ISSUE 15
October 2021
transformer-technology.com
ISSN 2642-2689

TRANSFORMER TECHNOLOGY MAG

TRANSFORMER TECHNOLOGY MAG

For the Love of Bushings

Critical Materials & Components

Why Is OLTC Monitoring So Important?

New Advancements in Fluid-based Insulation and More Sustainable Bushing Technology for the Green Revolution

Interview with Randy Williams, Development Manager with North American Substation Services

GEGridSolutions.com/MD

Take the Guess Work Out of **Transformer Bushing Monitoring**

Intellix™ BMT 330
Standalone Bushing Monitor

Kelman™ DGA 900 PLUS
Comprehensive Transformer Management System

Perception Fleet
Transformer Fleet Management System

Realtime monitoring systems for DGA, Bushings, PD and more

- C_1 capacitance and Power Factor (Tan delta)
- PD (partial discharge) and PRPD diagnostics
- Marine grade IP66 rated bushing sensor
- Safety system integrated within sensor
- Extensive library of adaptors (sensors) to retrofit on any transformer bushings
- Data Diagnostics via Perception software

GE, the GE monogram, Intellix, Kelman and Perception are trademarks of the General Electric Company.
© Copyright 2021, General Electric Company. All Rights Reserved.

THE H-J FAMILY OF COMPANIES INTRODUCES

The New
High Temperature Epoxy Line

A FORMULA ENGINEERED FOR 155°C INSULATION CLASS

SUITABLE FOR A VARIETY OF APPLICATIONS, INCLUDING WIND & SOLAR GENERATION

SPECIFICATIONS:

- Extensively engineered & tested formula
- Superior dielectric & mechanical strength performance
- Suitable for continuous operating temperature up to 155°C
- Indoor non-UV light exposure and/or fully enclosed outdoor applications
- Flexible design capability

THE H-J FAMILY OF COMPANIES
Quality Products Of International Reputation
Since 1969
OVER 50 YEARS OF SERVICE

QUALITY PRODUCTS OF INTERNATIONAL REPUTATION

H-J.com

Index

Table of Contents_**04**

Editors & Impressum_**10**

Editor's Letter_**14**

Why Is OLTC Monitoring So Important?_**16**

Interview with Randy Williams, Development Manager with North American Substation Services (NASS)_**22**

TOTUS – Transformer Monitor that can separate PD in the Bushings from PD in the Main Tank_**32**

New advancements in fluid-based insulation and more sustainable bushing technology for the green revolution_**34**

Women of Note - Karina Yonemoto_**45**

How to make a great quality polymer-bushing consistently_**46**

Table of Contents

16

Why Is OLTC Monitoring So Important?

Transformers equipped with OLTCs are crucial components in the power system due to their purpose of maintaining the voltage output desired. To maintain these voltages, they are required to perform frequent operations. This article documents some of these failure modes and steps that can be taken to detect the symptoms of failure before an undesired outcome occurs.

22

Interview with **Randy Williams**, Development Manager with North American Substation Services (NASS)

32

TOTUS – Transformer Monitor that can separate PD in the Bushings from PD in the Main Tank

45

Women of Note:
Karina Yonemoto

34

New advancements in fluid-based insulation and more sustainable bushing technology for the green revolution

This paper introduces the qualification of an extended OIP bushing with bellows in the expansion chamber, outlines the advantages of ester-impregnated bushings and provides an overview of the bushing monitoring state-of-the-art.

46

How to make a great quality polymer-bushing consistently

Index

Investigation and Teardown of OIP Bushings_**50**

The Importance of Continuously Monitoring Partial Discharges Online in HV Bushings_**58**

Interview with Francis Fisher & Tom Prevost, Weidmann Electrical Technology_**70**

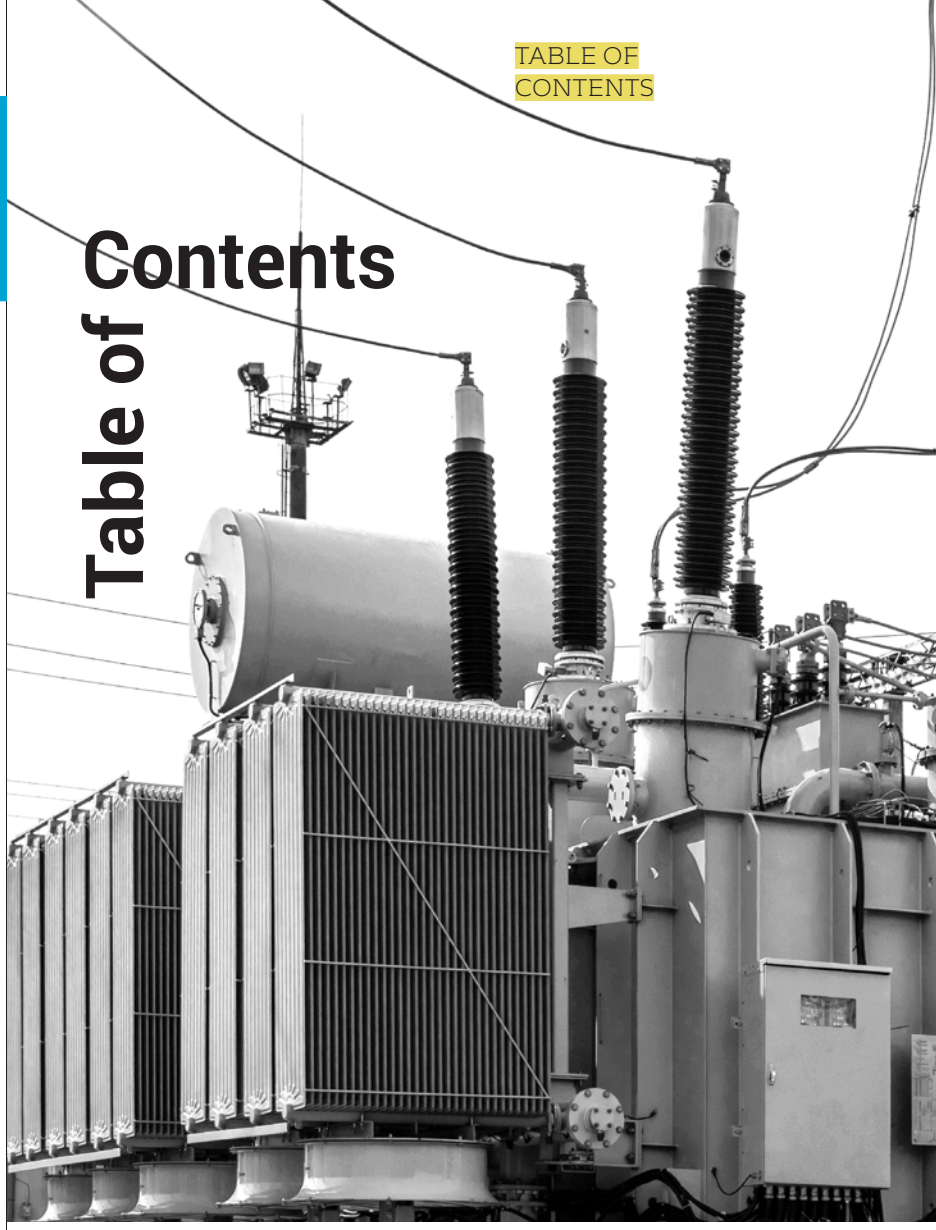
MSENSE® BM & ETOS® – Bushing monitoring: Early detection of high-voltage bushing failures_**78**

Onshore Wind Turbines: Is Bigger Still Better?_**82**

Power Transformers – Evolving, Remaining the Same_**90**

Coming in December_**100**

Table of Contents

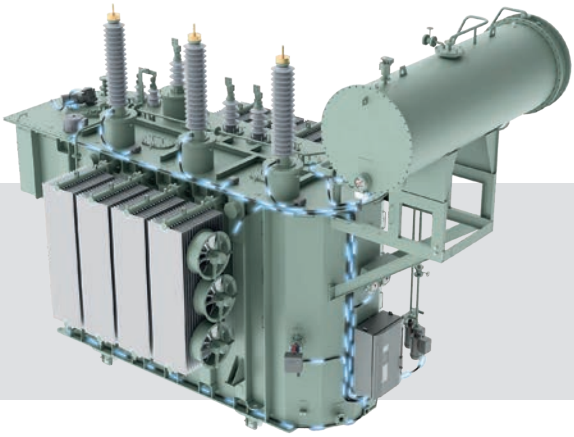


50
Investigation and Teardown of OIP Bushings

As an integral part of the electric delivery system around the world and the interface between the transformer and overhead bus, bushings failures have a significant negative impact. Because of this, there is a special focus on determining the root cause of the failure. A bushing teardown investigation is employed in cases where there is a need to determine the failure mechanism. This paper is a brief synopsis of how companies perform a bushing teardown.

70
Interview with **Francis Fisher** & **Tom Prevost**, Weidmann Electrical Technology

78
MSENSE® BM & ETOS® Bushing monitoring: Early detection of high voltage bushing failures



58
The Importance of Continuously Monitoring Partial Discharges Online in HV Bushings

Bushings are crucial components for large power transformers, being the termination points and physical electrical connections to the high and low voltage grid. Regular testing is of utmost im-portance since bushings account for 5% to 50% of transformer faults, but how are we to know which tests should be carried out in order to optimize time and budget?

82
Onshore Wind Turbines: Is Bigger Still Better?

This article is a researcher's approach to onshore wind turbines, an area of growing importance as we move away from total dependence on carbon-based energy generation. We are including it in this edition, and while it is not within the theme guidelines, it is timely and important. Enjoy!

90
Power Transformers – Evolving, Remaining the Same

An abbreviated version of this paper was written and published about 18 years ago providing insight in the transformer industry of the day. The unabbreviated paper published here provides recommendations for design, monitoring and maintenance, which remain valid in today's industry.

SEARCHING FOR NEW CUSTOMERS?

LET THEM FIND YOU!

LOOKING FOR NEW MARKETS?

WE WILL SHOW YOU HOW.

Advertize with TT

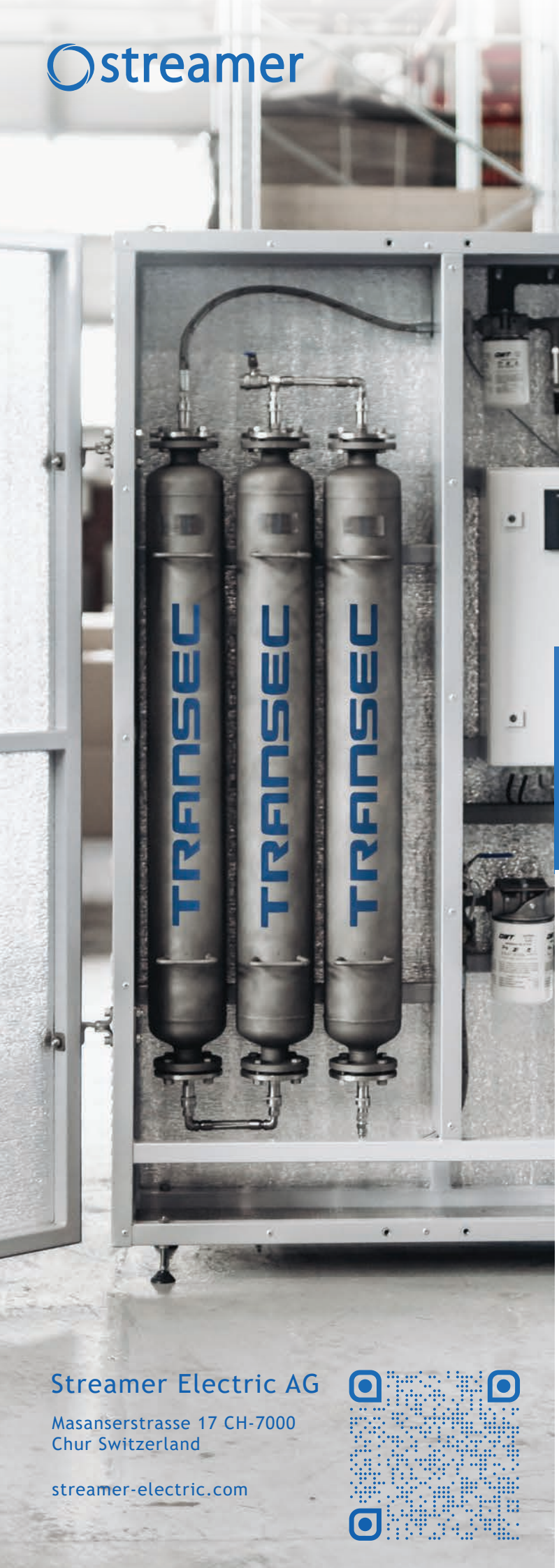
and strengthen your presence
in the transformer market.

Contact
transformer-technology.com

TRANSFORMER TECHNOLOGY MAG

streamer

TRANSEC



Online Moisture monitoring and drying solutions for oil insulated transformers

- Continuous monitoring of the temperature and of the moisture dissolved in the oil entering and exiting the TRANSEC unit
- Increases life expectancy of transformers by drying the insulation
- Maintain a safe and high breakdown voltage in oil
- Online installation and operation – no shutdown
- Cost effective solution – 24/7 continuous drying and monitoring
- No operator required. Stand alone unit LV powered

Streamer Electric AG

Masanserstrasse 17 CH-7000
Chur Switzerland

streamer-electric.com

Impressum

TRANSFORMER TECHNOLOGY MAG

Editor in Chief
Alan M. Ross, CRL, CMRP

Associate Editor in Chief
Corné Dames
Independent transformer consultant

Contributing Editors
Diego Robalino, PhD, PMP
IEEE Senior Member
Jon Trout, PE
Electric utility
Alan Sbravati, ME, MBA
Transformer insulating materials
Marco Tozzi, PhD
Diagnostics and asset monitoring
Curtus Duff
Power transformer design

Chair of the Technical Advisory Board
Corné Dames
Independent transformer consultant

Technical Advisory Board Member
Edward Casserly, PhD
Senior Scientist, Transformer oils
Maria Lamorey
Industrial OEM manufacturing

Graphic design
BE Koncept Communication Boutique

Photo Cover
Shutterstock

Sales & Marketing
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

Editors

Editor in Chief
Alan M. Ross CRL, CMRP
Transformer maintenance and reliability
26 years industry experience

Associate Editor in Chief and Chair of the Technical Advisory Board
Corné Dames
Independent transformer consultant
Transformer oils
20+ years industry experience

Contributing Editor
Diego Robalino PhD, PMP
IEEE Senior Member
Transformer condition assessment and diagnostics
20+ years industry experience

Technical Advisory Board Member
Edward Casserly, PhD
Senior Scientist, Transformer oils
35 years industry experience

Technical Advisory Board Member
Maria Lamorey
Industrial OEM manufacturing
35 years industry experience

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

DIGITAL Membership
Free

Transformer Technology magazine is a quarterly magazine published by APC MEDIA LLC, 11210 West Rd, Roswell, GA 30075, 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.

Copyright and reprint permission
Abstracting is permitted with credit to the source. Libraries are permitted to photocopy isolated pages for private use of their patrons.
For other copying, reprint or republication permission requests should be addressed to info@transformer-technology.com

Publisher:
APC MEDIA LLC
1317 Winding River Trail
Woodstock GA 30075, USA

transformer-technology.com

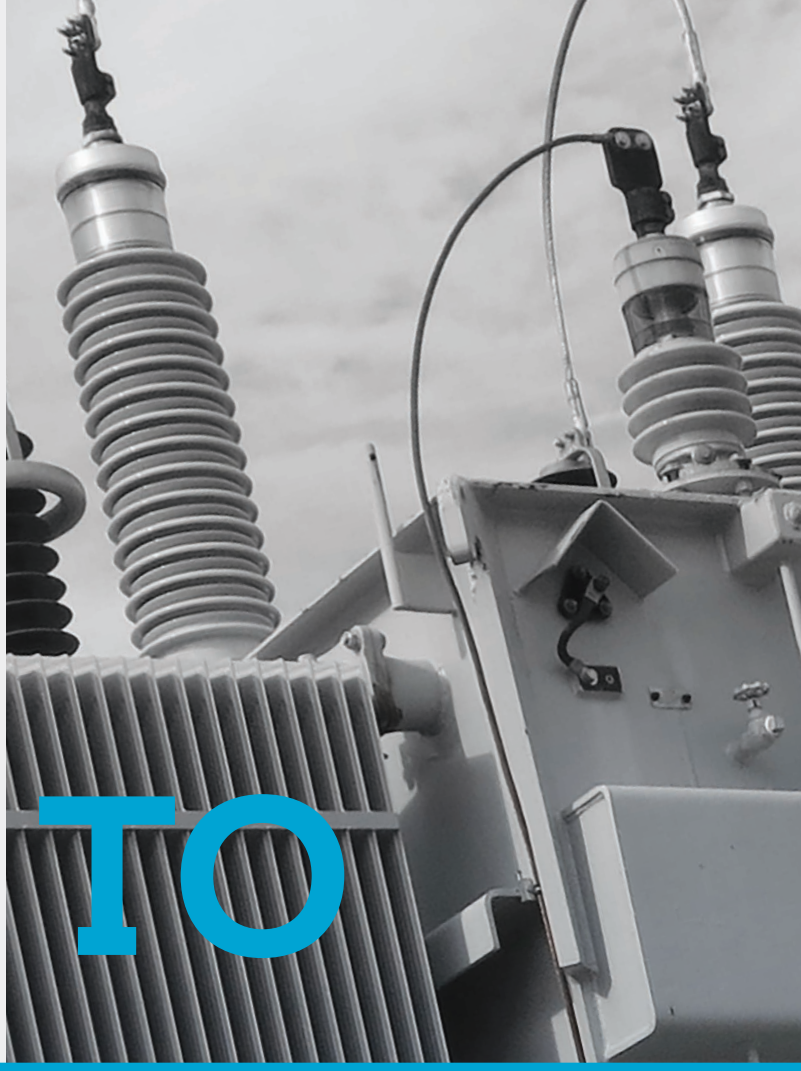
Contributing Editor
Jon Trout PE
Electric utility
14 years of experience

Contributing Editor
Alan Sbravati ME, MBA
Transformer insulating materials
18 years of experience

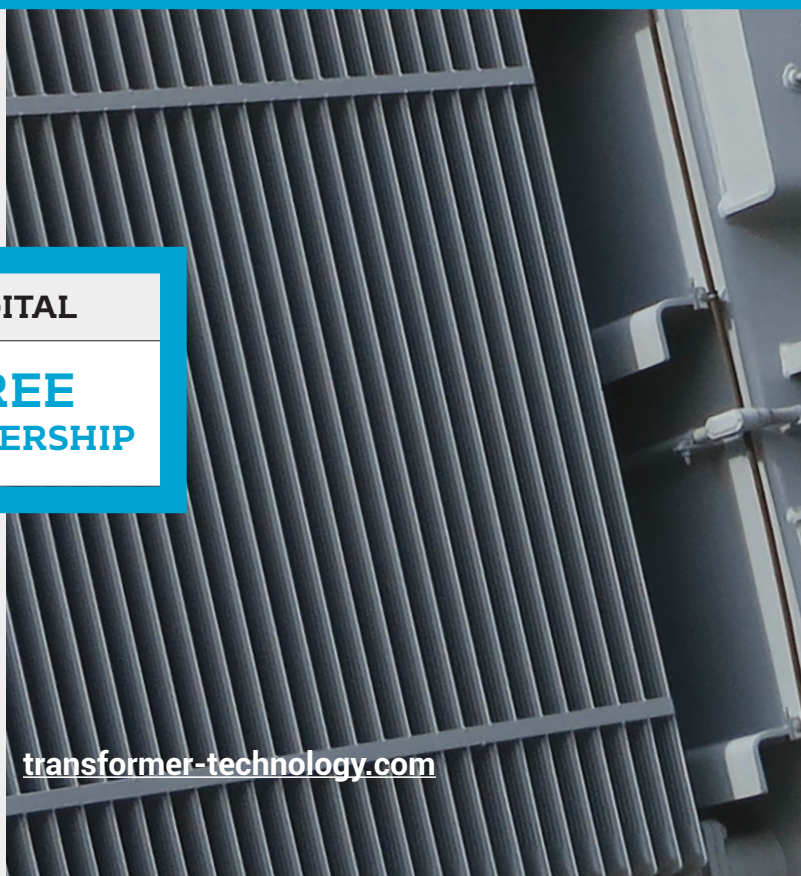
Contributing Editor
Marco Tozzi ME, MBA
Diagnostics and asset monitoring
15+ years of experience

Contributing Editor
Curtus Duff
Power transformer design
4 years of experience

SUBSCRIBE TO



TRANSFORMER TECHNOLOGY COMM



DIGITAL

FREE MEMBERSHIP

To subscribe visit transformer-technology.com

See Through

For the first time you can see continuous, real-time thermal data from inside the core and windings of your energized device.

Maximize Capacity

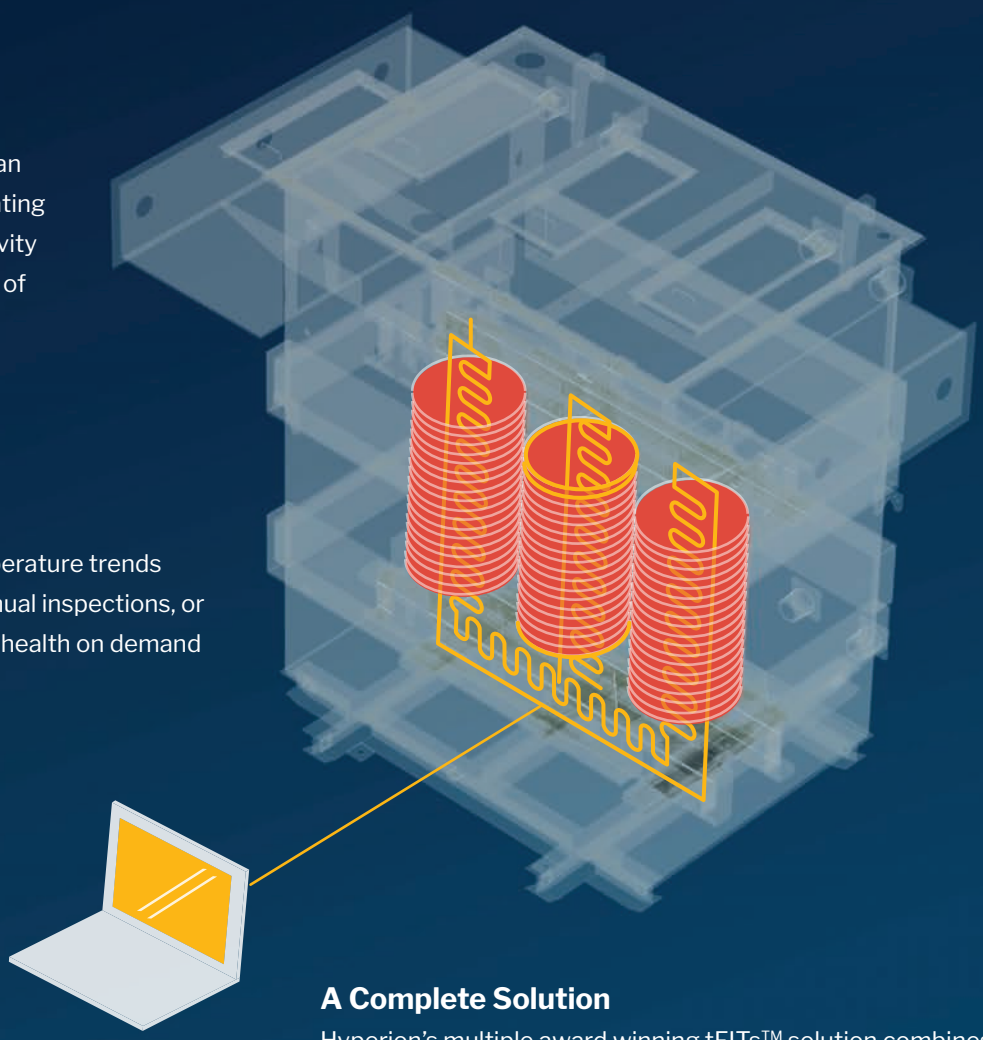
Complete thermal visibility means you can safely increase loads and optimize operating capacity. This means increased productivity and ROI by maximizing the performance of legacy assets.

Anticipate Vulnerability

Detect hotspots, fault damage and temperature trends 24/7, in real time. No need to rely on manual inspections, or periodic oil sampling to determine asset health on demand

Manage Assets Proactively

Full sensing coverage of windings, core and oil ensures greater operational certainty and prevention of unplanned failures. Operational maintenance is now truly proactive, not reactive.



A True Digital Twin

Real time, comprehensive thermal data from all parts of the asset means you have a true digital twin of the asset. You don't need to rely on assumptions, simulations and extrapolations.

A Complete Solution

Hyperion's multiple award winning tFITs™ solution combines a substation hardened Intelligent Electronic Device (IED) with our advanced optical sensing technology. The IED can be seamlessly integrated with SCADA through DNP. Our cloud-based Helios software suite allows advanced analytics and 3D visualization of the asset from anywhere.

2019 **AEP** ILLUMINATION LAB **WINNER**

OCE SmartStart Award Winner

HYPERION

hyperionsensors.com
info@hyperionsensors.com
1-866-407-4973

Dear Readers,

Is it possible to "**love a bushing**"?

When we decided to create the theme **For the Love of Bushings**, we also wanted to leave room for other external components like gages, monitors, radiators and possibly even LTCs. When Brian Sparling contributed his article on OLTC monitoring, I felt vindicated that there was more to love beyond bushings. But with contributions from Marco Tozzi who, as usual, provides a brilliant addition to our Body of Knowledge (BoK), I realized we are blessed to have so many excellent authors and interviewees - professionals who share their knowledge in truly unselfish ways, that it is almost impossible to pick just one theme, even though we love bushings.

The contribution from Lance Lewand shows once again that Doble has tremendous expertise that they share freely with our community, adding to our ever-growing BoK. The contribution from Francis Fisher and Tom Prevost of Weidmann in their interview, which is also featured in video format, is a fun, informative and important glimpse into the future. The article from Tim McLean, while not "loving bushings", provides a preview of our Green Energy focus coming in 2022, with his article on Wind Farms. Paul Pilliterri has a unique perspective of power transformers, also previewing things to come in 2022. This is just a sample of our "Bushings and Beyond" issue. Might that have made a better theme? Well, there's always 2022.

There is another interview, the one with Randy Williams of NASS, that was also created in video format, which captures the essence of who Randy is as he shares his new role and his continuing passion for everything bushings and, now, beyond. All our interviews are unique, in that I believe we capture not only technical knowledge, but also the personality of the professional. We connect, and by connecting, we add value to our community. It is not easy for my guests to do these video interviews because I often go off topic and have been known to get as interested in the person as much as I am interested in the topic. You will enjoy watching as much as you enjoy reading, so make sure to stay in the loop with our community activities and visit the Transformer Technology website to take in some great video interviews.

Being responsible for all editorial content of APC Media is a humbling experience because I realize how futile it would be without our contributors and our sponsors. They are the lifeblood of APC Media, and you, our loyal community members, are why we do it and what continues to drive us. It's what we are passionate about, serving our communities with excellence.

Coming in December: Oils & Fluids

Every year, the issue that seems to draw as much interest as any other theme is the Oils & Fluids issue. Again, this year, we believe we have assembled some tremendous contributions from industry leaders and practitioners, who cover the gambit of fluids, share practical testing and data management knowledge, and compare the next generation of fluids.

At APC Media we have set a standard for not only great content, but for the way that content is presented, with maximum color, sharp and high-quality photos, charts and graphs that enhance the content, making every article and every interview a pleasure to read. I must thank our team for their tireless efforts and hard work to maintain that standard, as we bring all this great content to life.

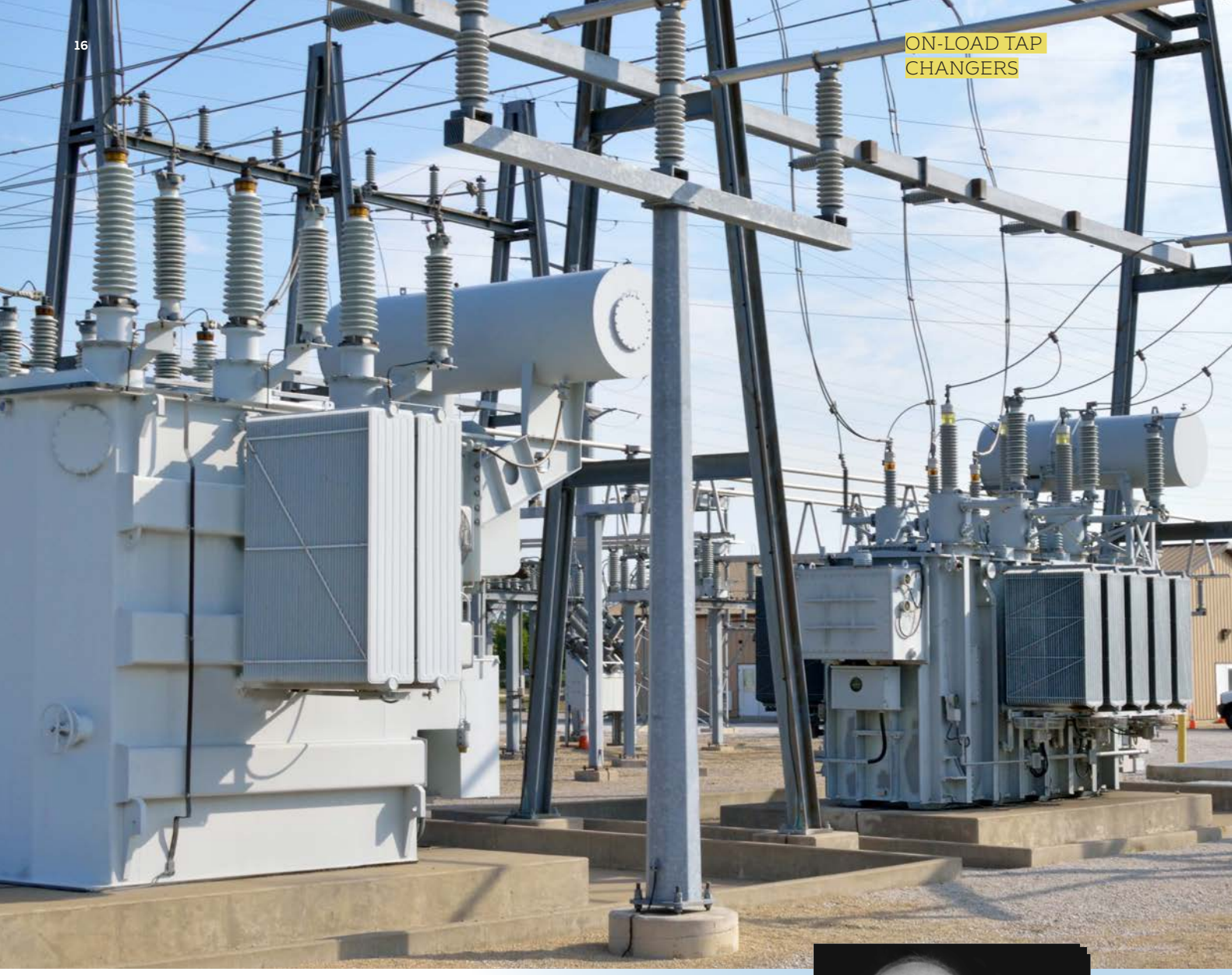
Planning for 2022

Over the next few weeks, we will finalize our Editorial Calendar for both Transformer Technology and Women in Power Systems, two communities that are growing and that provide a voice for unique and disparate communities. In 2022, we will also create another community, one I am certain will provide a voice for an even broader segment of power systems, which will be our third major contribution to our industry. With that said, we always look for new voices, whether it be for technical articles, webinars or interviews. We will share all the details in our final 2021 issue on Oils & Fluids, so look for it as we expand our communities to give you, our subscribers, a voice.

Being responsible for all editorial content of APC Media is a humbling experience because I realize how futile it would be without our contributors and our sponsors. They are the lifeblood of APC Media, and you, our loyal community members, are why we do it and what continues to drive us. It's what we are passionate about, serving our communities with excellence.

Please take a minute to drop me a line and let me know how we can get better, share a thought or idea, or just let us know how we are doing. On behalf of our entire staff, I want to thank you for trusting us to bring accurate, timely and significant information to you every week.

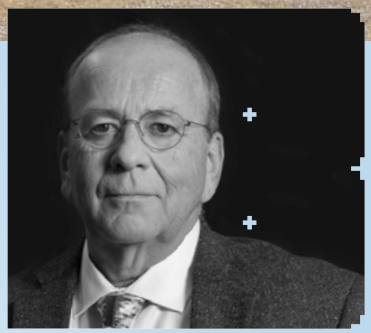
Alan M Ross
CRL, CMRP
Editor in Chief
Transformer Technology
Curator of the Community
President of EPRA



Why Is OLTC Monitoring So Important?

by **Brian Sparling**

Transformers equipped with on-load tap changers (OLTCs) are crucial components in the power system due to their purpose of maintaining the voltage output desired. To maintain these voltages, they are required to perform frequent operations. However, when maintained properly and operated within design limits, these components should provide many years of reliable service.



Brian D. Sparling, a Senior Member of IEEE, is a Senior Technical Advisor with Dynamic Ratings Inc. Brian has over twenty years of experience in the field of power and distribution transformers. For the last 30 years, he has been involved in all aspects of online monitoring and diagnostics and condition assessment of power transformers. Brian has authored and co-authored more than 37 technical papers, including eight columns in Transformers Magazine, and contributed to many guides and standards with the Canadian Electricity Association, IEEE Transformers Committee, and the CIGRÉ A2 Transformer Committee.

