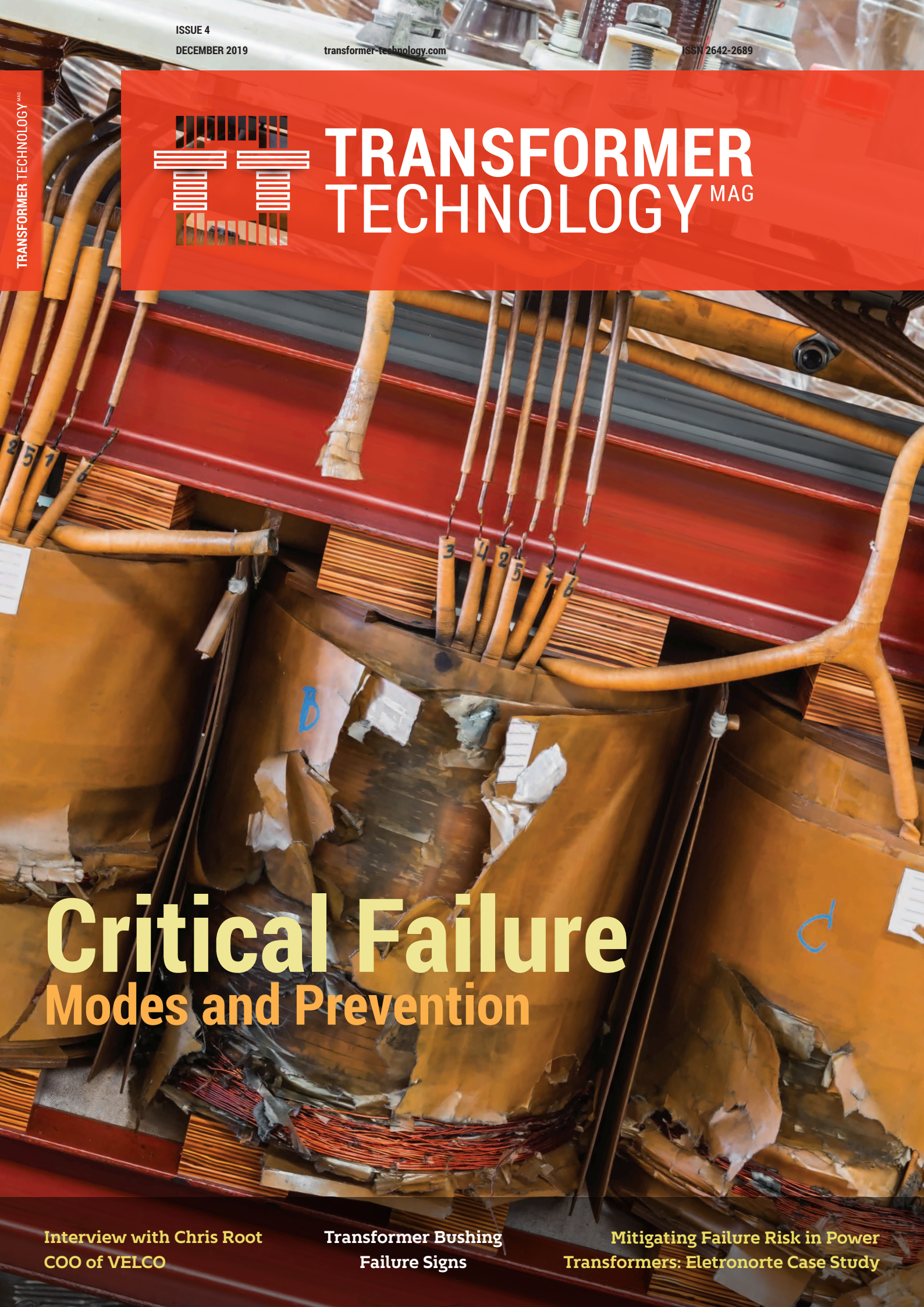
ISSUE 4
DECEMBER 2019
transformer-technology.com
ISSN 2642-2689

TRANSFORMER TECHNOLOGY MAG

TRANSFORMER TECHNOLOGY MAG



Critical Failure Modes and Prevention

Interview with Chris Root COO of VELCO

Transformer Bushing Failure Signs

Mitigating Failure Risk in Power Transformers: Eletronorte Case Study

KEEP YOUR CITIES SAFER

With the **VaultSafe Transformer Monitor**

Network transformer systems are used to improve grid reliability in major cities throughout the world. However, aging of system components has resulted in a dramatic increase to transformer failure rates, threatening the safety of the general public and disrupting power flow to critical infrastructure. The VaultSafe is an affordable solution, providing valuable insight to the internal conditions of network transformers.

Monitor the main tank, switch and cable compartments to see clearly into your vaults.

- Easy to Implement
- Low cost & Maintenance Free
- Monitors hydrogen gas and pressure

LEARN MORE AT WWW.DYNAMICRATINGS.COM/VAULTSAFE.

DYNAMIC RATINGS

www.dynamicratings.com

Dynamic Ratings provides condition based monitoring programs to the utility industry. We use our end-to-end comprehensive products and services to improve the safety and reliability of our customers assets.

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.

TRANSFORMER TECHNOLOGY MAG

Contact
transformer-technology.com

Index

Table of Contents_**04**

Editors & Impressum_**08**

Editor's Letter_**10**

At a Glance_**14**

Events Watch_**21**

Transformer Bushing Failure Signs_**28**

Mitigating Failure Risk in Power Transformers: Eletronorte Case Study_**34**

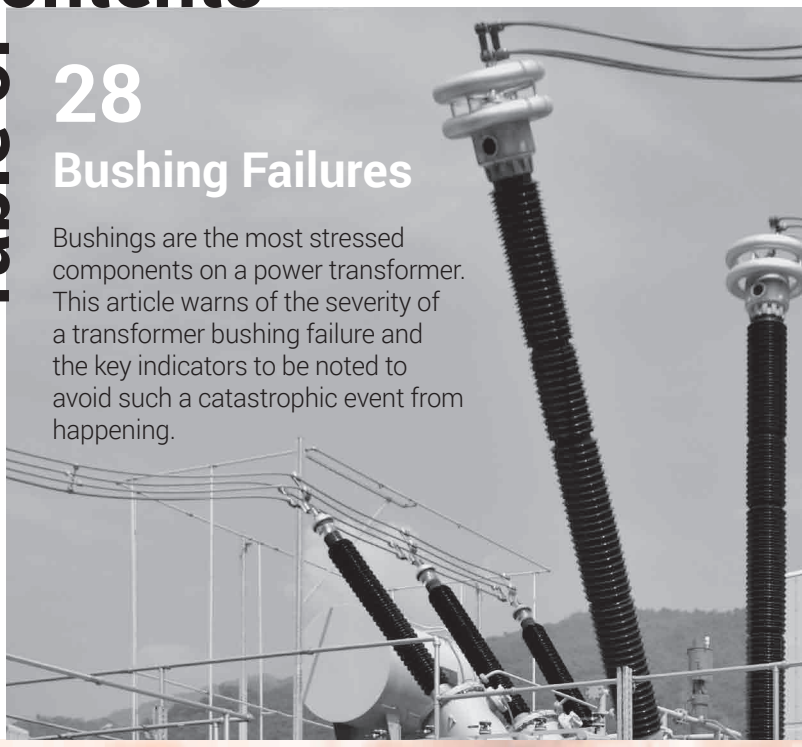
Load Tap Changers: Diagnostics and Fault Identification – A Key to Condition-Based Maintenance_**40**

Interview with Chris Root, COO of Vermont Electric Power Company_**46**

Managing the Reliability of an Industrial or Commercial Electrical Power System_**52**

Bringing Clarity to the Complexity of Condition Monitoring _**58**

Table of Contents



28

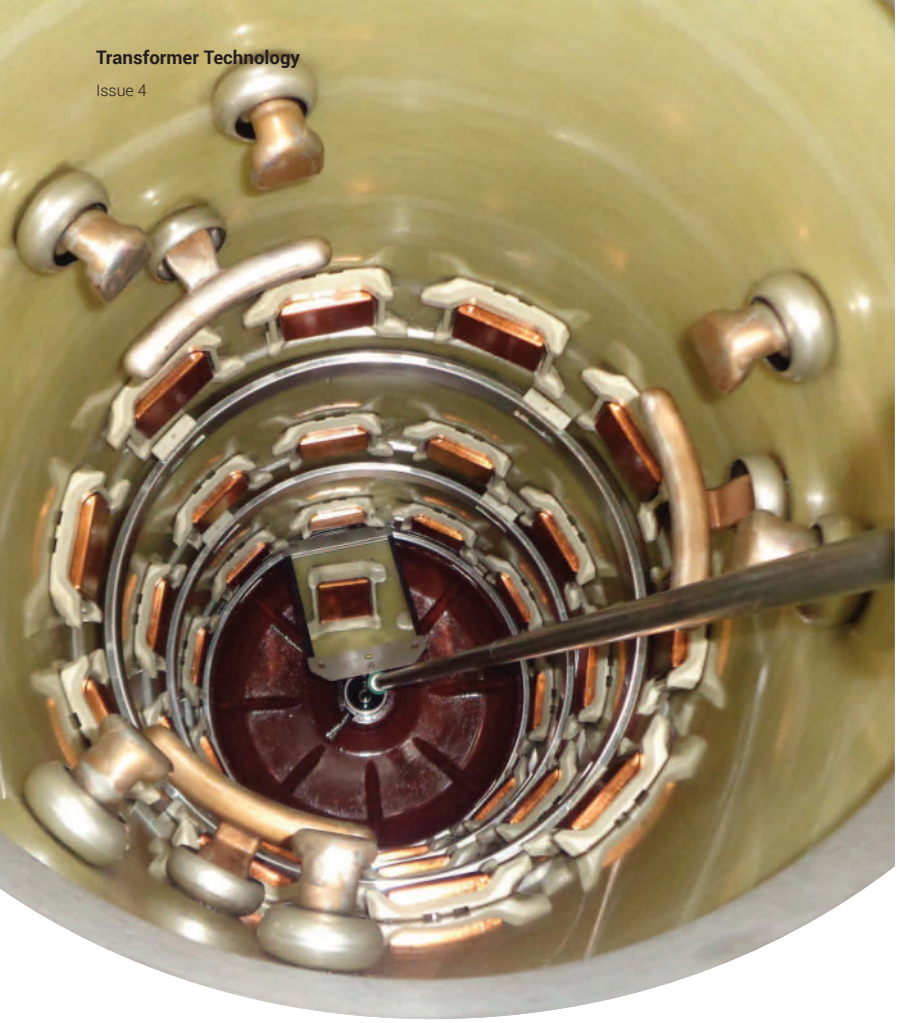
Bushing Failures

Bushings are the most stressed components on a power transformer. This article warns of the severity of a transformer bushing failure and the key indicators to be noted to avoid such a catastrophic event from happening.

34

The Eletronorte Experience

A risk of a major equipment failure is one of the biggest worries of any transformer operator. A Brazilian electricity company presents a powerful example of how the improvements in the design standards for the transformer and reactor fleet lead to better safety, reliability and resilience of the entire substation in the long term.



40
Tap Changer Fault Detection

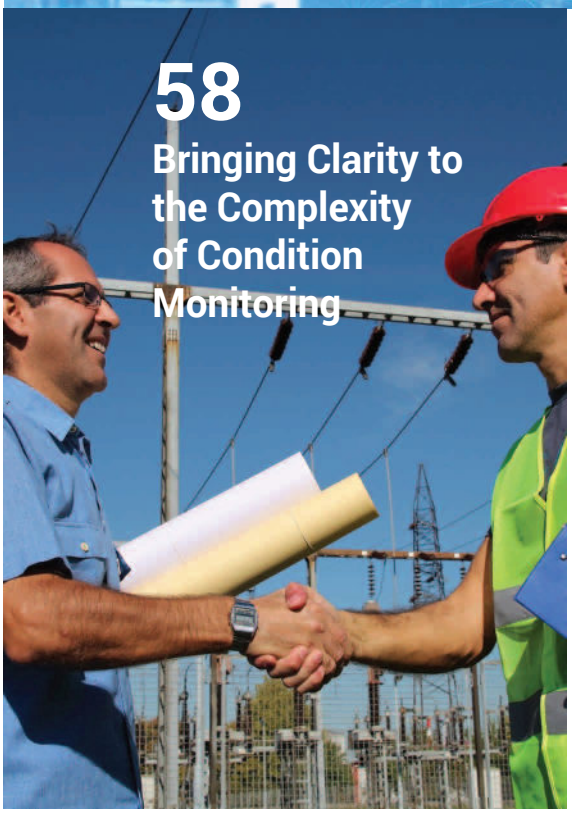
What are the different types of condition monitoring methods of load tap changers and what is their field application and accuracy in identifying faults? Find out in this article.

46
Feature Interview

Interview with
Chris Root
COO of Vermont Electric Power Company

52
Managing the System

Meet Andy, Reliability Manager of Electrical Power System you never knew you need to hire, and let him take you through the challenges and importance of implementing an electric power reliability and maintenance program that will increase the safety, compliance and protection of your plant and its critical assets.



