aged equipment. In order to assess the asset health, a combined set of data from the main transformer and its main components needs to be measured/ monitored. Besides other components/ parts, bushings are one of the main causes of transformer failures, contributing around 20% to the overall transformer major failures, depending on the type of transformer. Bushing failures can lead to catastrophic failures and can be accompanied by environmental disasters or fatal accidents to people. According to a transformer reliability study published in [2], 70% of all transformer fires are caused by bushing failures.

The causes of bushing failures vary from normal aging, moisture, quality issues during manufacturing, repeated thermal and mechanical cycling, transients, and external influences like external flashovers. As a result, a high number of bushing failures develop from partial breakdowns, thermal instabilities or degradations of longitudinal isolation interfaces.

	HIGHEST SYSTEM VOLTAGE (kV)					
FAILURES & POPULATION INFORMATION	69 kV < 100	100 kV < 200	200 kV < 300	300 kV < 500	700 kV	All
Failures	145	212	163	154	11	685
Transformer-Years	15220	48994	47473	41569	959	156186
FAILURE RATE/YEAR	0.95%	0.43%	0.34%	0.37%	1.15%	0.44%

Table 1. Transformer failure statistics [1]



Substation Transformers

Generator Step-Up Transformers

Figure 1. Failed component statistic [1]

To improve transformer reliability the demand of reliable bushing monitoring is increasing throughout the industry.

By using a voltage transformer (VT) as reference source, accuracies up to 0.1mrad in terms of measuring the phase shift can be achieved and small but relevant changes can be detected

Bushing Monitoring Parameters

The main bushing parameters that are used today for bushing online monitoring are the Power Factor in the IEEE world (or Dissipation Factor in the IEC world) and the bushing main capacitance. These two parameters can detect different failures in an early stage of its development.

Power Factor

The Power Factor reflects the condition and the health of the insulation itself. It represents the ratio between capacitive and resistive current, which in their summation give the leakage current.

The capacitive current is the result of the capacitive layer design and therewith provide a given value. The resistive current is defined by the resistivity of the insulation material and is a direct parameter of the quality of the insulation system. Each healthy solid and liquid insulation material has a typical resistive current component. An increasing resistive current will indicate a degradation of the insulation system and will increase the angle δ and decrease the angle θ resulting in an increase in Power Factor (see Figure 2).

The Power Factor measurement under online conditions requires high accuracy in order to detect small changes and to guaranty the detection of increasing moisture content in the insulation system, which is difficult to achieve under online condition. External influences like low frequency magnetic fields, external noise and harmonics as well as the lack of stable reference signal sources are the factors which influence these measurements.

The advantage of online monitoring is that the Power Factor of a bushing can be seen at different temperatures. Offline measurements without additional active heating of the bushing and online monitoring that use the sister bushings as a reference source to assess the condition of a bushing are not able to detect this kind of defects.

Figure 3 shows the behavior of the insulation system with increased moisture content. The accuracy of the measured power factor needs to be very high, considering the power factor difference at 20°C for a wet and dry insulation.

The advantage of online monitoring is that the power factor of a bushing can be seen at different temperatures. Depending on the load of the transformer, the temperature of the bushing will increase or decrease. It can be seen in Figure 3 that the power factor gradient of wet bushings is much higher at higher temperatures than for dry bushings. Offline measurements without additional active heating of the bushing and online monitoring that use the sister bushings as a reference source to assess the condition of a bushing are not able to detect this kind of defects.

Capacitance

As described above for the capacitive current, the capacitance is a parameter which represents the design of the capacitive layers. It will increase, if two or more layers of the electrical field control foils are short circuit (see Figure 4). If only two layers are shorted, the capacitance will increase by a percentage equivalent to the total number of layers. For example, if two out of total 50 layers will be short circuit, the capacitance will increase by 2%

Overview of the Reference Signal Bushing Monitoring Method

One of the newest methods used today for bushing monitoring is the reference signal method, which measures the phase shift of the leakage current of a bushing and its stable reference signal.

One of the newest methods used today for bushing monitoring is the reference signal method, which measures the phase shift of the leakage current of a bushing and its stable reference signal.