Photo: Dynamic Ratings

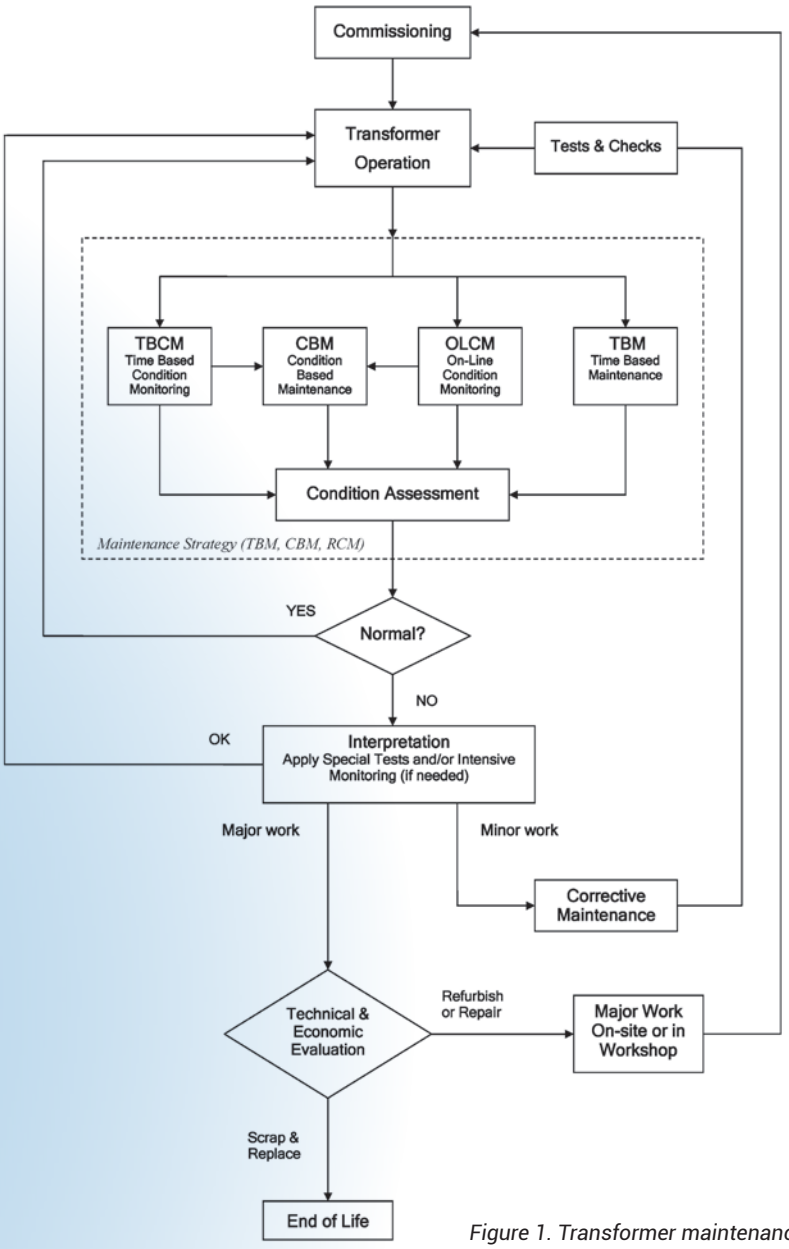


Figure 1. Transformer maintenance strategy [1]

Modern technology, such as vacuum interrupters in the diverter switch, has greatly improved OLTC performance. However, there are still many OLTCs in service today based on older technology which is much more susceptible to significant wear and tear on critical elements. This wear is frequently the cause of misoperation or even unexpected failures when not properly maintained.

This article will document some of these failure modes and steps that can be taken to detect the symptoms of failure before an undesired outcome occurs.

The suggested overall maintenance strategy is illustrated in Figure 1 [1].

There are several methods used to determine whether the equipment is operating normally. They include time-based maintenance (TBCM), condition-based maintenance (CBM),

Transformers equipped with on-load tap changers (OLTCs) are crucial components in the power system due to their purpose of maintaining the voltage output desired.

Figure 2. External type OLTC

online condition maintenance, and traditional time-based maintenance (TBM or number of operations). These various methods can be employed individually, but in most cases, they are combined for a more thorough analysis of operating condition.

The type of OLTC should influence the plan for inspections and online/out-of-service testing. There are two distinct types of OLTCs: bolt-on or welded-on OLTCs – designed to fit onto the sidewall of a transformer (Figure 2); and in-tank type OLTCs – designed to install inside the tank and suspend from the cover (Figure 3).

Both designs can include arcing in oil type diverter switches using resistors, series reactors or vacuum interrupters. These various components are designed to carry the circulating currents during a tap change.

There are still many OLTCs in service today based on older technology which is much more susceptible to significant wear and tear on critical elements. This wear is frequently the cause of misoperation or even unexpected failures when not properly maintained.

Failure Modes and Diagnostic Methods of Detection

The failure modes of both designs can be the same or segregated, depending on the type of testing or monitoring performed. Some methods are more effective than others. While some failure modes can be detected with sensors and systems, as noted below, others can only be determined with a combination of sensors and laboratory testing (oil, for example). The chart in Figure 4 [1] provides guidance on the most effective technique at detecting these common failure modes.

Figure 3. In-tank type [2]

Some examples of online monitoring techniques include a commonly used monitoring method know as temperature differential, which is most commonly used for externally installed OLTCs. While less common, in tank diverter switches can also be monitored in a similar fashion.

The technique employs the measurement of the oil temperature within the OLTC compartment and the oil temperature in the main tank. As there is little to no heat source inside a normally operating OLTC compartment, the oil temperature of the main tank, due to the heat generated by the core and coil assembly, should always be higher when compared to that of the OLTC compartment. The theory follows that the OLTC oil temperature is ALWAYS lower than the oil temperature of the main tank.

However, when contacts in the OLTC compartment begin to have an issue, they will overheat and contribute to the oil temperature that will exceed

Diagnostic Method	OLTC Type
Vibro-Acoustic (1 & 2)	Vacuum
	Reactor
	Resistor
Motor Energy or Torque (1)	All
Dissolved Gas Analysis (1 & 2)	Vacuum
	Reactor
	Resistor
IR Thermography NOT Possible	In-Tank
IR Thermography (1 & 2)	External Compartment
Dynamic Resistance (2)	All

On-Line Monitoring (1) Problem Detected
Off-Line testing (2) Problem Detected

L - Low
M - Moderate
G - Good
E - Excellent

Problems	Vacuum	Reactor	Resistor	All	External Compartment	In-Tank
Linkage/Gears				G	G G G	
Timing/Sequence	G					E
Controls/Relays				E		
Motor				G		
Brake				E		
Lubrication				E		
Contacts Alignment				G	G G G	
Arcing			M G E		E E E	
Overheating/Coking		G L	M E E		L M L	
Contact Wear	M				E M L	
Transition	E				E E E	

Figure 4. Diagnostic methods for OLTC problems (taken from [1])

Photo: Dynamic Ratings

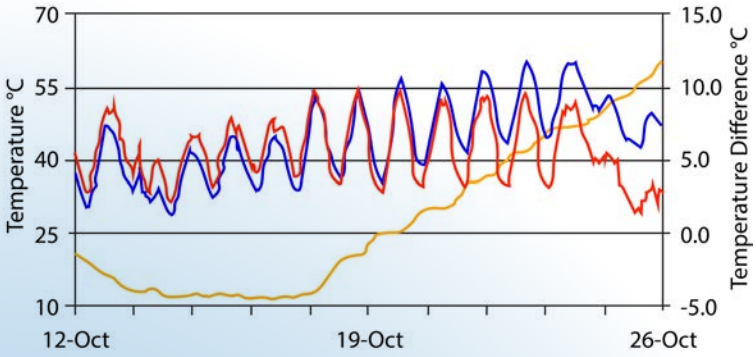


Figure 5. Details of OLTC oil (blue trace) and main tank oil (red trace) temperatures, together with a rolling average differential (yellow trace)

that of the transformer. Therefore, the rolling average difference between the two is normally below "zero". Once it reaches an alarm point (suggested at +10°C differential), the unit requires immediate attention. Figure 5 details an event where the differential (yellow trend) exceeds the zero crossing, and alarms about three days after that event.

As with any alarm, there needs to be some other correlating evidence to provide further confidence in the alarm. One such method, in this case, is IR Thermography. When scanning the equipment, it will become evident to the inspectors that the condition alarmed above is occurring. Figure 6 provides such example.

A further method used to provide evidence to confirm a fault is DGA testing and Duval Triangles developed for certain types of OLTCs (Figure 7).

This method uses the concept of comparing "hot metal" gases with "arcing gases". The area denoted as "N" equates to "consistent values" independent of the number of operations. It is crucial to note that each make and type of OLTC will have a different gassing signature. Therefore, one rule cannot be applied broadly.

IEEE C57.139-2015 – IEEE Guide for Dissolved Gas Analysis in Transformer Load Tap Changers, provides guidance on DGA for OLTCs and should be required reading for those involved in this work.

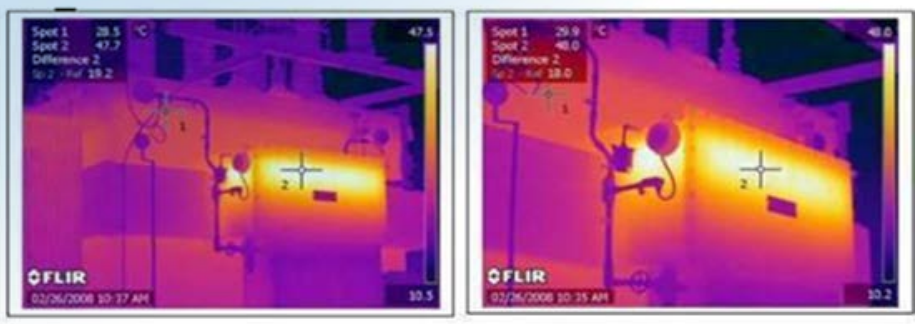


Figure 6. Confirmation of a serious issue inside the OLTC compartment using IR Thermography

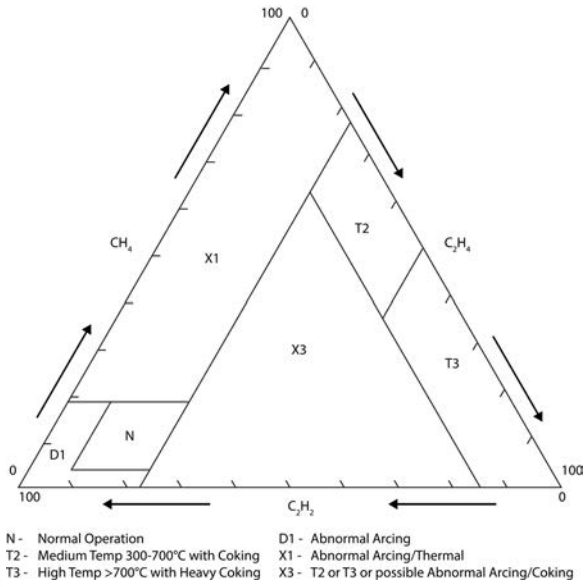


Figure 7. Duval Triangle [1,3]

Monitoring in-tank diverter switches using temperature differential would require RTDs to be installed in the diverter switch cover or fiber optic temperature sensors installed in the diverter switch oil tanks. When monitoring single phase diverter switches, the three diverter switches should be compared to each other as well as to the main tank. If any of the diverter switches varies by more than the programmed threshold, an alarm is set to alert the user that additional investigation should be performed to identify the problem.

Mechanical Defects and Observable Symptoms for Problems

The OLTC is the major mechanical moving device on a transformer. As with any mechanical device, movement equates to wear of components over time and frequency of operation.

There is a mechanical operations counter on every OLTC. It records an event (adding) every time the OLTC operates. It does not record which position it moved from and whether it moved up or down. The tap position indicator on every OLTC is a mechanical device that provides the current tap position and the 'range of movement' the mechanism has operated, which is recorded using resettable drag hands on the indicator.

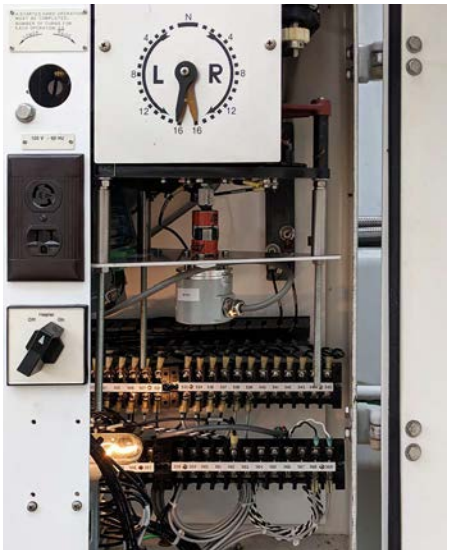


Figure 8. Retrofit of remote OLTC tap position sensor onto existing OLTC motor shaft

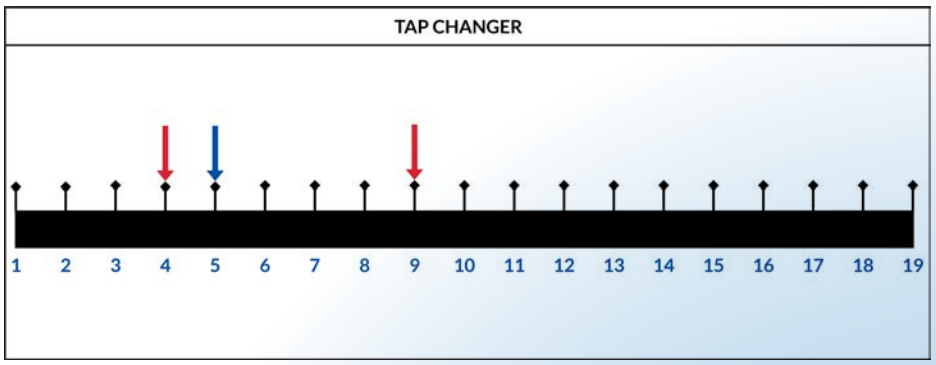


Figure 9. WEB view of OLTC range of motion (red arrows) and current position (blue arrow)

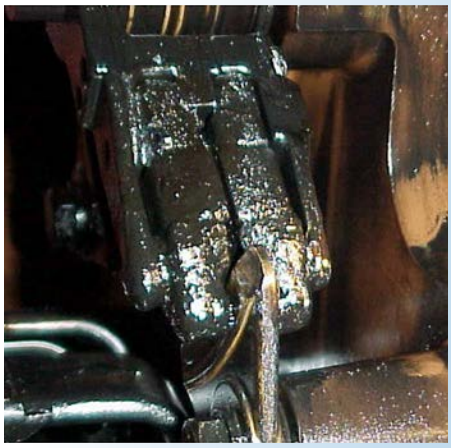


Figure 10. Coking due to excessive heating of a stationary contact

The motor current method is a common way to understand if there are lubrication problems with the mechanism, as shown in Figure 11.

A more refined method is to monitor the total motor energy for any deviation in the joules required to either load the springs of the OLTC or to operate the actual direct drive type of mechanism. Measuring both the voltage at the motor terminals and the current drawn for each motor operation records the trace and

By the relatively simple addition of a remote tap position sensor, a monitor will track and trend the total operations, number of operations at each position, and the I^2T to provide an idea of contact wear. If the monitoring system is also providing control, the tap position sensor may also be used to provide positive feedback to the control system that the tap changer successfully changed taps when the raise or lower command was issued.

It will also monitor and alarm on the frequency of reversing switch operations; the time since it last moved through that position to "wipe the contacts". When this reversing contact remains in a static state for extended periods, it can lead to overheating due to a high resistance film forming on the contact surface. This overheating, if not addressed, will result in an excess buildup of carbon on the reversing contact and eventual "coking", as illustrated in Figure 10, causing the tap changer to become inoperable.

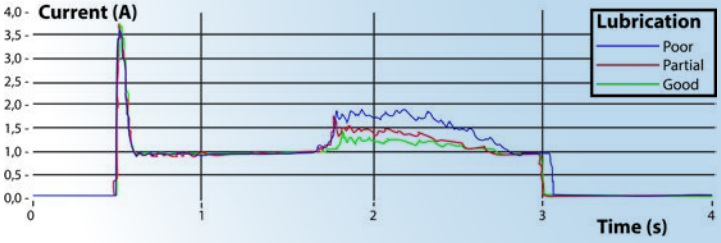


Figure 11. OLTC drive lubrication problem detected by motor current measurement

LTC Motor Energy	
Average Current RMS	5.6 A
Average Power	663 W
Average Voltage	117.8 V
Energy	1020 Joules
Peak Current	10.9 A
Peak Power	918 W
Duration	1.5 seconds

Energy Alarm Thresholds	
High (Neutral Tap)	2500 Joules
Low (Neutral Tap)	500 Joules
High (Other Taps)	2000 Joules
Low (Other Taps)	200 Joules
High Alarm	Off
Low Alarm	Off

Figure 12. Details of total motor energy consumed during a tap change

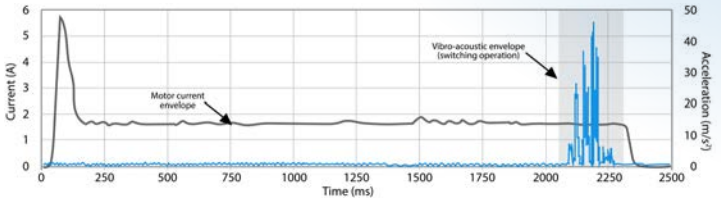


Figure 13. Typical OLTC acoustic signature [5]

Photo: Dynamic Ratings

computes the joules. Any variation in the amount of energy drawn (higher or lower) is an early indication of problems. Figure 12 provides a view of the data.

Vibro-Acoustic Diagnostic Principle

Every operation of any on-load tap changer produces a characteristic acoustic wave pattern that transmits through the oil and structural elements (beams, plates). It has been shown on numerous occasions, in the lab and in the field, that any degradation in the internal condition of the OLTC will produce detectable changes in the acoustic signature. Inversely, a stable OLTC will show consistent signatures [4].

Figure 13 shows typical measurements of motor load current and OLTC vibrations. These measurements make it possible to check various parameters such as operating times, current amplitude, current profile (particularly the inrush current), delays between motor start and switching, and switching time. Detailed analysis of switching vibrations also makes it possible to identify the amplitude and duration of events caused by separating- and closing-switch contacts [4].

Many legacy OLTCs remain in service, and most require frequent inspections/testing, often involving outages which can be difficult to arrange.

Online monitoring of the unique failure modes, which vary as a function of the design of OLTC, has proven to reduce unexpected failures and allowed the transformer owners to move from a time and/or number of operations-based maintenance to a condition-based maintenance program. This identifies the possible defect and allows for planning of the outage with the proper crew, equipment, and spare parts to bring the OLTC back into correct functional operation.

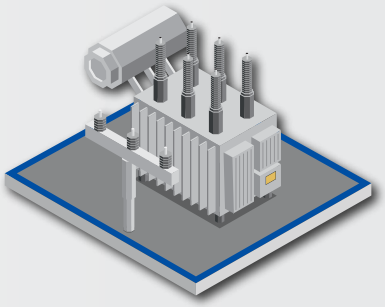
References

[1] Cigre Technical Brochure TB 445, Guide for Transformer Maintenance February 2011
[2] Photograph courtesy of Maschinenfabrik Reinhausen, Germany
[3] ABB Technical Bulletin 1ZSC000498-AAA en, "Dissolved gas analysis in on-load tap-changer oil"
[4] Marc Foata et al., "Field experience with the implementation of a new on-line vibro-acoustic diagnostic for on-load tap changers," Doble Paper 2005
[5] P. Picher et al., "A New technology for monitoring transformer tap-changers and bushings and their integration into a modern IT infrastructure," Paper A2-101, Cigre Conference 2012, Paris, France

DYNAMIC RATINGS

Increase the Reliability of Your Transformers with OLTC Monitoring

According to a recent CIGRE Transformer Reliability Survey,
OLTC has one of the highest failure rates of any transformer component!
If an OLTC fails, a transformer cannot regulate voltage.



Dynamic Ratings provides monitoring, control, and communication solutions to give you visibility into your transformers.

Learn more about our OLTC Monitoring Solutions:

Learn More

www.dynamicratings.com

Randy Williams

Development Manager with
North American Substation Services (NASS)

Interview with **Randy Williams**

Photo: NASS

Randy Williams is Business Development Manager at North American Substation Services (NASS), the largest independent provider of substation services in the USA. His career includes 38 years with ABB where he gained extensive experience with bushings. In this interview, Randy talks to Transformer Technology's Editor in Chief Alan Ross about the history of bushings, current trends and innovations in bushing manufacturing and predictions for the future of this critical transformer component.

Photo: NASS

Alan Ross: I am delighted to talk to a marketing guru, Randy Williams, who spent 38 years with ABB, the last 25 of which he was part of the ABB plant in Alamo, Tennessee.

Randy, you are a bushings expert, and I would like to hear your take on their history, where they are now and where you think they are going.

Bushings are both one of the most important parts of a transformer and one of its weakest links as they age. You have seen all of the problems with the way bushings were made and they are not made the same way that they used to be. If you were to describe the genesis of bushings from the very beginning, what would you say about the role they played and the common elements of manufacturing back when you started working for ABB?

Randy Williams: I was very fortunate to be at the Alamo plant when it was a start-up in 1981. It was primarily put there to build a new bushing technology. Westinghouse made their own bushings and sold them, but they had three

different bushing manufacturing facilities. GE was the leader with probably 60-70% of the market. That is the reason why there have been so many Type U bushings out there over the years. Most of those were mainly oil impregnated bushings, condenser bushings.

A standard bulk-type or stud-type bushing is normally just 15 kV, 25 kV. It is when you get to 25 kV and above that you want to grade the voltage as it is funneled in and out of your transformer or through that wall. The condenser itself hasn't changed much in design,

but the materials have changed from a plain paper or a metal foil used as the gradient to grade the bushing capacitance to a printed ink design. The printed ink design was not similar to GE because it was a herringbone. Westinghouse bought the license from the European company Micafil to do the ink printing type, which actually saved in manufacturing. If you take, for example, a 138 kV bushing which can have 30 sheets of aluminum foil to grade the bushing, and the sheets could wrinkle up or they could have gaps, that was very manufacturing-unfriendly. The printing type, on the other

hand, was done automatically with only one or two sheets, even in a 500 kV bushing of metal foil to get the contact from the ground into the test tap.

That has changed and everybody wants to get away from oil due to the risks to the environment. Porcelain has almost gone away because of manufacturing. Since there is no porcelain manufacturing in the U.S., all the porcelain has come in from overseas and a lot of it is not standard on nonstandard replacement bushings. Also, a porcelain delivery could be up to 26 weeks, so suddenly, time comes into play. Also, everybody wants to avoid leaks - gaskets deteriorate just like they do on a transformer, but nobody thinks about it on a bushing because of age and a permanent set over time.

Everybody wants to get away from oil because of leaks – gaskets deteriorate just like they do on a transformer, but nobody thinks about it on a bushing because of age and a permanent set over time.

Photo: NASS

To get away from oil, manufacturers have gone to resin-impregnated paper or resin-impregnated synthetics. With resin-impregnated paper, the lower end of the bushing was exposed and, since this was a machine lower end, you couldn't store the bushing out in the yard anymore. So, a spare bushing had to be stored in oil, otherwise it would take on moisture. And we know how most utilities store their bushings, if they can find them: somewhere, here, there, everywhere (laughs). So, they tried to solve the moisture ingress into the condenser by going to the synthetics because that material will not take on the moisture and deteriorate the bushing.

The key concern is the longevity of the bushing insulating material in the field.

Condenser design hasn't changed that much. It never caused the problem, there was just oil on the top. Such bushings last 60 years, as long as you maintain them correctly and test them. I know there are 60-year-old condenser bushings in service that have oil in them.

The key concern is the longevity of the insulating material in the field. As porcelain goes away and polymers and other types of insulating materials are introduced, nobody really knows how long they will last, while we know porcelain will last 100 years. That is why utilities have not moved in that direction yet; they may be waiting to see what happens. But many of the new materials used in the upper end on the air side are self-cleaning because of the use of silicone, which reduces maintenance. A porcelain plant is the dirtiest place in the world. If your bushings are in a highly contaminated environment, alternative materials are much better than porcelain.

Manufacturing has changed. Being able to do resin, paper-impregnated or synthetic condenser bushings and then apply some type of silicone insulator at the upper end allows you to make a bushing in two days and not wait 26 weeks for a porcelain. I think that is the direction that bushings are going - alternative materials improve the lead time of manufacturing.

AR Are there any differences in the silicone materials being used in HV bushing insulators?

RW That is a great question, Alan. There are three types being used: RTV (Room Temperature Vulcanized), which is a low grade material used in smaller insulators; and for HV insulators there are two premium materials - LSR (Liquid Silicone Rubber) and HTV (High Temperature Vulcanized), with the main difference between the two being that LSR is molded during the manufacturing process and HTV is an extruded method allowing for better flexibility for fit and better performance due to the tear drop shape at the end of the shed.

AR You previously said something really interesting as well - the basic use of the bushing hasn't changed. When you think about transformers, they haven't changed very much. One of the things that is changing is that we have become an inverter-based system instead of the traditional step-down system. Do you think this new "step-everywhere" system is going to change how bushings operate?

RW I believe there have been a few papers focused on that in the industry, especially in renewables, about different utilities that had events because of those concerns.

AR Yes, we see that it is going to create change. FERC Order No. 2222 just came out, which basically said to utilities that if somebody creates power, they need to figure out

how to get it in the grid, irrespective of finances. It is going to create a lot of changes in all of the components, especially when it comes to transformers used for gas and wind farms.

I would like to ask you one last thing concerning bushings. When you look at a transformer and see three porcelain bushings - two of them clean and cream-colored and one as brown as it could possibly be, and not brown from dirt - the brown color can be an indicator of overheating. And when that happens, you have to replace that bushing. One of the things you just mentioned was lead time. When you would get a call from a utility, giving you the specs and saying they needed that one bushing for the Westinghouse transformer made in 1976 - how would you address that?

RW The number one problem is that when somebody wants a replacement, especially these days, they usually don't have the people who can modify something on the transformer or even braze on connectors for the draw lead; they lack expertise in the field. So, what they need is a one-for-one fit. I didn't try to sell and get that business when I was with ABB, even though I believe we had 70% market share, especially on the replacement side for GE or Westinghouse.

Some bushings have a lead time of 26 weeks, so I would always recommend utilities to get spares for critical transformers.

What I did was sit down and ask questions - and it was a lot of work. I would sit down with the utility people and they gave me the list of their transformers. I would then put together a list so that we consolidate all of the bushings for critical transformers they had on their system. Sometimes it could be five hundred transformers. I would get all the data and put it in an Excel file. Then I would grade those bushings myself and determine - by design or by style - which are the high players, which ones may need to be tested more often, and which are good to go and can be tested normally. I would compile that list and then show which bushings are long lead time - 26 weeks. For the common ones, the lead time is two days from a manufacturing company. I would try to get the utility to buy spares for the critical transformers, so they don't have to wait 26 weeks for a new one.

I did that with most of the large utilities in the United States and they used that Excel spreadsheet to look at their minimum and maximum spare parting for critical bushings and which ones were off the shelf.

AR Randy, your reputation in the industry is that of diligence. You created the system that people talk about. That is a brilliant way to do it, and I hope people are still doing that today. Part of a great reliability program is a great spares program. The best way to keep yourself from having shutdowns is to do an analysis of critical components, not just assets, and then determine what your spares program should be.

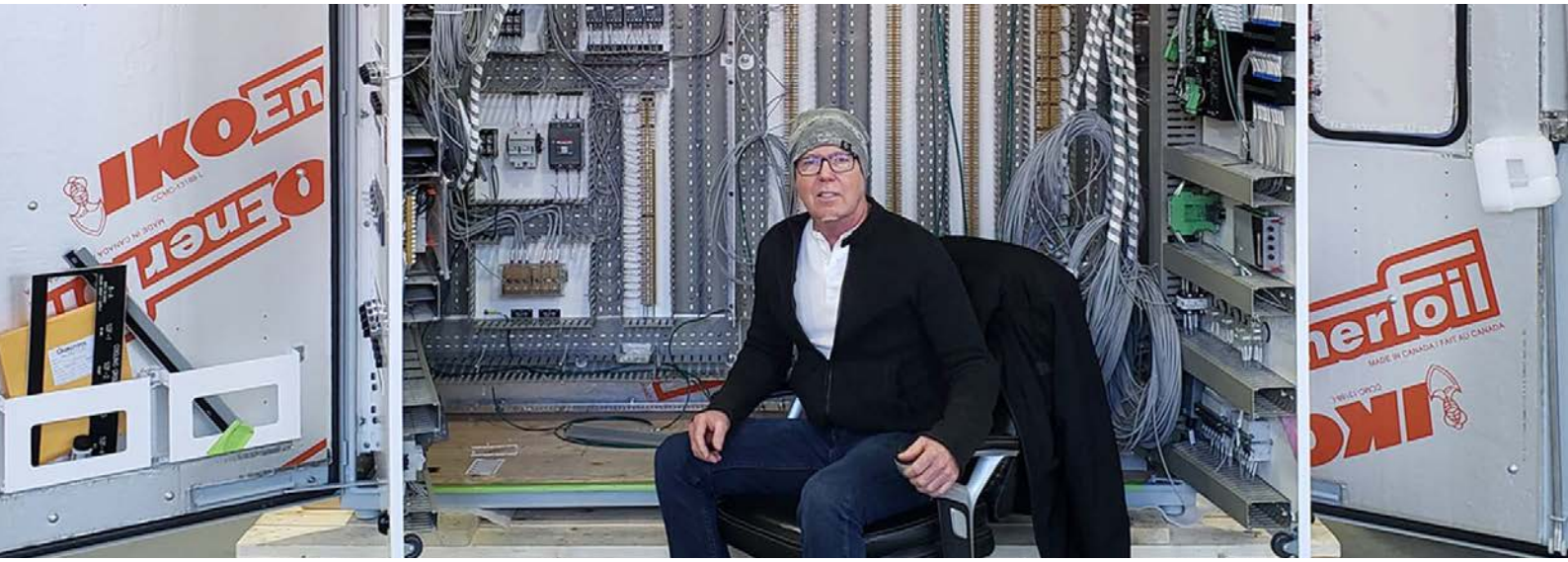


Photo: NASS

Randy, thank you so much for sharing your knowledge with our Transformer Technology community.

RW Thank you, Alan.
Always a pleasure.

NORTH AMERICAN SUBSTATION SERVICES

The Most Comprehensive Substation Services Offered to the Electrical Industry.

Generation, Transmission, Distribution, Renewables

Union and Non-Union ***Service Options***

- **Transformers** – Installation, Testing, Maintenance, Diagnostics, Repair, Life Extension
- **HV Breakers** – Installation, Testing, Maintenance, Diagnostics, Repair, Life Extensions
- **LTCs** – Testing, Maintenance, Diagnostics, Repair, Life Extensions, Retrofits
- **Ground Grid Testing**
- **Protection and Control** – Design, Installation, Commissioning, Maintenance, Testing
- **Power Transformer Control Cabinets** – Design, Manufacture, Install, Field Retrofit, Upgrades

The ***Most Responsive*** Substation Team with 400 highly skilled technicians along with owning, maintaining, and operating the largest fleet of equipment within the industry!

Equipment: 46 oil processing rigs - 10 SF6 Dilo Carts - 40 Doble Test Sets - 36 Sweep Frequency Response Analysis (SFRA) Test Sets - 20+ cranes - Mobile battery bank trailer—capable of providing 440 Ah for full discharge testing and battery replacement or testing

Investing in your ***Employee Training*** will save you time, money, and will create a ***Safer Work Environment***

The NASS Academy is our industry-leading classroom, practical, and field-based safety and services training that will prepare your employees across a variety of substation equipment, apparatuses, and situations. We specialize in developing and customizing training curriculum to meet specific protocols and procedures including:

- Substation Safety
- Protection and Control
- Protective Relay Testing
- Human Performance Toolkit
- Substation Apparatus Maintenance and Testing
  - Transformers, Breakers, and LTCs

NASS and **NOMOS** have all ***Solutions*** for your **Power Transformer Control Cabinet Issues**

NOMOS

NOMOS is the Premier Supplier of **Power Transformer Control Cabinets** for New OEM applications or Retrofits in the field.

Let NOMOS Engineer, Design, and **Standardize** your control cabinets to the **IEEE Standards** and **Specific** to your Utility or Industrial **Requirements**.