58
Bringing Clarity to the Complexity of Condition Monitoring

Index

Maximizing the Potential of Narrow Band DFR_**60**

Failure Prevention of Distribution Transformers: Technology Types and Their Market_**68**

Interview with Dan Smith, VP of Electric Service Delivery at Austin Energy_**78**

7 Tips from the Transformer Doctor_**84**

WHY Monitor Network Transformers_**86**

DVtesting Voltage Regulators_**92**

Coming in February_**98**

Table of Contents

60

Narrow Band DFR

The Narrow Band Dielectric Response (NBDFR) method of insulation power factor testing indicates changes in oil and paper condition which are in many cases undetectable with conventional line frequency power factor testing. Recent studies involving NBDFR have forced the industry to reexamine the application and interpretation of insulation power factor.

68

Market Research

This article provides an insight into the global market of transformers used in applications that require a focus on failure prevention. Focusing on three transformer types: the dry-type, ester-filled and digital transformers, the article gives a brief comparison of these technologies, their typical applications and global market opportunities.

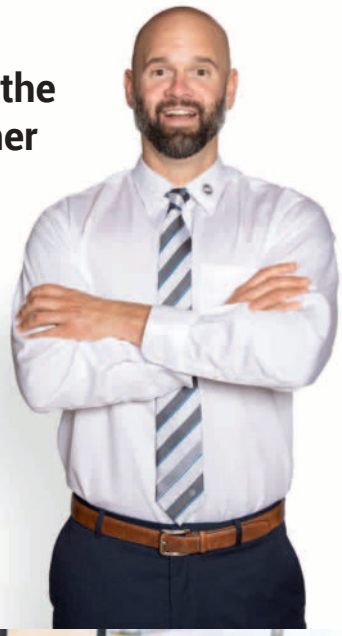
78
Feature Interview

Interview with
Dan Smith
VP of Electric Service Delivery at Austin Energy

86
Monitoring Network Transformers

While the application of online monitoring has become common for most substation items, outside the fence, the relatively low cost of distribution equipment makes it difficult to justify the expense associated with online monitoring. This article outlines the *whys* of the importance of monitoring network transformers.

84
Tips from the Transformer Doctor



92
Voltage Regulators

Diagnostic testing of voltage regulators should include condition assessment of on-load tap changers (OLTCs) by applying dynamic DVtest methodology. This article is an overview of voltage regulator condition assessment using DVtest, also known as dynamic resistance measurement (DRM).

Impressum

TRANSFORMER TECHNOLOGY MAG

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

Editor in Chief
Alan M. Ross, CRL, CMRP

Associate Editor
Rachel Linke
Member of Electric Power
Reliability Alliance

Contributing Editors
Diego Robalino, PhD, PMP
IEEE Senior Member
Corné Dames
Independent transformer consultant
Alan Sbravati, ME, MBA
Transformer insulating materials
Marco Tozzi, PhD
Diagnostics and asset monitoring
Jon Trout, PE
Electric utility

Graphic design
Bekoncept Communication Boutique

Photo
Shutterstock.com

Sales & Marketing
Kevan Sears
kevan.sears@apc.media

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
Rachel Linke
Member of Electric Power
Reliability Alliance
15 years of experience

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

Contributing Editor
Corné Dames
Transformer oil
20+ years industry
experience

DIGITAL Subscription rate
Free annual subscription

PRINT Subscription rate
$75/year - 4 successive issues per year

Transformer Technology 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
11210 West Rd, Roswell
GA 30075, USA

transformer-technology.com

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

Contributing Editor
Marco Tozzi ME, MBA
Diagnostics and asset monitoring
10+ years industry experience

Contributing Editor
Jon Trout PE
Electric utility
14 years of experience

Are transformers failing at a high rate today?

If we look at insurance company data, the answer is a resounding yes. This was one of the reasons we chose to focus our December edition on the theme of transformer failures. Hopefully, we have been able to shed a little light on why and how to prevent failures, and how to recover from them. Another reason is the age of the installed fleet, which is over 38 years old for power transformers - it is a testimony to the design and manufacturing capability of past generations that they have lasted as long as they have.

I think we owe a lot of their robustness to a problem that the "Greatest Generation" left us - primetime newsman gave us that moniker, the greatest generation. It refers to the generation who fought World War II and who laid the foundation as the dominating world force for innovation, manufacturing and ultimately craftsmanship. Most of what that generation designed and built was done with a level of robustness and durability that has been unmatched since. Transformers were no exception.

Then my generation came along - the "Boomers", and we created Just-In-Time, Lean, Six Sigma and globalization. We were so busy making more from less that we depended on transformers without thinking about them. Then along came CAD systems and competition, where manufacturers could not afford to overbuild their transformers because doing so would mean that you would not get the bid. Bid specs ruled the day, so we designed and built to spec.

And now, older transformers are failing simply because of their age, and middle-aged transformers are failing because they were never intended to last 40 years, nor could we afford to build them to last that long.

As a result, we have the December issue of Transformer Technology. From bushings to insulation breakdown, to aging, to LTCs, to moisture and even to complacency; we have covered a lot of the issues related to transformer failure, how to prevent it or what to do to remediate after a failure.

I especially enjoyed the Chuck Baker article (or is it a screen play?) that reads like a scene I have heard played out so many times - a scene where a transformer could have been saved from an unplanned or catastrophic failure if we had only done the basic maintenance required to keep it healthy. I think you will enjoy it too, and if you need to get your boss's attention, maybe forward a link to her/him. Or if you are the boss, ask if this is similar to your situation.

> We were so busy making more from less that we depended on transformers without thinking about them. And then along came CAD systems and competition...

Thanks again to our incredible and talented team who work with some of the most gifted and giving authors, who share their very best with you.

Whenever you enjoy or learn from an article, drop us a line to let us know and we'll share that with the authors. They love feedback. And so do we.

Alan M Ross
CRL, CMRP
Editor in Chief
Transformer Technology
Magazine

CWIEME SHANGHAI

THE APAC'S LARGEST COIL WINDING, ELECTRIC MOTOR, AND TRANSFORMER MANUFACTURING EVENT

24-26 March 2020 | Shanghai, SWEECC

6,880+
Visitors.
68% C-level management purchasers and engineers

200+
Exhibitors.
Over 20% growth from previous year

25+
Keynotes and presentations of technologies and industry trends

Part of Exhibitors

No particular order

kaneka · 巨峰股份 JUFENG INC. · NIPPONRIKA Designing Energy Drive · NORPLEX MICARTA · metastar 烟台民士达特种纸业股份有限公司 · 福润达 FRIEND · 瑞安绝缘 SUI ON INSULATING · isovolta · SYNFLEX · 誉翔 · 超美斯 X-FIPER · KREMPEL GROUP · VONROLL · ELANTAS · DUPONT

REGISTER FOR FREE

cn.coilwindingexpo.com

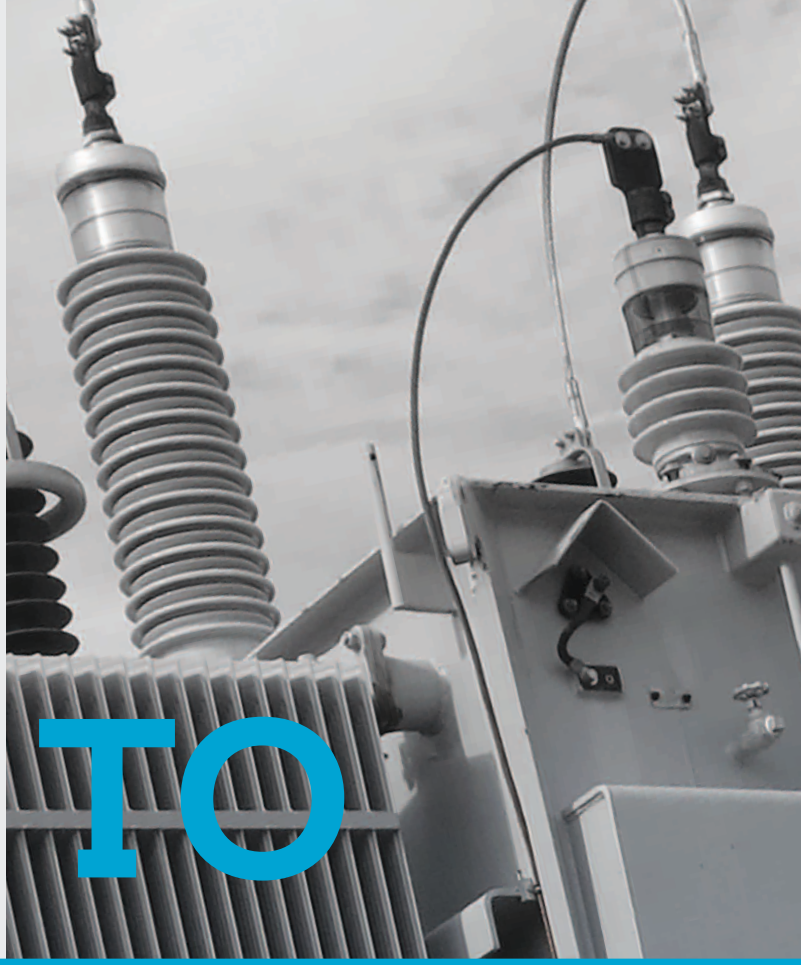
Contact us

SALES & STAND BOOKING ENQUIRIES
+86 21 6160 6789 * 877
cwieme.sh.exhibitor@hyve.group

MARKETING COOPERATION
+86 21 6160 6789 * 867
cwieme.sh.marketing@hyve.group

Organiser Hyve · Jointly Organised by CCPIT · Strategy cooperated by CEEIA · Supported by CECA

SUBSCRIBE TO



TRANSFORMER TECHNOLOGY MAG

DIGITAL

FREE

Annual subscription

Download and read unlimited number of articles published in Transformer Technology magazine

PRINT

$75/year

Subscription includes 4 successive issues per year

Receive print copies of the magazine in your letterbox and enjoy the joy of reading

To subscribe visit
transformer-technology.com

At a Glance

Mitsubishi Electric to sell transformer factory in Memphis to a rival

Mitsubishi Electric plans to sell its transformer manufacturing plant in Memphis, Tennessee and lay off 160 workers due to sluggish business.

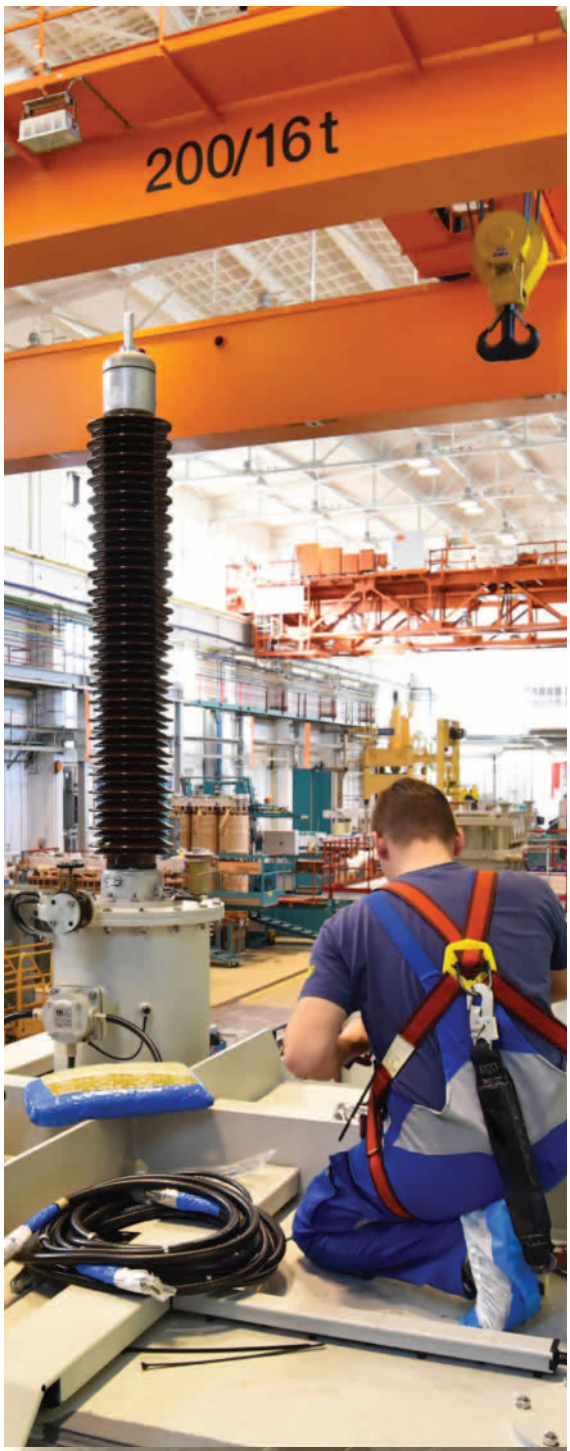
The Memphis transformer plant was launched just six years ago, after the company received tens of millions of dollars in tax incentives to open business in the Bluff City.

The factory makes the world's largest transformers for North American power companies, but due to sluggish business the Japanese company is reportedly looking to sell its plant to a rival.

The company is in advanced negotiations to sell the plant and the officials are hoping to conclude the deal in near future.

Joe Durante, general manager of the Memphis facility anticipates that the company that buys the plant will hire majority of the employees being laid off.

Source: Memphis Business Journal



Niagara Transformer to expand Cheektowaga plant with a new R&D center

Niagara Transformer will open a new $3.3 million research and development center next month at its Cheektowaga manufacturing plant in the state of New York.

Niagara Transformer is a family-owned company employing around 100 people. Once the research center opens, the company plans to add 10 to 15 jobs.