Today, the biggest drawback when it comes to increasing the accuracy in Power Factor and Capacitance monitoring is that the bushings will be compared to each other across the phases and the balances between

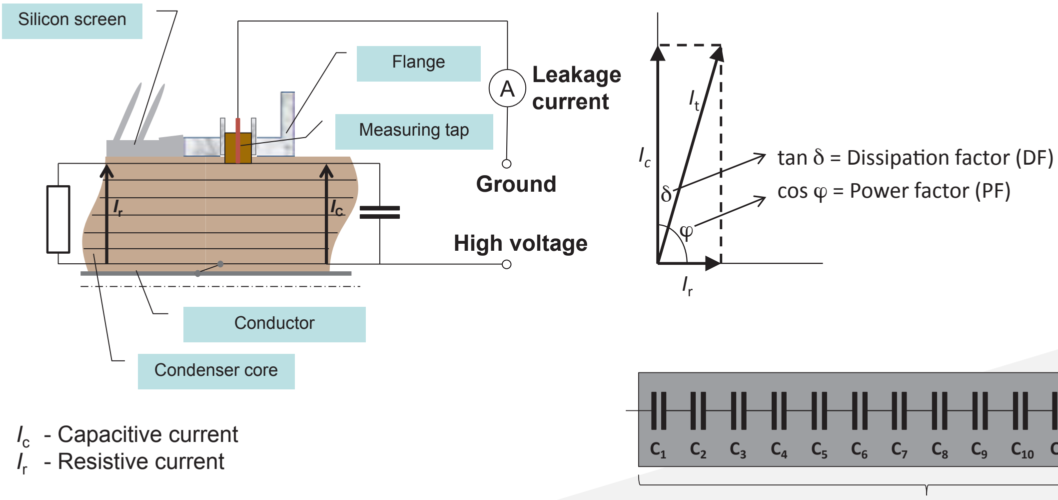
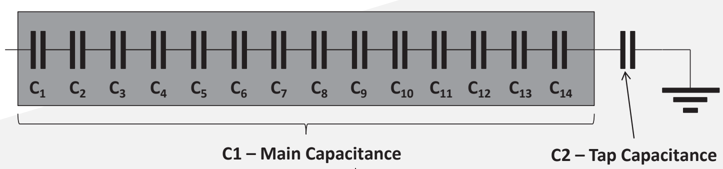


Figure 2. Leakage current and Power Factor



$$\frac{1}{C_{1\,total}} = \frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\frac{1}{C_4}+\frac{1}{C_4}+\frac{1}{C_5}+\frac{1}{C_6}+\frac{1}{C_7}+\frac{1}{C_8}+\frac{1}{C_9}+\frac{1}{C_{10}}+\frac{1}{C_{11}}+\frac{1}{C_{12}}+\frac{1}{C_{13}}+\frac{1}{C_{14}}$$

Figure 4. Bushing series capacitances

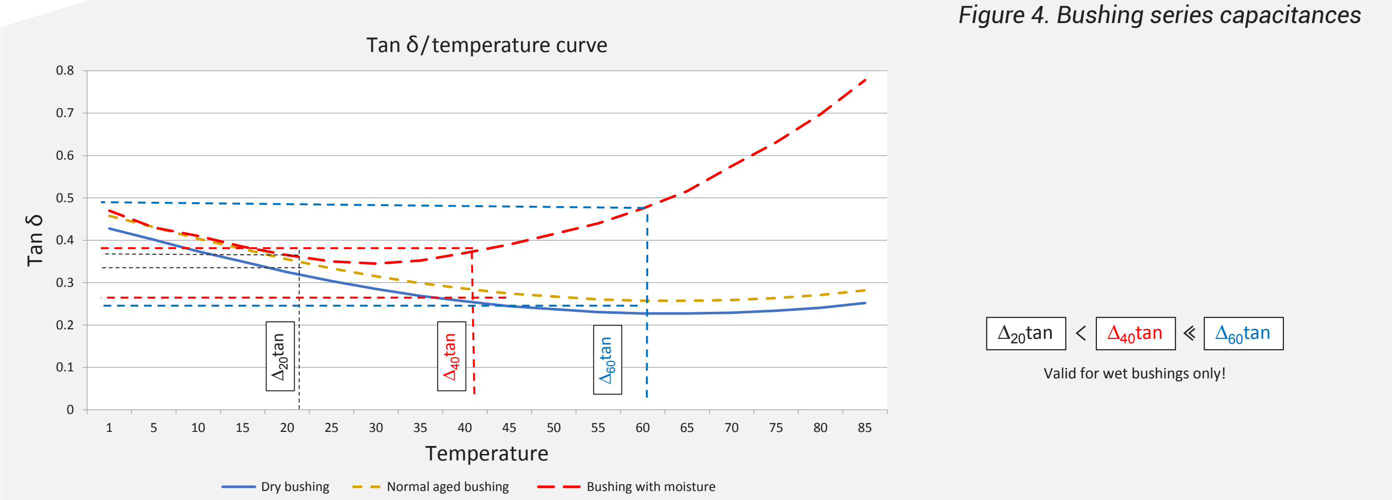


Figure 3. Power factor behavior over temperature due to increased moisture

the phases are not stable and are far from neglectable.