Safety by Design to Improve Human Performance with a common layout and components so that we can ***proactively prevent unwanted outcomes due to human error.***

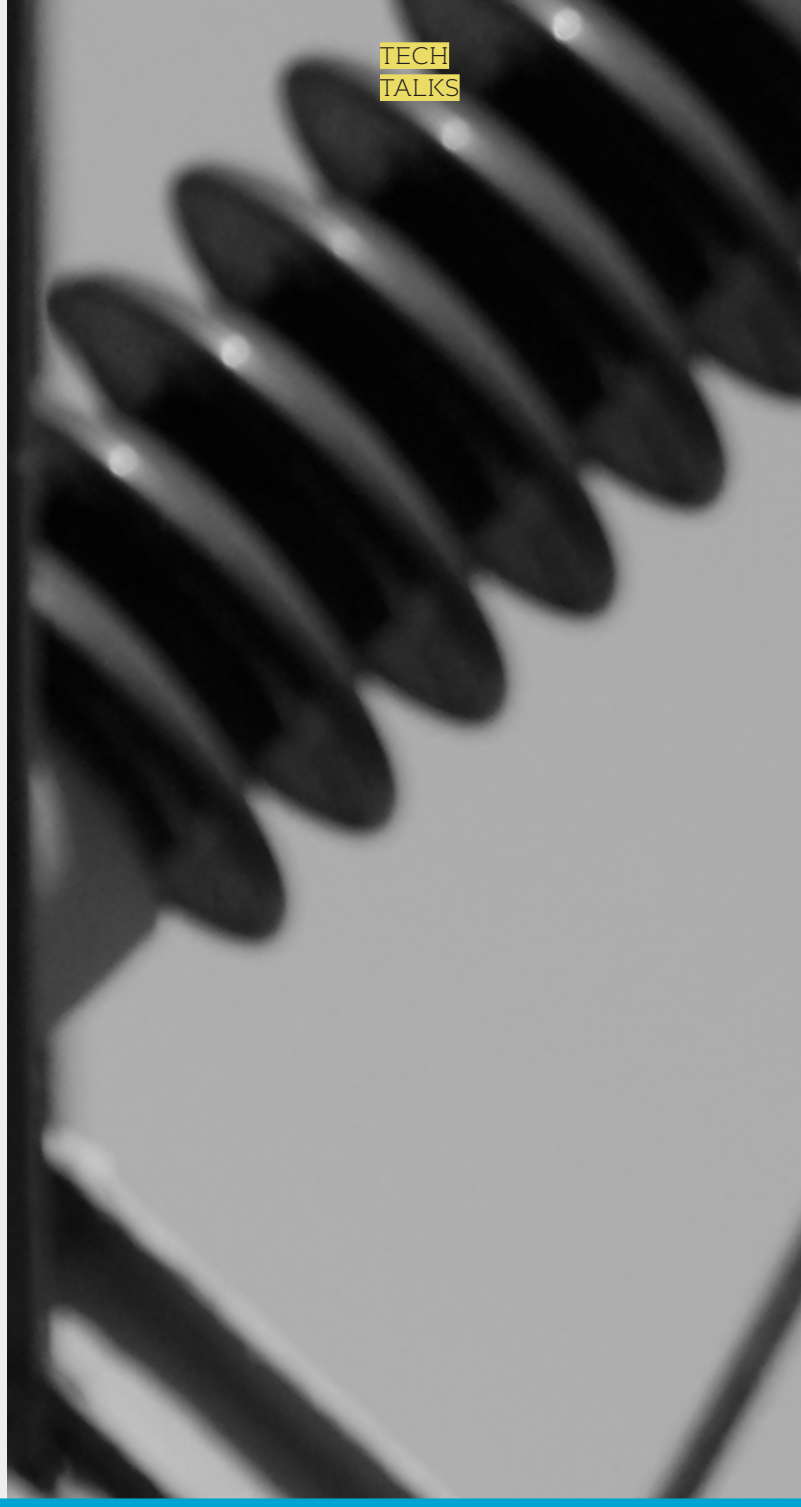
www.nassusa.com
Phone: 731-394-1300

YOUR PASSION AND KNOWLEDGE ARE IMPORTANT TO US

JOIN OUR

#COLLABORATIVE COMMUNITY

Are you passionate and knowledgeable about your area of business or expertise? Now You can contribute to knowledge sharing in the transformer industry by sharing your field experiences, case studies, research results, or simply your knowledgeable opinion on a topic of interest to the industry.



TRANSFORMER TECHNOLOGY COMM

Contact us at
info@transformer-technology.com

to find out how you can become part of the Transformer Technology community.

Tech Talks

TRANSFORMER TECHNOLOGY COMM

To watch and listen visit
www.transformer-technology.com/community-hub/tech-talks

camlin energy

TOTUS is the ONLY Transformer Monitor that can separate PD in the Bushings from PD in the Main Tank.

The benefits of monitoring PD in Bushings with TOTUS

Early detection of PD can significantly improve risk diagnosis, driving quick and accurate decision making. Analyzing the PD Pattern and correlating it with other parameters makes it possible to understand the nature of the defect and determine the best technical actions.

Why monitor PD?

In over 70% of cases monitored by Camlin PD was a factor, often in early stages.

Camlin bushing monitor including PD can identify:

- ✓ Capacitance short circuits
- ✓ Arcing
- ✓ Defects in the C2
- ✓ Internal contamination
- ✓ Surface tracking
- ✓ Internal cavities in RIP insulation

Online PD monitoring can:

- Detect anomalies at EARLY stage of degradation, in particular on RIP bushings
- Detect failures not easily detectable with standard tests
- Correlated PD with Leakage current to determine failure mode and indicate appropriate offline test

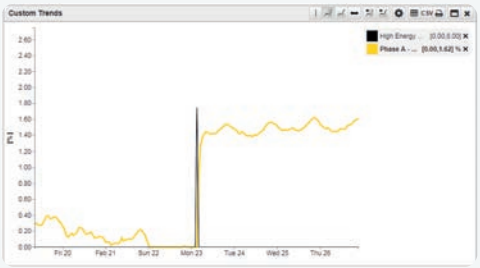
Data

1. Simultaneous Data collection

- Online Leakage Current
- Online Load
- Online Partial Discharges
- Online Arcing
- Online Temperature

2. Data Correlation and Information

A high energy Partial Discharge has occurred at the exact same instant of leakage current step increase in phase A



3. Application of Knowledge

In case of a short circuit between internal layers the current detected at the bushing can increase and partial discharges or arcing events could occur during the breakdown

4. Prescriptive Action

Due to the small change in the leakage current the capacitance test could be challenging: it is suggested to take an oil sample and test DGA.

OFFLINE DGA results for Phase A and C bushings		
	Phase A	Phase C
H_2	17	28
CH_4	40	39
C_2H_2	76	0
C_2H_4	44	1
C_2H_6	32	62
CO	71	53
CO_2	564	789
N_2	150.862	156.665
O_2	10.280	4.337

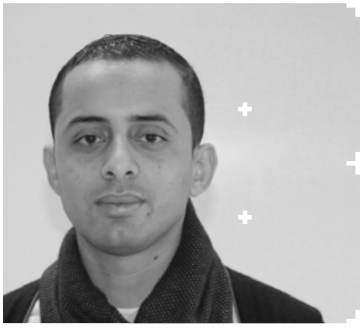
Decision

Acetylene >70 ppm confirms arcing activity detected by online monitor -> Replace bushing

New advancements in fluid-based insulation and more sustainable bushing technology for the green revolution

by **Stefano Iacono**
Esseddik Ferdjallah
Arturo Del Rio
and **Nathan Lange**

Stefano Iacono is an electrical engineer who graduated from Politecnico di Milano in Italy in 2011. He started his career as R&D engineer working on the design of HV bushings and he has been with Trench Italy, a Siemens Energy subsidiary, since 2016 as a product manager for the bushing product line.



Esseddik Ferdjallah is an electrical engineer who graduated from Ecole Polytechnique d'Alger in Algeria in 2012. He obtained his PhD from Polytech'Nantes in 2015 on the monitoring of insulation system for hydrogenators. He has been with Trench France, a Siemens Energy subsidiary, since 2016 as an R&D engineer working on the development of new insulation technologies, topics related to monitoring, as a technical advisor for the service department, and as a technical manager in high-voltage laboratories.

Arturo del Rio holds a bachelor's degree in electrical engineering from the Universidad Industrial de Santander, Colombia, and a MASc degree in the field of power devices and systems from the University of Toronto, Canada. He has been an IEEE member since 1988 and is a registered Professional Engineer in Ontario, Canada, since 1993. He is presently an IEEE PES Transformer Committee member, actively participating in the development of IEEE industry standards. He joined Trench Canada in 1991 where he held various design and engineering positions in the areas of instrument transformers, power electronics, HV transformer bushings and air-core reactors. In 2018 he joined Siemens Energy Inc. in Raleigh, NC where his function is product management manager for transformer bushings.

Nathan Lange holds a bachelor's degree with honors in electrical engineering from Western Sydney University, Australia, and has been an IEEE member since 2007. He started his professional career with Siemens Australia in 2010 focused on transmission products before transferring to the USA in 2015 to support HV bushings. Now under Siemens Energy, Nathan is responsible for business development of the transformer bushings portfolio throughout the IEEE market.

Photo: Siemens Energy

Introduction

The recent energy transition targets are highly motivated by environmental reasons. Such targets create new technical challenges due to operation modes of power installations, as well as cyclical conditions of renewable energy and the overloading necessary to ensure continuous supply of energy if required.

In fact, the cycling nature of renewable energies due to sun cycles, ocean tides or wind variations produces a cyclical thermal stress on the bushing insulation. As a result, connected to some operating conditions, in conventional OIP bushings this may lead to gas bubble generation, causing partial discharges and electrical failure if present in a critical area.

Apart from environmental advantages, development of ester based insulating technologies in high voltage equipment is additionally motivated by enhanced safety and overload capabilities. This article explains in more detail the advantages leading to the development of the capacitive ester-impregnated transformer bushing, an innovative solution that not only helps achieve substation decarbonization but also increases the performance of high-voltage equipment.

Capacitive ester-impregnated transformer bushing is an innovative solution that not only helps achieve substation decarbonization but also increases the performance of high-voltage equipment.

Unique OIP bushing design with bellows

One specific issue connected to the conventional design of OIP bushings with gas cushion in the top housing, for compensating the oil expansion due to thermal changes, is the gas bubbling effect.

In order to withstand the different environmental and operating conditions the product will be subjected to, the bellows are made of stainless steel, which guarantees the maximum reliability during the bushing life.

Figure 2. Stainless steel bellows assembly

Experimental observation has demonstrated the onset of internal partial discharges due to the formation of gas bubbles within the bushing oil. When oil and gas, such as air or nitrogen, is confined in a fixed volume space like a bushing, pressure equilibrium is reached over time at any given temperature. If the temperature changes, the volume of the oil changes and the gas space changes accordingly.

When this occurs, three variables come into play:

- First, the gas pressure changes with volume change.
- Second, the gas pressure changes with the gas temperature.
- Third, the ability of the oil to absorb gas varies with temperature.

As a result, with constant fluctuations in temperature there is a continuous change in the amount of gas dissolved in the oil. If the temperature rapidly decreases after being high for some time, the gas cannot escape quickly enough to avoid the formation of bubbles in the oil. Isolated examples of this can occur during transformer factory testing [1] or when the equipment operates under severe cyclic loading combined with rapid cooling [2]. More recently this phenomenon has been identified with applications such as solar and wind energy generation. This phenomenon can occur in any liquid insulated bushing; its occurrence is linked to many variables related not only to the bushing design, but also to operation and environmental conditions.

To provide an ultimate solution to this industry-wide issue, the complete

Figure 1. Detail of bellows assembled inside the bushing head

bushing portfolio with physical separation between oil and gas inside the bushing, was released into the IEEE market in 2018.

In order to withstand the different environmental and operating conditions the product will be subjected to, the bellows are made of stainless steel, which guarantees the maximum reliability during the bushing life.

The stainless-steel bellows contract and expand within the expansion chamber, eliminating the generation of gas bubbles within the oil, without causing overpressure or low pressure inside the bushing.

OIP design with bellows: Qualification tests

The new portfolio is fully type tested according to IEEE C57.19.00-2004 and C57.19.01-2017.

In addition, to provide the proof of design safety margins and long-term reliability in service, the full series is tested with stringent requirements: the tests are performed at the highest electric values between IEEE and IEC International Standards. Table 1 indicates some examples of the selected ratings for the design and tests.

An intense test plan was necessary to validate the product with unique feature of physical separation between oil and gas. Beside the complete type tests required by IEEE standard, performed on each product type, our R&D experts planned intense qualification tests, including:

Mechanical withstand test for bellows (>10.000 full cycles)

The scope of this test is to validate that the bellows can withstand a high number of cycles during their whole lifetime. Each bellow design is tested to check its ability to withstand one full cycle per day for 30 years, which is much more than the real mechanical stress that the bellow will see on site.

The test is performed by immersing the test object into oil which is put under pressure/vacuum, so that the bellow is contracted and expanded on its full stroke for each cycle.

Photo: Siemens Energy

The new portfolio is fully type tested according to IEEE C57.19.00-2004 and C57.19.01-2017.

An intense test plan was necessary to validate the product that has a unique feature of physical separation between oil and gas.

Figure 3. Mechanical test on the bellow

Standard	Nominal voltage [kV]	L-G[1] voltage [kV]	BIL[2] [kV]	PFW[3] [kV]
IEC	**145**	84	**650**	305
IEEE	138	**102**	**650**	**310**
IEC	**245**	141	**1050**	**505**
IEEE	230	**146**	900	425
IEC	**362**	209	**1175**	**560**
IEEE	345	**220**	**1175**	520
IEC	**550**	**318**	**1675**	**750**
IEEE	500	**318**	**1675**	**750**

Table 1. Design and test level values chosen as the higher between IEC and IEEE
1. L-G voltage: line-to-ground voltage; 2. BIL: BIL level; 3. PFW: dry withstand test voltage

Transportation tests as per ASTM D4169-16, including impact hazard and shake table test

Complete bushings are tested to validate that the bellow assembly is properly designed to withstand transport operations, even in case of severe shipping conditions, without being damaged.

The tests have been performed as per ASTM D4169-16 (Standard Practice for Performance Testing of Shipping Containers and Systems) with distribution cycle DC5 (Motor freight, TL, not unitized).

This cycle simulated during the test is equivalent to a road shipping with loading and unloading. The test is performed in two phases:

- A complete bushing stored in its crate is installed on a shake table, with another crate on top of it and the vibration profile corresponding to high level load is applied. Moreover, the test plan also included the simulation of the forklift truck and crane handling, by letting the crate drop to the ground from a given height at different angles.
- The bushing is then tested for leakage (2.5 bar / 36.25 psi for 9 hours)

The tested designs are representative of the complete product range from 25 kV to 230 kV.

Salt spray test

The target of this test is to validate that the selected stainless-steel grade used to manufacture the bellows is not susceptible to corrosion even in the most critical ambient conditions. The salt spray test was performed in very severe conditions: spray exposure of 250 hours on an open bellow without its top cover protection.

After the test, the bellows are cleaned with water and dried at 23°C to identify any rust mark on the inner surfaces of the bellow.

Test duration:	250 h
Location:	CETIM Mulhouse (France)
Test device:	Salt spray enclousure BRAIVE 400 liter (ref CC028 - verified on 18/10/2018)
Salt spray concentration:	5% NaCL
Salt reference batch:	N°17100140
Salt quality:	Cu, Ni, Pb <0.005%
Conductivity:	<20 µs/cm
Aggression:	72 g/m³

Parameters during the test:

Aggression	Required value	Minimum value	Maximum value
Salt solution collected in 24 hours	24 ml - 48 ml	24	26
Concentration (kg/m³)	1029 - 1036	1036	1036
Air pressure (bar)	0.7 - 1.7	6.5	6.56
Chamber temperature (°C)	6.5 - 7.2	1	1
pH	35°C /+-2°	35	35

Salt spray test

Figure 4. 69 kV bushing subjected to temperature cycle test under operating voltage

Temperature cycle tests under operating voltage

To have a test representative of the complete portfolio, the thermal cycles have been performed on two different voltage classes:

- 69 kV prototype: 2 months test
- 230 kV prototype: 3 months test

Variable load and temperature cycles are applied in order to simulate the real conditions present in a solar plant: oil temperature is raised to 90°C (transformer oil temperature in service) during the day and external infrared panels simulate solar radiation. Oil heating and radiators are switched off during the night (oil cooled down to 40°C).

At regular intervals during the test execution, the bushing parameters are analyzed (C1, tanδ, dissolved gas) and the PD measurement is performed to validate that there is no evolution in the internal insulation of the bushing, especially no development of gas bubbles.

The extended OIP design with physical separation between oil and gas in the expansion chamber is a perfect solution to eliminate the gas bubble issue, which can occur in any oil insulated bushing under specific operating conditions. In particular, the proposed design prevents accelerated ageing phenomena when the bushing is subjected to cycling load operation, removes the possible occurrence of problems during transformer factory testing and allows higher flexibility in product handling.

Advantages of ester insulation in HV bushings

Esters are currently very popular among high voltage power transformers manufacturers because of their outstanding advantages in terms of thermal performance and extended overload possibilities, beside the obvious advantages of environmental compatibility and eco-friendliness, providing a

The extended OIP design with physical separation between oil and gas in the expansion chamber is a perfect solution to eliminate the gas bubble issue. The proposed design prevents accelerated ageing when the bushing is subjected to cycling load operation, removes possible occurrence of problems during transformer factory testing and allows higher flexibility in product handling.

Photo: Siemens Energy

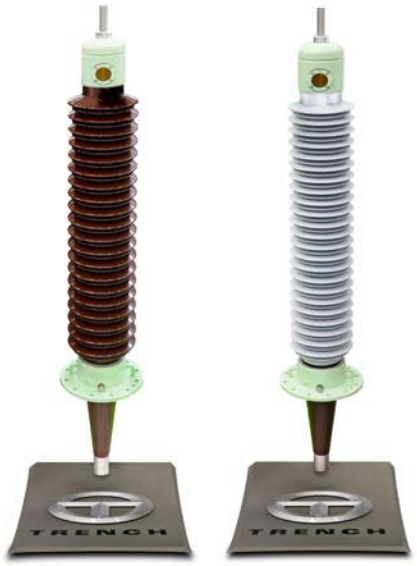


Figure 5. First capacitive ester-impregnated transformer bushing

Combining monitoring options with high thermal performance of synthetic ester allows ester-impregnated bushings to meet the technical requirements of high-voltage transformers, enabling customers to mitigate the risks when operating in overload conditions for longer periods than those allowed by international standards.

The first high-voltage bushing insulated with biodegradable ester fluid has been introduced into the market in 2020.

step further towards substation decarbonization.

Combining the monitoring options with the high thermal performance of synthetic ester allows ester-impregnated bushings to meet the technical requirements of high-voltage transformers. It's therefore possible for customers to mitigate the risks when operating in overload conditions for longer periods than those allowed by international standards.

Motivated by feedback from site investigations and from discussions with customers who are continuously looking for ways to improve service conditions and minimize costs, the first high-voltage bushing insulated with biodegradable ester fluid has been introduced into the market in 2020 (see Figure 5).

Thermal performance

One of the key advantages of using synthetic ester for bushing application is its enhanced thermal performance compared with mineral oil. The international standards organizations IEEE and IEC agreed that the thermal class of the complex kraft paper/synthetic ester is 120° (Class E) instead of 105° (Class A) for the complex kraft paper/mineral oil (IEC 60076-14 and C57.154-B3). For liquid-filled bushings this is a huge improvement because they are vital components in the power system network. The increased thermal performance of bushings can positively impact the transformer's condition by allowing many options for overload operation. It also offers a greater design margin that can be exploited to improve the thermal performances of transformers.

The capability of bushings to withstand thermal loading varies depending on bushing design, insulation material used, the ambient conditions in which bushings operate and the energy demand. According to IEEE C57.19.00, the hottest-spot temperature of Oil Impregnated Paper (OIP) bushing, operated at rated current, is limited to a 75°C rise over ambient with 30°C ambient temperature – or a 105°C total temperature. This limitation is due to the use of temperature index 105 insulating mix for the bushing condenser. If ambient temperature exceeds 40°C for long time or the transformer in case of long overload develops a top oil rise exceeding 65°C, the normal life expectancy of bushing will be shortened due to accelerated aging of the insulating complex. To overcome this situation, the solution is either to use bushings that have nameplate ratings greater than the transformer current ratings or by using bushings with special high temperature insulation. Ester bushings are developed to offer this possibility.

The calculation of the overload capability of ester bushing portfolio [8] is shown in Table 2. We note a maximum tolerance of 49% additional capability for the 100 kV type, which means that for normal life expectancy (normal aging conditions), the bushing can be operated with 49% additional load while respecting a maximum hottest spot temperature for solid insulation in accordance with IEEE C57.154 given informative data.

	Bushing types					
Rated voltage [kV]	72.5	100	123	145	170	245
Rated current [A]	800	800	800	800	800	800
Overload capability [p.u.]	1.27	1.49	1.27	1.41	1.3	1.3

Table 2. Overload tolerances for ester bushings

One of the key advantages of using synthetic ester for bushing application is its enhanced thermal performance compared with mineral oil.

Increased fire safety

The ester based dielectric insulation offers an excellent fire safety, thanks to his high flashpoint and high firepoint compared to traditional insulation liquids, therefore is the perfect solution in terms of fire risk mitigation. The firepoint and flashpoint of synthetic esters compared with mineral oils are shown in Table 3 [3]. The synthetic ester used in the new bushing portfolio is classified according to IEC 61039 as a Class K3 fluid, which provides the following advantages:

- No fire risk in the event of a major failure
- Low-density non-toxic smoke
- Lower costs for installation and maintenance of fire safety equipment
- Lower associated insurance costs

Moisture tolerance

Another aspect that provides ester bushings with excellent technical performance is the high moisture tolerance of synthetic ester. This means that it maintains its electrical characteristics even when water content is high (see Figure 6) [5]. Its use in ester bushings prevents several known failure modes, including:

- Bubble formation during overloads: according to IEC 60076-14, the temperature for bubble creation is directly related to the moisture content of cellulose. For example, at one percent paper humidity, bubbles will form at 170°C, while at three percent, bubbles will appear at 125°C.
- Condensation: during cycling service conditions (solar energy), water migration between paper and liquid is contained by ester with no effect on electrical performance.
- Hydrolysis: water is one of the degradation products of paper. Unlike mineral oil, the water tolerance of synthetic ester allows for more water to be trapped, which may slow down cellulose aging.
- Oxidation: development of ester bushings included a completely sealed design, so there is no risk of cellulose oxidation.

	Natural ester type 1	Natural ester type 2	Synthetic ester	Mineral oil
Fire safety class	K2	K2	K3	O1
Readily/fully biodegradable	✔	✔	✔	✘
Breakdown voltage kV (regular configuration)	>75	>75	>75	>70
Moisture saturation (ppm) at 20°C	1.1	1.1	2.7	55
Kinematic viscosity at 40°C	32	37	29	8.7
Relative permittivity	3.1	3.1	3.2	2.2
Pour point °C	-18	-31	-56	<-50
Flash point °C	>315	>315	275	150
Fire point °C	>350	>350	316	170
High temperature	Good	Good	Excellent	Poor

Table 3. Basic properties of different insulation fluids

Photo: Siemens Energy

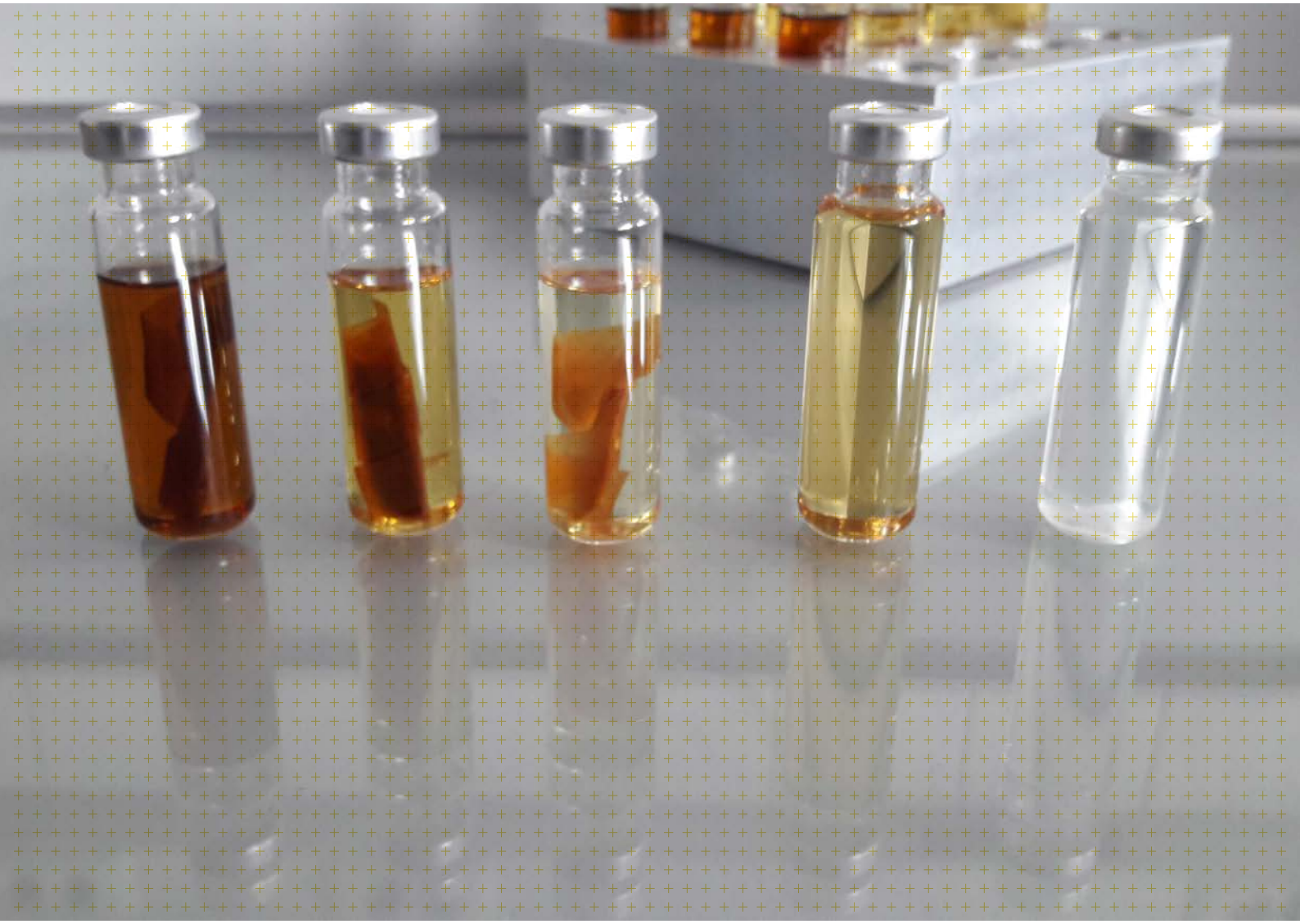


Figure 7. Material compatibility test

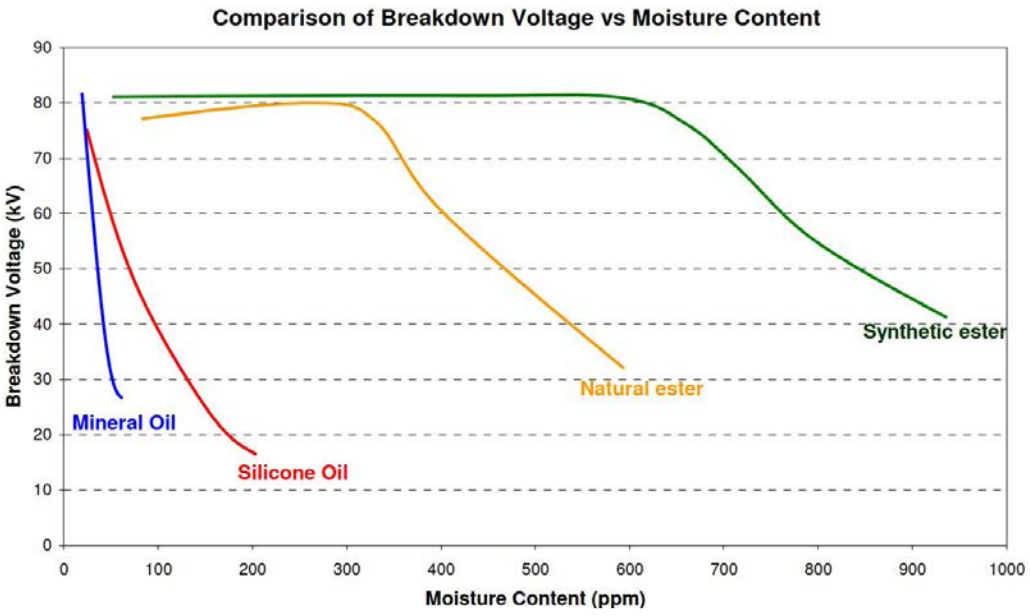


Figure 6. Breakdown voltage dependence on moisture content with common insulating fluids

Online monitoring

Despite being designed according to state-of-the-art guidelines, bushings are subjected to stresses during their operating lives, which reduce their lifetime and in general contribute up to 35% to the power transformer failure rate [10]. As the transformer runaway is a deleterious and unwanted situation, utilities need to know when a bushing is starting to deviate from the standard behavior.

The traditional approach used so far, consisting of regular and periodic offline tests, has proved not to be highly effective, as it provides poor correlation with the present bushing conditions and especially as it often requires unnecessary tests on healthy equipment.

Digitalization is creating a new approach, allowing for a more detailed and refined monitoring strategy, which involves:

- Online measurements: carried out at full stress (making it less difficult to interpret the measurement results)
- Continuous measurements: not performed at regular intervals but starting from the first day of transformer energization onwards. This will allow a full product transparency and identification of early failure modes development
- Automatic data processing and elaboration, through statistical and artificial intelligence models. When switching from offline to online measurements, the measurements that can be done on the transformers get more limited, and the level of data elaboration needs to be more sophisticated. FDS or PDS methods (both offline) are indeed able to provide the direct measurement of the insulation condition while only the bushing leakage currents can be measured online. Getting the insulation status from the leakage currents is a non-standard and complicated task, as this requires high statistical and machine learning capabilities.
- Global and complete measurements: to ease the diagnosis on the entire transformer. Digitalization and data handling from different sources (e.g., bushing, transformer windings, on load tap changer) have opened up a completely new scenario unknown some years ago, where monitoring and data were confined to individual products. Having the possibility to cross-correlate data (and automatically!) can help increase the level of reliability of the diagnosis and improve the diagnostic effectiveness.

Conclusion

OIP bushings with bellows and ester insulated bushings are a solution to many technical challenges of traditional Oil Impregnated Paper (OIP) technology connected to energy transition, both in terms of environmental compatibility and to satisfy the requirements introduced by new operation modes of power installations.

The bushing design with bellows represents an extension of conventional OIP technology to meet the challenges of cyclical loading conditions of renewable energy.

New ester-insulated bushings provide innumerable benefits, not only answering to the growing demand for reliable and sustainable energy generation and transmission, but also providing higher technical performances when compared to OIP technology.

The online monitoring system, which can be a standalone device or integrated within the power transformer to provide a more comprehensive set of information, complements the advantages of the above mentioned solutions to allow the bushing to operate close to the maximum design performance, without compromising its lifetime expectancy.

Photo: Siemens Energy

References

[1] Bubble evolutions in bushings, ABB publication 1ZBC000001C2704, 2011

[2] Parts and Service News for the Power Transformer and Circuit Braker Maintenance Community, March 1998, Special No. 1

[3] Midel selection guide, www.midel.com, accessed on August 14, 2020

[4] F. Bachinger and P. Hamberger, "Measurement of thermal behavior of an ester-filled power transformer at ultra-low temperature," CIGRE 2018, A2-111

[5] "Experiences in service with new insulating liquids," CIGRE 2010, WG A2.35

[6] J. Dai and Z. Wang, "A Comparison of the Impregnation of Cellulose Insulation by Ester and Mineral Oil," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 15, n. 2, 2008, pp. 374-381

[7] M. Lashbrook, A. Gyore, R. Martin, R. Cselko and B. Nemeth, "Creepage Discharge Investigations with Biodegradable Ester-based Liquids and the Implications for Transmission Transformer Design," CIGRE 2018, D1-207

[8] E. Ferdjallah, O. Richer, K. Kaineder and F. Negri, "Improved thermal resistance and overload capability of the new Ester Bushings," 2021 Electrical Insulation Conference (EIC), June 7th – 28th, 2021

[9] E. Ferdjallah, "Ester-impregnated bushings: One step closer to sustainable energy," *Transformer Technology*, Issue 8, October 2020

[10] S. Tenbohlen, "Diagnostik elektrischer Betriebsmittel 2014," 6. ETG-Fachtagung, Nov 25, 2014, Berlin, Germany

SIEMENS energy

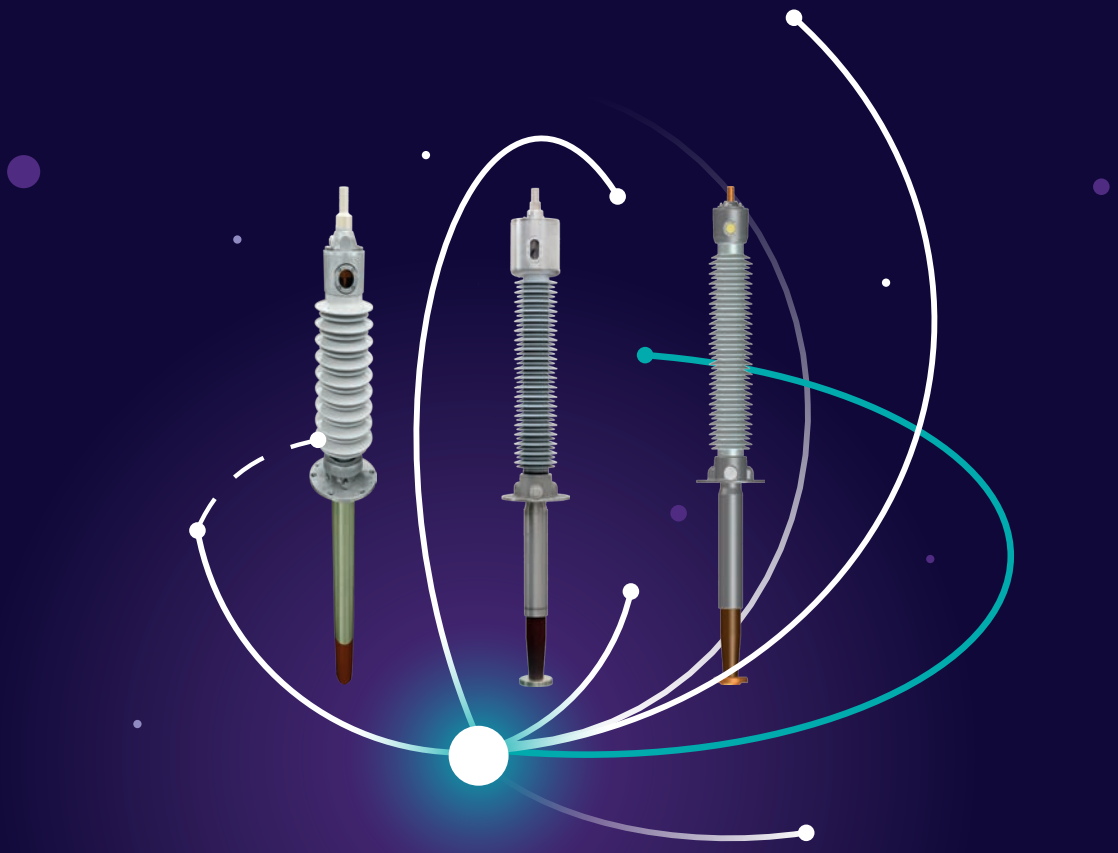
Next generation of IEEE transformer bushings featuring Sensbushing™, a dedicated on-line monitoring system

Our transformer bushing portfolio is designed to satisfy customer requirements in terms of reliability and better performance.