The company makes substation transformers up to 50 MVA base rating, 138 kV 650 kV BIL high voltage, and 90,000 Amp secondary current ratings.

Source: The Buffalo News

Tennessee transformer manufacturer to expand manufacturing operations

Tennessee Gov. Bill Lee, Department of Economic and Community Development Commissioner Bob Rolfe and ERMCO, Inc. officials announced that ERMCO will expand its manufacturing operations in Dyersburg.

The transformer manufacturer will invest approximately $12 million in the facility expansion and create 150 new jobs in Dyer County. ERMCO is adding to its footprint by expanding its operations into a third building, adding an additional 8,000 square feet to the facility.

With all of its products produced in the U.S., ERMCO is a manufacturer of oil-filled distribution transformers and transformer components. The company has been operational in Dyersburg, Tennessee since 1971.

"The new factory we are adding to our footprint in Dyersburg will allow us to continue to serve our partners with the short lead times they depend upon," said ERMCO President and CEO Bill Reffert.

Source: Tennessee Department of Economic and Community Development

Delta Star honors first employee with 50 years of service at Lynchburg facility

Lynchburg, VA-based transformer manufacturer Delta Star has honored its employee George Hudson as he became the first employee at the Lynchburg manufacturing facility to celebrate 50 years of service.

Hudson, aged 70, started at the company back in 1969 when it was called H.K. Porter. He was 20 years old and it was only his third job.

Fifty years later he continues to work at the company, now called Delta Star, as a transformer assembler level 5, the highest rank an assembler can have before becoming a supervisor.

With this honor, the company recognizes the importance of pivotal employees who have made significant contributions to the company throughout the years with noteworthy years of service.

Source: Delta Star; Photo credit: The News & Advance (Taylor Irbi)

Dominion Energy files proposal for largest offshore wind project in the US

Virginia's Dominion Energy has filed a proposal with PJM, a regional transmission operator, for a 2,600 MW offshore wind project, which, if approved, would be the largest such project in the United States.

Dominion Energy plans to complete the project in three phases, with each 880 MW coming online in 2024, 2025 and 2026, respectively.

The project would be located in the 112,800 acres Dominion Energy is leasing from the Bureau of Ocean Energy Management 27 miles off the coast of Virginia Beach.

Following the filing with PJM, Dominion expects to begin ocean survey work in 2020 and submit a Construction and Operations Plan in 2022.

In June, the company began construction on the 12 MW Coastal Virginia Offshore Wind (CVOW) project, the first fully permitted wind project in U.S. federal waters, expected to become operational in 2020.

The two offshore wind projects support Dominion's goal of reducing its carbon emissions by 55 percent by 2030.

Source: Daily Energy Insider

Resa Power names new Director of Service

RESA Power, LLC, a U.S. provider of life extension solutions for power distribution equipment, has named Bill Hartman as the Director of Service, Eastern Region.

Hartman brings with him over 20 years of experience in the power generation industry.

In this newly created role for RESA, Bill will be overseeing the Syracuse, New York and Shelton, Connecticut service organizations as well as assisting in the expansion of the company's footprint in the Eastern region.

J. Monte Roach, CEO of RESA Power, said, "We are looking to Bill to assist us in our growth plan in the East with brownfield startups as well as acquisitions."

Hartman will be based out of the RESA Syracuse office.

Source: RESA Power

Michael Sen

Jochen Eickholt

Siemens selects CEO and announces new management team for Siemens Energy

The Supervisory Board of Siemens AG proposed Managing Board member Michael Sen as CEO of Siemens' new energy business Siemens Energy.

Siemens Energy has presented its new management team which, in addition to an Executive Board, will have an expanded international management team – the Group Management Committee.

In addition to his current role as Chief Operations Officer, Tim Holt will be nominated for the position of Labor Director of Siemens Energy.

Jochen Eickholt, who is currently Chairman of the Portfolio Companies (POC) of Siemens AG, is a new member of the Siemens Energy management team.

Once Siemens Energy becomes a legally separate entity, this team will be instrumental in implementing the company's strategic approach.

The new business should be publicly listed in September 2020.

Source, Photo: Siemens

ABB tests one of the world-first subsea power technology systems

ABB successfully completed a 3,000-hour shallow water test on its subsea power distribution and conversion technology system – a $100 million research, design and development project between ABB and Equinor with its partners, which brings groundbreaking potential for cleaner, safer and more sustainable offshore oil and gas production.

For the first time energy companies will be able to access a reliable supply of up to 100 MW of power over distances up to 373 miles and down to 1.8 miles water depth, at pressures that could shatter a brick, according to ABB.

This is all achievable with a single cable with little or no maintenance for up to 30 years, making oil and gas production feasible in far out and deep ocean environments.

ABB's complete subsea power distribution and conversion system includes a step-down transformer, medium voltage variable speed drives and switchgear, control and low voltage power distribution, and power electronics and control systems.

Source, Photo: ABB

Hyundai Electric announces job cuts due to economic slowdown

South Korean media have reported mass layoffs are hitting Korea Inc. companies as they are rushing to downsize their workforce to cope with falling sales and rising costs due to deteriorating economic conditions.

Among these companies is Hyundai Electric & Energy Systems, South Korean transformer manufacturer, which also announced job cuts attributing the decision to declining orders from its main client, the Korea Electric Power Corp.

The Hyundai Heavy Industries Group unit said it will receive retirement letters from all of its executives and accept 40 percent of them.

"We have made many efforts to overcome the current crisis while keeping the current workforce, but decided to launch a restructuring plan as both domestic and overseas markets continue to slow down," Hyundai Electric CEO Jung Myung-rim said.

Source: Korea Times

First smart transformer commissioned in UAE

Abu Dhabi Transmission & Despatch Company (Transco) is implementing a pilot project which uses the latest technology to utilize data to optimize the performance of substations.

Transco and Siemens recently installed a connected power transformer, the Sensformer, at Al Foah 220 kV substation, which is the first time such technology has been used in the UAE.

"The installation and activation of this smart transformer is part and parcel of the digital transformation journey we launched under the umbrella of our vision to be one of the top quartile utilities in the world by 2024," said Dr Bruce Stedall, Transco MD.

Source: MEP; Photo: Siemens

Nynas introduces world's first bio-based high-performance transformer fluid

Nynas has launched the first product in its new bio-based range, completing its portfolio of high-performance transformer fluids.

NYTRO BIO 300X is a fully recyclable product that offers exceptionally good cooling thanks to its ultra-low viscosity, according to the manufacturer.

The new fluid allows significant reduction of the transformer's winding hot spot temperature, with initial studies showing up to 10 degrees improvement compared to average mineral oils and around 20 degrees lower compared to ester liquids, Nynas said in the press release.

According to Carl Wolmarans, Technical Advisor Electrical Industry at Nynas, the new fluid is the only in the world that combines ready biodegradability with superior oxidation stability.

This solution allows transformer OEMs and utilities more flexibility in selecting the best suited fluid for a certain application, making it easier to meet the requirements on weight and size of transformers.

Source, Photo: Nynas

KEMA Laboratories to change ownership from DNV GL to CESI

DNV GL, the world's largest resource of independent power and renewables experts and CESI, a company specializing in testing, inspections and technical consulting services in the energy sector, have signed an agreement to transfer the ownership of KEMA Laboratories to CESI.

The transfer comprises KEMA and all the high-voltage and high-power testing and inspection activities performed by its personnel in its own laboratories in Arnhem (NL), Prague (CZ) and Chalfont (USA).

The completion of the transaction is expected to take place at the end of 2019, subject to customary closing conditions, including regulatory approvals.

The KEMA testing and inspections facilities include the world's largest high-power laboratory, with the highest short circuit power of 10,000 MVA, and the world's first laboratory capable of testing ultra-high voltage components for super grids, as well as the Flex Power Grid Laboratory, for advanced testing of smart grids components.

All former KEMA advisory employees will remain within DNV GL including all the advisory services as well as DNV GL's testing and verification services for power failures, battery testing, transformer oil testing and smart grid testing.

Source, Photo: DNV GL

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 MAG

Contact us at
info@transformer-technology.com

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

Events Watch

Elecrama 2020
January 18-22, 2020
GREATER NOIDA, INDIA

DistribuTECH International
January 28-30, 2020
SAN ANTONIO, TEXAS

Doble - Life of a Transformer Seminar
February 10-14, 2020
ORLANDO, FLORIDA

TechCon North America 2020
February 18-20, 2020
ORLANDO, FLORIDA

PowerTest 2020
February 24-28, 2020
CHICAGO, ILLINOIS

Middle East Energy
March 3-5, 2020
DUBAI, UAE

CWIEME Shanghai
March 24-26, 2020
SHANGHAI, CHINA

Photo by Shutterstock

HIGHVOLT and CEPCO to equip largest electrical testing lab in Middle East

HIGHVOLT and CEPCO have been awarded a contract to provide equipment for GCC Electrical Testing Laboratory (GCC ETL), the largest testing laboratory in the Middle East region and the largest testing laboratory in the world ever built in a single construction phase.

The laboratory will offer a range of test bays for testing low, middle and high voltage equipment like transformers, cables and switchgears.

The biggest and most important part will be the high voltage test laboratory, which will be equipped with test systems for voltages up to 1,200 kV and an impulse voltage test system for over 3,000 kV, as well as a three-phase AC voltage test system with a capacity of 4,000 kVA specifically for testing power transformers.

The scope of delivery also includes test systems for on site testing, including a system for testing complete transformer stations with switchgears, transformers and short supply cables.

Built in close cooperation with a global testing service provider CESI, the GCC Lab is slated for completion by 2021.

The project volume for supply and construction of high-voltage test systems is around $22.3 million.

Source: PowerTech Review

Tobias Hansson takes on leadership of ABB in Ludvika

As of October 1, 2019 Tobias Hansson is the new head of ABB in Ludvika, adding to his current responsibilities as the head of ABB's Transformers Business Unit in Sweden.

In this role Tobias Hansson succeeded Magnus Ström, who decided to leave ABB.

As site manager, Tobias will coordinate operations in Ludvika, where ABB Group runs its most complete operations in the area of power transmission.

Tobias Hansson began his career at ABB as a trainee in 2002. He has since held several leading positions in ABB's Power Grid business.

Source, Photo: ABB

New transformer oil manufacturing plant opened in Sharjah

India's oil and lubricant firm Texol Lubritech opened a new $12 million manufacturing plant at the Hamriyah Free Zone Authority (HFZA) in Sharjah, its first automated unit outside the Indian subcontinent.

The plant will, among other oils and lubricants, manufacture transformer oils and have the annual capacity of 100,000 metric tons.

The plant was opened by the director of HFZA in the presence of the chief executive officer of the company, Simon Philip, and Gandhar group chairman of Gandhar Oil Refinery India.

Source: Construction Week Online

MR and GRASIM form JV for the manufacture of composite hollow core insulators

Grasim Industries Limited and Maschinenfabrik Reinhausen GmbH (MR) signed an agreement to form a joint venture company in India for manufacturing and sale of composite hollow core insulators to serve the global power transmission and distribution industry.

The new company called Aditya Birla Power Composites Limited will set up a new composite hollow core insulators manufacturing plant at Halol, in the state of Gujarat.

The production will serve the insulator requirements of Indian and global OEMs in the power equipment industry.

The new facility will be the first large scale plant for this range of products in India and the largest such plant outside of China.

Source, Photo: MR

GE to supply vegetable oil filled transformers for a Brazilian wind project

GE Grid Solutions has signed an agreement with a Brazilian utility company Engie Brasil to expand the company's Campo Largo II wind farm substation.

To support the environmental sustainability of the Campo Largo complex, located in Sento Sé in the northern state of Bahia, GE will deliver two 230 kV power transformers that use 99% biodegradable vegetable oil.

In addition to the delivery of transformers and high voltage equipment – circuit breakers, switches, measuring transformers, and disconnect switches – GE will also be responsible for engineering, electromechanical assembly, civil works, materials supply, automation, and all substation commissioning.

Source: GE Grid Solutions

Siemens launches new protection relay series for digital substations

Siemens has launched a new is series of protection relays as part of its offerings for medium-voltage and industrial power networks.

The first device applications of the new generation of protection relay will be overcurrent and earth fault protection and transformer protection in substations.

The new device includes comprehensive functionality as standard, with enhanced process data such as faults, events and waveform records enabling the power network to be effectively managed. It also includes cyber security features such as digitally signed firmware.

Its withdrawable design ensures easy replacement without disturbing the switchgear connections.

Source, Photo: Siemens

China's State Grid buys Sempra's T&D assets in Chile for $2.2b

Sempra Energy has entered into an agreement to sell its equity interests in its Chilean businesses, including its 100% stake in the Chilean third-largest distributor of electricity Chilquinta Energía, to China's State Grid subsidiary State Grid International Development Limited (SGID).

Sempra Energy's interests will be sold for $2.23 billion in cash.

The sale to SGID is expected to be completed in the first quarter of 2020, subject to customary closing conditions.

Today's announcement follows Sempra Energy's agreement to sell its equity interests in its Peruvian business, including its 83.6% stake in Luz del Sur S.A.A., to China Yangtze Power International (Hongkong) Co., Limited.

That sale is also expected to be completed in the first quarter of 2020.