The only approach to overcome this drawback is to find a load independent reference signal source within the same phase as the monitored bushing. A voltage transformer (VT) always has a stable load on its secondary winding. Furthermore, the VTs do not change their transfer behavior according to the load of the network. As pure measurement principle, the phase shift measurement between leakage current and reference signal reduces the needed hardware to a minimum because after digitizing the signal, all signal processing will be done by software algorithms. Figure 5 shows the principles of the reference signal method using VTs from the same phase.

Due to the circumstance that the reference signal from the same phase is used, the achievable accuracy does not depend on phase asymmetries anymore. Existing phase constant shifts from VT, cables etc. are compensated for.

The major challenges using this method are noise reduction or noise elimination and the availability of a stable reference source. The latter is especially not always given.

Sometimes there are only VTs/CVTs on the high voltage side or far away in a separate switchyard (especially in power plants) or VTs/CVTs existing only for one phase (mostly the middle phase). A comparative monitoring in these cases can be applied, which then increases the inaccuracy of the system due to the comparison of different phases as described above. Alternative methods are under development.

Noise elimination or limitation of is one of the major requirements to achieve the necessary accuracy in the phase shift measurement of 0.0057 degree (or 0.1 mrad).

Figure 6 shows a noisy signal before and after signal processing which is illustrating the efficiency of the noise elimination algorithm.

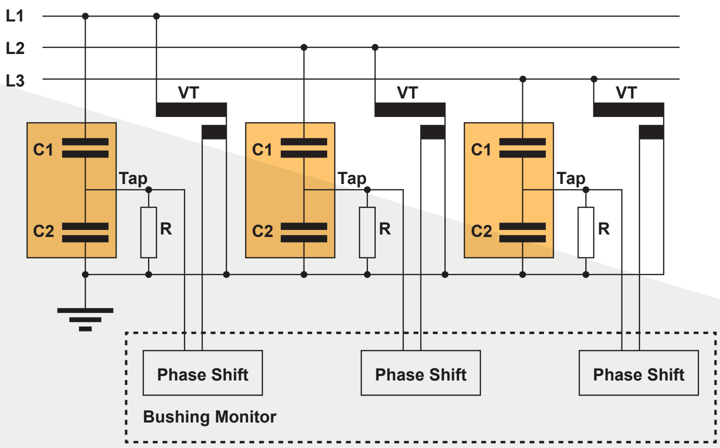


Figure 5. Principle of Reference signal method

Signal processing

- Noise and harmonics need to be eliminated by advanced software algorithms
- The accuracy of the phase measurement is better than 0.1 mrad (0.0057 degree)
- The accuracy enables detecting changes in tan δ form, e.g. 0.325% to 0.340%
- It enables early detection of moisture increase, insulation system aging and degradation
- Temperature compensation will be necessary to achieve this accuracy

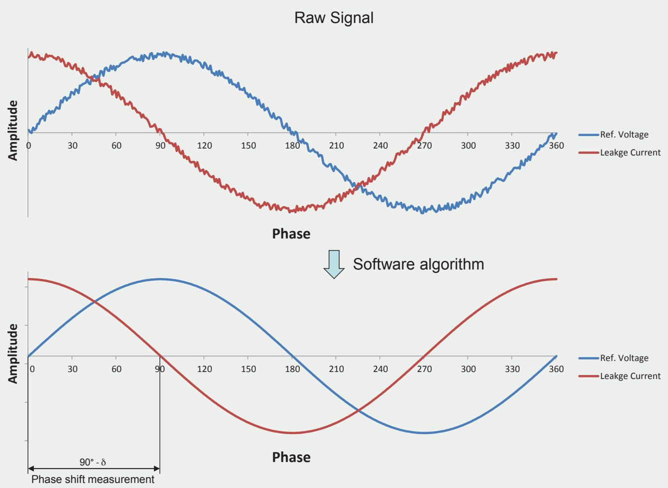


Figure 6. Example of effective noise elimination

Conclusion

Lab measurements done by bushing manufacturers with real bushings and results from onsite installations show that the accuracy of the power factor values measured/monitored using this method is far better compared to the methods which compare bushings from different phases. The results achieved in the lab showed even better results in stability and accuracy (less than 0.0057 degree).

Extensive tests and first applications of this method for bushing monitoring showed that using the reference method with a reference source from the same phase has the ability to detect small changes in power factor and capacitance changes due to partial breakdowns between two capacitive layers even for voltage levels up to 1 MV installations. Furthermore, this method can also be used for single phase transformers/reactors without limitations.