We are committed to continuous innovation. The new bio-degradable synthetic ester insulation is our environmentally friendlier solution contributing to the reduction of CO_2 emissions of our bushings.

STARON & STAROIP*: 25 kV to 500 kV
(*Innovative design: internal oil volume compensation by means of built-in bellows)

Green evolution
120 Thermal Class Ester insulation: coming soon to the IEEE market



siemens-energy.com/bushings

Siemens Energy is a trademark licensed by Siemens AG.

A BETTER ENERGY FUTURE IS A FUTURE OF COLLABORATION

Inspire. Empower. Advocate.

WPS Women in Power Systems

Women in Power Systems (WPS) is a community that advocates for women in all power systems roles, celebrates their successes and helps them achieve a balance between their professional and private life.

Become a Sponsor of Women in Power Systems and bring positive change to your company and the industry.

- Be a though leader
- Benefit from female talent in diverse roles and build a collaborative workforce
- Position your company as a socially aware and desirable employer
- Get promoted through WPS social media campaigns
- Reach over 100,000 industry professionals through WPS Alliance Partners' platforms

Find out more about **WPS Sponsorship opportunities** here.

Check out the **WPS Community Hub** for stories, news and more here.

WPS Alliance Partners

TRANSFORMER TECHNOLOGY COMM · epra · THE ELECTRICITY FORUM · energycentral. · CWIEME GLOBAL

Karina Yonemoto

Karina Yonemoto is a great believer in the power of attitude and leadership based on creativity, sensitivity, and empathy. Karina is a financial controller at the Order Management for Industrial Applications Division (Oil & Gas) of Siemens Energy for Mexico, Central America and the Caribbean. She leads *#EnergíaSinLímites* (Unlimited Energy), the company's program for developing cutting-edge leadership.

Source: **Karina Yonemoto**

Karina studied Economics at the Instituto *Politecnico Nacional* (IPN) and graduated in Finance and Accounting from the *Instituto Tecnologico Aútonomo de México* (ITAM). She started her journey with Siemens in 2011, gaining experience as a trainee and later focusing on finances, particularly planning and reporting. Working in divisions such as Healthcare Diagnostics, she provided critical information to top management for business decision-making and was nominated to participate in Siemens' 5th "Top Challenge" internal program for the development of a project to improve the company performance. In 2018 she was part of the Power Generation Service controlling group with major government and private company projects to supply electricity to Mexico's homes. Since February 2020, Karina has taken over the position of financial controller at Order Management for Industrial Applications Division (Oil & Gas). She is currently leading the *#EnergíaSinLímites* program at Siemens Energy which fosters inclusion and diversity. The program promotes a multidisciplinary environment, driving growth, purpose, and a versatile mindset for all collaborators. Karina believes that the future of the business world calls for female talent as the main cornerstone. *#EnergíaSinLímites* is envisioned as an accelerator of equal opportunities for women, developing disruptive leadership.

Photo: Karina Yonemoto, rawpixel.com

HOW TO MAKE A

GREAT QUALITY

POLYMER-BUSHING CONSISTENTLY

Transformer bushings are components of critical importance in the operation of a transformer. Their failure is one of the major causes of transformer failures, which sometimes can lead to fatal consequences, such as explosions, fires and oil spills.

A failed transformer bushing can thus cause a lot of trouble in the field. Not only is there a significant cost to replacing the bushing, but also the resulting transformer failure can incur additional costs, much higher than the cost of the failed bushing, and lead to downtime resulting in more costs to the operator. Additionally, there is the question of the reputation of the transformer supplier, as well as a possibility to be subjected to penalties for power interruptions and failure to deliver electricity to customers.

Polymer

In bushing manufacturing, choosing the correct polymer, which is typically an epoxy system (resin/hardener combination) is critical. The epoxy must be carefully selected so that the combination of cured properties will accommodate the changing conditions encountered in service. This applies to both mechanical strength and electrical insulation properties. In general, careful consideration must be given to the following specific properties:

- Dielectric strength
- Heat deflection temperature
- Heat aging
- Moisture absorption
- Tensile strength
- % Elongation
- Material type (for indoor or
- outdoor service)

These properties can be verified by standard test procedures.

Most Common Failures

The most common failures in the material include:

- Cracking
- Leaking bushings
- Direct short to transformer tank (catastrophic failure)
- Loss of dielectric properties over time (aging)
- Reduction in tracking resistance over time

Part Design

Part design is regulated by standards such as those set by NEMA and IEEE. In addition to meeting these standards, part design is also closely related to and dependent on the properties of the polymer that is used to manufacture bushings. Fulfilling requirements such as creep distances, mounting, shed design and configuring cable connections is influenced, to some degree, by optimized polymer properties.

Part design is regulated by standards such as those set by NEMA and IEEE

Photo: CrossLink Technology Inc.

Things to look for in this area include the following:

Optimizing thermal cycling ability – A good polymer must be able to withstand extreme temperature changes. If overloading/overheating occurs due to a poor contact, the bushing material may degrade. Therefore, it is important to know the glass transition temperature of the polymer. According to IEEE C57.19, the glass transition temperature must be higher than the allowed hot-spot temperature.

Cantilever strength requirements – To ensure higher cantilever strength of the material, it is important that all welded joints are free of pores. A porous weld will cause hot-spots and lower the cantilever strength.

Maximizing creep and strike distances – Maximizing the creepage and strike distances of the insulator is essential in avoiding flash overs. To achieve this, all sharp edges should be rounded with radius. It is also important to have a good polymer in order to avoid dirt which, over time, may lead to flash over.

Maximizing heat dissipation – In order to maximize heat dissipation, it is important to ensure that the adhesion between the polymer and the conductor is not compromised, as this adhesion will prevent any leakages during operation.

Manufacturing

In bushing manufacturing different production methods are used. While some of these methods work quite well, others do not. The difficulty is that the customers buying the bushings have no way of confirming the quality of the product unless they do full testing on every bushing, which is not feasible.

In order to overcome this issue, it is essential to ensure whichever method is employed to manufacture the parts, it must be accurate and repeatable. For example, being off ratio in the resin/hardener mix is not readily detectable by the end user, but chances are that the bushing will fail in operation.

So, there is no room for error in the manufacturing process. Some of the most common causes of failure that occur as a result of improper processing are:

Insufficient conductor preparation – To avoid this, electrical grade copper must be used with proper brazing between the joints to ensure good contact. Otherwise, poor contact will be the source of hot spots.

Insufficient air removal from the mix – As a result of this, air voids may be trapped causing partial discharge (PD) and flash over.

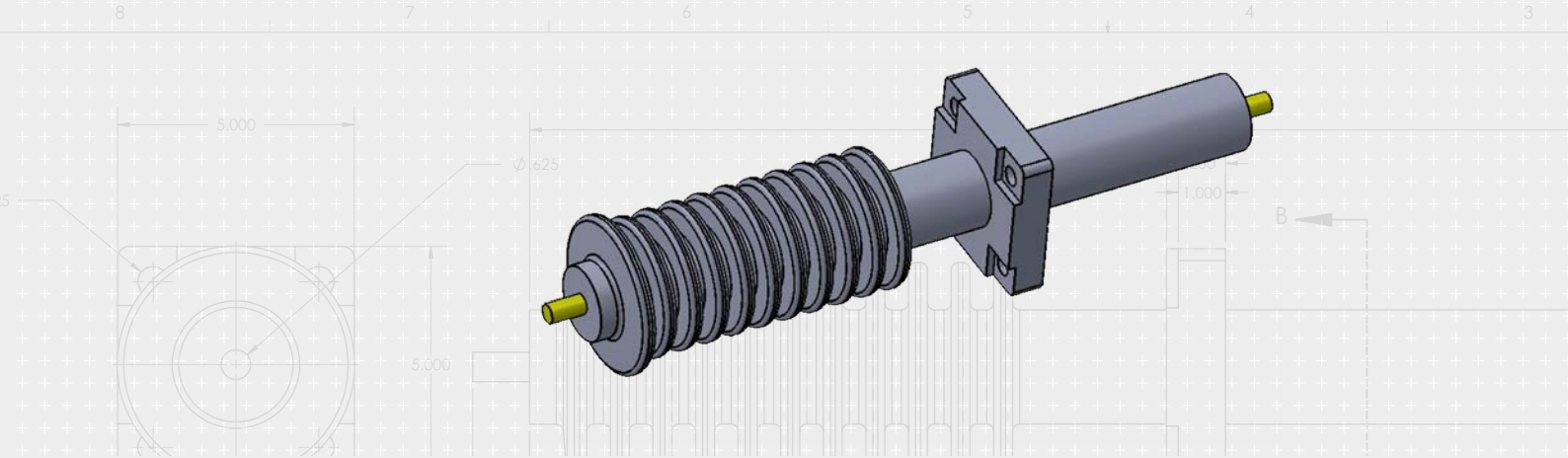
Improperly dispersed fillers within the epoxy mix – This weakens the integrity of the epoxy.

Incorrect processing temperatures (epoxy, mould and conductor) – Applying incorrect temperatures may lead to void formation and cause the epoxy to be brittle, have poor adhesion and shorter service life.

Off ratio epoxy mix – Off ratio epoxy mix will compromise the integrity of the material, so that the epoxy will not have its full physical or electrical properties to meet the requirements for its application.

Less than completely cured epoxy – This compromises the integrity of the epoxy.

Inadvertent thermal cycling of components which are not fully cured – This may cause premature failure in the field and compromises the full potential of the epoxy.



Most Common Failures

The most common failures that develop as a result of improper processing include:

Bushing leaks developing over time in operation – Most commonly, bushing leaks are caused by ageing or by improper gaskets, as well as the weak adhesion between the epoxy and the conductor.

Excessive partial discharge – If the material is not de-aired properly, this may result in excessive partial discharge.

Cracking during mounting or under maximum cable load – Cracking can be caused by using improper epoxy. To avoid this problem, the epoxy should be customized to different temperatures.

Tearing when conductor temperature rises due to high current – In order to avoid this issue, it is important to know the coefficient of thermal expansion of the conductor and the epoxy, as well as the glass transition temperature.

Selecting Your Supplier

Considering the gravity of the consequences of a bushing failure, it is important to carefully select the supplier that is consistent and dependable.

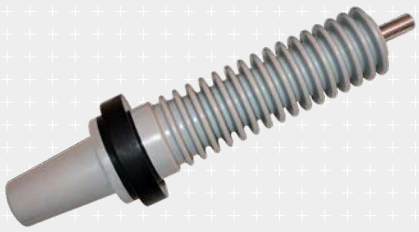
An ISO quality system is a great place to start because consistency is an absolute must. This is important because the end user cannot detect all things in a bushing that can cause problems down the road, usually without warning.

It also helps to work with suppliers who are not only experienced in manufacturing the bushings, but are also engaged in developing, formulating and manufacturing the epoxy resins that are used to make the bushings.

Some of the issues discussed above can be eliminated through "type testing" different parts because those properties will remain consistent as long as the supplier's process is repeatable. On the other hand, issues related to the manufacturing process are particularly important because they are truly dependent on consistency, while at the same time are difficult to detect by the user and will likely lead to field failures over time.

At Crosslink Technology, we are vertically integrated, developing, formulating and manufacturing our own epoxy resins, but also designing and manufacturing the bushings. Our Epoxy Transformer Bushings are manufactured to the highest quality standards and are available for both indoor and outdoor, and low to medium voltage use. Crosslink has 40 years of experience with no field failures.

Our epoxy bushings are non-tracking and weathering resistant, so they offer outstanding performance in all types of environments, even highly contaminated areas. Far lighter (60% lighter) and sturdier (10 times the tensile strength) than porcelain, epoxy bushings will not crack due to thermal shock.



Epoxy bushings also have:

- A low partial discharge
- Superior Compression strength
- Flexural strength of cycloaliphatic that is up to 15 times greater than porcelain
- Resistance to high-power arcs (great dry arcing distance)

Through a dedicated research and development approach, Crosslink Technology Inc. is constantly working to create innovative epoxy and polyurethane formulations, and reliable high-quality cast components. Call or email us today to discuss your needs for reliable transformer bushings.

Crosslink is more than a supply chain vendor. We are a reliable partner.

Through a dedicated research and development approach, Crosslink Technology Inc. is constantly working to create innovative epoxy and polyurethane formulations, and reliable high-quality cast components. Call or email us today to discuss your needs for reliable transformer bushings.

Speak with us about:

- Stocking Part Stocking Program
- Direct to End User Shipping/Labelling plan.
- Raw Material Volatility procurement plan.
- Inventory management plan.

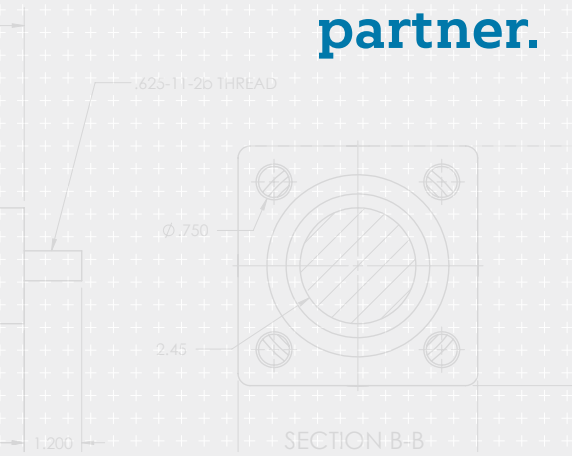


Photo: CrossLink Technology Inc.

40 YEARS
Crosslink Technology Inc.
Epoxies, Urethanes • Custom Cast Parts

The Crosslink Cast Components Division manufactures Epoxy cast transformer bushings and standoff insulators. The Crosslink Liquids Division manufactures both Epoxy and Polyurethane custom formulations.

Our mandate is simple: be innovative, provide the highest quality components, and offer exceptional service to our customers.

From our North American plant, we have supported our global customers for 40 years with low and medium voltage resin bushings and insulators. With our in-house design capability, we assist our customers with their concepts. We formulate our own world class resins to meet most electromechanical challenges you may face. With our high-volume capacity and stocking programs, we are able to service most lead time demands.

Crosslink Technology Inc.
www.crosslinktech.com
+1-905-673-0510
info@crosslinktech.com

We look forward to partnering with your team.

Investigation and Teardown of OIP Bushings

by **Lance Lewand**
and **Leah Simmons**

Introduction

Utilities and other types of system operators are always trying to find methods to mitigate forced outages. Of the number of forced outages that do occur on an electrical system, oil-in-paper bushings (OIP) failures can result in severe havoc. Oil-in-paper bushings are the interface between the external bus and the windings of a transformer and thus are an integral part of the electric delivery system. The results of a bushing failure are numerous; first and foremost, possible harm to substation personnel from spraying hot oil and flying porcelain and other debris. Additional issues include fire, internal damage to the transformer such as collateral damage to the windings, leads and other components, which can result in damage so severe that the transformer may not be salvageable. External collateral damage includes damage to the other bushings on the same transformer and nearby transformers and can result in harm to other substation components mostly from flying shrapnel.

Other concerns include outages to affected customers, length of outages, the cost to remove the failed bushing(s) and others if severely damaged, cleanup of the substation yard from sharp porcelain, replacing overhead lines if necessary, cost of new bushings along with installing them, testing of the transformer and internal inspections with the possibility of complete oil removal if deemed necessary. If the transformer is a generating unit, then substantial loss revenue can be realized. There are many other concerns and issues that a system operator must face because of a bushing failure that are too numerous to mention.

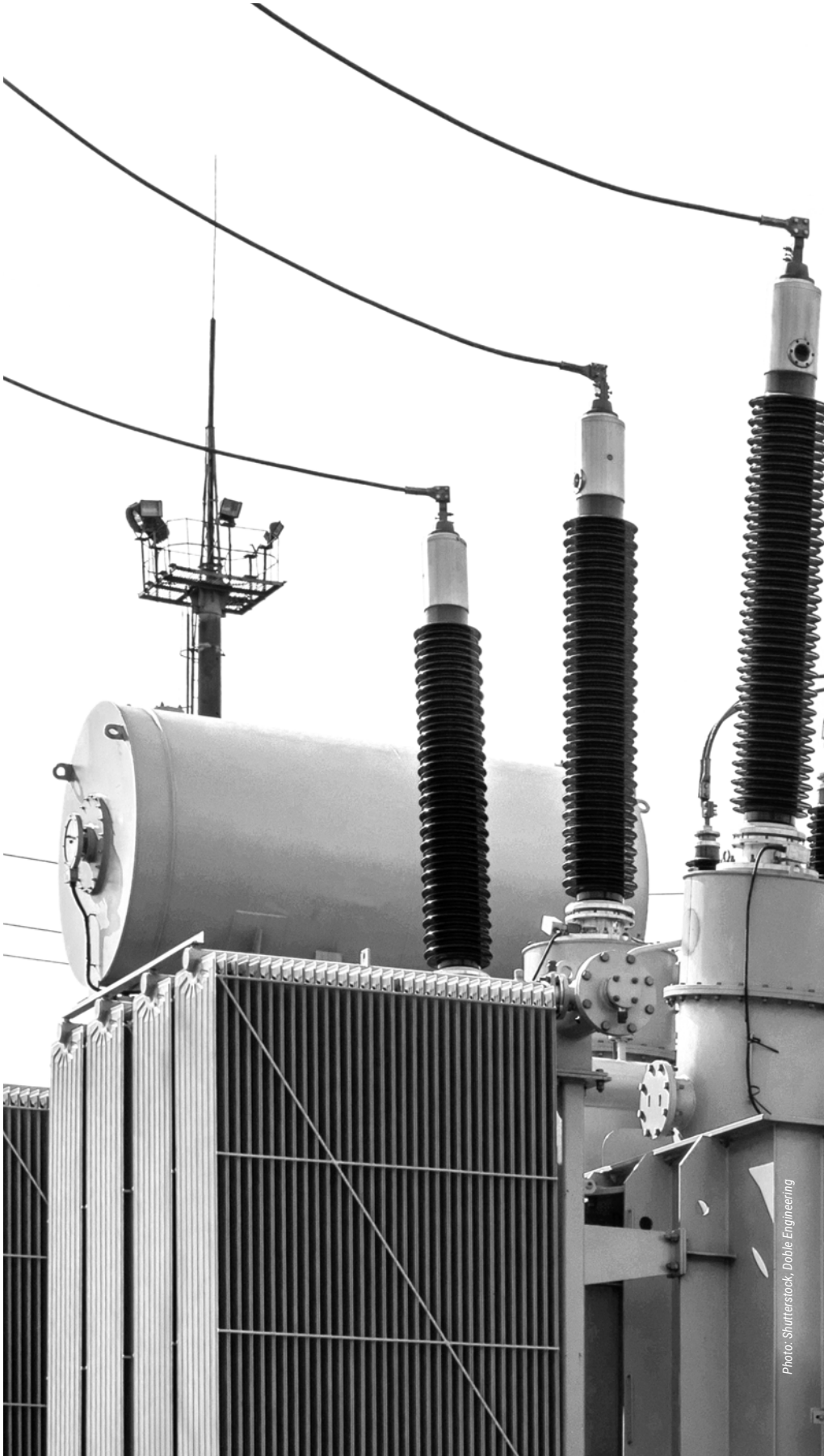


Photo: Shutterstock, Doble Engineering

The results of bushing teardown analysis may result in a bushing replacement plan for similar types, restrict their use and may involve additional maintenance practices, more frequent testing or controls, and possibly online monitoring so that the risk of future bushing failures is reduced.

Lance Lewand is the Technical Director for the Doble Insulating Materials Laboratories. Since joining Doble in 1992, Mr. Lewand has published over 75 technical papers pertaining to testing and sampling of electrical insulating materials and laboratory diagnostics. He received his Bachelor of Science degree from St. Mary's College of Maryland. Lance is actively involved in professional organizations including the American Chemical Society, CIGRE, a representative of the U.S. National Committee for TC10 of the International Electrotechnical Commission (IEC) and ISO TC28, ASTM D-27 since 1989. He is the current chair of ASTM committee D-27 on insulating fluids, the subcommittee chair 06 on Chemical Tests and a recipient of the ASTM Award of Merit.

The Aftermath

In reviewing a bushing failure, the system operator may decide to look more in depth at the bushing in question and perform what is called a bushing teardown. This can be performed by the system operator if they are able to do so, the manufacturer of the bushing or a contractor. Some teardowns may be performed by a contractor with the operator personnel on site or, in some cases, also with the manufacturer on site. Whatever the case, it should remain unbiased so that the evidence found is to be the primary driver of the endeavor.

Bushing teardowns and forensics aid to determine root cause failures and are important to understand possible weaknesses in the bushing construction or its inservice use and if similar bushings are at risk.

The results of such study may result in a bushing replacement plan for similar types, restrict their use and may involve additional maintenance practices, more frequent testing or controls, so that there are no future failures, or the risk is severely reduced.

What Is a Bushing Teardown?

A bushing teardown is a stepwise and controlled approach to dismantling a bushing piece by piece, gathering measurements and evidence so that some final conclusion(s) can be made as to the root cause of the failure. It can be a very tedious and lengthy process. This is especially true when combing through the wreckage of a bushing in which the paper has been engulfed in a fire. Removing the carbonized paper while looking for evidence is a very delicate and painstaking operation. Some bushings may be too badly damaged to go through a teardown, but even those that are damaged so extensively may yield some small piece of evidence that will make the process worthwhile.

Additionally, the teardown of a sister bushing that is still intact provides useful information so that a comparison to the failed unit can be made along with the examination of the bushing design and the final manufactured product. Not all bushing teardowns, however, will yield conclusive results.

Data

In analyzing any bushing failure and that of an intact unit, the prefailure data is invaluable. Information such as loading, storms before the failure,

As an integral part of the electric delivery system around the world and the interface between the transformer and overhead bus, bushings failures have a significant negative impact. Because of this, there is a special focus on determining the root cause of the failure.

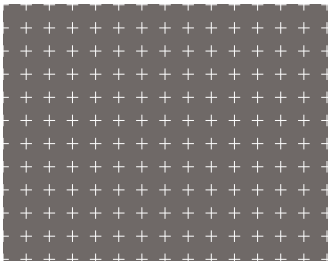


Photo: Shutterstock, Doble Engineering

A bushing teardown investigation is employed in cases where there is a need to determine the failure mechanism.

operating temperatures, through faults, mechanical disturbances, work on the transformer or bushings prior to the failure, electrical test results especially power factor and capacitances, oil analysis test results performed on the bushing, and if a service advisory has been issued by the manufacturer is some of the information that can play a vital role in the investigation. Even cantilever forces of the overhead lines to the top connection point of the transformer bushing may have to be calculated and explored. Manufacturer bushing schematics along with any other literature about the bushing must also be included. Pictures of the failed bushing before removal from the transformer may also provide important information.

Lacking this data or the access to it can seriously hamper a bushing failure investigation and may not make the process worthwhile.

If the failed bushing has been subjected to water from rain, firefighting activity or deluge systems, it is imperative that the company performing the teardown is informed.

Receiving the Bushing

Most companies performing bushing teardowns, especially in the United States and Canada, will require the bushing oil to have less than 2 ppm (mg/kg) polychlorinated biphenyls (PCBs). Some companies may accept a certificate that came with the bushing when it was manufactured, stating that it is less than 2 ppm, but most will require the results of a recent oil sample. Packaging and shipping must be performed in such a way as to not alter the as-found condition of the bushing(s).

Collection of the bushing shrapnel and sending it along with the bushing to be inspected will benefit the investigation. If the bushing is a drawlead type, and the draw lead was damaged in the failure, include it with the bushing as there may be evidence as to what occurred.

Testing Prior to Disassembly

The first step in this process is a visual inspection and measurements. The visual inspection will provide overall condition and any anomalies that might be present. Record all the nameplate information as it will prove useful in the overall review of the bushing and the data associated with it. Depending on the size of the bushing, information may include the serial number, style, class, drawing number, catalog number, BIL rating, C1 and C2 power factors and capacitances, and amperage rating.

Deposits on the bushing sheds (see Figure 1), the oil level in the sight glass, the color of the oil, any deposits in the sight glass, and arc marks on the flange, the lower assembly below the flange, upper porcelain or the head of the bushing is additional information to gather.

It may also be possible at this point to determine if any gasket or

Figure 1. Hot oil and fire soot deposits

O-ring compromises have occurred as seen by the elastomeric material exuding from the gasket/O-ring groove or material crumbling (refer to Figure 2) away from areas that they were supposed to seal. In all, some bushings can have as many as 20 gaskets and O-rings, each of which must be fully studied and most of which will be found during disassembly.

A bushing teardown is a stepwise and controlled approach to dismantling a bushing piece by piece, gathering measurements and evidence so that some final conclusion(s) can be made to determine the root cause of the failure.

In analyzing any bushing failure and that of an intact unit, the prefailure data is invaluable. Information such as loading, storms before the failure, operating temperatures, through faults, mechanical disturbances, work on the transformer or bushings prior to the failure, electrical test results especially power factor and capacitances, oil analysis test results, and if a service advisory has been issued by the manufacturer is some of the information that can play a vital role in the investigation.

Measurements of the overall length, and lengths of various components, diameters, and location of various bushing components provide a means to compare the bushing being tested to the original shop drawings.

If able and safe, electrical testing provides critical information that is especially valuable in reviewing the bushing failure. Comparison to the nameplate data, acceptance test results and in-service test results will indicate a slow deterioration of the bushing over time or an abrupt failure or possibly something else. These failure routes can dictate the way in which the bushing is torn down.

Disassembly (Teardown)

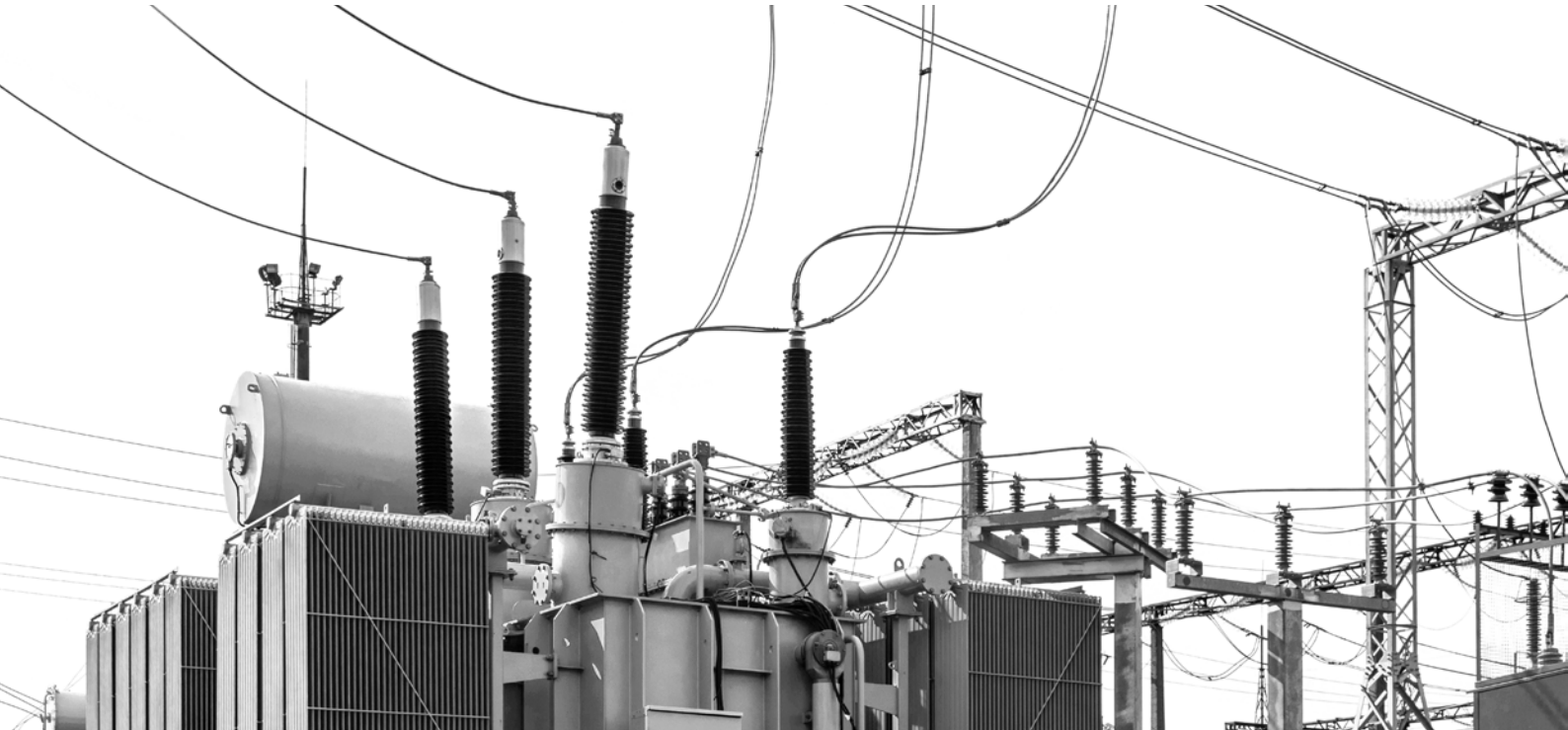
Before the bushing is disassembled, oil samples need to be taken and the bushing drained. Oil sampling is vital and critical to the process.

Dissolved gas-in-oil analysis (DGA) will provide information on arcing, partial discharge, overheating of the oil, overheating of the paper and possibly other issues. Oil quality tests will provide information on the condition of the oil and can determine if air and water ingress has occurred. This is important as water ingress is one of the primary drivers of bushing failures. The photo in Figure 3 shows a broken and deteriorated O-ring from the oil fill plug which allowed water and air ingress into the bushing.

Other oil tests can provide information on the degradation of the paper insulation, particulates in the oil and the makeup of those particles. This all relates to the operation of the bushing and therefore is an important part of the process.

Figure 2. Compromised bushing gasket at flange-upper porcelain interface

Figure 3. Broken and deteriorated oil fill plug O-ring



Once the oil is drained, the toughest part of the teardown procedure begins, especially on larger bushings rated 230 kV and higher as the bushings are large and heavy. Using a facility that does not have the ability to lift, maneuver and turn the bushing can result in broken porcelain, destruction of evidence and injury to personnel. The compression pressure on the bushing must be released without breaking the porcelain as porcelain shards are sharp, can cut the paper insulation and personnel and will contaminate the bushing teardown scene. Bushing manufacturers used a variety of different mechanisms to apply the requisite sealing pressure to the bushing and to then secure it so the method to release the pressure will be different from manufacturer to manufacturer. Breaking the porcelain to release the pressure is a technique that should not be used.

Once the pressure is released, dismantling can begin but it must be performed in a managed way, so no evidence is missed. The head of the bushing can provide a variety of evidence that will be useful, so it needs to be inspected inside and out and possible samples retrieved for analysis such as the sludge found on the internal surface of the aluminum head housing shown in Figure 4.

In the head will be a variety of O-rings and gaskets which will need to be inspected and categorized. The sight glass may also yield some evidence along with inspection of the spring basket assembly. Figure 5 provides a photograph of heavy x-wax formation on the corona ring of a bushing.

Once the head is removed, removal of the porcelain can ensue but there maybe one or more separate pieces of porcelain above the flange, so they need to be removed one by one without damaging the paper insulation of the core. Inspection of the internal surface of each piece of porcelain removed can also yield evidence. Figure 6 shows arcing found on the inside porcelain of one failed bushing.

Depending on the circumstance, the flange could be removed next, or instead the bushing bottom connection removed than any porcelain, or composite/epoxy material that may be present. The order all depends on the damage down to the bushing and the ability to access the area. Again, all these must be inspected, and samples taken for analysis if necessary.

The tap assembly is attached to the core thus it will have to be removed without damaging the core before the flange can be removed. Depending on the bushing manufacturer there are a variety of methods that were used to attach the tap to the core. In larger bushings, there may multiple taps all of which need to be disconnected prior to flange removal. Once all the pieces are removed, the inspection of the core can commence as shown in Figure 7.