Source: BN Americas

Pioneer Transformers acquires Power Partners

Pioneer Transformers L.P., a portfolio company of Mill Point Capital, has acquired Power Partners, LLC, a designer and manufacturer of high-quality pole-mount and pad-mount power transformers.

Power Partners, headquartered in Athens, GA, manufactures a range of custom, semi-custom and standard transformer products for investor-owned utility, public power, industrial and commercial OEMs and international customers.

"By combining Power Partners with the existing Pioneer platform, we have created a leading pure-play transformer company in North America, enabling us to better serve all customers," said Antony Besso, Executive Chairman of Pioneer and an Executive Partner of Mill Point.

Source: Business Wire

Hitachi receives order to supply 5,600 distribution transformers in Myanmar

Hitachi Soe Electric & Machinery, a subsidiary of Hitachi Industrial Equipment Systems, has received orders from the Myanmar Ministry of Electricity and Energy for the supply of approximately 5,600 distribution transformers.

Hitachi will start production of the distribution transformers within this year and is planning to deliver all units by the end of 2020.

The project is part of Myanmar government's medium- to long-term goal of increasing its electrification rate from less than 50% in 2018 to 100% by 2030.

Source: NS Energy

ABB wins $30m transformer order to boost Germany's renewable energy integration

ABB has won an order worth around $30 million from Amprion GmbH, a German transmission grid operator, to supply phase-shifting transformers that will optimize power flow in the German electricity network and help in the integration of renewable resources.

As part of the order ABB is supplying two phase-shifting transformers with 2,494 MVA capacity each from its transformer factory in Bad Honnef, Germany.

These transformers will enable Amprion to integrate wind power more efficiently.

They also have the potential to offer savings of more than $110 over 3 years, according to the manufacturer.

Amprion provides electricity to more than 29 million people, from the Alps in South of Germany to Lower Saxony.

Source: ABB

TMC Transformers acquires HPS' transformer business in Italy

TMC Transformers, Italian manufacturer of low and medium transformers announced the acquisition of Hammond Power Solutions' transformer business branch in Marnate, Italy, formerly owned by Marnate Trasformatori.

With this acquisition TMC Transformers is aiming to consolidate its growth on the dry type transformer market, building its technical expertise and increasing its production capabilities.

Source: TMC Transformers

Holger Michalka joins MR Management Team

Effective April 1, 2020, Holger Michalka will join the management team of Maschinenfabrik Reinhausen GmbH (MR) succeeding Michael Rohde, who will retire at the end of 2019.

Holger Michalka will join MR coming from RITTAL, a systems supplier for enclosures, where he spent 15 years in various management positions, currently as Executive Vice President Sales Europe.

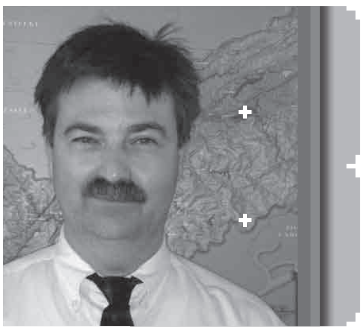
Holger will work for MR as Managing Director, Products & Operations.

With the new addition, MR's three-headed management team will be led by Wilfried Breuer, responsible for systems business and sales; Holger Michalka, responsible for the components business and production; and Dr. Nicolas Maier-Scheubeck, responsible for diversification and administration as Spokesman of the Management Board.

Source, Photo: MR

Transformer Bushing Failure Signs

by **Mark B. Goff**
and **Cassandra H. Goff**



Mark Goff has 34 years of experience working for one of the largest electricity providers in the U.S. where he spent seven years working as a field test engineer and 25 years working as a system engineer for the TVA transmission organization. At that time, Mark actively worked to build an effective transformer, breaker and infrared testing and maintenance program as well as to build talent to support the maintenance and programs. His last position at TVA was manager of the Electrical Energy Conversion group in Generation Engineering. Mark holds BSc and MSc degrees in Electrical Engineering. He is a registered professional engineer in the state of Kentucky since 1988. He is also a member of the T&D World Executive Insights Board.

Small Avoid stakes

Photo: Shutterstock

The power industry experience shows that a failure of a high-voltage oil-filled bushing will most likely lead to a catastrophic transformer failure. The fire triangle requires the coexistence of fuel, oxygen and an ignition source. First, the transformer has a large volume of oil as a fuel source. Second, the atmosphere is the source for oxygen. And third, the ignition source which is created by an internal arc from the faulted bushing completes the fire triangle. As the bushing fails, the pressure wave created by an electrical short circuit inside of a faulted bushing will crack the bushing insulator, thus allowing the bushing oil to atomize. Next, the massive amount of oil from the transformer tank is exposed leading to a catastrophic failure. In extreme cases, the transformer tank will split thus releasing the transformer oil at a higher rate. If the electrical protection scheme is slow to operate, then the fire suppression system will have a difficult time in extinguishing the fire.

What is a high voltage bushing?

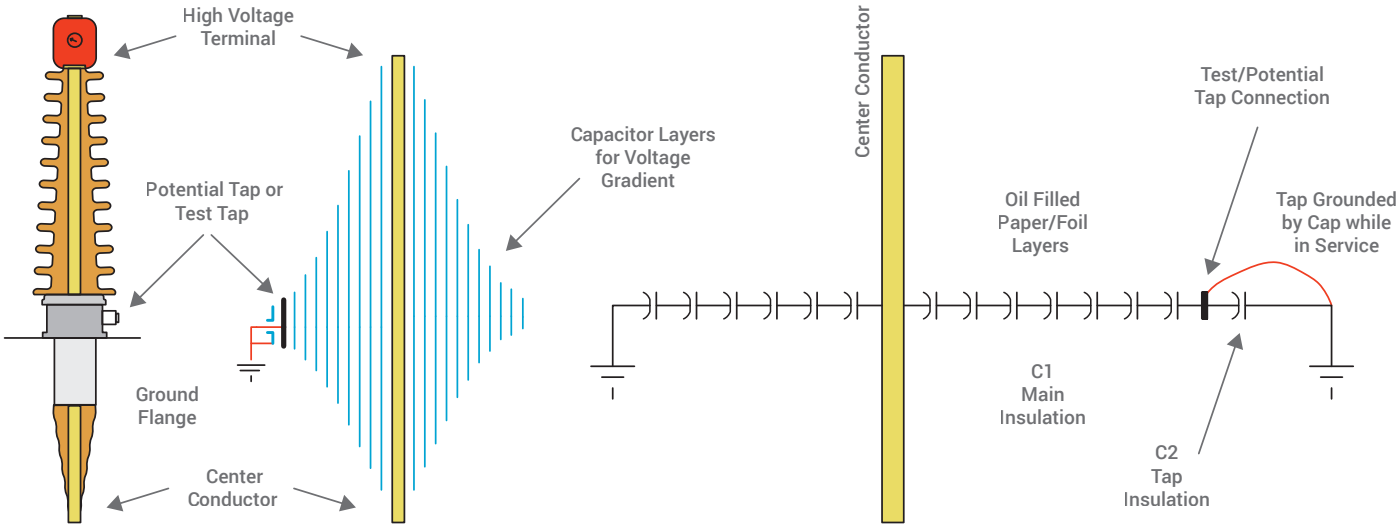
A bushing is a combination of electrical and mechanical components that allows current to pass through a barrier while providing electrical isolation from the barrier. In most cases, the barrier is at ground potential. The core is a conductor usually made of copper or aluminium. The current rating is based on the size and conductivity of the material used. The inside conductor is surrounded by some type of electrical insulation. Lower voltage bushings (34 kV and below) can be made of a solid material such as solid porcelain or some type of oil/resin composite.

In bushings greater than 34 kV, the inside has a different design to deal with the unevenness of the voltage gradient. This design consists of concentric layers of insulation and conductor foils that are contained in an outer porcelain or composite shell. The paper/foil layers form concentric capacitors, which allows the voltage to be graded in a uniform method between the high voltage core and the bushing flange which is at ground potential. This design has a voltage/potential or test tap. While in service, this point is normally tied to ground through a tap cover, but for bushings rated greater that 69 kV, the cap can be replaced with an adapter to feed other instrumentation. In all cases, this tap is used while performing offline electrical test.

The bushings are the most stressed components on a power transformer because the voltage gradients are much higher than the internal windings and components. In simple terms, the physical distance between the high-voltage points and ground potential in a bushing is much smaller compared to the distance from the high-voltage components inside the transformer tank and ground.

In most modern bushings above 26 kV, paper provides the skeleton for the insulation system. The paper is impregnated with mineral oil to provide more insulation and allows for better heat transfer. The outer shell is typically porcelain; however, due to the availability and long lead time for the porcelain shell, bushing manufactures are moving to other designs. But until all of the oil-filled bushings are replaced, a good understanding of the failure signs is needed to prevent catastrophic transformer failures.

Figure 1. Three Illustrations of the same bushing

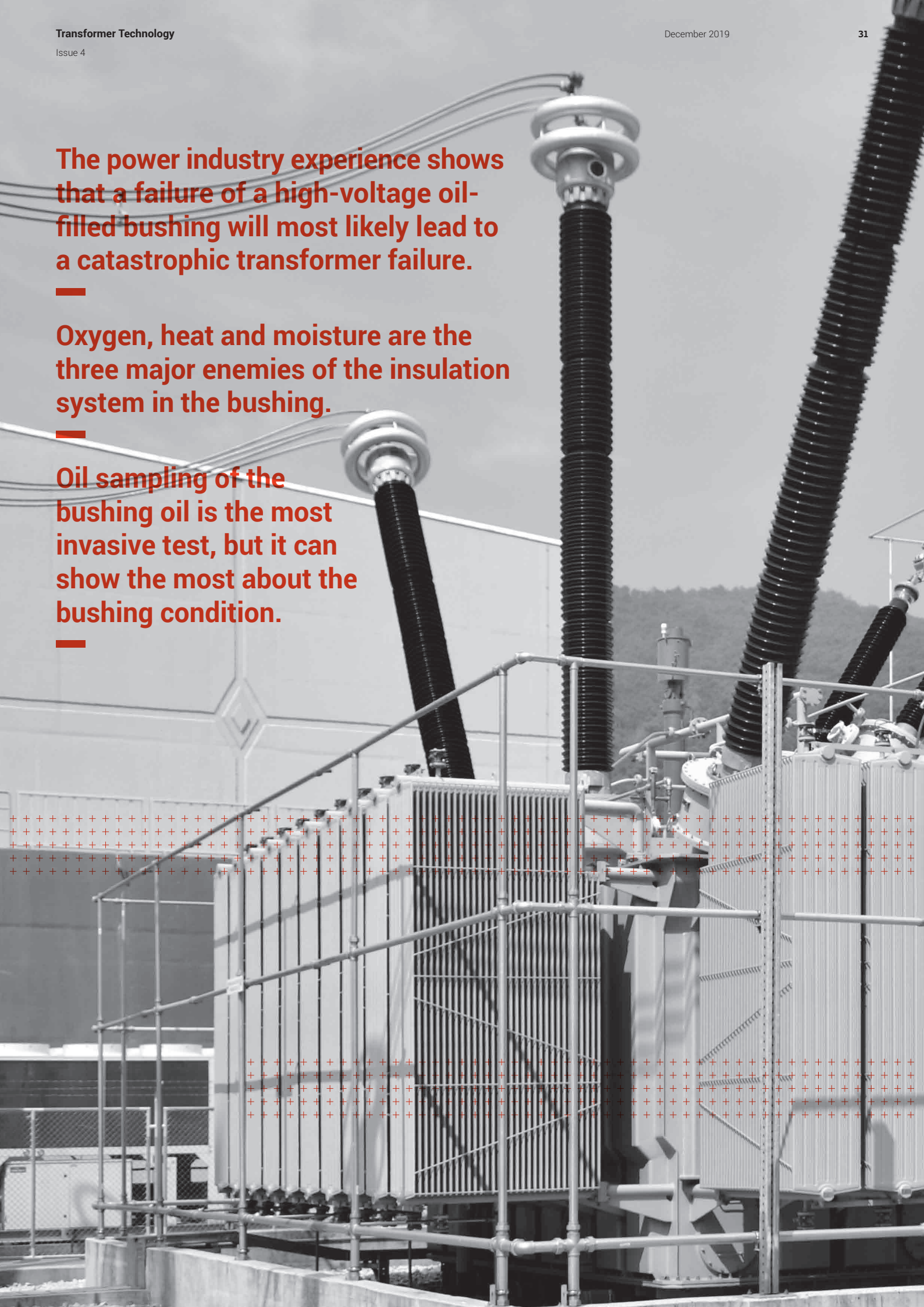


Enemies of the bushing

Oxygen, heat and moisture (Ohm's Law for an insulation system) are the three major enemies of the insulation system in the bushing. Since bushings are sealed from the outside atmosphere, any break in the seal will allow oxygen and moisture to enter the bushing. A good visual indication of a break in the seal are oil level and oil stains. C1 and C2 power factor test is another indicator that contamination has entered the bushing.

Heat is usually caused by a loose external connection. Infrared (IR) imaging, while the transformer is in service, is the tool of choice when looking for a bad or hot connection. IR can also be used on transformers to see the oil level. While oil sampling of the bushing oil is the most invasive test, it can show the most about the bushing condition. Oil sampling can quantify the amount of moisture that has entered the bushing, and also, allow the detection of fault gas accumulation, which gives a good idea of the deterioration of the internal insulation.