References

[1] 1. CIGRE WG A2.37. *Transformer Reliability Survey: Interim Report*. s.l., No. 261, ELECTRA, 2012

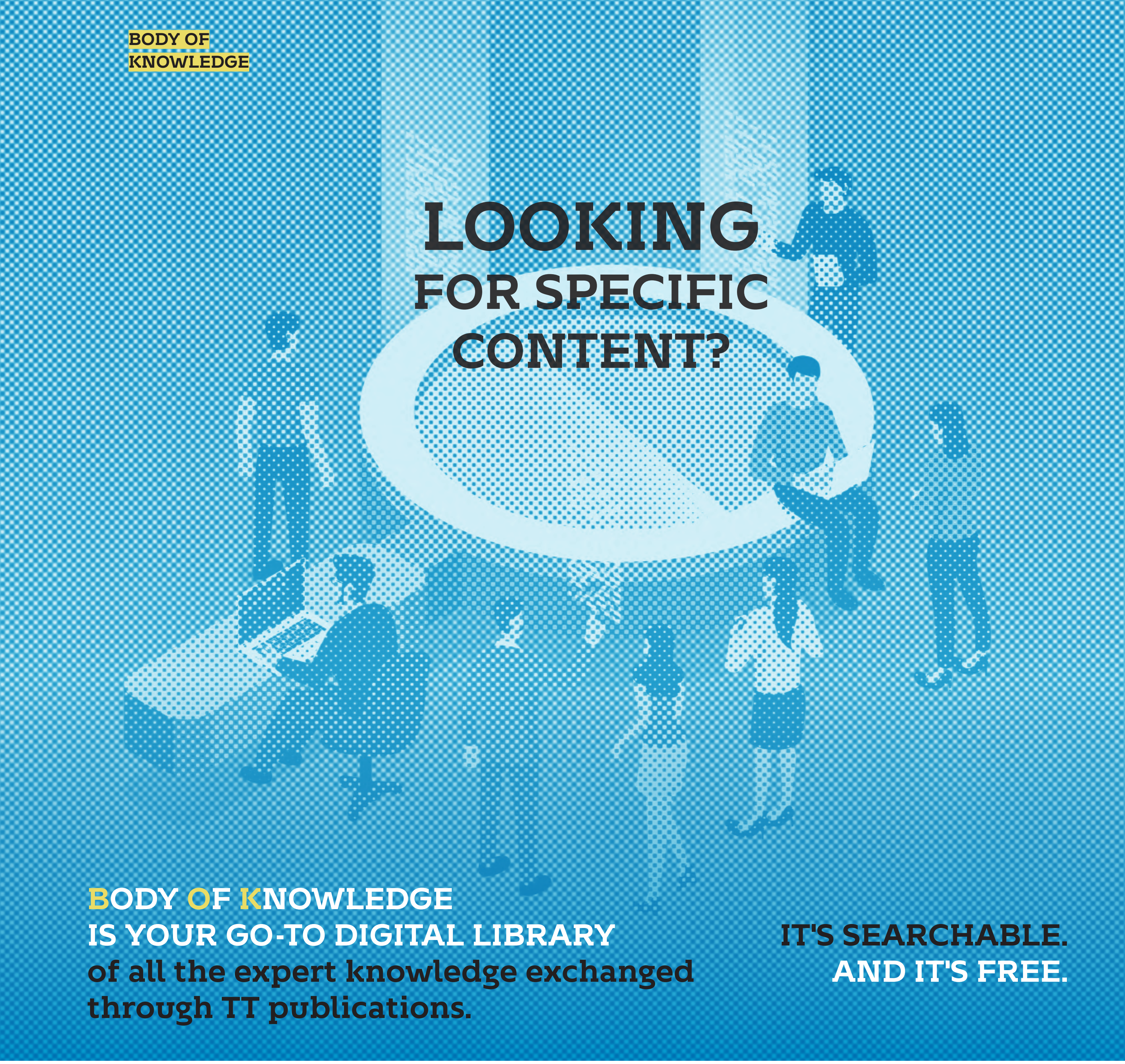
[2] Berg, H.-P. and Fritze, N. *Reliability of Main Transformers*, Salzgitter, Germany, Bundesamt für Strahlenschutz, 2011

TRANSFORMER TECHNOLOGY COMM

READY TO HEAR MORE?

VISIT OUR CHANNELS

TT Web transformer-technology.com
TT YouTube youtube.com


BODY OF KNOWLEDGE
LOOKING
FOR SPECIFIC
CONTENT?
BODY OF KNOWLEDGE
IS YOUR GO-TO DIGITAL LIBRARY
of all the expert knowledge exchanged
through TT publications.
IT'S SEARCHABLE.
AND IT'S FREE.