Figure 4. Sludge found in bushing head

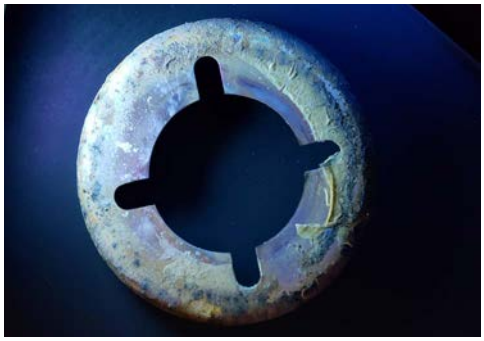


Figure 5. X-Wax on the corona shield of a bushing and other debris

Photo: Shutterstock, Doble Engineering

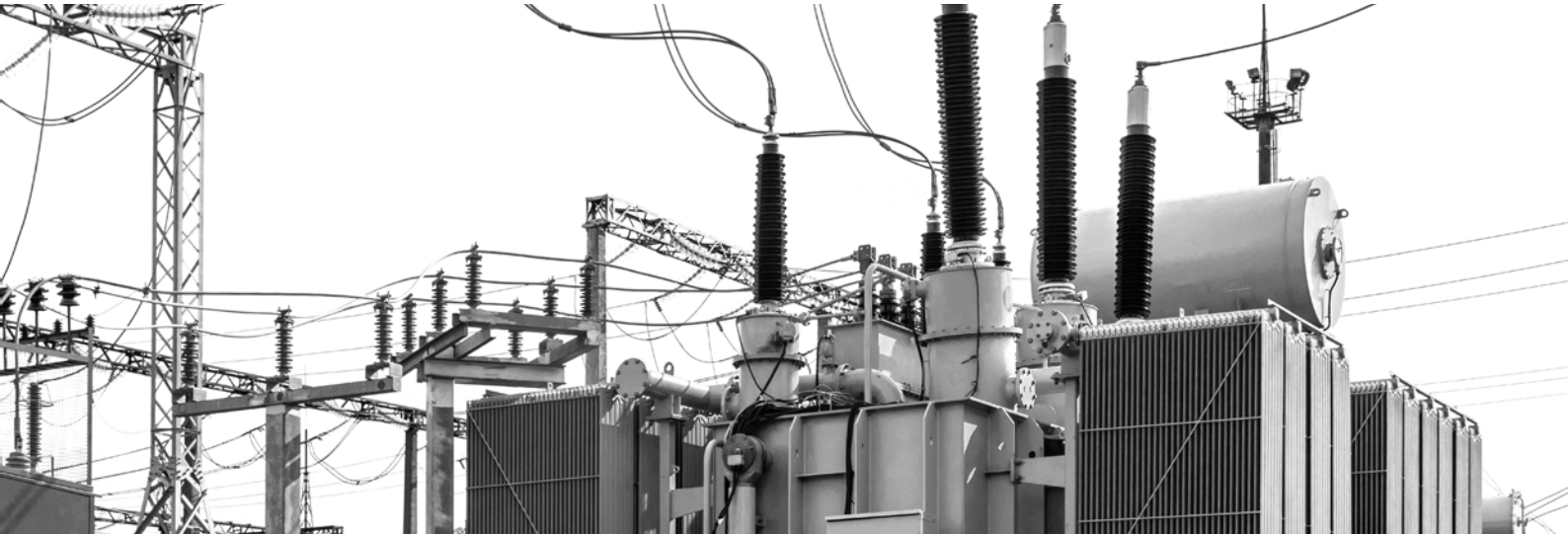


Figure 6. Arc tracking on internal porcelain

Figure 7. Partial core of a bushing showing tap foils

Figure 8. Arcing though core

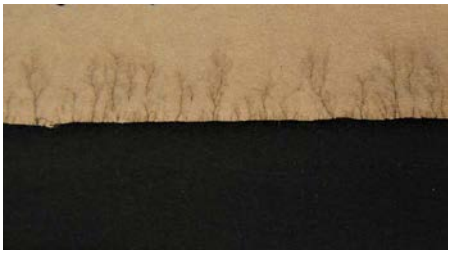


Figure 9. Partial discharge treeing from edge of ink layer

Figure 10. Arc hole through copper conductor

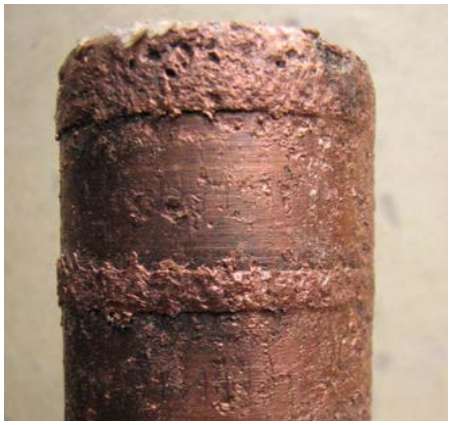


Figure 11. Pitting and melting of copper conductor

Figure 12. Copper sulfide formation on copper conductor

During the course of unwinding the core and depending on how detailed the inspection is to be conducted, measurements may be taken to include such things as the distance from the top and bottom of the paper wraps to the respective ends, diameters, number of paper layers, location of capacitive layers and whether or not they are aluminum foil, conductive ink or herring bone ink. The width, length and location of the conductive layers may be measured to be used for a finite element analysis.

Often paper samples are taken at different depths and positions within the core so that they can be analyzed for degree of polymerization (DP) and water content along with a variety of other physical, chemical and electrical analyses. Along the way, area of discharge may be found as shown in Figure 8 or partial discharge treeing in Figure 9.

Once the unwrapping of the core is completed, the actual center conductor can be inspected. Most often copper is used in lower kV bushings whereas aluminum is used in larger voltage bushings to reduce weight. Occasionally, a combination of the two may be present. Some examples of damage done to the center conductor are found in Figures 10 through 12.

Often there is much data collected as part of any bushing teardown investigation. All that data from in-service operation of the bushing, electrical and oil test results, all the measurements and all the findings and information from each part of the bushing have to collated, sifted through, analyzed and then put together in a coherent report, the final step of the investigative process, that may take weeks to months to produce after the final disassembly of the bushing.

Conclusions

As an integral part of the electric delivery system around the world and the interface between the transformer and overhead bus, bushings failures have a significant negative impact. Because of this, there is a special focus on determining the root cause of the failure. A bushing teardown investigation is employed in cases where there is a need to determine the failure mechanism. A brief synopsis of how companies perform a bushing teardown was explained in this paper.

The results of such an analysis may result in a bushing replacement plan for similar types, restrict their use and may involve additional maintenance practices, more frequent testing or controls, and possibly online monitoring so that the risk of future bushing failures is reduced.

Acknowledgement
The author wishes to thank Leah Simmons of Doble Engineering for all her contributions to this summary paper. Leah Simmons is the Senior High Voltage Test Engineer where she provides diagnostic and forensic testing and data analysis including writing reports and technical documents. Leah and the author head most of the bushing dismantling and forensic analysis that occurs at Doble.

Photo: Doble Engineering

DOBLE LABORATORY SERVICES:

ANALYSIS AND ENGINEERING GUIDANCE TO HELP MANAGE CRITICAL ASSET RISK

Since 1933, our experienced team of engineers and chemists has helped customers determine the health of transformers and other oil-filled assets. Whether it's routine oil testing or development of cost-effective testing programs, customers rely on our expertise for independent interpretation of results and high quality data. Doble also offers in-depth reporting and consulting services to help clients analyze test results and make informed decisions about asset health and maintenance.

At five ISO 17025-accredited laboratories located throughout North America, Doble offers over 200 tests and testing packages on both solid and liquid insulation, including:

- Dissolved gas-in-oil analysis (DGA)
- Furanic compounds-in-oil
- A multitude of oil quality test packages
- Water content
- Corrosive sulfur
- Degree of polymerization of paper
- Wear metals in oil (Doble Test Method)
- Dissolved metals in oil
- Load tap changer analysis program
- Breaker analysis program
- Material compatibility programs
- New insulating liquid and solid insulation development programs
- Forensic analysis of oils and apparatus components
- Methanol, ethanol and furanic compound analysis

For comprehensive data analysis and fleet asset management, automatically load your test results into Doble's INSIDEVIEW® software.

doble®

100 EST. 1920 *Reliable Safe Secure*

For a full menu of Doble's laboratory services, visit: doble.com/lab-services. To request information on consulting services or proposals, please contact us via email at Labservices@doble.com.

The Importance of Continuously Monitoring Partial Discharges Online in HV Bushings

by **Marco Tozzi**

Dr. **Marco Tozzi** is Sr. Product Manager for CAMLIN POWER, responsible for product portfolio and an expert in diagnostic methods for high-voltage asset monitoring. After receiving his Ph.D. degree in electrical engineering in 2010 on methods for analysing partial discharges in medium-voltage asset, he worked as Project Manager and Technical Advisor in Techimp Srl, Italy, where he was involved in research on diagnostics of insulating systems through partial discharges analysis. In 2012 he joined Camlin based in Northern Ireland, where he was initially involved in developing partial discharge permanent monitoring systems for transformers and rotating machines. He is author or co-author of more than 40 technical and scientific papers, co-owner of patents on partial discharge denoising technique and UHF detectors, and an active IEEE Transformer Committee member.

Photo: Camlin

BUSHINGS ARE CRUCIAL COMPONENTS FOR LARGE POWER TRANSFORMERS, BEING THE TERMINATION POINTS AND PHYSICAL ELECTRICAL CONNECTIONS TO THE HIGH AND LOW VOLTAGE GRID. REGULAR TESTING IS OF UTMOST IMPORTANCE SINCE BUSHINGS ACCOUNT FOR 5% TO 50% OF TRANSFORMER FAULTS, DEPENDING ON DESIGN AND APPLICATION.

Introduction

Bushings are crucial components for large power transformers, being the termination points and physical electrical connections to the high and low voltage grid. There are different designs and technologies, however, failures in those components can cause unplanned outages, huge direct and indirect financial losses and, in some cases, catastrophic consequences involving fire and explosions. Regular testing is of utmost importance since bushings account for 5% to 50% of transformer faults, depending on design and application [1].

There is a variety of offline measurements that can be carried out in the field to check the insulation condition at a particular point in time [1-5], such as: Dielectric Frequency Response (DFR) [2], Power Factor (PF) Tip-up, Power Factor at different temperatures, Dissolved Gas Analysis (DGA), oil quality, DC insulation test, and Partial Discharges (PD). However, all of them required the transformer to be de-energized, as well as significant time and skills are needed to carry out a meaningful diagnosis. Due to time constraints and difficulties in interpretation, the most common tests that are typically performed are the Capacitance and Power Factor (a.k.a. Tan Delta or Dissipation Factor) test, done at just one temperature at the moment of testing, voltage and frequency.

These tests can assess and highlight an advanced stage of degradation like short circuits across internal control layers or a bulk degradation of the oil/paper insulation due to severe contamination. However, there are also faults and level of degradations that cannot be easily detected in this way [5-7]. Indeed, there are many different possible failure modes [1,8] such as: insulation ageing, moisture contamination, crack in porcelain, oil leakages, broken or loose connections, particle contamination, contamination in either the internal or external surface of the porcelain, presence of local amount of moisture, electrical surface tracking phenomena, internal PD and arcing. In order to identify those failure modes and save a bushing before the degradation is at an advanced stage it would be required to choose the most appropriate offline tests, or a combination of multiple tests, thus investing quite a significant amount of time. But how are we to know which tests should be carried out in order to optimize time and budget?

A solution is represented by monitoring the bushings online, under real operating conditions. Historically, this is done by collecting the 50/60 Hz leakage current at the test (or voltage) tap (Figure 1) and then comparing the currents in each bushing to check for anomalies in one bushing current in terms of either amplitude or angle [7]. Modern devices can do something more, by extending the frequency range of the sensor and acquisition system within the MHz range in order to detect another important parameter: Partial Discharges (PD). However, this technology is not widespread and is rarely requested as a mandatory requirement from end-users. Why?

THERE ARE MANY DIFFERENT POSSIBLE FAILURE MODES THAT CANNOT BE EASILY DETECTED BY OFFLINE MEASUREMENTS.

MONITORING BUSHINGS ONLINE, UNDER REAL OPERATING CONDITIONS, OFFERS A SOLUTION TO IDENTIFYING DIFFERENT FAILURE MODES AND SAVING A BUSHING BEFORE THE DEGRADATION IS AT AN ADVANCED STAGE.

Because there are mainly two barriers:

- Difficulties in Partial Discharge interpretation
- Concerns with PD detection capabilities

The first item is quite reasonable since it is true that the understanding and interpretation of Partial Discharges require experience and skills. However, if the monitoring system is properly designed, acquiring data in a meaningful format and removing most of the noise and disturbances, it is then possible to use algorithms and simple graphical tools to make the information more accessible to the end-user. Also, PD monitoring suppliers can make their experience available to the end-user, sharing and transferring knowledge and helping in building trust in this technique [6].

The second item is driven by a general misconception, where the typical thinking is that "accurate PD measurements are very difficult to perform on site and with the bushing installed on the transformer" or that "due to high level of noise online PD detector cannot reach the same sensitivity (in pico-Coulombs) required during the factory offline tests". Hence the typical questions such as "How many pico-Coulombs can you detect? What is your monitoring system sensitivity? At how many pC shall I switch the transformer off?". This is an example of confusion, and at times obfuscation, when it comes to PD and its application to power transformers. End users care about the transformer and its condition. The science and art of PD measurement can be a distraction if not applied correctly. Does a transformer owner really care about the nuances of pico-Coulombs specification on a 20-year-old transformer? Likely not! Rather than focusing on pico-Coulomb measurements, focus on the failure modes your PD monitors detects. That way the focus is on the real issues and the failure modes your monitor can reliably detect. That must always be the priority.

In fact, by analyzing the shape and characteristics of the PD [9-10]

Photo: Camlin

and its changes over time, together with the other monitored parameters like load, temperature, and leakage current, it is possible to better describe the degradation phenomenon, identify the possible failure mode, and enable a more effective maintenance planning program.

Principles and requirements for effective online Partial Discharge monitoring in bushings

PD measurements are generally carried out in the factory during the acceptance tests (FAT), in an environment that is arranged to be free from electrical noise, thus achieving a detection sensitivity able to detect very small discharges in the range of a few pico-Coulombs (<5 pC). Due to the normally high amount of noise in the field and the difficulty of interpreting the PD results, this diagnostic parameter is rarely considered in permanent monitoring systems. The general view of it is that online sensitivity is too poor to detect less than 5 pC.

THE CONDITION AND CHEMICAL/ MECHANICAL CHARACTERISTICS OF BUSHINGS THAT HAVE BEEN IN SERVICE FOR DECADES IS VERY DIFFERENT FROM THE CONDITION AT THE TIME OF THE FAT, RESULTING IN UNIQUE SITUATIONS WHEN IT COMES TO PD MEASUREMENTS.

The purpose of online monitoring is neither to replace, nor exactly replicate the factory acceptance tests or offline measurements. Instead, its purpose is to detect anomalies in real operating conditions that could not be identified otherwise and, therefore, to identify the most suitable test for the final confirmation and action.

To achieve this purpose, it is therefore not necessary to use systems capable of detecting a few pC and in total absence of noise. Rather the key is in detecting, in a reliable way, discharges caused by defects originated during the operating life of the transformer, i.e., after decades of thermal, electrical, and mechanical stress, like disconnection of equipotential connections, generation of large voids and cracks in the insulation, short circuits between multiple layers and many others. In fact, it should be considered that the bushings that are 10, 20 or 30 years old will have an aged oil, with the possible presence of humidity, particles of various kinds, sludge and residues. Also, the cellulose will have different mechanical and chemical characteristics, potentially weakened by the presence of water or excessive thermal heating.

The condition and chemical/mechanical characteristics of bushings that have been in service for decades is very different from the condition at the time of the FAT, resulting in unique situations regarding PD measurements.

The same identical defect could generate discharges of different intensity depending on the age of the surrounding insulation, the operating temperature, the oil breakdown voltage, the presence of particles in oil, the cellulose mechanical strength and many other factors linked with the normal bushing ageing in the field.

Therefore, the key is not to focus on the pico-Coulomb detection, but rather on the failure mode, correlating PD phenomena together with variations in temperature, load, capacitance and power factor under real operating conditions.

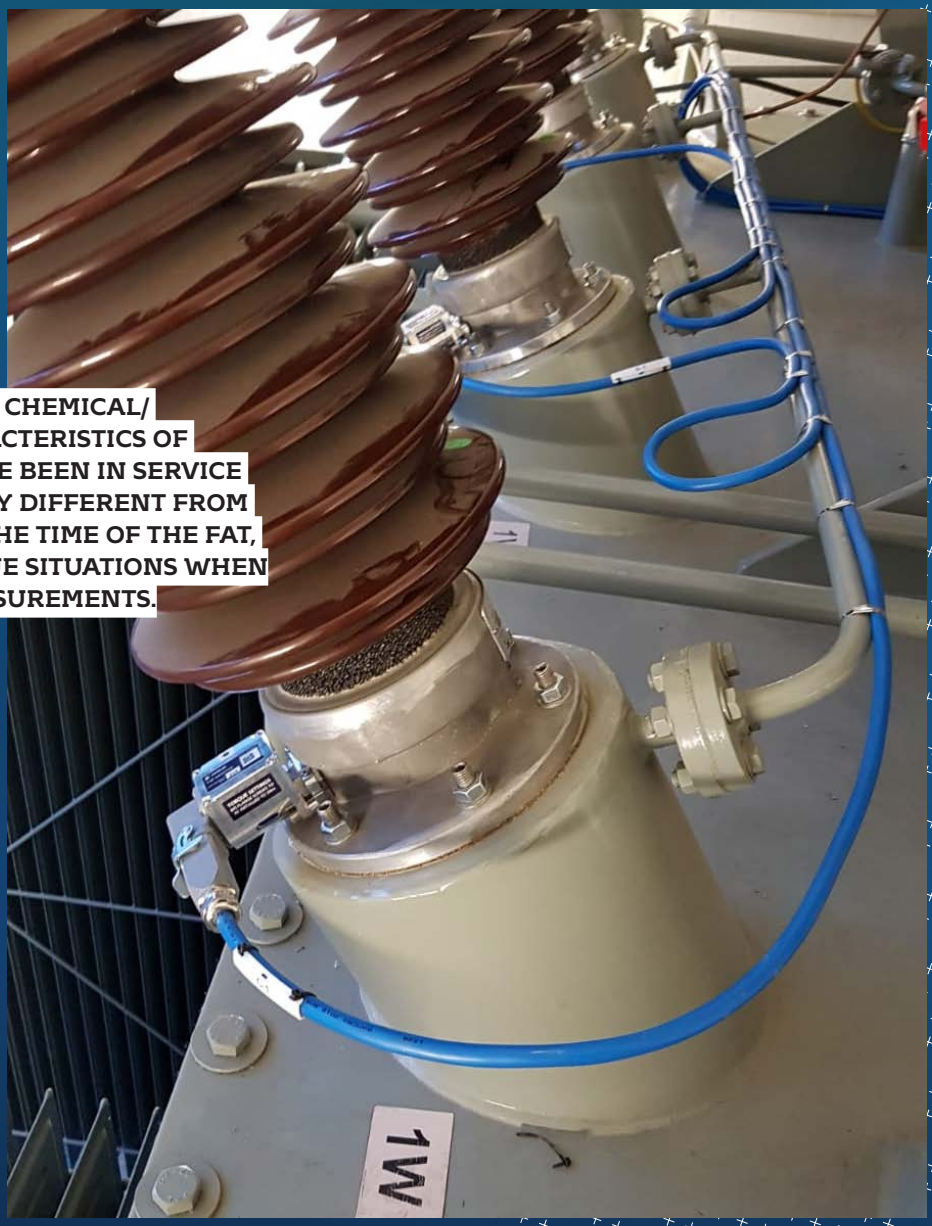


Figure 1. Bushing adaptor installed at the test tap for PD and Leakage Current online monitoring.

Are all the PD detectors and monitors suitable for online PD detection in real operating conditions? No, they are not. Adapting a standard portable unit or offline kit for online purposes might not work. The online monitoring system should be properly designed considering transformer and bushing application, thus following a number of solid principles and requirements:

Principle #1: Capabilities of acquiring PD continuously, thus not scheduling several measurements per day

Acquisition gaps are not allowed. This is very important to detect arcing event happening during a short circuit between layers or due to floating shields/connections that accumulate charge and sudden discharges. By making only a set number of acquisitions per day there is very high probability of missing such events [6, 11].

Principle #2: Capabilities of automatically removing noise and disturbances, and also removing the cross coupling from the other phases

This is important because these interferences can overlap to the actual PD and affect the evaluation of amplitude and repetition rate, i.e. PD intensity and its trending over time. Figure 2 shows an example of a PD acquisition in three phases. Each phase has a PRPD pattern, but the defect is actually generated from Phase B only. Without the automatic denoising logic, the system would record and keep pulses in each phase (Figure 2, top), instead of focusing on where the actual PD source is (Figure 2, bottom) and this would affect the statistical amplitude and repetition rate evaluation. Furthermore, it would make the pattern analysis difficult, relaying on experts to help in understanding if that PD is an actual PD or a cross-coupling event.

Principle #3: Capabilities of separating the PD in the bushings from those in the main tank

There are several elements to be considered that can allow the conception of an intelligent algorithm capable to discriminate if the recorded PD activity is inside the bushing or not. One of the most known elements, as an example, relates to the ability of analyzing the PD pulse polarity with respect to the applied voltage. Indeed, the PD pulses coming from the main tank have opposite polarity from those coming from the bushing condenser core when detected by an impedance installed between the test tap pin and ground. This is quite complex but can be summarized by the difference between having the measuring impedance in either "direct" or "indirect" circuit within the Equipment Under Test (EUT).

Principle #4: Capabilities of synchronizing the PD pulses with the true voltage applied at the bushing

The position of the PD pulses with respect to the zero crossing of the applied voltage is very important to understand the source of PD and its degradation stage [12-13]. Few degrees of differences can make a huge difference in the diagnosis. For that reason, the synchronization voltage must be accurate and be recorded from the test tap together with the high frequency pulses, i.e. not from external power supply sources in the substation to which a manual phase shift has then to be applied.

Principle #5: Capabilities of using an extended full scale to detect arcing events

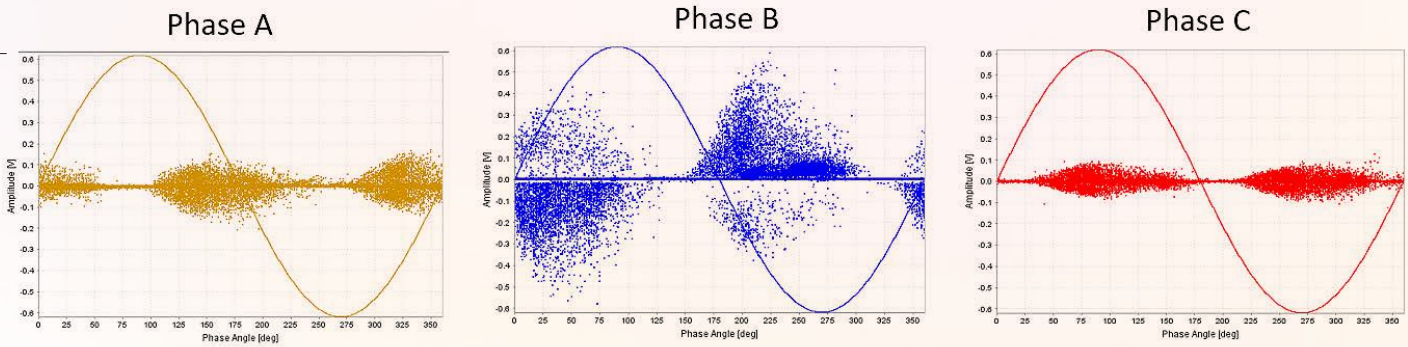
PD instruments used for factory acceptance tests or periodic measurements might have too small of a full scale, mainly focused on detecting small PD activities with a few pC. For reliable online monitoring application, it must be different, focusing also on the large events that can be many orders of magnitude larger, in the range of hundreds of nano-Coulombs. This has been shown previously as crucial whenever there is a floating object [11] or an arcing event between layers [6]. In terms of Volts, with a typical bandwidth of 20-30 MHz, the full scale must at least be equal to 20 Volts peak-to peak.

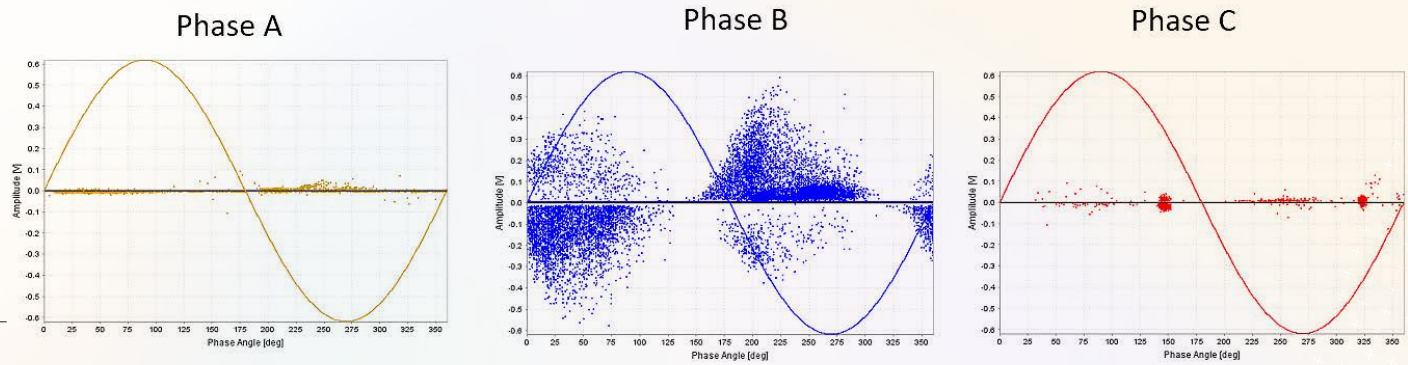
Figure 2. Differences between an acquisition with (bottom) and without (top) an automatic denosing and cross coupling rejection logic.

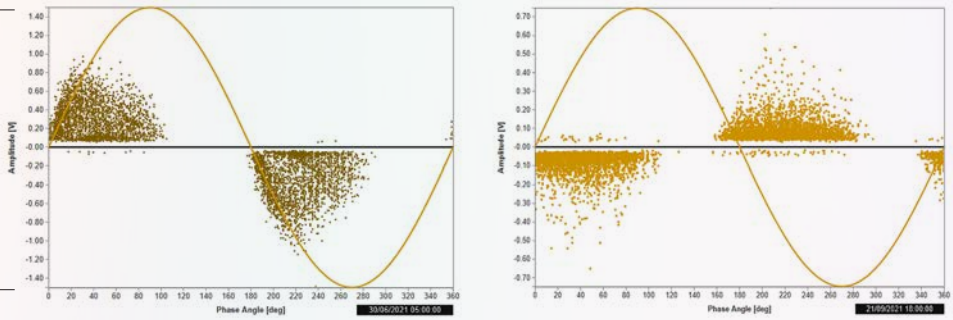
Figure 3. PRPD pattern of a PD acquired in the bushing (left) against a PD on the top of the winding (right). They have opposite polarity under the same sinewave.

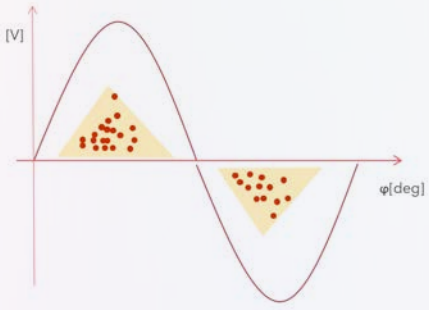
Figure 4. The same PRPD pattern could show a very early (left) or quite advanced (right) stage of degradation depending on its position with respect to the zero crossing of the applied voltage, which must be very accurate and acquired from the bushing tap together with the PD.

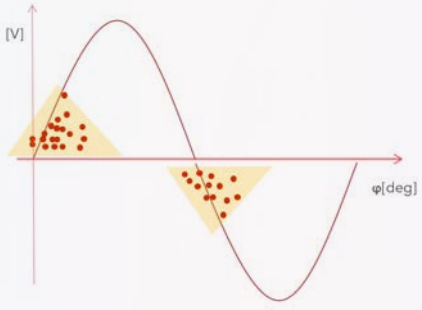
Photo: Camlin


Phase A
Phase B
Phase C
Amplitude [V]
Phase Angle [deg]


Phase A
Phase B
Phase C
Amplitude [V]
Phase Angle [deg]


Amplitude [V]
Phase Angle [deg]


[V]
φ[deg]


[V]
φ[deg]

Success Story #1: 130 kV OIP bushing contamination during manufacturing

A batch of 130 kV OIP bushings manufactured in 2016 was installed in a fleet of new transformers in North America. After about a year, an alarm was notified by the monitoring system for increased power factor in two bushings.

Figure 5 shows the increasing trend of the relative Power Factor, estimated from the variation of the angles of the currents (red trend line). The estimated Power Factor started to rise in March and reached a relative value (incremental change to be added algebraically to the nominal value) of 0.7%, thus justifying a further investigation. It is interesting to note the black trend line, showing the number of Partial Discharges per second detected in the same bushing (X3). After some sporadic events during the months of October and November, the PD activity was quiet, occurring intermittently until April, when it started again with more frequency, together with an increase of the Power Factor, until the transformer was de-energized. Looking at the Phase-Resolved Partial Dis-charge (PRPD) pattern, provided every hour by the monitoring system, we can recognize how the PD activity has grown over time and how the PD polarity is "direct", which means positive under the positive sinewave, i.e. inside the bushing. The shape of the pattern also recalls studies published on PD in oil in presence of metal particles [14].

Analyzing and correlating both the PD and the Power Factor, it was speculated there was a possible contamination of metallic material. It was suggested to carry out a DGA measurement, to confirm presence of PD, plus an oil quality measurement.

Table 1 shows the results of the oil analysis, with exceptionally high levels of hydrogen and with abnormal BDV and Tan Delta, confirming not only the presence of PD, but also a significant reduction in dielectric strength, both probably due to the metal contaminants.

It was therefore decided to inspect the bushing and a significant amount of aluminum particles and carbon deposits were found, confirming the assumptions made and the online analysis of the monitoring system.

The bushing was replaced but at the same time a DGA measurement was planned for all the bushings from the batch (which had no monitoring system), which found two additional bushings were in a similar condition. According to the asset manager:

- The monitoring system was mainly installed to monitor the main transformer tank and no problems were expected on bushings, especially considering they were new.
- By implementing a standard program of electrical testing every six years, it would not have been possible to detect the problem in time and prevent a possible unexpected failure.
- Thanks to the monitoring system, three new bushings were saved. A failure might have possibly been catastrophic.

Success Story #2: 110 kV RIP bushing short circuit between internal control layers

Although the resin insulated bushings are considered to be less prone to PD activities by design, due to a specific manufacturing process that avoids the presence of vacuoles in the solid insulation, it is certainly possible that these bushings, after a certain amount of time in service or even prematurely, due to problems during transport and installation, show defects that can generate Partial Discharges. Unlike OIP bushings, the solid insulation system does not tolerate PD activities and in presence of PD it can quickly deteriorate, creating a conductive channel between the control layers.The case depicted here describes a 110 kV RIP wall-mounted bushing (Figure 7), monitored by the same type of system used in the previous cases.

After about two years the system gave an alarm for a sudden relative capacitance increase of about 14% in bushing K. The bushing was taken out of service and tested offline,

Table 1. Oil analysis results

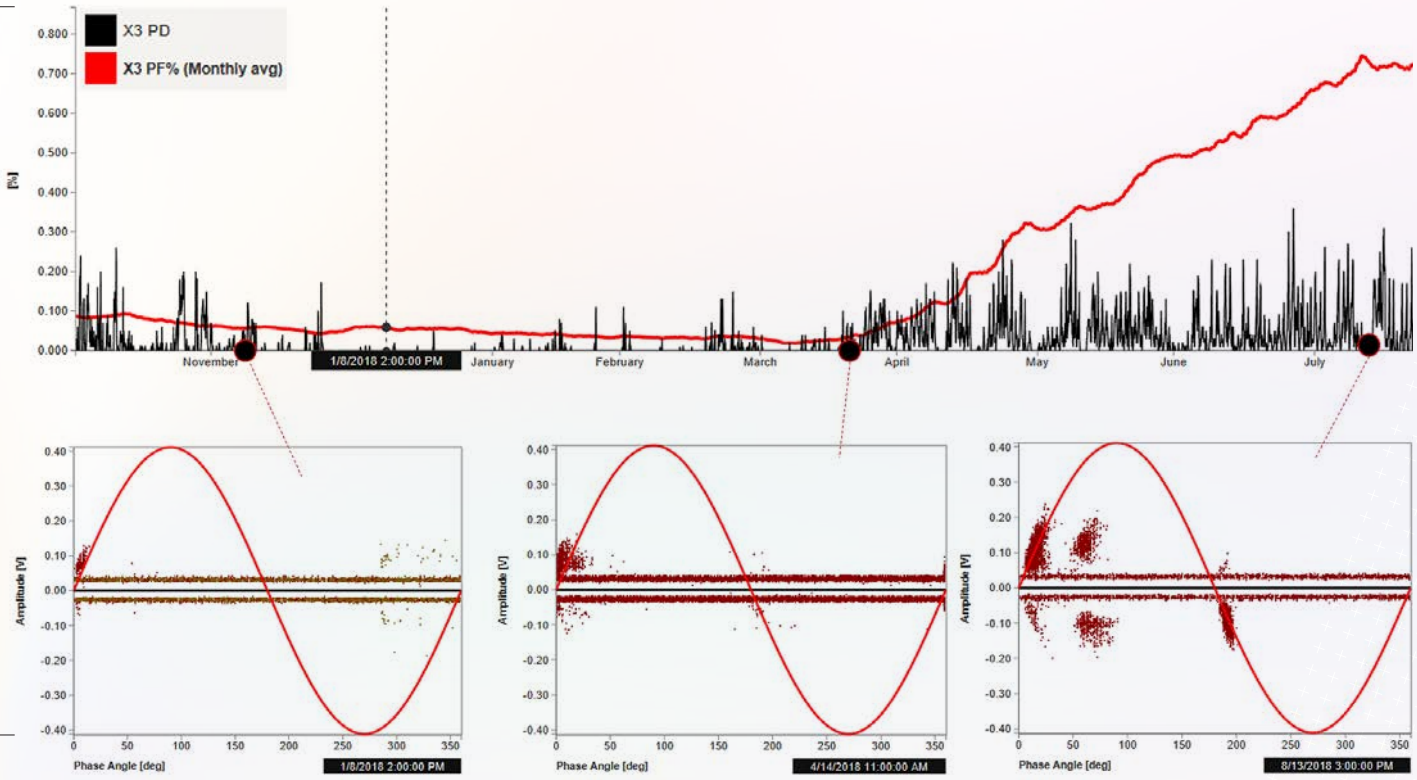
Figure 5. Increase of Power Factor (red trend line) in X3 bushing correlated with PD occurrence increase in the same bushing (black track)

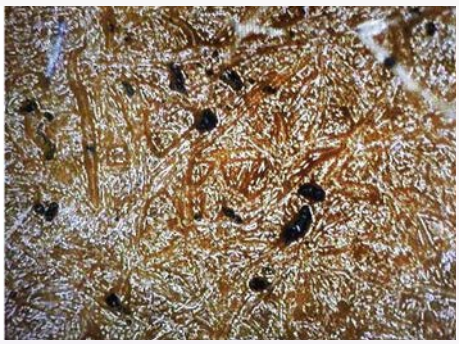
Figure 6. Metallic particles on the surface of the C1 core and in paper samples during microscopic analysis

Figure 7. RIP bushings, wall-mounted

Photo: Camlin

DGA - Hydrogen	9780 ppm
DGA - Methane	278 ppm
Oil Interfacial tension (IFT)	23.6 mN/m
Oil Dielectric Breakdown (BDV)	26 kV
Oil Tan Delta at 100°C	1.1%





confirming the increase detected by the monitoring system (Figure 8).