Photo: Shutterstock



The power industry experience shows that a failure of a high-voltage oil-filled bushing will most likely lead to a catastrophic transformer failure.

Oxygen, heat and moisture are the three major enemies of the insulation system in the bushing.

Oil sampling of the bushing oil is the most invasive test, but it can show the most about the bushing condition.

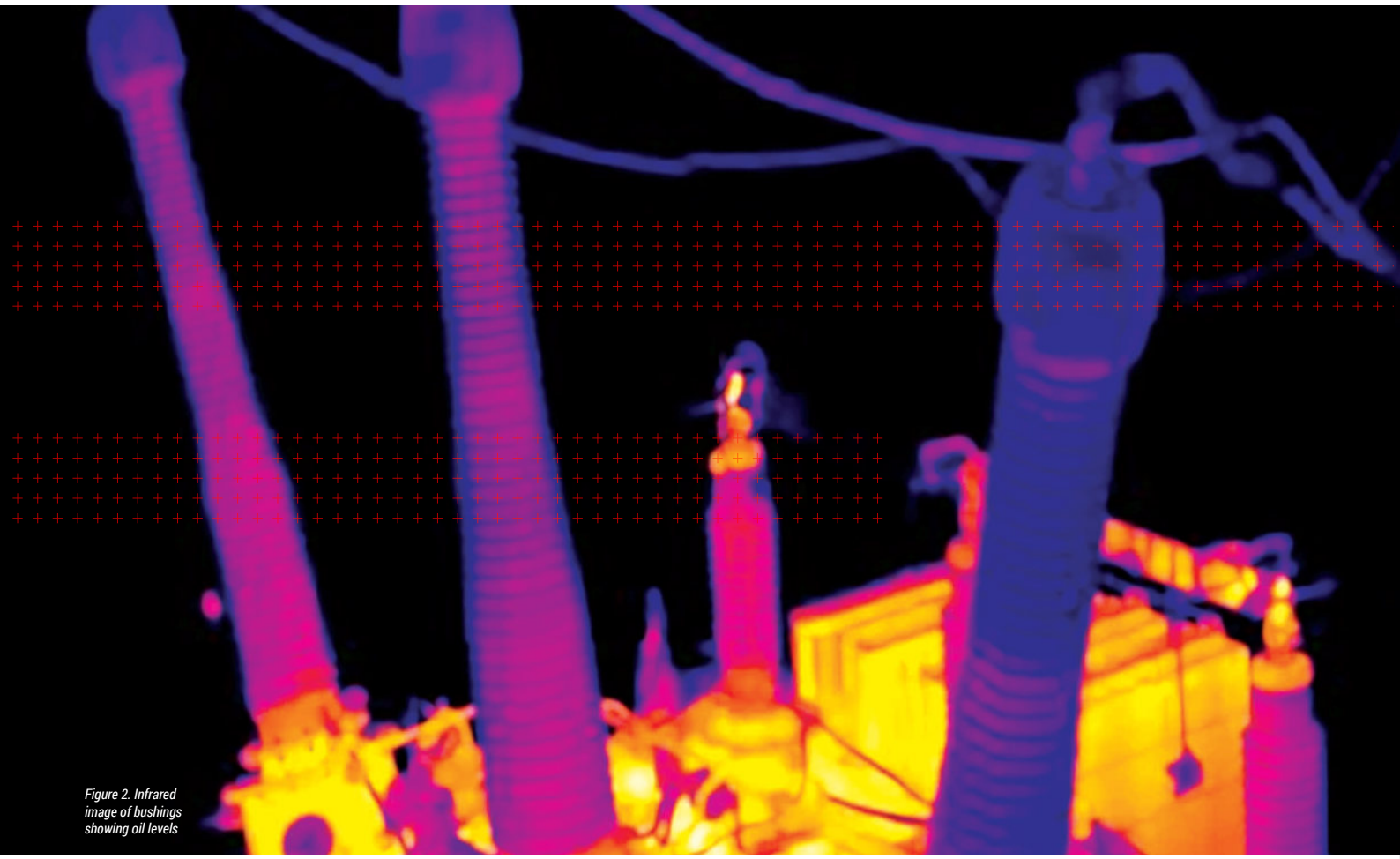


Figure 2. Infrared image of bushings showing oil levels

100 kV – 765 kV bushings

If one of the following statements is true, then use extreme caution around the transformer until it can be de-energized:

- Bushing oil level pegged high or pegged low according to the oil level gauge, sight glass(es) or infrared (IR) image.
- Bushing is showing signs of leaking around the oil level gauge/ sight glass(es)

If one of the following is found while testing, DON'T return the bushing to service:

- C1 power factor is in the "Investigate" range according to Engineering Limit file.
- C1 capacitance is greater than 10 percent of nameplate.
- C1 capacitance is greater than 5 percent of nameplate for a unit more than 25 years old.
- C2 power factor is in the "bad" range according to Engineering Limit file.
- Moisture in oil is 20 ppm or greater.
- Acetylene is 1 ppm or greater.
- PCB is 50 ppm or greater.

Samples are recommended to be taken by only one crew for the entire company to keep consistency with company's oil sampling procedures.

Bushings rated above 345 kV are NOT recommended to be refurbished. If the bushing shows NO acetylene and is rated below 345 kV, it can be refurbished by disassembling, drying, inspecting, re-gasketing, and re-assembling the bushing, which MUST be performed by the OEM or a trusted bushing shop with expertise. After refurbishment, the bushing must pass the overall C1 and C2 power factor test (any voltage level) as well as a partial discharge test (100 kV – 230 kV units).

Special bushing testing recommendations and criteria

It is recommended to perform one-time bushing oil sampling in the following circumstances:

- 345 kV – 500 kV bushings are more than 25 years old.
- 100 kV – 230 kV bushings are more than 30 years old.
- Any bushing greater than 100 kV that shows signs of an oil leak.

Photo: Snell

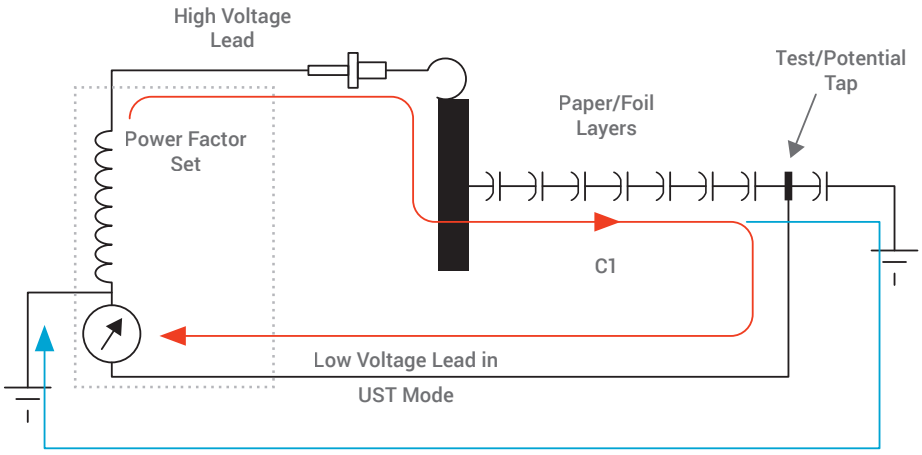


Figure 3. Power factor testing of a bushing (UST test measures C1 power factor and capacitance)

Samples are recommended to be taken by only one crew for the entire company to keep consistency with company's oil sampling procedures [1].

Caution: Oil sampling requires extreme precautions not to introduce contamination into the bushing.

References

[1] Mark B. Goff and Ahmed H. Elton, "Oil Filled Bushing Secrets Revealed," Appendix A, IEEE 978-1-4673-5202-4, IEEE IACC Conference, 2013

Mitigating Failure Risk in Power Transformers: Eletronorte Case Study

by **Iran Prado Arantes**
and **Geraldo Nicola**

Power transformers are highly reliable electrical equipment. Still, failures can occur regardless of the application of the best design, production and operation techniques. A global transformer reliability survey conducted by the Cigre working group A2.37 in 2015 [1] concluded that the failure rate of substation transformers was 0.53% per year, and 0.95% per

Iran Prado Arantes obtained his electrical engineering degree in 1986 from the Faculty of Engineering at Ituiutaba in Minas Gerais. He worked at CELG S.A. from 1977 to 1988 in the area of substation maintenance. Iran joined Eletronorte Eletrobras in 1988, where he worked as a substation maintenance engineer until 2004, and since then, works as a substation design and construction engineer. He ia a member of GT A2 09 Transformers Committee of Cigré and CE-03-14.01 Power Transformers of ABNT – Brazilian Standard Committee.

Geraldo Nicola graduated as an electrical engineer in 1977 from the University of Brasilia. He spent most of his career with Eletronorte, where he started designing AC and DC substations some decades ago. He has managed several R&D projects of large power transmission systems across Brazil, including the development of the 1,000 kV (12 GW) dual-circuit project to interconnect wind and solar energy farms. During his career, he inspected and performed numerous tests of large power transformers as well as other electrical equipment in Brazil and abroad. Since 2018 he works as a consultant in the industry.

Photo: Shutterstock

year for generator step-up transformers. Such data leads us to estimate that a power transmission company can expect one or two failures per year for each group of 200 transformers in its fleet. This figure becomes more relevant when taking into perspective the potential impacts and external effects of each of these occurrences.

Based on the same Cigre report [1], 76.56% of the failures did not lead to any reported external effects. The remaining 23.44% resulted in the following events:

- Fires: 7.16%
- Explosions: 5.91%
- Leakages: 4.25%
- Collateral Damage: 1.24%
- Other: 4.88%

According to this, for each group of 200 transformers we can expect a failure with significant external consequences to occur once in two to four years. Fires and explosions can lead not only to economic losses and long periods of outages, but also to serious injuries or even casualties, often an unacceptable risk.
(At this writing, the fires in California and the power cut-offs are a significant issue for the entire state, as they were last year and are expected into the future. Editor's note).

Setting the right transformer specifications at the design stage can have a huge impact on the safety and reliability of transformer assets in the long term.

2005

Figure 1. Catastrophic failures at the Tucuruí hydroelectric plant in 2005 (left) and 2007 (right)

Eletronorte Experience

Having an installed generation capacity exceeding 9,000 MW, Eletronorte, a company of the Eletrobras Group, operates over 11,000 kilometers of transmission lines as well as 57 substations to bring electricity throughout Brazil through the National Interconnected System.

Like other companies in the electricity sector, in its daily operations Eletronorte is faced with a possibility of explosions and fires in its assets. The company is therefore continuously searching for alternatives to mitigate the risks and consequences of such events.

Power outages associated with failures can cause huge losses due to lost profit and penalties imposed by regulators. Another aspect strongly impacted by the occurrence of explosions and fires is the company's image.

Often the failure is initiated by an electrical arc resulting from the dielectric breakdown either due to overvoltage or insulation failure, which may be caused by material degradation, manufacturing defect or unforeseen design conditions.

Such failures involve very high energy values and an abrupt rise in temperature and pressure, with insulating oil vaporization and formation of gases whose pressure waves may lead to tank rupture, and consequently, contact of the high-temperature insulating oil with the atmospheric air.

The gas law, PV=nRT, states that the increase in gas volume (V) is followed by an almost instantaneous increase in temperature (T). In the event of a transformer tank rupture, high-temperature gases are released into the atmosphere. This expansion contributes to the increase in the temperature of the gases and may lead to mineral oil self-ignition, at 250°C, causing a pool fire.

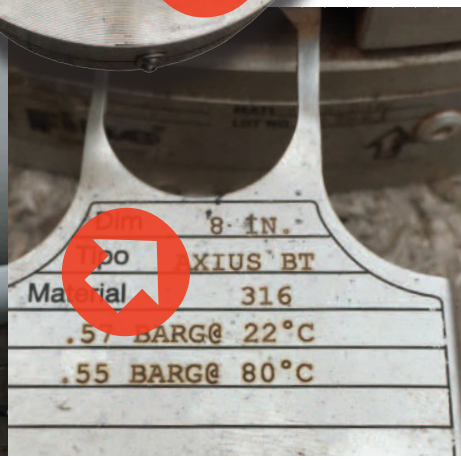
From 1988 to 2008, Eletronorte observed twelve incidents of fire in power transformers whose damage extended to entire GIS substations, neighboring equipment, auxiliary transformers and buses. The four most significant occurrences were at the 8,370 MW Tucuruí hydro power plant located in the state of Pará, in the northern region of Brazil, which has been in operation since 1984 (Figure 1).

Photo: Eletronorte

2007

From 1988 to 2008, Eletronorte had twelve incidents of fire in power transformers with catastrophic consequences, four of which took place at the Tucuruí hydroelectric plant.

Figure 2. A ruptured disc in the confined discharge explosion tube in a 245/145-15 kV, 100 MVA autotransformer



From Better Design Standards to Higher Resilience

In 2003, following the occurrence of transformer leakages, explosions and fires at its substations, Eletronorte started a reassessment of transformer designs and their specifications, adopting the following basic assumptions:

- Under normal operating conditions and during the service life, maintain tightness and avoid contamination of oil, active part and the environment.
- In a fault condition, the tank must withstand the internal overpressure without causing the containment rupture and, consequently, occurrence of fire.