From the retrospective analysis of the data recorded by the monitoring system, it was possible to find some discharge activities in the same bushing about one month before the capacity increase (Figure 9).

The PD at that time was small, at inception stage, and with not enough intensity to warrant an alarm. However, they were already showing a typical PRPD pattern for cavities in resin [15].

The discharges remained active for no more than two days and then disappeared completely until the increase in capacitance, during which they were active again but, this time, increasing in both amplitude and repetition rate, as shown in Figure 10.

Conclusions

By adding the online Partial Discharges analysis to the relative variations of leakage current in transformer bushings it is possible to find out correlation patterns that enable failure mode identification and better planning of offline tests and maintenance.

In the cases reported in this article, it was possible to see how the PD analysis has helped to detect several different failure modes – internal arcing between control layers in OIP bushings; presence of metal particle-type contaminants in OIP bushings; and internal PD and control layer short-circuits in RIP bushings.

It must be pointed out that the PD system must be designed in a proper way to be effective and easy to interpret, i.e. following five important requirements:

- Continuously monitor PD
- Remove noise and cross-coupling automatically
- Discriminate whether the PD is in the main tank or in the bushing
- Detect arcing events with an extended amplitude range
- Get the synch reference signal from each bushing
- Provide at least one PRPD pattern per hour and trend with other parameters such as load, temperature, and leakage current

Particular attention should be paid to RIP bushings. Although they have much better PD characteristics if compared with RBP and OIP bushings, they can still be affected by defects after installation (due to bad storage or external events such us through-faults or over voltages) that can precipitate PDs.

BY ADDING THE ONLINE PARTIAL DISCHARGES ANALYSIS TO THE RELATIVE VARIATIONS OF LEAKAGE CURRENT IN TRANSFORMER BUSHINGS IT IS POSSIBLE TO FIND OUT CORRELATION PATTERNS THAT ENABLE FAILURE MODE IDENTIFICATION AND BETTER PLANNING OF OFFLINE TESTS AND MAINTENANCE.

From this experience it was decided to consider new alarm thresholds for PD activities in RIP bushings, as this case clearly indicated PD could be an important precursor of possible short circuits between the bushing control layers, thus allowing preventive and planned actions well in advance.

It should also be considered that in the absence of oil, and, therefore, of possible feedback given by DGA laboratory test, the Partial Discharge analysis acquired even greater importance in the context of RIP bushings, as a valid confirmation method whenever there is a correlation with the variations of the leakage current.

Failure mode analysis enhanced by online PD analysis

Table 2 shows a very simple summary of the influence and effectiveness of online PD monitoring during the diagnostic process in a number of real cases.

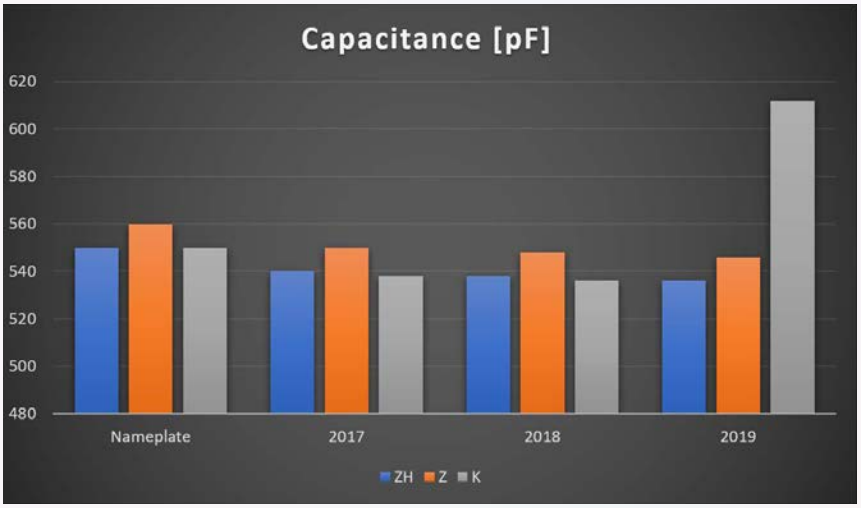
Figure 8. Results of offline Capacitance measurements over the years; Bushing K shows a Capacitance increase ranging between 14% and 15%

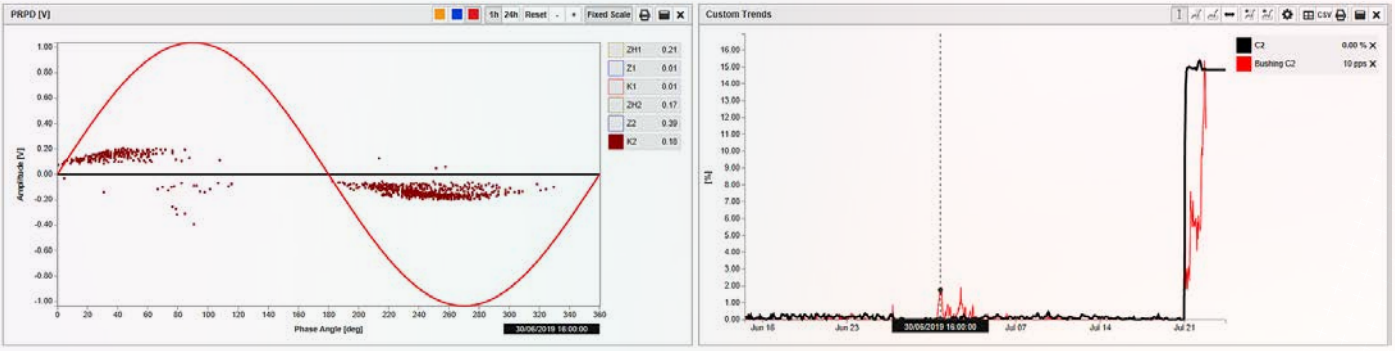
Figure 9. PRPD pattern recorded 20 days before the Capacitance increase

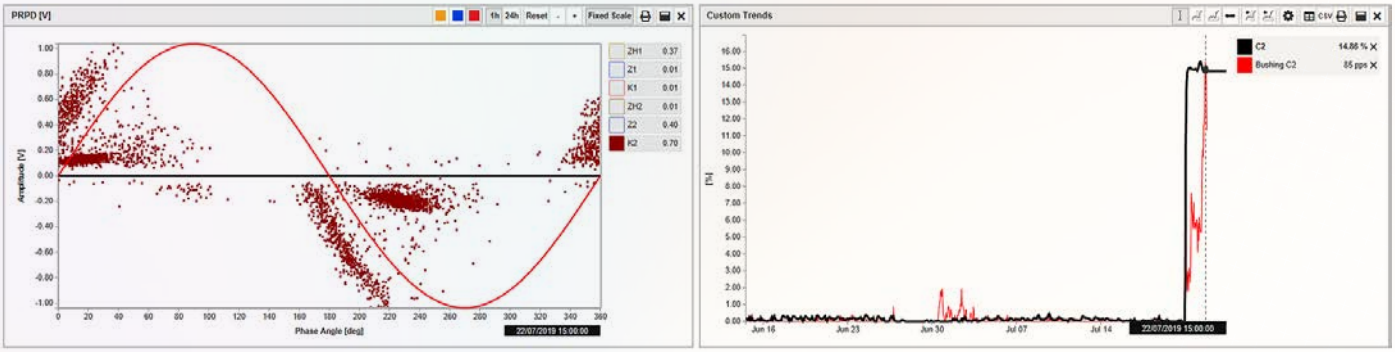
Figure 10. PRPD pattern right after the Capacitance increase (same full scale as Figure 9)

Table 2. Influence and effectiveness of online PD monitoring during the diagnostic process in a number of real cases

Photo: Camlin







Bushing technology and voltage	Primary marker	Hypothesis	PD characteristics	Diagnosis and suggested action	Offline test and evidence
OIP 345 kV (South Korea)	Capacitance step increase <2% alarm	Short circuit between layers, but absolute value too small to justify action	Single arcing PD event occurring at the same time of capacitance increase	Internal Arcing, make DGA test	DGA test showing >70 ppm C_2H_2 in the bushing. Replaced [6]
OIP 345 kV (North America)	Capacitance step increase <3% alarm	Short circuit between layers, but absolute value too small to justify action	Single arcing PD event occurring at the same time of capacitance increase	Internal Arcing, make DGA test	DGA test showing >20 ppm C_2H_2 in the bushing. Replaced [6]
OIP 130 kV (North America)	Relative Power Factor increase 0.5% alarm	Moisture contamination	Repetitive PD with increasing occurrence with Power Factor increase. Typical shape for particles in oil	Metallic contamination, make DGA and oil test	DGA test showing >9000 ppm H_2, low BDV. Bushing Replaced and inspected. Metallic particles found
RIP 110 kV wall-mount (Eastern Europe)	Relative Power Factor increase 0.5% alarm	Moisture contamination	Repetitive PD with increasing occurrence with Power Factor increase. Typical shape for particles in oil	Metallic contamination, make DGA and oil test	DGA test showing >9000 ppm H_2, low BDV. Bushing Replaced and inspected. Metallic particles found

Different from paper-oil technology, the epoxy resin cannot withstand PDs, which can quickly evolve into a short circuit between internal layers. While the DGA test of the bushing's oil represents a valid technique to confirm the occurrence of an arcing between layers, it does not apply to RIP bushings due to the absence of oil. But case #2 shows that PD online can be an equally valid alternative to confirm or prevent failures in the RIP bushings, especially if correlated with capacitance changes.

Acknowledgments

Many thanks to industry experts, friends and end-users for their contribution on this subject, with special thanks to Colin Clark from Altalink (Canada) and Claudio Angelo Serafino from Terna (Italy).

References

[1] CIGRE TB 755, Transformer Bushing Reliability, Feb 2019

[2] Dr. P. Werelius, Dr. D. Robalino, J. Cheng and M. Ohlen, "Dielectric Frequency Response Measurements and Dissipation Factor Temperature Dependence," 2012

[3] M. Ohlen, P. Werelius, "Dielectric Frequency Response and temperature dependence of power factor," 2010 IEEE International Symposium on Electrical Insulation

[4] Dr. D. Robalino, "Accurate Temperature Correction of Dissipation Factor Data for Oil-Impregnated Paper Insulation Bushings: Field Experience," 2011

[5] C. Clark and M. Lau, "Evaluation of Effectiveness of Dissolved Gas Analysis on Bushings," 2004

[6] M. Tozzi, "Risk Management Requires Actionable Insight: Adding Value with Truly Integrated Transformer Monitoring," *Transformer Technology*, Issue 3, pp. 88-96, 2019

[7] M. Tozzi, "Bushing failure prevention through the use of online monitoring: Detection under operating conditions, offline investigation and failure mode explanation," *Transformer Technology*, Issue 7, pp. 42-49, 2020

[8] V. V. Sokolov and B. V. Vanin, "Evaluation and identification of typical defects and failure modes in 110-750 kV bushings," 64th Int'l. Conf. Doble clients, 1997

[9] L.A. Dissado and J.C. Fothergill, "Electrical Degradation and Breakdown in Polymers," Institution of Engineering and Technology, 2008

[10] A. Cavallini, G.C. Montanari and F. Ciani, "Analysis of partial discharge phenomena in paper-oil insulation systems as a basis for risk assessment evaluation," IEEE International Conference on Dielectric Liquids, 2005

[11] M. Tozzi, C. McIlroy, C. A. Serafino and M. Rebolini, "Condition Based Maintenance on 400 MVA Autotransformers: A Case Study," CIGRE VII Workspot, A2 PS1, Rio de Janeiro, 23-26 Nov, 2014

[12] A. Cavallini, F. Ciani, M. Conti, P. F. H. Morshuis and G. C. Montanari, "Modeling memory phenomena for partial discharge processes in insulation cavities," 2003 CEIDP, pp. 723-727

[13] A. Cavallini, F. Ciani and G. C. Montanari, "The Effect of Space Charge on Phenomenology of Partial Discharges in Insulation Cavities," 2005 CEIDP, pp. 410-413

[14] K. Azmi, A. Zuhairi, D. Ishak, N. A. Muhamad and M. Kamarol "Partial discharge characteristics of spherical metal particle in mineral oil and PFAE under AC voltage," IEEE Region 10 Conference (TENCON), 5 - 8 Nov 2017, pp. 2588 - 2593

[15] J. M. Rodríguez-Serna, R. Albarracín-Sánchez, M. Dong and M. Ren, "Computer Simulation of Partial Discharges in Voids inside Epoxy Resins Using Three-Capacitance and Analytical Models," Polymers 2020, 12(1), 77

Photo: Camlin

The most trusted name in Transformer Oil Purifiers since 1975

Mobile

Trailerized transformer oil purfication rigs in numerous sizes, configurations and flow rates to work with the transformers in your substations.

In-Plant

Transformer oil purifiers for single or mult-pass performance to meet your production's product filling needs. Vacuum storage tanks and other accessories also available.

Online Energized

Portable, vacuum-based machines for efficient online, energized drying, gas reduction and filtration without the need for media regeneration or replacement.

Cold Traps

Cascade and Liquid Nitrogen traps to capture moisture during vacuum evacuation and drying.

Vacuum & Dry Air

In numerous pumping speeds and pump combinations for evacuation and dry air vacuum break of vacuum chambers, transformers and other devices.

Fullers Earth

For improvement of color, acid no. interfacial tension and power factor.

Vacuum Chambers

For heating, vacuum drying & oil filling / impregnation of transformers, capacitors, bushings, medical components & other devices.

Baron USA, LLC

www.baronusa.com * leads@baronusa.com

Francis Fisher &

Vice President of Global Marketing
at Weidmann Electrical Technology

Interview with **Francis Fisher**

Tom Prevost

WEIDMANN

Vice President of Innovation and R&D for the Americas

and **Tom Prevost**

Photo: Weidmann Electrical Technology

Weidmann's Saint Johnsbury Center in Vermont

Weidmann Electrical Technology is a leading integrated solutions provider in the energy sector. The company has been at the heart of the global transformer industry for over 140 years. In this interview, we talked to Francis Fisher, Vice President of Global Marketing, and Tom Prevost, Vice President of Innovation and R&D for the Americas.

Weidmann headquarters in Rapperswil, Switzerand

Photo: Weidmann Electrical Technology

Alan Ross: Weidmann has a unique perspective in the transformer industry, being an energy solutions leader for almost a century and a half. I would like to hear your take on the trend that we are seeing due to a global change taking place as transformers are aging. There are new installations going up, and we have moved from a step-down system to an inverter-based system which I call the step-everywhere system. The other interesting thing is the innovation that Weidmann is working on in the field of transformer cooling.

Francis, tell us about Weidmann and why we know you as the ubiquitous leader in the electrical insulation market.

Francis Fisher: Thank you for the introduction, Alan. I think the longevity of Weidmann in the industry speaks for itself. We invented Transformerboard over 80 years ago and through the efforts of people like Tom and many before him, we continued with an innovative internal culture. Weidmann began life as a carton producer and eventually recognized that far more could be achieved with this material than basic boxes. From there we developed a technological process to produce Transformerboard. We took the material and went further with it through innovation, creating cylinders, components, eventually Barrierboards and all the technologies within the insulation world that most transformer manufacturers are very familiar with today. We also produce thermally upgraded papers, developed a relationship with Dupont™ and began producing Nomex® Transformerboard for use in electrical insulation applications. And still today we further innovate with our materials, branching out into other non-electrical fields with our Weidmann CSM business and Fiber Technology areas.

Apart from being around for a long time, we are also known for working closely with our customers around the world. Tom and I were talking about the expansion of our global footprint recently, and we recalled the saying "The sun never sets on the British Empire" and wondered if the sun ever sets on Weidmann today (laughs). There's a big gap between Shanghai and the West Coast of the U.S., but we are pretty close. We have 25 locations across the globe, a mix of production sites, diagnostic laboratories and sales offices. Apart from major production plants here in the U.S. - such as the one in Vermont where Tom is located - and our paper center of excellence in Ohio, we have a production site in Mexico, as well as key sites in Europe and Asia, so we are well covered in the global market.

Weidmann invented Transformerboard over 80 years ago and through the efforts of people like Tom and many before him we continued with an innovative internal culture.

A lot of the transformer industry is becoming more globalized today. We see it every day, with requests from our customers to provide global contracts and supply agreements. I think we are well positioned. We have a good footprint, and, ultimately, we do our best to produce a reliable, quality product, so our customers seem to stick around.

Weidmann has 25 locations across the globe, a mix of production sites, diagnostic laboratories and sales offices. We have two key production plants in the U.S., Mexico, as well as sites in Europe and Asia.

AR Tom, what is your perspective as Weidmann's head of innovation?

Tom Prevost: When Francis was talking about the history, it really shows our focus on innovation. What I think brought Weidmann to the forefront of the supply of electrical insulation material was the invention of the pre-compressed Transformerboard around 1950. At the time, it really solved an industry problem of load going up. The fault current was going up considerably and transformers were often failing due to short circuit faults. The pre-compressed Transformerboard has much higher density and better compression characteristics, which solved the industry problem by making transformers much stronger and able to withstand the forces from the faults.

That became the norm. Once Weidmann patented Transformerboard, other people adopted that technology, and it is the standard for cellulose boards today. That was truly the innovation that brought Weidmann to the forefront and the reason they came from Switzerland to the Americas. The technology was developed and then it was known worldwide.

AR What are some of the innovative projects that Weidmann is working on now that you think are going to be the standard come tomorrow?

TP One of the real hot topics in the industry right now is the electrification of the energy sector - everything from vehicles to smart buildings - that is largely driven by the goal to be green. Renewable resources allow for much better control of greenhouse emissions, but that is going to change the whole grid. And because transformers are integral to the movement of electricity across the grid, it is the transformers that are going to see significant change in the way that they are loaded, and also how much they are loaded.

What brought Weidmann to the forefront of the supply of electrical insulation material was the invention of the pre-compressed Transformerboard. Once it was patented, it became the norm and it is the standard for cellulose boards today.

A big effort in the industry right now, which we at Weidmann are also focusing on, is how you can take that load and not affect the life of the transformer, be it the same size transformer or a bigger one. What we are doing is trying to increase the temperature capability of the insulating materials.

Renewable resources are going to change the whole grid. And because transformers are integral to the movement of electricity across the grid, they are going to see significant change in load.

AR Tom, I remember hearing your presentation at the Weidmann conference about the unique approach to the insulation material to be able to handle high heat generated as the result of increased loads. Sitting in the audience I thought, That's brilliant, I need them to talk about it. Could you address that?

FF I think this is a really interesting topic, not just for transformer operators or transformer producers, but also for power consumers. I always want to know about the real application in the non-engineer world. A topic Tom and I recently discussed was the shift from people working in central offices and more towards remote home offices or smaller regional offices. I asked Tom what the impact is going to be. If EV charging is attached to residential areas, there is going to be an increase in load, but predominantly overnight. That is

Photo: Weidmann Electrical Technology

not necessarily overloading the transformers or grid - but it will certainly impact the load profile. But what happens when I turn up at a small regional office with ten colleagues and we have come from different parts of the state or the region all in EVs? Alan, you mentioned the Weidmann conference, which we usually have at a hotel. What if all the participants plug their cars in and we run the hotel to death because of the high-power consumption? That is not an everyday occurrence, but how do we prepare for such days when they do come along? What do you think, Tom?

TP I think we have a solution (laughs). And it is not just Weidmann. I think there are two opposing situations going on in the industry right now. One is that we want to be as efficient as possible, and that is being driven by the Department of Energy and efficiency standards. But at the same time, we are looking to increase the load on our system more and more.

When we talk about thermal issues, that is because heat is an inefficient byproduct of running current in a transformer; it is a waste. So, one of the things that we are looking at in the industry, and there was a presentation about it at IEEE transformer committee two meetings ago, is a dual-rated distribution transformer. The idea is that the transformer would be sized for the typical load that you would see, so the efficiency ratings on it would be at that base loading. There would be the ability, by using high temperature insulation, to have a higher thermal rating for those times that the transformer is overloaded. It would have lower efficiency, but greater longevity. If this was done with a normal transformer, it would last five years and it would have to be replaced, which is again waste. Here, you are able to use higher temperature insulating materials and get the dual rating.

The challenge there is how much more you want to pay for this dual-rating transformer. We are currently working with innovation to give the transformer buyer or the manufacturer more options. For example, Weidmann makes paper called INSULutions® DPE (Diamond Pattern Enhanced), which gives a 10-degree higher thermal rating than normal paper. With the 10-degree higher rating, the transformer could be overloaded by 12% and have no loss of life.

You can then change out the typical mineral oil, and replace it with some of the higher-temperature fluids, such as natural and synthetic ester, to get another 10 degrees. That is a bit more expensive, but it provides another option. Dupont™ makes a material called Nomex®, which is now, actually rated at 200 degrees. This allows a 95-degree temperature rise, 30 degrees higher than normal, and then you can add up to 50% more load. A lot of different options are coming out, which we are going to need as the grid evolves. It's difficult to know what your load profile is going to be, and you would sure want to avoid switching transformers as that load profile changes.

One of the technologies that we are looking at in the industry is a dual-rated distribution transformer with higher thermal ratings at the time of overload due to its high-temperature insulation. It would have lower efficiency, but greater longevity.

AR Exactly, the world is changing, and the whole grid is changing. People are trying to go greener. I would like you to go a little bit further ahead. What is Weidmann's vision for the new engineers just coming out of college? What kind of a situation in the industry do you think they are going to be facing in a decade or two?

TP Everything will be electric. I have always imagined that my grandkids would drive EVs, that they wouldn't even have the choice to drive a gas-powered car unless it's an antique. The integration of renewables will be figured out. Our power supply will be at least 50%, probably 70% powered by renewable energy. And a lot of that is going to be rooftop solar energy, local power plants, etc. The day of power going in one direction from the power plants into homes will be gone. There will be power going in all directions, and the load profiles that we have been used to will be entirely different. Most of that power is going to be generated by DC, and I think that we are going to have DC grids. The standards for low-voltage DC grids are being discussed right now. Why bother to convert it back to DC and then to AC when we can keep it in DC and have a DC grid?

Energy consumers in the future are going to be more energy-aware, more involved and more demanding for energy providers.

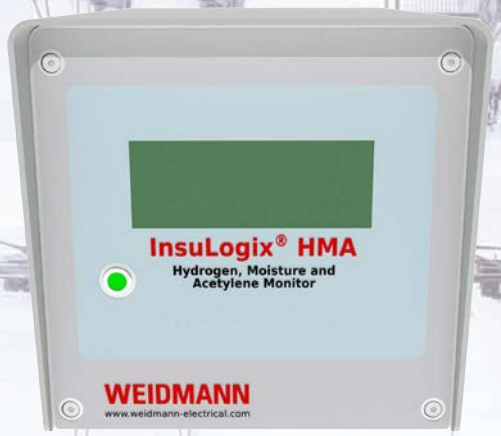
FF What we are also seeing today is the change in consumers of energy. Far more information is accessible. In the past, people used to have a lot less insight into how much energy is generated and consumed. You would receive your bill at the end of the month and you paid it. Our energy consumers in the future are going to be more environmentally aware, and also more demanding for energy providers. There is a requirement for reliability, but also for power quality. The distribution companies who operate transformers have to become a lot more transparent as electricity is becoming much more front and center in our daily life. People are more aware that energy is a critical part of their lives today. More and more automation is incorporated into households, and that is only going to increase the consumers' interest in energy consumption, reliability and quality.

AR Thank you, gentlemen, this was very insightful.

Photo: Weidmann Electrical Technology

InsuLogix® HMA

HYDROGEN, MOISTURE AND ACETYLENE MONITOR



Will you MAINTAIN or REACT?

The missing link between Hydrogen & Multi-Gas transformer monitors

World's first online transformer DGA monitor using highly accurate laser technology

The lowest total cost of ownership of any Acetylene capable online DGA

Prioritize critical gases identify transformer faults

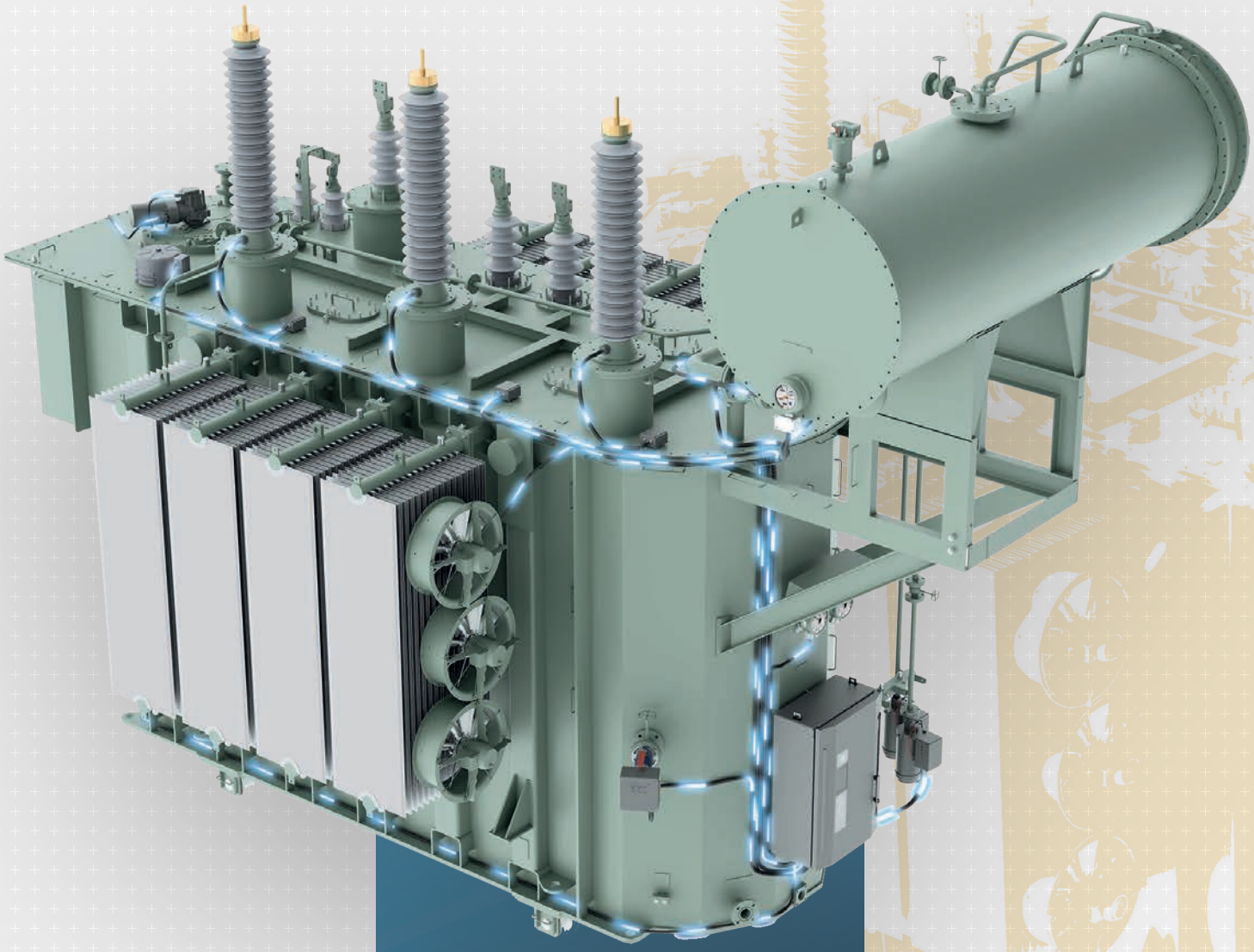
Hydrogen + Acetylene = Maintain or React

WEIDMANN

WANT TO LEARN MORE?

www.weidmann-electrical.com/hma

MSENSE® BM & ETOS® - Bushing monitoring



Early detection of high-voltage bushing failures

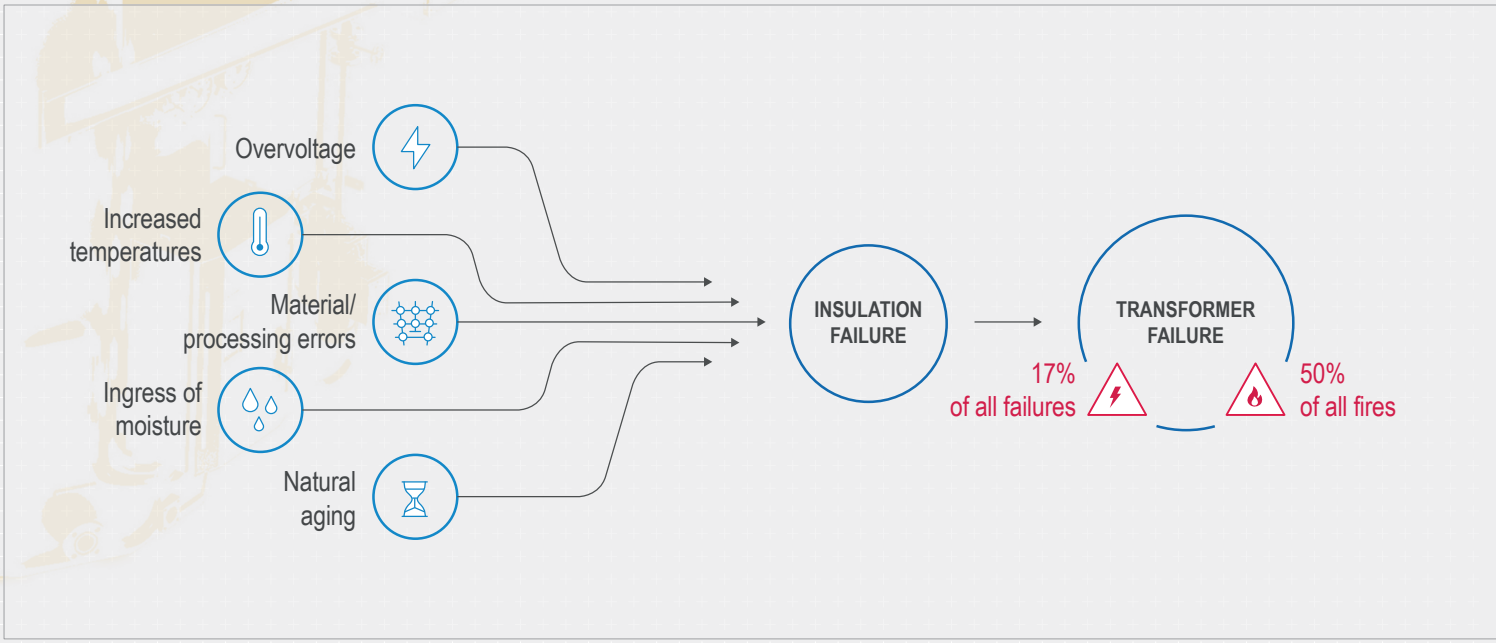
Photo: Maschinenfabrik Reinhausen GmbH

The requirements for the availability and reliability of power transformers are constantly increasing – as is the grid load, which can cause critical problems. 17% of transformer failures can be traced back to defective bushings, which are also the main cause of 50% of transformer fires [Cigré A2.37]. A typical manufacturer-specific service life of capacitance-controlled high-voltage bushings is 25–30 years, which is typically less than the service life of transformers. Online condition monitoring and assessment of bushings is therefore recommended. Bushing monitoring from Maschinenfabrik Reinhausen (MR) makes it possible to detect errors in bushings early and derive actions before the transformer is greatly damaged.

For electrical field grading, high-voltage bushings above a certain voltage level are almost exclusively equipped with capacitive grading layers which are exposed to high electrical, thermal and mechanical loads during operation. Bushings can age prematurely due to transient overvoltages, increased temperatures, temperature fluctuations or the ingress of moisture. This can cause partial breakdowns, which can quickly lead to failure of the insulation in the bushing or even serious transformer malfunction.

Bushing monitoring from Maschinenfabrik Reinhausen (MR) makes it possible to detect errors in bushings early and derive actions before the transformer is greatly damaged.

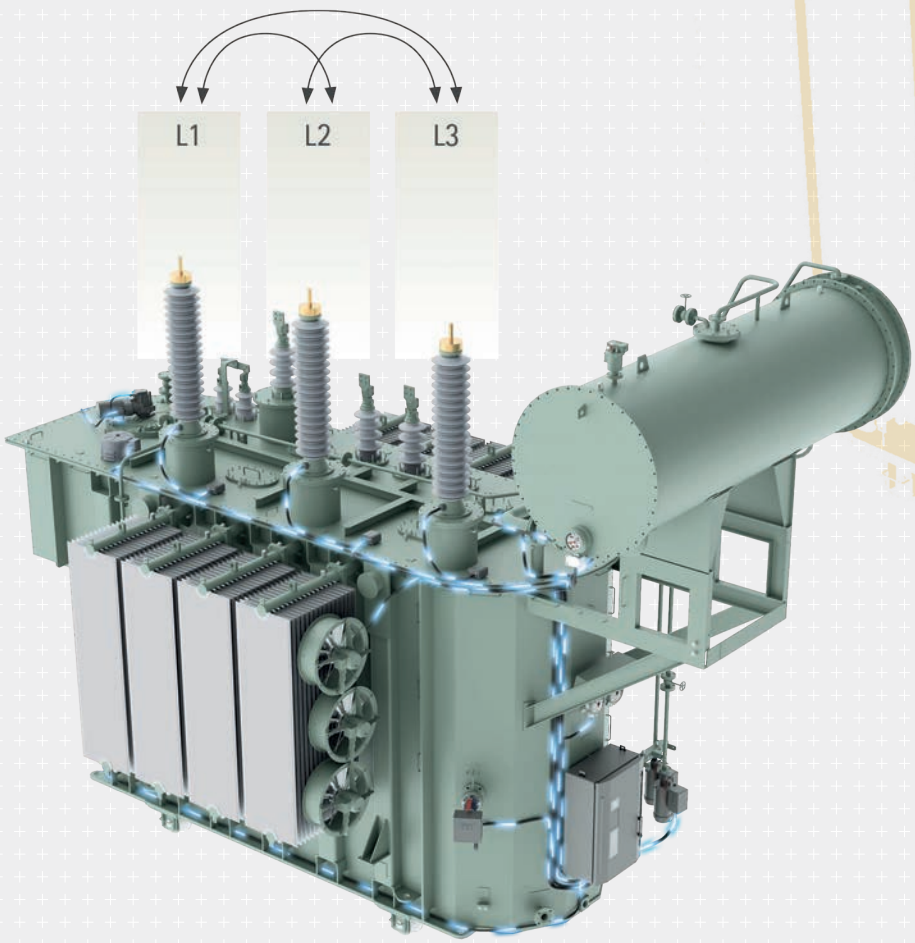
To optimally prevent this kind of damage, the MSENSE® BM online monitoring system and the bushing monitoring function of ETOS® continuously measure condition-related variables directly on oil-impregnated (OIP) or resin-impregnated (RIP) paper bushings, or resin-impregnated synthetic bushings (RIS/RIF) in the voltage levels Um = 66 kV...420 kV (more available on request). Continuous online condition monitoring enables early detection of changes in the insulation condition.



Several methods for online condition monitoring of bushings have been developed in recent years. Along with oil analyses and partial-discharge measurements, the main capacitance (C1) and the dissipation factor (tan δ) are the two definitive parameters for determining the insulation condition of high-voltage bushings. For online monitoring, two facts in particular must be noted. Firstly, a suitable reference system that functions under field conditions is needed. Secondly, the dielectric parameters of the bushings are heavily dependent on operating conditions such as temperature. These two factors make it difficult and complex to monitor an individual bushing online using specific temperature reference curves.

MSENSE® BM and the bushing monitoring function of ETOS® use an innovative, field-tested and patented 2/3 reference method which monitors the condition of the inner capacitance linings for bushing field grading in terms of a change in capacitance (C1) and dissipation factor (tan δ). The key aspect of this process is that because the algorithm continuously incorporates all three bushings per field in the mutual monitoring, the temperature dependence on loading or weather is eliminated due to the globally patented 2/3 reference method. Furthermore, the signals of the respective voltage transformers are used as the reference for detecting the symmetry of the three-phase system. The measurement is checked for validity, and grid asymmetries are effectively equalized and eliminated. The 2/3 reference method ensures that the influence of temperature and voltage fluctuations on a bushing monitoring system is effectively limited.

MSENSE® BM and the bushing monitoring function of ETOS® use an innovative, field-tested and patented 2/3 reference method which monitors the condition of the inner capacitance linings for bushing field grading in terms of a change in capacitance (C1) and dissipation factor (tan δ).



Changes to the capacitance and the dissipation factor of the bushings are compared with limit values. Only the measurement of system-side voltage transformers is required to determine the symmetry of the line voltage. Thus, a reliable and clear evaluation of the condition of the high-voltage bushings can be ensured – regardless of grid asymmetries or voltage fluctuations. If the bushing values of one phase (C_1 or tan δ) deviate from the specifications, the user is alerted via a two-stage limit-value process. This means that faults in the insulation system can be effectively detected and the user can intervene in good time, before a fatal failure occurs.

Photo: Maschinenfabrik Reinhausen GmbH

MSENSE® BM and the bushing monitoring function of ETOS® essentially consist of three or six bushing coupling units (one for each bushing), three or six bushing adapters (one for each bushing) and the evaluation unit. The bushing adapter accesses the measured voltage at the test tap of the bushings. The bushing coupling unit with suitable capacity is responsible for adapting the measured voltage and sends the values to MSENSE® BM or ETOS®.

At Slovenian energy provider ELES, MSENSE® BM has been in operation successfully for about a year on a 600 MVA phase shifter transformer (PST). As part of yearly maintenance, the previous monitoring system was replaced by the new MSENSE® BM bushing monitoring system from MR on both PSTs.

All elements have an IP66 degree of protection. Communication takes place in all common control system standards (e.g. IEC 61850). The modern graphical display and intuitive user interface support the user and make the system easy to use.

At Slovenian energy provider ELES, MSENSE® BM has been in operation successfully for about a year on a 600 MVA phase shifter transformer (PST). As part of yearly maintenance, the previous monitoring system was replaced by the new MSENSE® BM bushing monitoring system from MR on both PSTs.

MSENSE® BM was quickly and easily attached to each of the twelve OIP (oil-impregnated paper) bushings of all phase shifter transformers, and the parameters already stored in the system were individually adjusted as needed. Since then, electricity has flowed between Slovenia and Italy more reliably than ever.

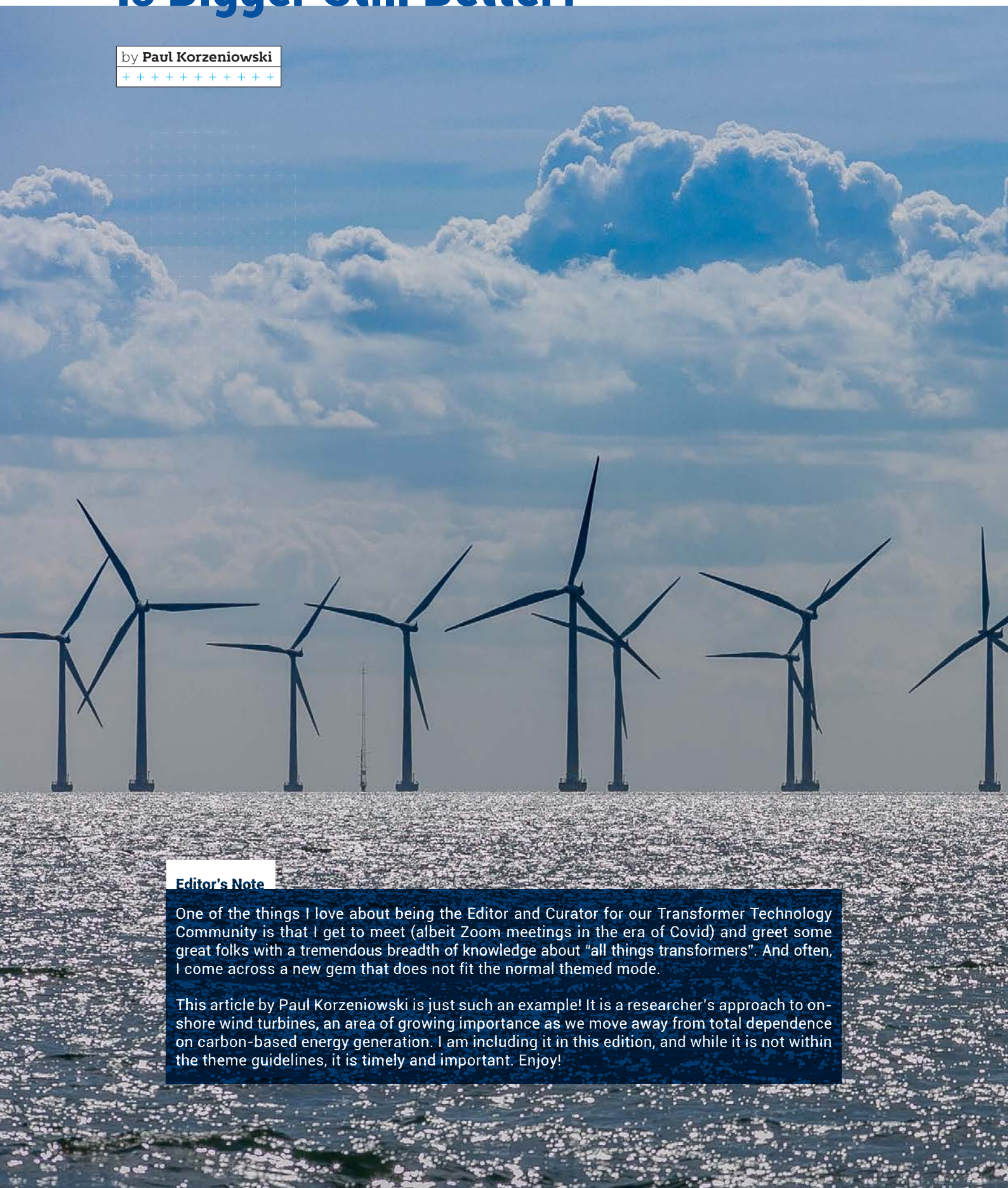
Aleksander Polajner, Head of the High-Voltage Device Department of ELES, explains the decision. **"Overhauling phase shifter transformers is challenging and must be carefully planned. These devices control the flow of powerful electrical loads between two countries, and therefore guarantee the safe, reliable, interruption-free transfer or exchange of electricity. The service technicians' main area of focus during maintenance is the bushings. Bushings are some of the most important parts of the transformer. Fault-free operation of these transformers depends greatly on the various weather conditions, which means that continuous condition monitoring is essential. Because the existing system had to be replaced, we began looking for a new solution, and we chose the MSENSE® BM from MR. Our experience in recent years has demonstrated that MR offers excellent support as well as innovative, reliable and safe solutions. By deciding to implement the MSENSE® BM monitoring system going forward, we are already benefiting today from service from a single source."**

Maschinenfabrik Reinhausen GmbH
Falkensteinstraße 8
93059 Regensburg, Germany

Contact:
Janusz Szczechowski
Product Manager
J.Szczechowski@reinhausen.com
www.reinhausen.com

Onshore Wind Turbines: Is Bigger Still Better?

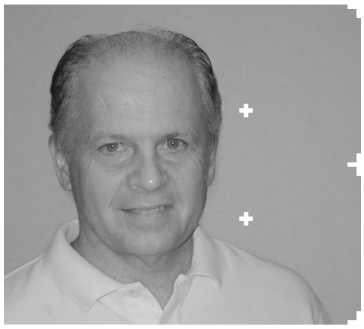
by **Paul Korzeniowski**



Editor's Note

One of the things I love about being the Editor and Curator for our Transformer Technology Community is that I get to meet (albeit Zoom meetings in the era of Covid) and greet some great folks with a tremendous breadth of knowledge about "all things transformers". And often, I come across a new gem that does not fit the normal themed mode.

This article by Paul Korzeniowski is just such an example! It is a researcher's approach to onshore wind turbines, an area of growing importance as we move away from total dependence on carbon-based energy generation. I am including it in this edition, and while it is not within the theme guidelines, it is timely and important. Enjoy!



Paul Korzeniowski, BCC Research, is a market research analyst and energy industry consultant with more than two decades of experience. He is a contributing editor to a variety of business and industry publications, including *Energy-Biz, Forbes, Investor's Business Daily* and USA Today. His work has centered on determining major market trends in the development of new energy markets and on the emergence of new technologies such as wind turbines. He has authored reports on markets for emerging technologies, like the Internet of Things, data analytics, artificial intelligence and machine learning.

Many factors are driving increased energy demands across the globe. Urbanization is impacting impoverished areas in Africa, Asia, and South America. Concerns about the environment are growing and countries are trying to lower carbon emissions. As a result, interest in renewable energy is increasing. In fact, there is a growing chorus that considers climate change the most significant problem the world faces today. Onshore wind is a much more environmentally friendly energy source than alternatives such as coal, oil and natural gas. Consequently, wind is expected to become a more significant energy contributor in coming years. These solutions have been used for decades and are becoming popular energy sources in many countries. Onshore wind energy equipment sales generate billions in revenue globally. Long-term contracts ensure that revenue will continue to flow in the coming years. These factors are driving market growth, which is expected to average 4.6% through 2025.

Onshore wind energy equipment sales generate billions in revenue globally. Long-term contracts ensure that revenue will continue to flow in the coming years. These factors are driving market growth, which is expected to average 4.6% through 2025.

Large new wind turbine devices have been making their way to market. They offer vendors the opportunity to deliver more wind power at lower rates. However, the technology needed for these devices, and their transportation and installation hurdles, means there is limited acceptance. The adoption of such devices is taking place but should be a slow, steady growth rather than a dramatic surge.

However, not all of the signs are positive. Through the years, vendors struggled to build cost-effective business models, and the challenges are increasing. Delivering these systems is a significant, complex undertaking. Onshore wind solutions are complicated pieces of machinery that become more complicated every day. These systems are difficult to build, transport, deploy, and maintain. With computer technology evolving at a breakneck pace, the onshore wind system marketplace is ever changing.

To date, governments have been underwriting market development with various tax breaks and other incentives, but the offsets have been subject to the whims of different political parties. Changes in regulations in Germany have proven dire for three of industry's market leaders: Enercon, Nordex and Senvion. They have seen revenue plummet, sparking various transition plans, including selling off their core assets.

As a result, the onshore wind market is at a key transition point. The market is consolidating. The top four suppliers account for 69% of the market total. Moving forward, the emphasis is on building bigger turbines. While they do offer greater performance, they are complex and expensive to build. Vendors take on that work with no guarantee of success. Any significant missteps will result in additional consolidation, leaving the top suppliers in even more dominant positions.

Market Projections

The onshore market is showing growth, but its development has come in different global phases. The technology first sprouted in Europe in areas like Denmark, where wind power had historical roots. Such areas have matured after investments by early market developers, Germany and the U.K. The U.S. has been near the front as well with a great deal of work taking place in large energy-producing and energy-dependent states, like California and Texas. Recently, Asia, due mainly to investments in China, has become the market bellwether. China has a number of wind projects that are coming online and others that are working their way into the pipeline. North America, which has been slow to adopt the technology, also shows promise. The European market has slowed down and its outlook is cautious during the next few years (Figure 1, Table 1).

Nordic Countries Spur European Growth

Vendors have had success with new European projects. In November 2019, Siemens Gamesa won the bid to supply the Stavro project, a large onshore wind order in Sweden. Stavro is located in the northern part of Sweden, northwest of Umeå, and divided into two sub-sites: Blodrotberget, with 40 turbines, and Blackfjället, with 22 turbines, for a total installed capacity of 254 MW. The 62 turbines built, each with a 4.1 MW rating, will help power a Google data center with clean energy as well as the area's paper and board business. The commissioning of the wind farm is scheduled for the end of 2021 and the project will be covered by a 30-year service agreement also delivered by SGRE. To connect to the country's grid connection, Siemens Gas and Power will create two 150/33 kV sub-sites.

In December 2019, Vestas was awarded a 101 MW order from Puhuri Oy, a developer and investor in wind energy overseeing the Parhalahti and Hankila developments in Northern Ostrobothnia, Finland. Both projects will use EnVentus V162-5.6 MW turbines with a 166 m hub height and a 25-year full scope service agreement.

In March 2018, Senvion installed 3.0M122 wind turbines for BayWa r.e. and its wind farm Les Landes, located in the French department of Haute Vienne. The turbines have a tip height of 200 meters.

The European market has been showing signs of maturity. With the continent showing low economic growth, governments have begun to cut back on their subsidies. As a result, fewer new projects are being undertaken, and growth is mainly coming from expansion to existing farms.

Despite headlines, the European market has been showing signs of maturity. With the continent showing low economic growth, governments have begun to cut back on their subsidies. As a result, fewer new projects are being undertaken, and growth is mainly coming from expansion to existing farms. Germany has been a staunch supporter but dramatically cut back its wind investment. This change forced vendors to take dramatic actions, like selling off product lines and reducing headcount, to remain viable.

China Drives Asian Growth

The Asian market grew at high rates in the 2010s. China, which had been on an unprecedented path of economic growth, began to emerge as the world's second-leading economic engine and the fastest-growing one among established nations. China has the world's largest population; it is the third largest country geographically, with abundant natural resources and a rapidly expanding economy. The country's GNP started to increase by double-digit numbers near the turn of the millennium. By 2019, the country generated $13 trillion in GNP and

Photo: Shutterstock

Region	2019	2020	2025	CAGR% 2020-2025
North America	7.2	7.6	9.3	4.1
Asia	6.9	7.5	10.4	6.8
Europe	7.7	8.0	9.9	4.4
Total	21.8	23.1	29.6	4.6

Table 1. Global market for onshore wind systems, by region, through 2025 ($ Millions) [Source: BCC Research]

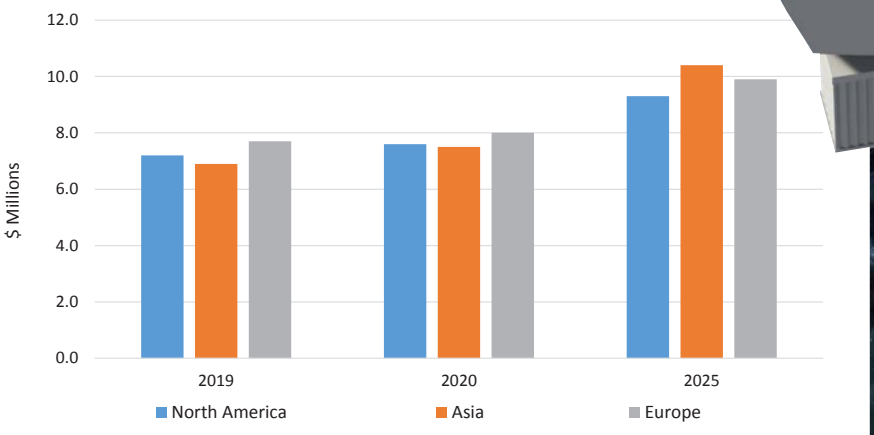


Figure 1. Global market for onshore wind systems, by region, 2019-2025 ($ Millions) [Source: BCC Research]

became the world's second-largest economy. As successful as the U.S. was economically in the 20th century, China is on a more impressive path in the 21st century. As a result, the country has become a major market force. The changes moved the country to a prominent market position in many markets, including onshore wind.

China has an interesting business model. The country opened itself up and joined the world as a trading partner at the turn of the millennium, but it did so in such a way that would enable it to maintain control over its own markets. Foreign companies are not allowed to come into China by themselves; they had to partner with a Chinese firm, which is to always maintain the majority position in any joint venture. As a result, China maintains tight control over internal developments. In addition, the contract awarding process is done by local government officials, which has resulted in Chinese suppliers being in extremely strong positions to emerge as the winners in competitive bidding situations. With respect to wind energy, the end result is that the Chinese are cultivating their own wind turbine suppliers and shutting out much of the rest of the world. Domestic suppliers such as Envision, Goldwind, MingYang and SEwind command the bulk of the domestic market. A few outsiders have had some success.

Asia's Economic Growth Broadens

Other countries in Asia have also been gaining economic mass and market appeal. Japan has long had a strong economic foundation. Recently, India and South Korea gained momentum and are among the world's top ten GNP revenue generators. Taiwan has aggressive plans in the wind turbine market. The result of these developments is that a number of new projects are coming online in this region.

Interest Increases in the U.S.

The U.S. market has been slowed by the actions of the federal government, which had been offering tax incentives and other incentives to encourage the growth of wind products. When the time period for those items was closing, utilities and vendors rushed to deliver those systems. The ongoing back-and-forth in the trade wars also had a chilling effect on the market. But some new projects were commissioned, nonetheless.

The U.S. market has been slowed by the actions of the federal government, which had been offering tax incentives and other incentives to encourage the growth of wind products.

MidAmerican Energy Company chose Siemens Gamesa equipment for the Southern Hills Expansion wind power project in Iowa, in August 2019. The plans include 21 SG 4.5-145 wind turbines, operating at 4.8 MW. This contract includes a service and maintenance agreement for three and a half years.

In December 2019, Vestas received an order for 149 MW of turbines, consisting of 12 V110-2.0 MW turbines and 57 V120-2.2 MW turbines for a wind project in the U.S. The order includes a multi-year service agreement. Turbine delivery will begin in the second quarter of 2020 with commissioning scheduled for the fourth quarter of 2020.

In August 2018, Potentia Renewables Inc., a Toronto-based company, opted for Goldwind turbines for its windfarm project.

Size Matters

Through the years, suppliers have tried to improve returns by moving toward larger turbines and bigger rotors. In the 1980s, turbines produced less than 0.1 megawatts. Today's systems supply multiple megawatts. The movement is driven by the desire for lower energy generation costs.

Wind systems generate more power in a few ways. One option is to build bigger rotors and blades. As a result, the turbine capacity increases because it engulfs a bigger area. Placing the blade higher up in the atmosphere also improves performance. There, winds blow stronger and more consistently, so the system creates more power during the day.

Large turbines are making headway in the market. A number of vendors have showcased their big blade systems. Goldwind Americas deployed its GW 3MW(S) Smart Wind Turbine test unit at the UL Advanced Wind Turbine Test Facility located at West Texas A&M University at the end of 2018. The 3-megawattt turbine has an assembled hub height of 130 meters and a blade tip height of 199.2 meters.

In May 2019, Senvion launched its latest turbine model, the Senvion 4.2 MW turbine, with two rotor diameters: the Senvion 4.2M140 and 4.2M148.

Suppliers are transitioning their systems from smaller designs generating less power to larger systems and more power.

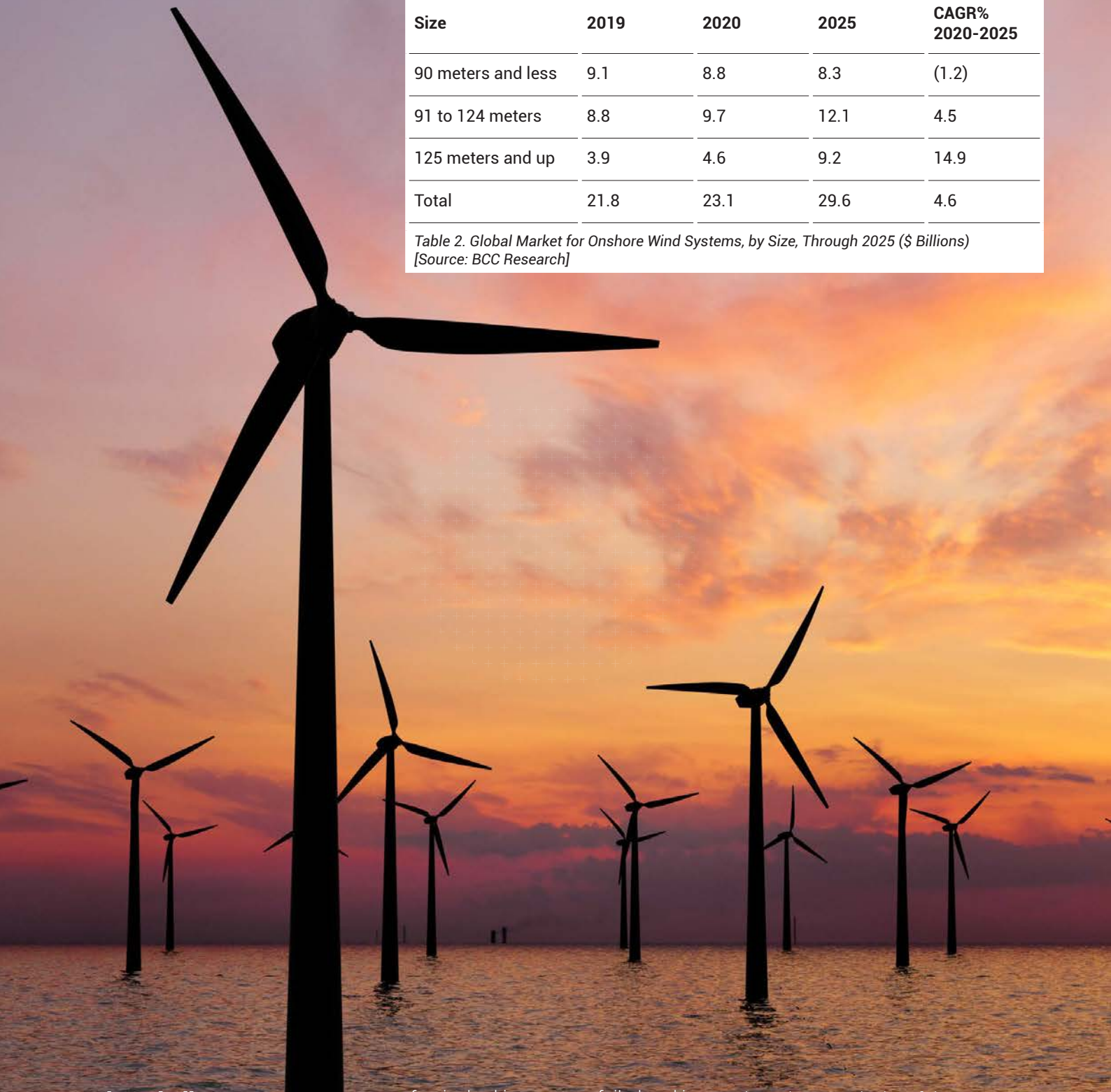
Siemens Gamesa installed 42 4.X systems with 145-meter rotor units creating 4.8 MW of energy in China. The company will provide operation and maintenance services for five years at a 200 MW project developed by utility Xinjiang TBEA Group.

Suppliers are transitioning their systems from smaller designs generating less power to larger systems and more power. The bulk of their income comes from recurring revenue streams with existing long term (multiple decade) contracts. The newer, larger systems will come online in the next few years and account for larger slices of the overall market. The market now falls into three categories designated by turbine size: 90 meters and lower; 91 to 124 meters; and 125 and up (Table 2).

Photo: Shutterstock

Size	2019	2020	2025	CAGR% 2020-2025
90 meters and less	9.1	8.8	8.3	(1.2)
91 to 124 meters	8.8	9.7	12.1	4.5
125 meters and up	3.9	4.6	9.2	14.9
Total	21.8	23.1	29.6	4.6

Table 2. Global Market for Onshore Wind Systems, by Size, Through 2025 ($ Billions) [Source: BCC Research]

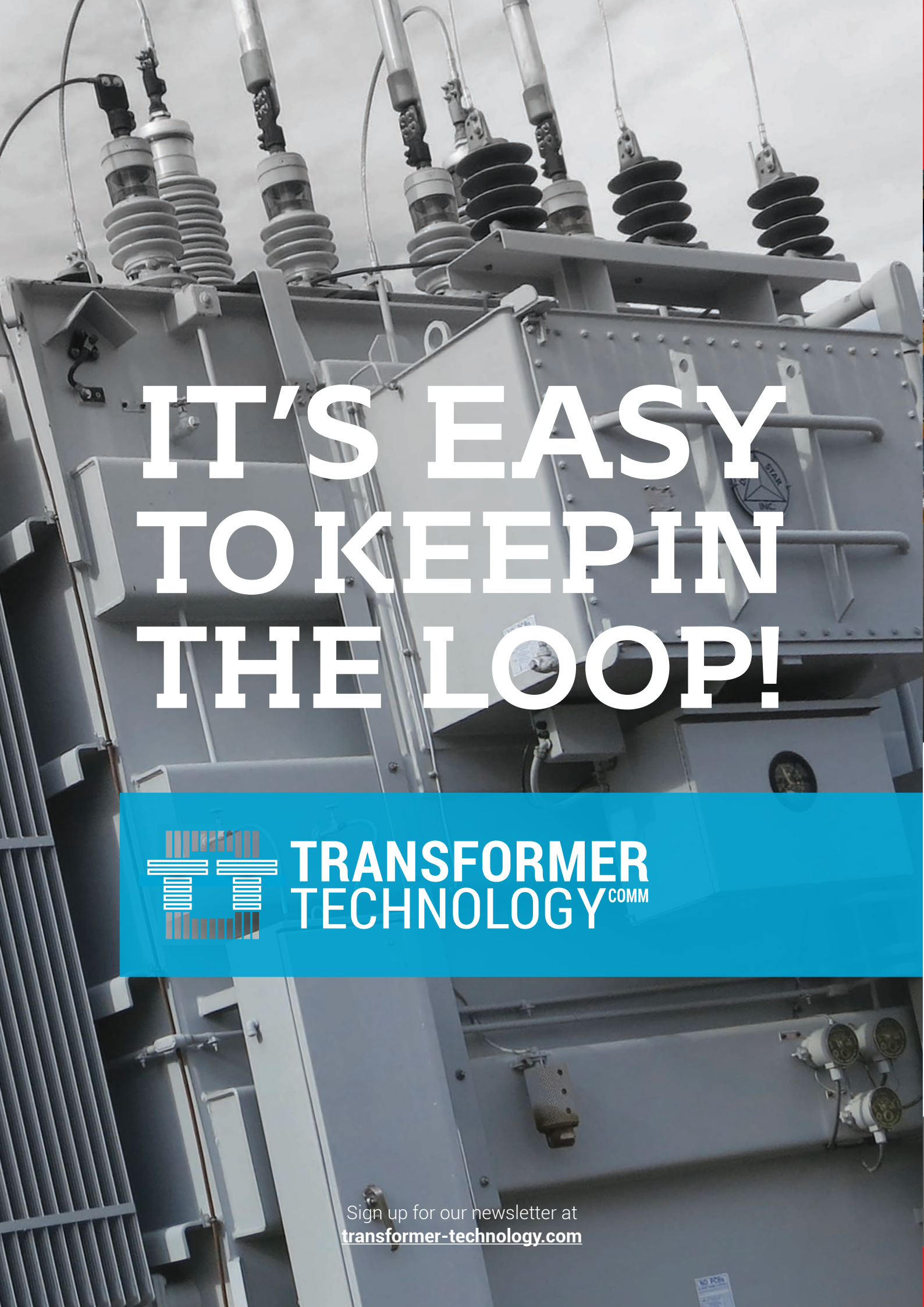


Market Challenges

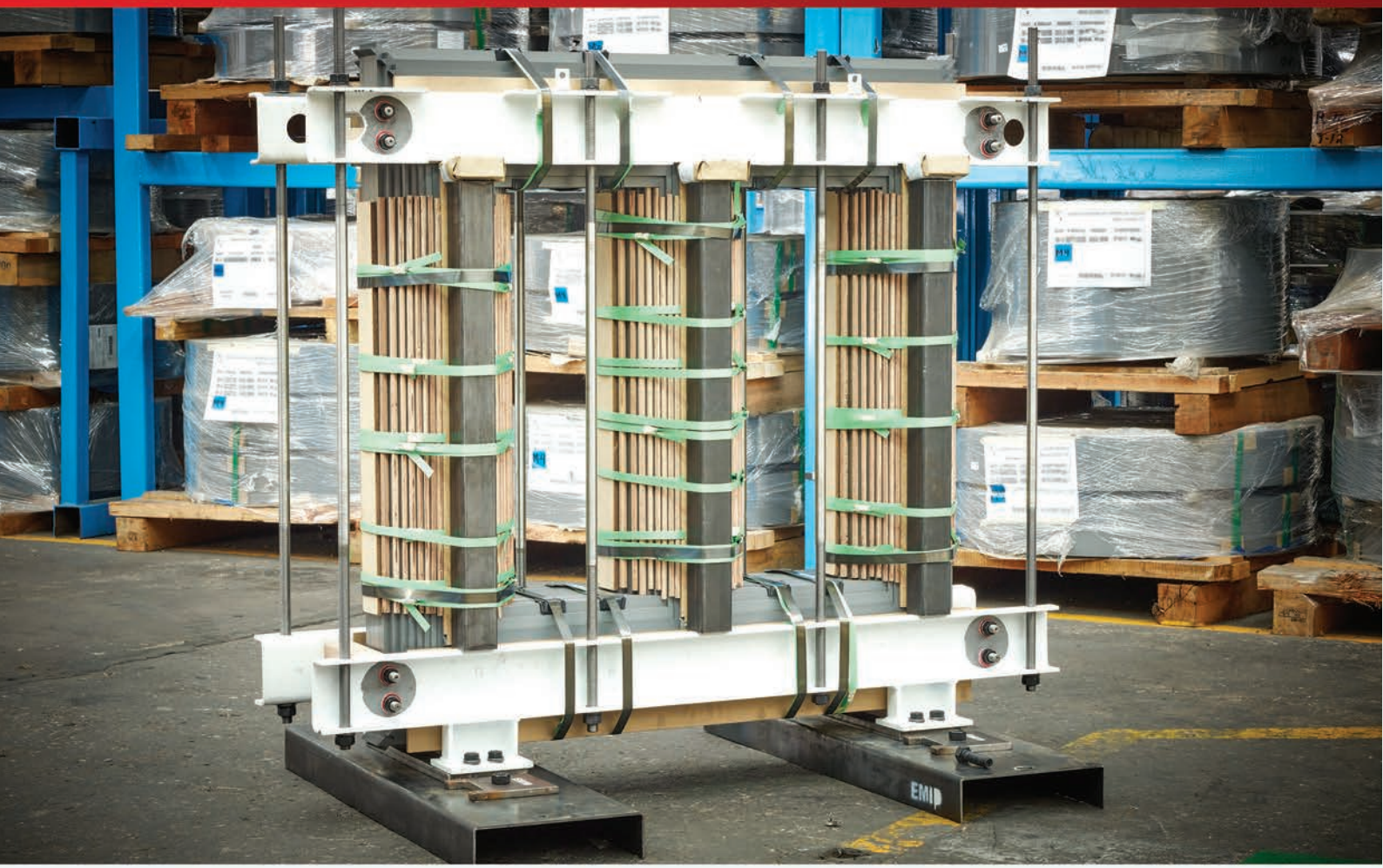
Progress has been slow and steady rather than dramatic for a variety of reasons. The increases in energy generation can be offset by higher expenses stemming from working with the more sophisticated equipment. The larger sizes stress system design and materials. As more force is exerted against the system, its elements bend, flex and in some cases even break. In 2008, one system crashed into the tower after its braking system failed and it spun out of control. Vendors only fully understand all of the potential impact after studying devices that have been in the field for a while. Consequently, designs constantly morph.