As a result of this effort, the transformer and reactor specifications were updated and improved with the following requirements:

- Tank: Design and testing according to ASME code, section VIII; standard design of weld joints; welded main tank cap; 100% inspection of structural welds with LP and ultrasound; use of flats with flat faces.
- Joints: Adopted PTFE – expanded Teflon – for the joints, on flat flanges.
- Load tap changer (LTC): Use only vacuum-type LTCs.
- Natural ester insulating liquid: Fire resistant, with a fire point above 360°C; protects insulating paper and reduces environmental impact.
- Pressure relief: Pressure relief valve opening adjustment considering expansion tank oil column as per NFPA-30 recommendation and use of rupture disc burst tube as per NBR 5356-1 and confined discharge.

Implementing these improvements in the transformer and reactor design and specifications has drastically reduced the risk of explosion and fire, as well as increased the service life, facility availability, and revenue assurance. There was also a reduction in the following items:

With the implementation of improved design standards for transformers and reactors, the company recorded a significant reduction in catastrophic failures, with no failures taking place at the Tucuruí plant in the period from 2008-2019.

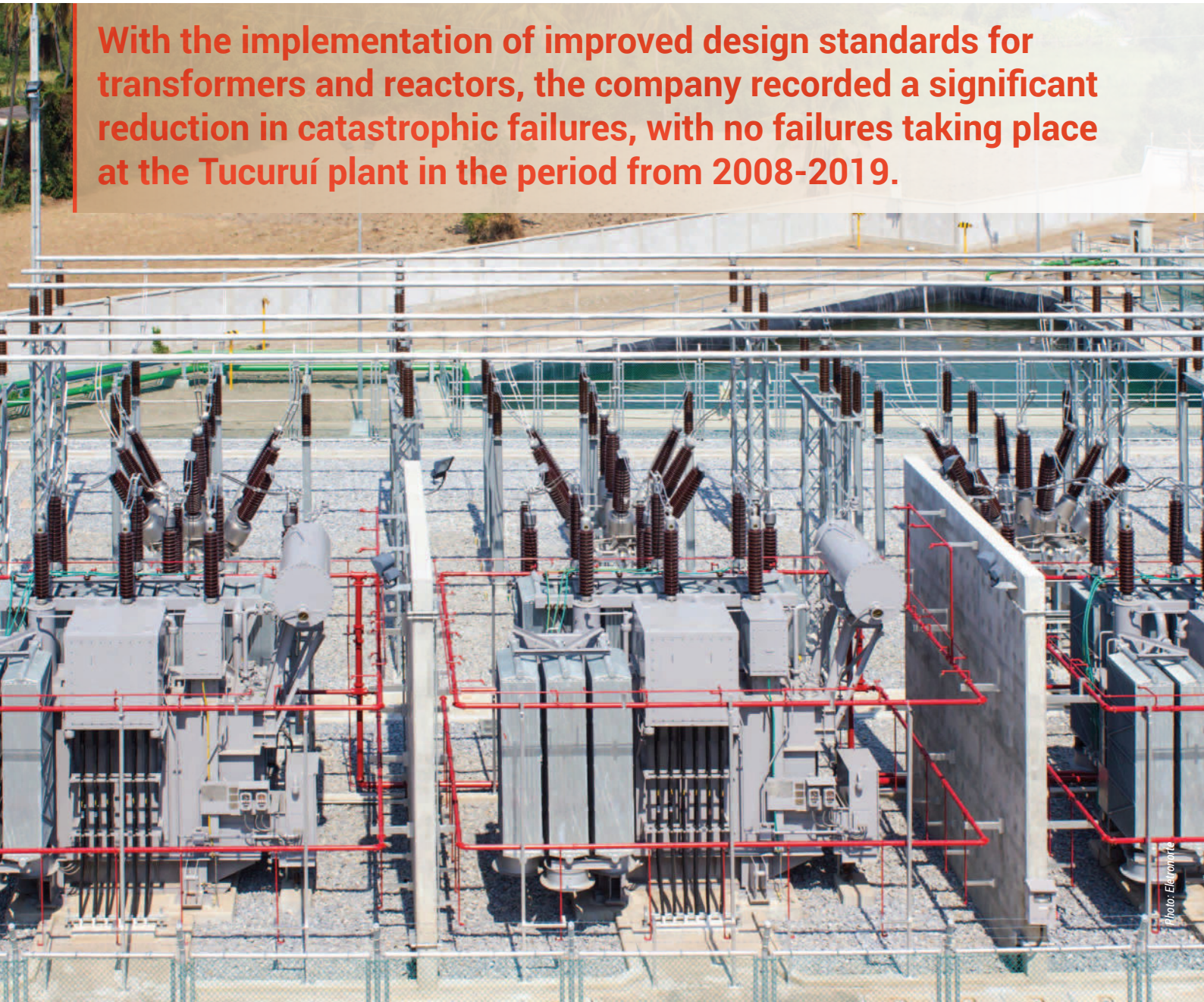


Photo: Eletronorte

restoration time of electricity supply, insurance premium and, most importantly, reduction of risk to operating or maintenance personnel and the environment.

With the improvements in the conventional protection of its electrical system and having limiting some operations at generating units, Eletronorte effectively recorded a reduction in catastrophic failures in its assets. Particularly in relation to the Tucuruí plant, there have been no failures in the period between 2008 and the time of writing this article.

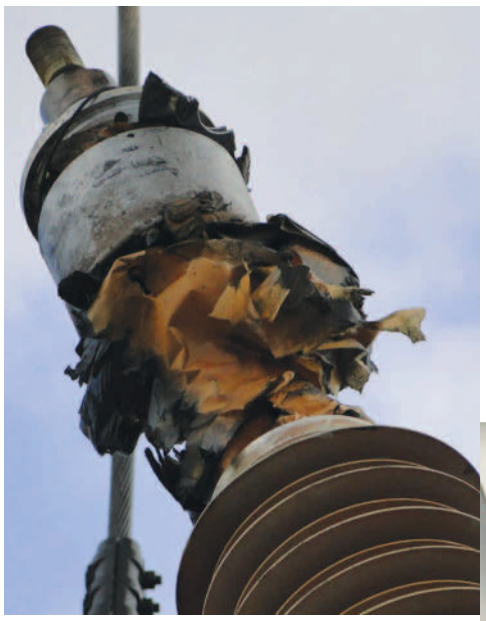


Figure 3. A bushing failure in 2018 had minimal impact on the operation of the substation.

Since 2006, when Eletronorte started specifying power transformers and reactors immersed in natural ester, more than twenty units have been installed up to 245 kV voltage class, all of which in continuous operation. The specifications allow use of vegetable insulating oil for all voltage classes, including 550 kV.

Figure 4. An internal failure in an auxiliary service 75 kVA natural ester immersed transformer in 2012 was limited to the tank deformation for pressure relief – no fire occurred.

Thanks to the measures taken, a bushing failure in early 2018 (shown in Figure 3) that would possibly have led to major external effects was reduced to replacing only the components: the bushing and the rupture disc (as shown in Figure 2).

They also faced an internal arcing in a small 75 kVA natural ester immersed transformer from the early days of the assessment of the technology (Figure 4). Although the tank deformation makes clear the amount of energy, possibly reaching temperatures in the level of thousands of degrees in the arcing region (plasma), no fire happened.

These events are good examples of the effectiveness of the adopted measures, which minimize external effects of a real failure.

Conclusion

Safety, reliability and resilience starts at the design phase, a fundamental principle of the Electrical Power Reliability Alliance (EPRA); www.myepra.com and is an essential element within the Body of Knowledge (BoK) of all of the reliability societies and Safety, reliability and resilience starts at the design phase organizations; www.smrp.org and www.reliable-web.com. The Eletronorte experience is a powerful example of how design standards can and do effect safety, reliability and resilience.

References

[1] Cigre Working Group A2.37, "Technical Brochure 642 – Transformer Reliability Survey," Cigre, Paris, December 2015

Load Tap Changers:

Diagnostics and Fault Identification – A Key to Condition-Based Maintenance

by **Corne Dames**

Corné Dames is the Managing Director of Independent Transformer Consultants, always striving to keep on top of new developments and research. She has expertise as Laboratory Manager in the analysis of transformer oils and as diagnostician identifying problem areas in transformers, as well as profiling of transformers according to available results thus empowering the customer to take preventative steps in maintenance. Corné has vast practical and theoretical knowledge on reliability maintenance programs. Coming from a strong chemical background she has insight in all the chemical processes that is part of the transformer system coupled with technical insight helps customers optimise their reliability maintenance and electrical asset lifetime.

Photo: Shutterstock

Load tap changers (LTCs) are an extremely important element in the reliability of any transformer in the utility network and in many industrial applications. This part of the transformer is the only actively moving mechanism, which must operate continuously to ensure a constant voltage output. LTCs have been reported to be accountable for approximately 22% of failures in transformers [1]. Their dominant failure modes are found to be contact wear, weak springs and breakage of components in the driving mechanism [2]. This article will look at the different types of condition monitoring methods of LTCs and their practical application in the field as well as the accuracy in fault identification and ease of use for the types of monitoring.

As the only actively moving mechanism in a transformer, load top changers are an extremely important element in the reliability of transformers which must operate continuously to ensure a constant voltage output.

Diagnostic and Monitoring Methods

The load tap changers diagnostic and monitoring methods that will be discussed in the following are:

1. Infra-red (IR) scanning
2. Differential temperature measurements
3. Oil and insulation analysis – DGA (Dissolved gas in oil analysis) and particle profiling
4. Electrical testing (ET)
5. Mechanical analysis – Vibration signatures (Vibro-acoustic diagnostic method)

IR Scanning to Assess LTC Health

LTC failure will cause the transformer to shut down, causing loss in revenue and in the case of industrial applications, severe potential failure of mission critical systems.

Thermal imaging will identify any parts that have increased operating temperatures. Under normal circumstances the tap changer functions at approximately the same temperature as the transformer tank, unless certain start-up of high energy consuming processes in the plant are present. When a problem is developing in the tap changer an increased operating temperature would be noted, with this increase continuing up to the critical point of failure.

A thermal image sensor can record or monitor temperatures in real-time, which can help us to understand the temperature trends of the LTC and assist the end user in making critical decisions before the transformer/tap changer fails. This continuous monitoring will warn us as soon as the problem arises and will give ample time to address the problem.

This method warns you that there is a problem but won't pinpoint the problem. The tap changer unit needs to be opened, an inspection needs to be done to identify and rectify the problem, but it won't give you an indication of the severity of the problem [3].

Differential Temperature Measurements

Thermal and electrical faults dissipate energy. The normal operating temperature of the LTC is lower than the operating temperature of the transformer main tank. This will change if there is an electrical problem in the tap changer unit, if this unit is separate from the main tank. If incorporated in the main tank this change in temperature might not be as significant since the body of oil is much larger and the increase in oil temperature around the tap changer will be distributed throughout the main tank. A sudden increase in operating temperature of the tap changer tank will indicate that a problem has begun, and a visual inspection might be needed. Since this testing method is not able to diagnose the problem, but merely signal that there is a problem, thermal imaging should not be the only option in reliability maintenance testing protocols for LTCs.

Thermal imaging is not able to diagnose the problem, but only signal that there is a problem. So, this method should not be the only option in reliability maintenance testing protocols for LTCs.

Oil and Insulation Analysis – DGA and Particle Profiling

Oil tests that can be performed on LTCs include the following measurements:

Dielectric Breakdown – The oil in the LTC should maintain a minimum breakdown voltage [4]. Online filters are used to contain the particles discharged during arcing in order to maintain a better breakdown strength. This application ensures that the maintenance cycle interval is further apart and reduces contact wear in the tap changer.

Water Content – Excessive water accelerates aging of contacts. Compartments with arcing contacts will be vented to ensure that there is no build-up of combustible gases in the chamber, as the formation of combustible gases during the tap changing cycle is normal. An oil temperature that is higher than ambient temperature will ensure relatively less saturation of the oil with water. Sealed LTC chambers with desiccant breathers will display standard ppm concentration levels in the compartment and a relative saturation in percent (%) can be applied.

Dissolved Gases in Oil – This is the most important diagnostic test for LTCs. The gassing behavior of the LTC changes as problems arise, and the amount and relative concentrations of the gases change as problems develop and escalate. Localized overheating and excessive arcing are some of the problems that might arise when a problem occurs in the LTC. Carbonization and byproduct polymeric films can form on conductors, which can lead to a thermal runaway condition, which leads to failure if not stopped. The hydrocarbons generated during this process are methane, ethane, ethylene and acetylene – the ratios between these gases enables the diagnostician to identify the problem area as well as the severity (Table 1).

Dissolved Gases in Oil is the most important diagnostic test for LTCs

The ratio of ethylene over acetylene is important to consider in order to predict when inspection on the load tap changer should occur. Low, moderate and severe heating conditions can be detected based on the ratio of ethylene to acetylene. These ratios are independent of the number of operations in the tap changer and are also resistant to changes due to loss of gasses to the atmosphere. For vacuum type LTCs, tracking of the total combustible gas over time can give some indication of when the unit needs to be inspected. Also please consider the diagram in Table 2 as an indication of sampling frequency needed to ensure safe operation [5].

Table 1.

	Arcing Type LTCs (Resisitve & Reactive)*	
Ethylene	<5	Normal. Continue annual sampling.
Acetylene	0.5<X<1	Warning. Sample more frequently; trend.
	>1	Severe heating/coking probable. Inspect.
		** Ethylene & Acetylene >50 ppm*
	Vacuum Type LTCs	
Total Combustible Gases	<10 ppm	Normal. Continue annual sampling.
	10<X<25 ppm	Warning. Sample more frequently; trend.
	>25 ppm	Heating/coking probable. Inspect.

Table 2.

$$\frac{(CH_4)\ \text{Methane} + (C_2H_4)\ \text{Ethane} + (C_2H_6)\ \text{Ethylene}}{\text{Acetylene*}\ (C_2H_2)}$$

**Acetylene >500 ppm*

Ratio	Diagnosis	Recommended Sampling Frequency
<0.5	Normal	Sample annualy.
0.5 to 1	Possible heating	Sample every 3-6 months.
1 to 3	Possible heating	Sample every 1-3 months.
3 to 5	Possible heating	Sample weekly to monthly.
>5	Heating probable	Remove from service and inspect.

Particle count – Larger particles indicate advanced deterioration. The particles are formed from three main mechanisms: wear, arcing and overheating. These wear metal particles are formed when two metal surfaces are in contact with each other - the size, morphology and types give an indication of the source of the problem as well as the severity.
The main advantages of oil testing in LTCs include:

- Early detection of problems arising
- The severity of the problem can be determined with relatively high accuracy
- Cost-effective and nonintrusive

Electrical Tests

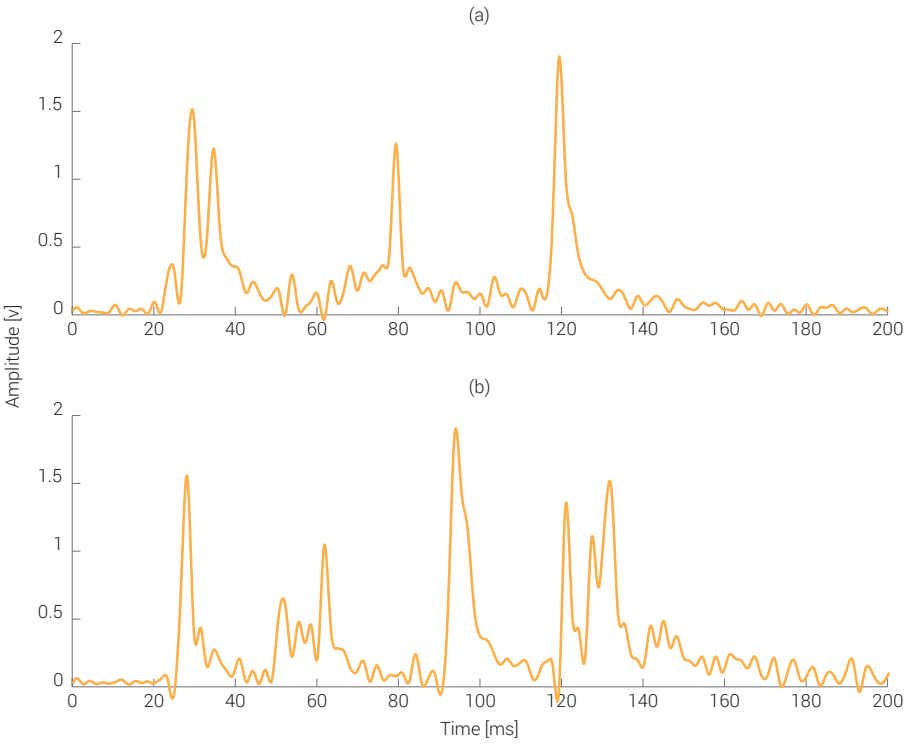
There are a number of electrical tests available to identify LTC faults.

- **Exciting current tests on all tap positions** detect contact or connection problems in the taps, as well as shorted turns and core problems in the autotransformer.
- **Turns ratio** tests detect shorted turns in the autotransformer.
- **Power factor** tests are used to identify insulation deterioration and carbonization of solid insulation.
- **Contact resistance** tests detect excessive contact wear, poor contact pressure (worn out springs) and coking or polymeric films on contact surfaces.
- **Sweep Frequency Response Analysis (SFRA) and leakage reactance measurements** detect winding movement/deformation and contact problems.
- **Tap changer divertor resistor and contact analysis** is a condition assessment test of tap changers, providing results necessary to establish the state of the tap changer to make informed decisions on planned maintenance or corrective action minimizing the need for intrusive inspections [6].

Oil testing of LTCs has many advantages, including early detection of faults with a relatively high accuracy in determining the severity of the problem.

Photo: Shutterstock

Figure 1. (a) The signature of the tap operation from 7 to 8 of a faulty condition, (b) the signature of the tap operation from 7 to 8 of the normal condition



Vibration Analysis

The OLTC monitoring system consists of various modules connected to a PC. The system simultaneously captures high and low frequency signals and can be triggered manually or automatically, depending on customer requirements. Automatic triggering allows online data acquisition. Noninvasive transducers minimize the cost of installation and are essential in the measurement of essential parameters. The whole system can be installed while the transformer is online.

Condition monitoring

If there is a significant degree of variation in the "normal" signatures, this is due to variation in load conditions which cause bursts in amplitude and shifts in time between individual vibration events. The shifts in time are caused by data acquisition system delays. The alignment of the burst envelopes can be acquired by normalized auto-correlation functions – manipulation of the data to line up.

Any out of bounds deviation is then labelled as an abnormality and an alarm is sent out.

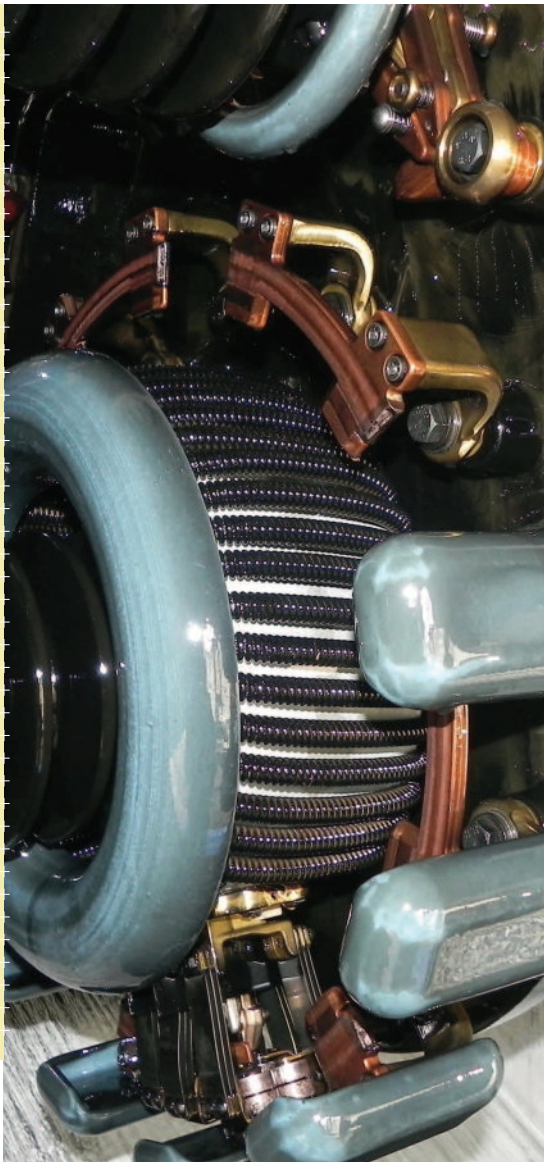
A database of OLTC signatures needs to be established to determine normal operating conditions. The vibration signal is acquired by monitoring the contact movements, and there should be various signatures for different transformer loads. The change in the OLTC condition is a gradual series of steps, sometimes with shorter increments depending on the severity of the abnormality.

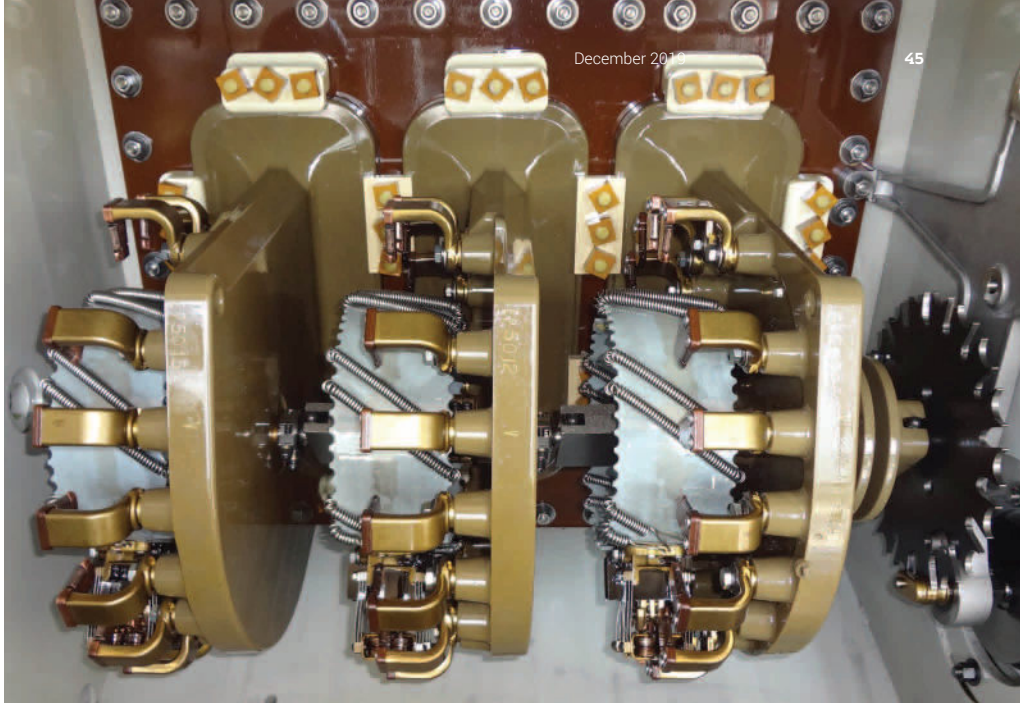
Field Application

Abruptly occurring faults

In the following example, the maintenance was completed on September 14. A year later, in early October, the monitoring system gave a warning that a fault had suddenly occurred. Figure 1 (a) shows that one of the bursts that normally appears in Figure 1 (b) is missing,

A reliable OLTC condition monitoring system, which can be readily used or applied by maintenance and reliability engineers, will not only assess the current condition of the equipment but will also help to make informed decisions for future applications.





indicating that a set of contacts was not making contact, causing improper contact positioning. This could have been caused by a missing contact or by problems in the driving mechanism. As this faulty signature only appears on occasion between the normal signature, this could be due to slipping of the drive shaft. The concern was that the abnormal contact sequence could lead to early catastrophic failure, so inspection was recommended.

Upon inspection the slippage on the shaft was identified. There was an approximate 1-2 mm of play within the keyway, which, if unchecked, could have resulted in a catastrophic failure [7].

Delay of maintenance

An OLTC of the same type displayed a normal signature during inspection, so it was decided not to perform maintenance as all the key indicators on the signature indicated a "healthy" OLTC. The maintenance was thus deferred by 1.5 years for this unit.

This method of monitoring is very accurate, nonintrusive and ongoing.

Conclusion

In conclusion, it is necessary to identify the type of monitoring that would suit the profile of your company, your budget and the outcome you require. A reliable OLTC condition monitoring system, which can be readily used or applied by maintenance and reliability engineers, will not only assess the current condition of the equipment but will also help to make informed decisions for future applications. The method used should enable maintenance engineers to check the quality of maintenance already performed, ensuring peak performance and value for money. The method should also ensure immediate identification of a problem at the onset point, so they can effectively identify source of the problem and decide on the action needed to rectify the problem, avoiding production loss or equipment damage.