In addition, the increased size makes it difficult to transport the different parts to project sites. Special equipment is needed to carry, secure and configure the devices, and the fact that farms are often located in remote regions exacerbates such issues.

Given the complexity of the systems, the investments needed to develop such products have been significant, costing hundreds of millions of dollars to design and deliver. When making such investments, conglomerates look for double digit returns. A transition point is occurring as many of the early wind turbines are ending their lifespans and seeing contraction. Vendors are rolling out larger systems, and they will account for a larger share of the market moving forward.


IT'S EASY
TO KEEP IN
THE LOOP!
TRANSFORMER
TECHNOLOGY COMM
Sign up for our newsletter at
transformer-technology.com

Your one source supplier of electrical insulation and wire materials for the motor and transformer industry.



PRODUCT LINE

- Magnet Wire (Also available in 6” spool)
- Insulation Materials (Slot Insulation, Wedges, Phase Insulation and others)
- Rigid insulation (Sheets, Rods, Dog Bone)
- Varnishes & Liquids
- Tubing and Sleeving
- Tapes & Adhesives
- Lead wire
- Telecommunication & Building Wire
- Specialty Papers & Fibers (Nomex. NMN, Copaco and others)
- Transformers Cores
- Pressboard
- Misc Supplies

EMID

Seneca, SC Branch
514 Concord Industrial Drive
Seneca, SC 29679
(864)-985-1106

Ft. Wayne, IN Branch
4808 Kroemer Rd. Building #2
Ft. Wayne, IN 46818
(260)-423-9529

Miami, FL Branch
2025 NW 102nd Ave.
#105 Miami, FL 33172
(305)-392-5508

www.emid-usa.com

Power Transformers
Evolving, Remaining the Same

by **Paul Pillitteri**

The basic concept of power transformer design has not changed in the last 130 years. Design details and manufacturing concepts are changing based on two factors:

- **The environment factor, which has influenced the use of new insulating materials and Distributed Energy Resources (DERs), and**
- **Economics, which will constantly be a factor in our competitive deregulated marketplace.**

An abbreviated version of this paper was written and published about 18 years ago providing insight in the transformer industry of the day [1]. The unabbreviated paper that follows also provides recommendations for design, monitoring and maintenance, which remain valid in today's industry.

Paul Pillitteri has been in the medium and large power transformer industry for 50 plus years. He has worked for three leading transformer manufactures prior to becoming a transformer consultant for the last 20 years. His experience covers most areas of power transformers including design, manufacturing, testing, repair/refurbishment, field service, and facility operations manager.

Photo: Shutterstock

The single most important factor in the life of the transformer is the condition of the insulation system.

A transformer that is properly specified, manufactured, tested and installed should require minimal maintenance throughout its lifetime. The aim of any maintenance program should be to prevent unplanned outages and to extend the life of the transformer. The most important factor in extending the life of power transformers is maintaining the integrity of the oil/insulation system. The different types of transformer preservation systems are the main accessory item responsible for maintaining this integrity, but quite often the least considered and most neglected. This paper will briefly discuss the following items as applied to small, medium and large power transformers:

+ The life cycle of a transformer and its dependence on the oil/insulation system and economic factors
+ The application and maintenance of the four basic types of transformer preservation systems used on small, medium and large power transformers
+ A pro-active diagnostic maintenance plan
+ A re-active diagnostic maintenance plan using an event-action item matrix

Basic transformer design technology is over one hundred years old. During these 100 years, transformer technology has advanced and continues to advance but the basic concepts of design, application and protection are essentially the same. R&D concentration for the last fifty years was limited to new materials and manufacturing processes and in the last quarter century, condition monitoring and diagnostics have taken precedence. The transformer technology evolution is dependent upon and restricted by one basic fact – economics or Asset Management.

A CIGRE article published in April 2003 [2] provides a model of the three Es of the past, present and future (Figure 1). This general model is a good example of the factors that determine technological advancements or stagnation within the power transformer industry.

Economics will never be at the bottom of the totem pole model, as long as competitive or deregulated markets prevail. Unless major technological advances are made in transformer design and/or manufacturing, economics will remain at the top of the totem pole for the foreseeable future. So, what is the best plan to obtain a quality transformer at a competitive price that will require minimal maintenance throughout its life cycle? This depends on the cycles in the life of a transformer.

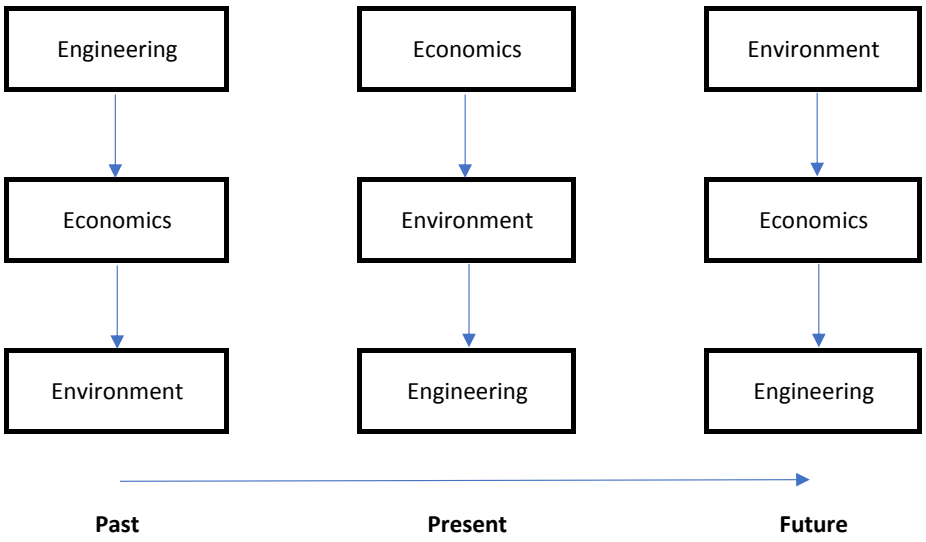


Figure 1. The three Es of the past, the present and the future [2]

The Life Cycles of a Transformer

The life cycle of a transformer can be viewed as nine major events that determine the ultimate quality and operational longevity of a power transformer [3]. The events in the order of sequence are shown in Figure 2.

Most end users consider the specification and manufacturing as the most critical stages in obtaining a quality transformer. In many instances the **specification**, **manufacturing** and **testing** of the transformer are thought to be the only critical cycles in obtaining a quality product. This misconception is quite often held by both the transformer end users and manufacturers.

Experience has shown that this misconception all too often results in new transformer failures upon energization, unplanned outages or abbreviated operational life. Quality manufacturers of medium and large power transformers have large capital equipment and human resources costs tied up in the processes necessary to provide an oil/insulation system of the highest possible integrity. The processes of **shipment**, **receiving**, **storage**, **installation**, **operation** and **maintenance** should be equally important in maintaining the integrity of the oil/insulation structure. While these events cannot be totally ignored, the driving factors that minimize the importance of stages 4 to 9 are lack of knowledge, lack of standards and ultimately, the economics.

Consideration of all aspects within each of the transformer life cycles requires considerable human and economic resources. When the necessary resources are utilized by both the end users and manufacturers, the results can be no unplanned outages and large power transformers with an average life span of 30 to 60 years or beyond.

When the necessary resources are applied at the specification cycle through the operations cycle, maintenance becomes the least important and most **economic** cycle.

Presently, economics remains the dominant factor in purchasing new transformers or maintaining transformers in use. Available resources should be focused on areas that will do the most to prevent unplanned outages and transformer failures.

Quite often the specification, manufacturing and testing of the transformer are thought to be the only critical cycles in obtaining a quality product. Experience has shown that this misconception often results in new transformers failing upon energization, unplanned outages or abbreviated operational life.

The single most important factor in the life of the transformer is the condition of the insulation system. This statement is emphasized in many different forms by all power transformer manufacturers. With this in mind, resources may be focused in the following two areas for both new transformers and transformers in use:

+ Application and maintenance of the transformer preservation system
+ An economic diagnostic maintenance plan

tank/cover assembly and the gas plus the oil volume remains constant over a temperature range. Initial shipment from the manufacturer and/or prior to energizing in the field, the transformer gas space is normally purged with an inert gas such as dry nitrogen and sealed with a positive dry gas pressure. The sealed-tank system is normally designed with sufficient gas space to accommodate the expansion and contraction of he oil due to thermal cycling with varying loads.

Benefits:

+ A practical and efficient application for small power transformers that do not experience extreme temperature fluctuations. It is recommended that sealed-tank systems be limited to transformers with maximum voltage levels of 35,000 volts.
+ Economical for the manufacturer and end user, both from the application (size) and maintenance standpoint

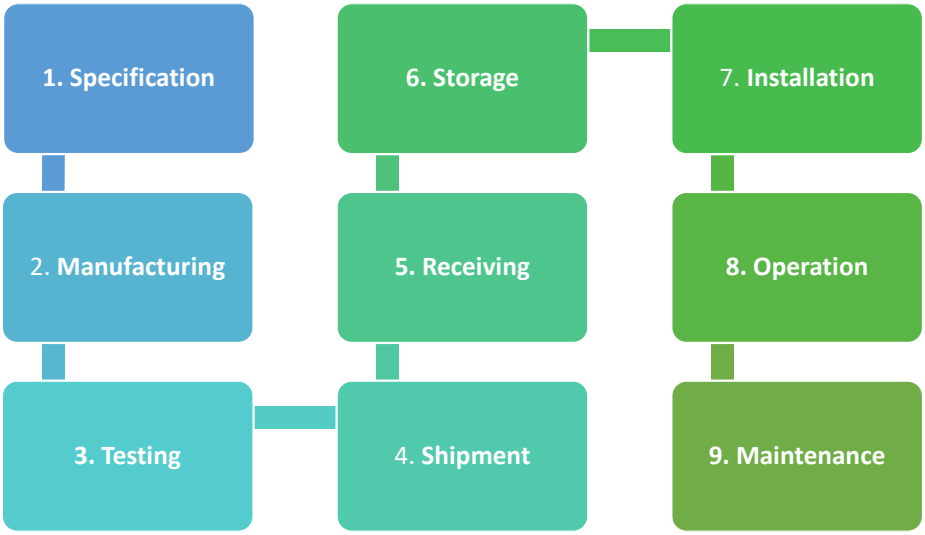


Figure 2. Transformer life cycle events

Recommendations:

+ DBPC oil inhibitor should be specified and maintained at 0.15% to 0.30% by total weight of oil. DO NOT exceed 0.34% DBPC by weight of oil.
+ Sealed-tank systems may frequently operate in an energized or deenergized state while having a negative pressure (partial vacuum) above the oil level. When the transformer is energized or de-energized and has a negative pressure head above the oil level, DO NOT obtain an oil sample from the transformer. It is recommended to place the following warning labels at all oil valves on all sealed-tank transformers:

  Warning – Never open the transformer oil sampling valve if there is a vacuum on the transformer tank. Check the pressure-vacuum gauge on the oil preservation system to be certain there is a positive pressure reading. If you open the sampling valve when there is a vacuum on the tank, air bubbles may be drawn into the transformer. Air bubbles may cause an insulation failure and result in equipment damage, severe personal injury or death.

+ With the transformer de-energized, all welds and gasketed joints above the transformer oil level should be periodically checked for gas leaks.

Application and Maintenance of Transformer Preservation Systems

Medium and large power transformers have four basic types of transformer oil/insulation preservation systems. There are many variations of the four systems described in this paper, based on differences in manufacturer designs or end user field modifications. The intent of this paper is to supply the basics for application, clarify possible misconceptions and provide quality pointers to avoid operational problems. To the best of my knowledge, there are no domestic or international standards for the application or design of transformer preservation systems. The four basis systems are as follows.

1. Sealed-Tank System

The sealed-tank system is one in which the oil/insulation system is sealed from the atmosphere by the

Various accessory items may be provided on the external tank wall gas space as a regulating device to protect the tank structure from excessive positive or negative pressure and to regulate the positive/negative pressure within a designated range. The most common device is a pressure-vacuum bleeder, with sampling valve, normally preset at the factory based on the manufacturer's standard design or the customer's specification. Transformer users should be fully aware that the sealed-tank system cannot assure that the tank will not systematically breathe (take in atmosphere) or systematically expel gases contained in the transformer gas space. This can and will occur due to changes in ambient temperatures in combination with load or absence of load. A common misconception is that the sealed-tank system will prohibit oxygen and moisture from being absorbed into the oil/insulation system. In many circumstances, it will not.

2. Inert Gas-Pressure System

The inert gas-pressure system is one in which the interior of the main transformer tank is sealed from the atmosphere, over the temperature range specified, by means of a positive pressure of inert gas maintained from a separate inert gas source and reducing valve system. The inert gas most commonly used is dry nitrogen. Gas blanketed transformers which are properly maintained will eliminate the possibility of atmosphere being drawn into the transformer tank. Because of this and the overall physical size of an inert gas-pressure system, many utilities prefer this system for small and medium power transformers.

Recommendations:

+ It is important for systems that apply constant gas pressure to the transformer to have scheduled periodic maintenance. All seals in the transformer gas space and in the preservation system must be maintained for the system to function properly. In addition to the many seals in the transformer gas space, there are numerous seals within the common gas-pressure systems such as pressure regulator fittings, valve fittings, piping connections, and gas bottle connections.
+ Do not use teflon sealing tape on gas pressurized fittings. Excess teflon can be torn away and will clog the small orifices in the system. This will disable the system.
+ **Never** use SF6 gas in a transformer gas blanketed system. SF6 gas is three to four times more soluble in transformer oil than either nitrogen or air. SF6 gas has an extremely high probability of producing gas bubble evolution in transformer oil. In addition, SF6 in the presence of arcing and corona discharges will produce corrosive by-products.
+ Argon gas is sometimes used in gas blanketed systems. I would NOT recommend argon in place of dry nitrogen. Nitrogen is more common and abundantly produced. In addition, most dissolved gas analysis (DGA) will indicate argon as being oxygen unless the testing laboratory is told to check for argon.
+ Transformers with a constant gas pressure on the oil surface (inert gas-pressure system) are more susceptible to gas bubble evolution and failures during startup and shutdown. A startup and shutdown procedure using manual or modified automatic cooling controls should be in place for all inert gas-pressure transformers. The object of the procedure should be to circulate the oil past the interface with the gas blanket to speed the release of nitrogen (inert gas) from the oil. This should be accomplished with as gradual temperature increases during startup as possible and as gradual temperature declines during shutdown as possible. Transformers with pumps (forced oil) must also consider the potential of static charge buildup if oil circulation becomes excessive at lower temperatures during the startup or shutdown procedure. Because of the potential for gas bubble evolution in gas pressure systems, I would not recommend inert gas-pressure systems on transformers with a voltage higher than 138,000 volts.
+ Inert gas-pressure systems that malfunction can cause the transformer gas space to have negative pressure. I recommend that gas pressure systems have warning labels at all oil valves as follows:

Warning – Never open the transformer oil sampling valve if there is a vacuum on the transformer tank. Check the pressure-vacuum gauge on the oil preservation system to be certain there is a positive pressure reading. If you open the sampling valve when there is a vacuum on the tank, air bubbles may be drawn into the transformer. Air bubbles may cause an insulation failure and result in equipment damage, severe personal injury or death.

Photo: Shutterstock

3. Conservator System

The conservator system is one in which a separate oil expansion tank allows the main transformer tank to remain full of oil despite expansion or contraction of the oil with temperature changes. The expansion tank also reduces the rate of oxidation of the oil, primarily because less oil surface is exposed to the air and because of the reduced temperature of the oil that is exposed to air. In most cases the expansion tank is mounted on the LV side of the transformer tank, above the level of the transformer cover.

Common accessories that may be provided with the conservator expansion tank assembly are as follows:

+ The pipe between the expansion tank and transformer tank may utilize a trap (with drain plug) which retards the oil circulation between tanks and permits the draining of condensation that may collect in the pipe.
+ A relief device mounted on the transformer cover with an elevation such that the relief device is above the maximum oil level in the expansion tank.
+ Oil level indicator, oil sampling valve, and a handhole.
+ Gas accumulator device mounted in the piping between the expansion tank and transformer.
+ Open air breather or a dehydrating breather. A dehydrating breather is recommended.

Recommendations:

+ Many expansion tanks are not braced for full vacuum although the main transformer tank may be good for full vacuum. Always follow the manufactures instructions for filling the main transformer tank and the conservator tank.
+ Large power transformers are often initially installed or maintained by a hot oil circulation process. A common field mistake is to fill the transformer or its expansion tank to the "normal" or 25°C level even if the hot oil is at 80 to 90°C. This will present future problems. Manufacturer's instructions should be adhered to for determining proper oil levels based on oil temperature.
+ DBPC oil inhibitor should be specified and maintained at 0.15% to 0.30% by total weight of oil. DO NOT exceed 0.34% DBPC by weight of oil.
+ A dehydrating breather should be used rather than an open-air breather.
+ A variation of the conservator expansion tank is known as the gas-oil seal expansion tank. The gas-oil seal expansion tank is an enlarged expansion tank with a constant positive inert gas pressure above the oil level in the expansion tank. I recommend a conservator-diaphragm system rather than the gas-oil seal expansion tank for all transformers with voltages above 138,000 volts.

4. Conservator-Diaphragm System

As defined by ANSI/IEEE C57.12.80 [4], the conservator-diaphragm system is one "in which the oil in the main tank is completely sealed from the outside atmosphere, and is connected to an elastic diaphragm tank contained inside a tank mounted at the top of the transformer. As the oil expands and contracts within a specified temperature range the system remains completely sealed with an approximately constant pressure." Contact between the oil and the atmosphere is prohibited by the elastic diaphragm tank (air cell) in the expansion reservoir.

More so than any of the previous preservation systems listed in this paper, in theory and practice this system can assure that gases and moisture from the atmosphere will not come in direct contact with the transformer oil/insulation system. All skeptics should note the word "direct" in the last statement as being a form of disclaimer.

Conservator-diaphragm systems all operate on the same principles but vary in name and mechanical aspects from one supplier to another. While the conservator-diaphragm system is possibly the best system to extend the operational life of large power transformers, individual end-users should start at the specification stage to be sure that this system is the best fit for their environmental, maintenance and asset management plans.

Recommendations:

+ Many conservator-diaphragm expansion tanks are not braced for full vacuum although the main transformer tank may be good for full vacuum. Always follow the manufactures instructions for filling the main transformer tank and the conservator-diaphragm tank. In addition, DO NOT pull vacuum on a conservator-diaphragm tank specified good for full vacuum unless the conservator diaphragm and all accessories with diaphragms, such as gas detectors, are totally isolated from the negative pressure (vacuum).
+ Some older transformers and possible new transformers are designed such that the minimum oil level in the conservator-diaphragm tank is physically located below the top of the main transformer tank. When this occurs, a negative pressure can develop in the top of the main transformer cover and all associated fittings/parts that would normally contain oil. When this occurs, it is very common for gas accumulator relays to alarm due to the accumulation of atmosphere breathed in through fittings, gaskets or weld leaks on the top of the transformer cover. The minimum oil level in the conservator-bladder tank should always be located above the highest oil filled accessory located on the transformer cover. This does not include self-contained oil accessories such as HV or LV bushings.
+ Conservator-diaphragm tanks may be supplied with free breathers or a filter/dehydrating breather. It is recommended to use a filter/dehydrating breather to protect the diaphragm material from air borne pollutants and moisture.
+ Conservator-diaphragm systems should have a gas-detector relay mounted on the transformer cover. It is also recommended that a gas/oil-flow detector be provided in the piping connection between the transformer main tank and the conservator tank.

+ DBPC oil inhibitor may be used to retard oxygen absorbed during maintenance outages requiring opening of tank seals. DBPC oil inhibitors should not be used to forgo the maintenance required to maintain the transformer seals and the integrity of the conservator-diaphragm system.
+ The conservator diaphragm may be made from synthetic rubber or other elastic materials. The diaphragm (air cell) is often damaged during transportation, field installation or during maintenance operations. It is not uncommon to weld on the surface of the conservator tank during the initial field installation or during a maintenance outage. All diaphragm material should have sufficient clearance or be insulated from the tank weld area so as not to be damaged by the welding.
+ Final oil filling of transformers with conservator-diaphragm systems often requires a heated oil circulation process. Manufacturers instructions for filling the conservator tank based on oil **temperature** should be adhered to.

An Economic Diagnostic Maintenance Plan

The old cliché "beauty is in the eye of the beholder" can very practically be applied to "**Economics** is in the eye of the beholder". In pre-deregulation days, many utilities had top executives and managers with engineering backgrounds. Today, top managers have financial backgrounds. In plain English, in a deregulated market, operations are expected to run at maximum capacity and minimum maintenance [5].

Prior to deregulation, the most common term applied to transformer maintenance programs was Preventative or Scheduled Maintenance. With the advent of deregulation within the power industry, many different names have been applied to transformer maintenance. Examples are Reliability Centered Maintenance (RCM), Condition Based Maintenance (CBM), Predictive Maintenance, Condition Monitoring Maintenance (CMM), Computerized Maintenance Management System (CMMS).

In practice, present day transformer maintenance procedures are a combination of pro-active diagnostics and re-active maintenance.

I believe that there are only two basic types or categories of transformer maintenance: Pro-active and Re-active. In practice, present day transformer maintenance procedures are a combination of pro-active diagnostics combined with re-active maintenance. This combination can be reliable and **economical** only if the necessary diagnostic skills are available and the re-active procedures are applied properly and timely [6].

The following diagnostic maintenance plans are an attempt to provide a general pro-active and re-active plan. The intent of both plans is to have or obtain a "genetic signature" of the transformer. The "genetic signature" being the initial diagnostic test values from which to determine the future operational integrity of the transformer. Once again, these plans or any diagnostic maintenance plan cannot succeed without the proper diagnostic skills and proper/timely maintenance procedures.

A Pro-Active Diagnostic Maintenance Plan

For any diagnostic maintenance plan to be pro-active it should contain two elements. First, determine the criterion (genetic signatures) to be used to monitor the operational integrity. Second, determine a schedule for periodic re-testing or monitoring of the chosen criterion. *The schedule for re-testing, monitoring and/or possible maintenance should be based on the end user's asset management plan and the available diagnostic criterion.*

Transformers with identical name-plate ratings but from different manufacturers can have large variations in their "genetic signature(s)". These differences occur due to design, materials, factory processes and procedures. Initial diagnostic testing to obtain the "genetic signature" should begin at the initial field installation. These test results can then be compared to factory test results. An aged "genetic signature" can be obtained at any point during the operational life of the transformer if there were no previous diagnostic tests available. This will make the evaluation process more difficult. Complete "genetic signature" testing requires both de-energized and energized tests as follows.

In pre-deregulation days, many utilities had top executives and managers with engineering backgrounds. Today, top managers have financial backgrounds. In other words, in a deregulated market, operations are expected to run at maximum capacity and minimum maintenance.

De-energized oil-filled transformer testing (genetic signatures) includes:

+ Ratio tests (TTR) on all windings and all tap positions
+ Insulation power factor
+ Single phase exciting current measurements
+ Insulation resistance test from each winding to ground and to the other windings
+ Measure the core resistance to ground
+ Power factor and capacitance tests on all condenser bushings
+ Sample oil for both an oil screen test and dissolved gas analysis (DGA)

Photo: Shutterstock

Energized transformer testing includes:

+ After the transformer is energized and carrying load for a minimum of 24 hours, do a complete infrared scan. A complete infrared scan should include all wall surfaces including the cover, all external bushings, external bushing connections, all individual coolers, transition compartments, load tap changer compartment, control cabinet, power supply connections and all other accessory devices. A log of infrascan results should include percent of load and ambient temperature at the time of the infrared scan. This infrared thermography scan should be preformed at minimum once per year.
+ After the transformer is energized and carrying load for a minimum of 24 hours, take an oil sample for dissolved gas analysis (DGA). Recommend that DGA be performed at a minimum of twice per year. More frequent DGA tests may be required dependent upon the type of gases being generated and/or their rates of acceleration.
+ A visual inspection should be made at least twice a year. Inspection should include checks on all the following:

    1. Oil and/or gas leaks at all transformer seals, auxiliary tanks, LTC compartments, individual coolers and weld seams
    2. Transformer preservation system
    3. Oil level in the main tank, auxiliary tanks, LTC compartment, and bushings
    4. All control cabinets

A Re-Active Diagnostic Maintenance Plan

A re-active diagnostic plan should begin with establishing the same "genetic signatures" that are used in the pro-active plan. The basis for all future actions taken will partially rely on the data ("genetic signatures") obtained from both the de-energized transformer testing and the energized transformer testing. The difference is that future outages for testing and/or maintenance are NOT scheduled based on a preset pre-ventative maintenance plan. Planned outages or unplanned outages are based on events in combination with on-line diagnostic tests, data collection and on-line monitoring if applicable.

The event-action item matrix that follows is for a typical generator step-up transformer rated OA/FOA/FOA by old standards or ONAN/ODAF/ODAF by new standards. End users should determine events and action items based on the following:

1. type of their transformer
2. system requirements
3. asset management plans

Event	Transformer Action Requirements				
	Date	% Load	Visual inspection	Internal inspection	Infrared scan
Visual inspection	DR	DR	DR	NA	DR
Overload	DR	DR	DIN	DIN	DR
Overvoltage	DR	DR	DIN	DIN	DIN
Through-fault	DR	DR	DR	DIN	DIN
Environmental	DR	DR	DR	DIN	DIN
Transformer trip	DR	DR	DR	DIN	NA
Transformer alarm	DR	DR	DIN	DIN	DIN
Loss of control power	DR	DR	DR	DIN	DR
Pump problem	DR	DR	DR	DIN	DIN
Bushing problem	DR	DR	DR	DIN	DIN
Bus duct problem	DR	DR	DR	NA	DR
Before maintenance	DR	DR	DR	DIN	DIN
After maintenance	DR	DR	DR	NA	DR

Conclusion

A realistic maintenance plan begins at the specification stage. A successful plan will combine operational objectives with human resources, equipment environment, and asset management objectives. Considerations for the addition of optional on-line monitoring equipment at the specification stage are very important for any re-active maintenance plan. Monitoring equipment applied at the design stage will be more reliable due to pre-designed locations, application and testing on the transformer prior to shipment.

The majority of engineers responsible for design, operations or maintenance functions prefer scheduled preventative maintenance for critical equipment rather than a re-active maintenance plan. The partially deregulated power industry and the end user markets for electrical power do not lend themselves to preventative maintenance or pre-scheduled outages. The majority of power transformers presently and in the future will combine pro-active diagnostics with re-active maintenance.

Table 1.
A re-active diagnostic main-tenance plan

DR = Data Required
DIN = Determine if Necessary
NA = Not Applicable
DGA = Dissolved gas analysis

***Note:** Events and Transformer Action Requirements should be determined by the type of transformer, system requirements, system anomalies and the asset management plan.*

	Cooling status and all temperature indicators	**DGA**	**Oil screen**	**Particle and metal analysis**	**Degree of polymeri-zation**	**On-Line PD and vibration**
	DR	DR	DR	DIN	NA	DR
	DR	DR	DIN	DIN	DIN	DR
	DR	DR	DIN	DIN	DIN	DR
	DR	DR	DIN	DIN	DIN	DR
	DR	DR	DIN	DIN	DIN	DR
	DR	DR	DR	DIN	DIN	DR
	DR	DR	DIN	DIN	DIN	DR
	DR	DR	DR	DIN	DIN	DR
	DR	DR	DR	DR	NA	DR
	DR	DR	DIN	DIN	NA	DR
	DR	DR	DIN	NA	NA	DR
	DR	DR	DR	DIN	NA	DR
	DR	DR	DR	DIN	NA	DR

References

[1] P.J. Pillitteri, "Back to Transformer Basics – Economic Diagnostic Maintenance," *Proceedings of the IEEE SoutheastCon 2006*, Memphis, TN, USA, 2006, pp. 51-57

[2] CIGRE-ELECTRA, April 2003, Joint Advisory Group SC15/D1-TF03, "Emerging Technologies and material changes"

[3] Paul Pillitteri, "Life Cycle of a Transformer," VA Tech Elin USA, J.W. Harley Monitoring Conference 1997

[4] ANSI/IEEE C57.12.80, Terminology for Power and Distribution Transformers

[5] PowerMarketers, The Power Report, "Blackout Reignites Deregulation Debate", Akron Beacon Journal, Ohio, August 24, 2003

[6] Terry Krieg, "Transformer monitoring: Key to cost-effective asset management," *Electrical World*, March/April 2001

COMING
IN DECEMBER

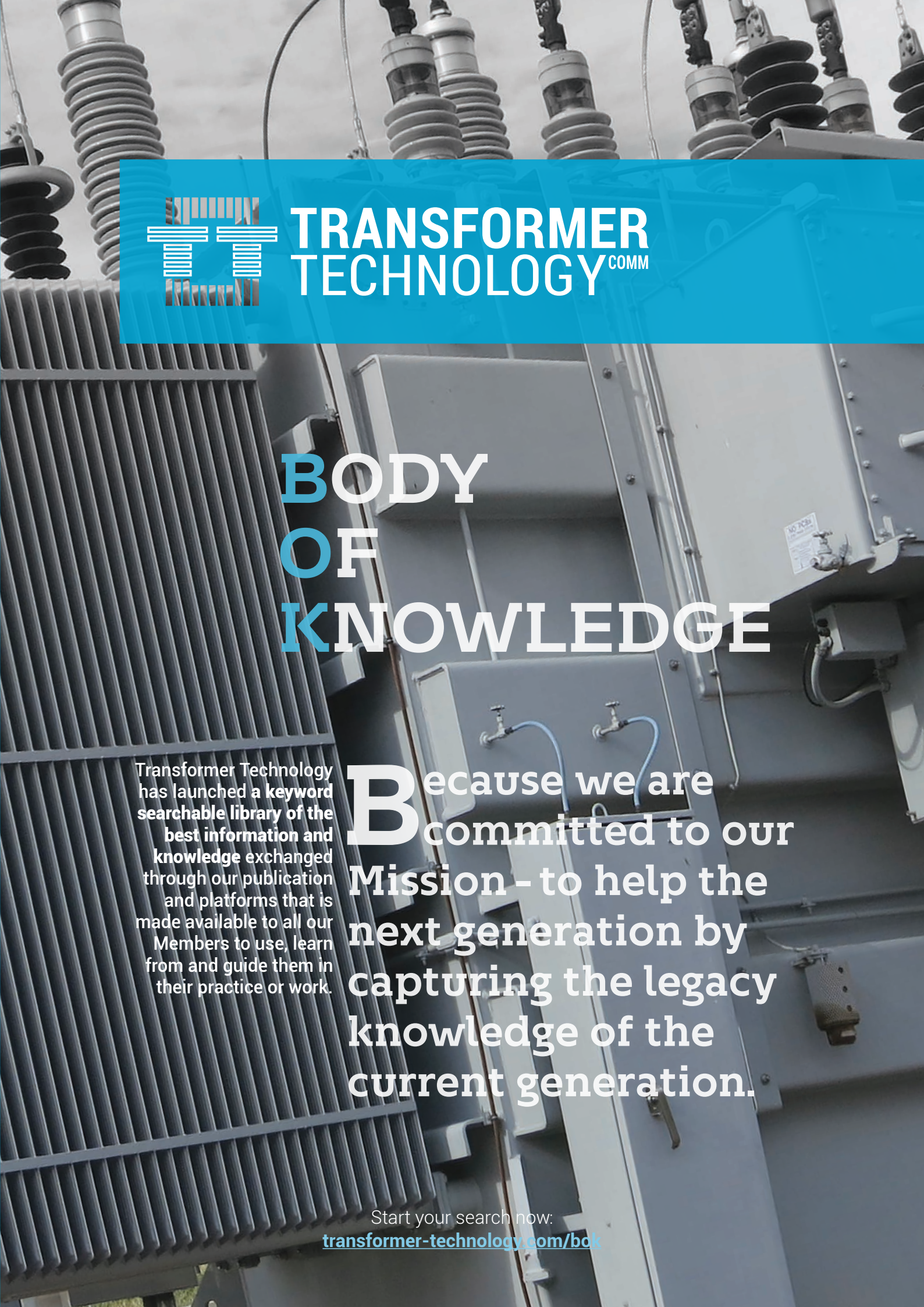
Transformer Lifeblood: Oils & Fluids

One of the biggest and most read, downloaded and archived issues we do every year is our **Oils & Fluids** edition, which is coming in December.

While we already have a great lineup of articles, interviews, and information planned, there is still room for new authors and articles. If you have something you believe would advance the Body of Knowledge for our TT Community, then please send your Title and Brief Description to my email.

The full theme is Transformer Lifeblood: **Oils & Fluids**, so be creative and be imaginative. You never know, you might become one of our frequent contributors. Thank you.

Alan Ross
Community Moderator and Editor in Chief



TRANSFORMER TECHNOLOGY COMM

BODY OF KNOWLEDGE

Transformer Technology has launched **a keyword searchable library of the best information and knowledge** exchanged through our publication and platforms that is made available to all our Members to use, learn from and guide them in their practice or work.

Because we are committed to our Mission - to help the next generation by capturing the legacy knowledge of the current generation.

Start your search now:
transformer-technology.com/bok

THINKING ABOUT STRENGTHENING YOUR POSITION IN THE MARKET?

THINK ABOUT YOUR PRODUCT

THINK ABOUT YOUR COMPETITION

THINK ABOUT YOUR SERVICE

THINK ABOUT YOUR TIME

THINK ABOUT...

DON`T THINK ABOUT MARKETING

LET US DO IT FOR YOU

TRANSFORMER TECHNOLOGY COMM

Contact us to find out more:
info@transformer-technology.com
www.apc.media