References

[1] *International conference of data mining, civil and mechanical engineering*, Bali, Feb. 1-2, 2015

[2] P. Kang, D. Birthwhistle, "Online condition monitoring of tap changers –Field experience," Queensland University of Technology, Australia

[3] *Assess LTC Health with Thermal Imaging*, FLIR. Available: https://www.theengineer.co.uk/supplier-network/product/assess-transformer-health-with-thermal-imaging/

[4] P. Griffin, L. Lewand, R. Peck, N. Letendre, D. Frieze, J. Johnson, "Load tap changer diagnostics using oil tests – a key to condition-based maintenance", Doble Engineering Company

[5] *Why oil analysis is important to the health of your load tap changer.* Available: https://www.spxtransformersolutions.com/resources/white-papers/why-oil-analysis-is-important-to-the-health-of-your-load-tap-changer/

[6] I.A.R. Gray, "Condition based assessment of on-load tap changers," Available: https://www.ee.co.za/article/condition-based-assessment-of-on-load-tap-changers.html

[7] P. Kang, D. Birthwhistle, "Condition monitoring of power transformer on-load tap-changer. Part 2: Detection of ageing from vibration signatures," Queensland University of Technology, Australia

Photo: Shutterstock

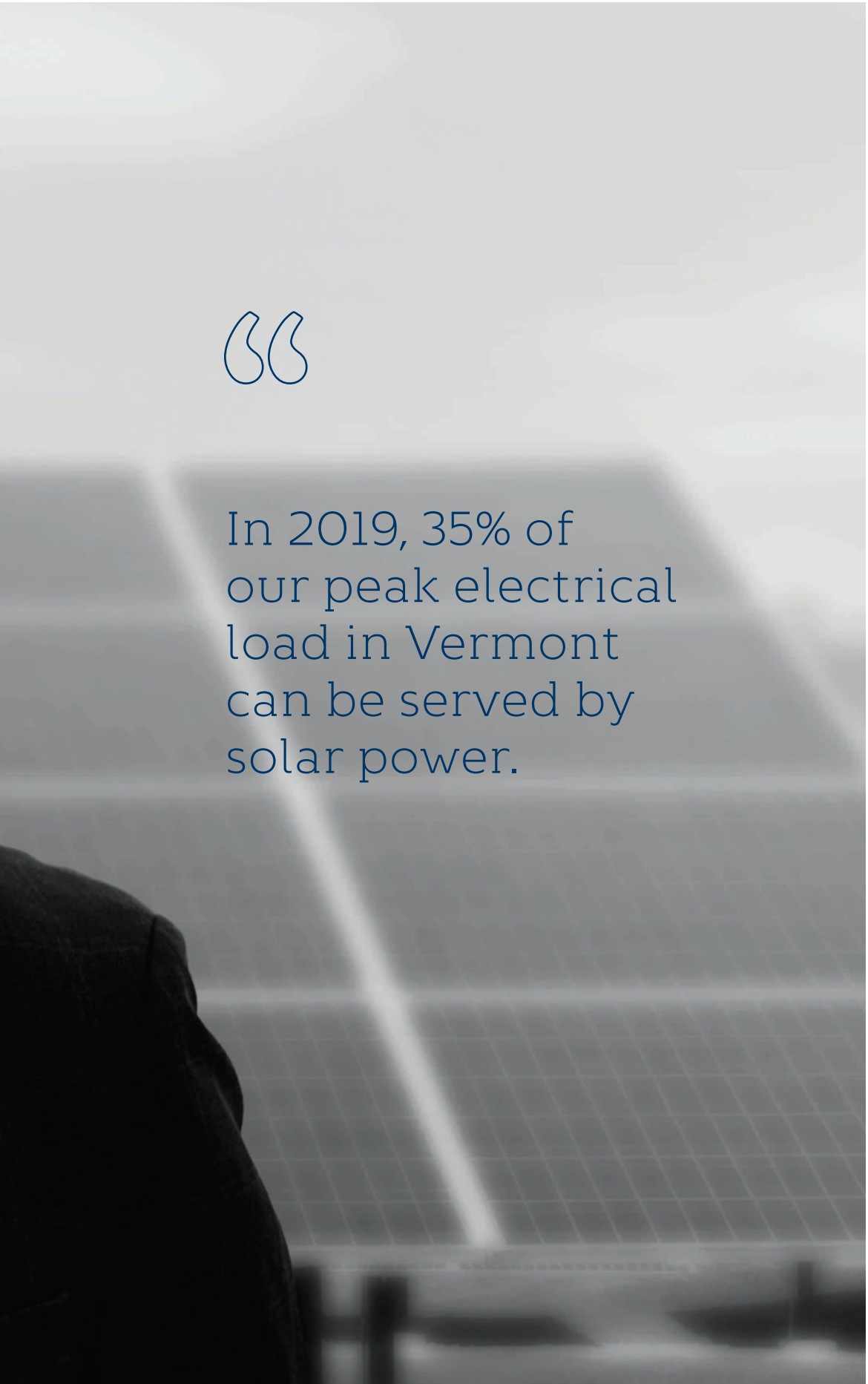
Chris Root

COO of Vermont Electric Power Company

Interview with **Chris Root**

Photo: VELCO

vermont electric power company
VELCO



Alan Ross, our Editor in Chief recently spoke with Chris Root, COO of Vermont Electric Power Company, on the changes that Distributed Energy Resources and battery technology is having on the New England grid, or at least the part that Vermont Electric provides.

Alan Ross, our Editor in Chief recently spoke with Chris Root, COO of Vermont Electric Power Company, on the changes that Distributed Energy Resources and battery technology is having on the New England grid, or at least the part that Vermont Electric provides. What happens when you depend on wind and solar, but the wind doesn't blow and the sun doesn't shine? Find out what Chris Root does.

Transformer Technology: Can you tell us more about Vermont Electric Power Company and some of the things that you see regarding changes in technology and what you do from the grid standpoint? And by technology, I mean solar and wind and the Distributed Energy Resources (DER) you have going on.

Chris Root: In Vermont we are very environmentally conscious and have aggressive state goals about climate change and controlling carbon. In 2019, we have 35% of our peak electrical load in the state which can be served by solar today, which is a very high number.

TT Do you use much wind power?

CR Yes, about 18% of our power is wind. We have five different wind farms, much smaller from the type of wind farms you would find in California. They are smaller in nature, but they are effective. It's interesting that they are very seasonal - In the summertime, we don't have a lot of wind. Our windy time is in the fall, winter and in the spring. When we don't have a lot of wind, it is really the perfect time for our solar which is in the summertime.

TT Our grid was built on a step-down system, from generation to distribution, but Distributed Energy Resources is changing that to a step-everywhere system. How is that affecting your grid?

CR The vast majority of our solar is connected at the distribution level. There is only one solar plant that is actually connected to transmission; everything else is at a lower voltage. There are a couple of things associated with that. The impact on the distribution system is when the sun is shining, obviously, which changes the voltage profile on the circuit, so the distribution companies have been trying to make sure that they get their voltage regulation correct. The other thing is that we have several substations between distribution and transmission which means that the power flows from the distribution system into the transmission system daily when the sun is out. That is a classic step-up caused by DER as you mentioned.

When these stations were put in, nobody originally envisioned them to need to handle that change, so we have had to change some technologies to make sure that the system works when the power is going either way, supplying into the transmission system to be sent to another location. Additionally, one of the interesting things is that we are different from the Southwest which does not have a lot of clouds. We do get clouds and we have partly cloudy days quite often. One of the interesting things we have noticed is that when a cloud comes over, a large solar plant of 20 megawatts, which is a plant that would use about 100 acres, a big geographical space - does not go to zero, but it goes to maybe 10.

Then when the cloud passes, it jumps right back up to 20. So, what you have is a generation pattern that is completely weather dependent, but you can't just let that be the case. You have to handle those unique changes. It's intermittent generation on days when it's cloudy, which raises challenges to make up that power. How do you do that? You have to do that with another type of generation.

TT As a result of that balancing act, have you had to rethink your transformer fleet in terms of what you purchase, when you purchase it, etc.? Has that changed anything?

CR It hasn't yet, but at some point in time, I could see a couple of things: Your transformer ratings are very much dependent on the load cycle, or how much current for how much time. So, now that these flows are radically different, you have to run your ratings again to make sure that there is enough cooling time for these transformers.

It hasn't been a problem so far, but it's a different way of thinking. One thing we have had to do is modify the times when we need to trip off the solar because of an operating condition. We've had to put in place a lot of protection schemes that go between the transmission and substation and reach into

Photo: Shutterstock

The generation patterns of wind and solar are completely weather dependent. This intermittent generation requires balancing between the two types of generation to make up the power.

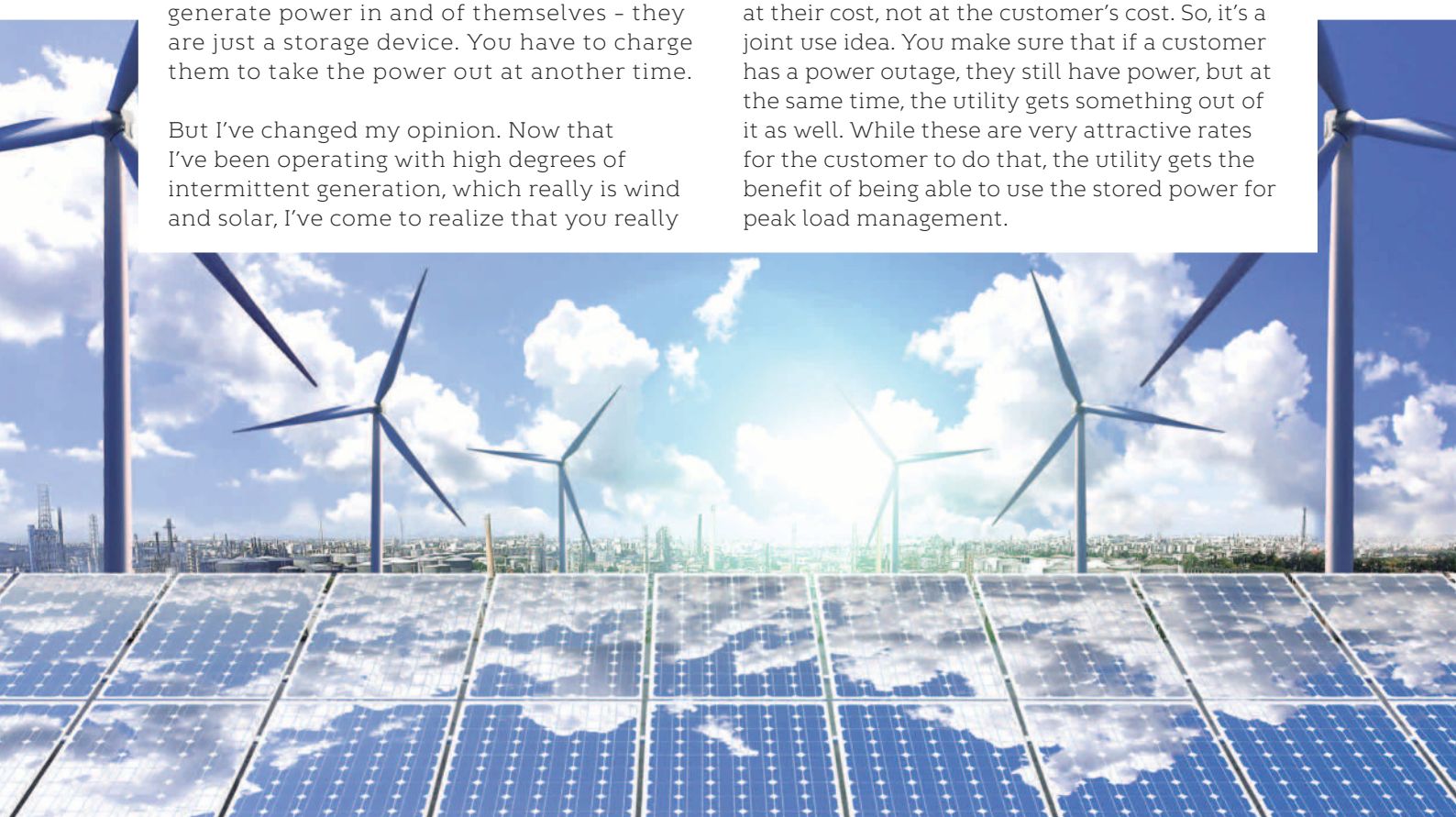
the distribution system. We need to shut off plants if there is a problem to avoid creating a safety issue of islanding.

TT I want to ask you about battery technology. If you are dealing with a lot of intermittent generation, you need to have good battery technology. Where are we and where are we going with that?

CR I've come a long way in my thinking of batteries. A couple years ago I would say "Boy, it's pretty expensive technology, how can we justify it?" We have to remind ourselves that batteries don't generate power in and of themselves - they are just a storage device. You have to charge them to take the power out at another time.

But I've changed my opinion. Now that I've been operating with high degrees of intermittent generation, which really is wind and solar, I've come to realize that you really need to fill those valleys in. But how? I think storage is your best solution to be able to do that. It operates very quickly so you can use it exactly when needed. Therefore, in Vermont we have two utility scale storage devices that are owned by customers and they use that for peak load management.

He also have 2,000 Tesla® power walls installed in customers' houses and those are rented from the utility to use as an interruptible power supply, but also if there is an electrical outage at the house. At the same time, the utility can control these power walls for peak load management, or for other purposes, and then it fills them back up at their cost, not at the customer's cost. So, it's a joint use idea. You make sure that if a customer has a power outage, they still have power, but at the same time, the utility gets something out of it as well. While these are very attractive rates for the customer to do that, the utility gets the benefit of being able to use the stored power for peak load management.



TT How did you choose the locations for all these power walls?

CR Some are sold with solar, but the vast majority of them are being sold to people who may have a second home and worry about it - what if the lights go out, will the heating system be off, will their well work, can they get water? Those are the types of reasons for purchasing a power wall. Vermont is a rural state. People are pretty excited about being able to use technology and it's been well received.

TT Wow, that's excellent. I know Elon Musk thinks he's going to change the world with his Tesla power walls, but to a certain extent, he is already changing Vermont. We're all waiting for that next great leap in

CR I think right now everyone is in love with lithium-ion batteries, just because they're available. But that doesn't necessarily mean that they are the best technology for use on the power system. It has a charged and discharged fixed number of cycles and there are all kinds of other issues. I think a lot of the utility people are waiting for the "flow battery" breakthrough. Flow batteries use two types of liquids that make reactions, so the energy can be stored chemically in these liquids and then run back into generating power.

The good thing about it is that it's completely expandable, so you can use bigger tanks and more membranes to generate the electricity which is creating and storing power.

When operating with high degrees of intermittent generation, battery storage can be your best solution.

That is very attractive to utilities. And also, the fact that there isn't a fixed number of stops to starts before you have to change them out is extremely attractive to utilities as this ensures longer time frames. Lithium-ion batteries go for around three or four hours, but with flow batteries, the potential is to go for eight to nine hours, which would have big benefits for the utility.

It looks more and more like pumped storage - like a hydropower storage plant that we've been using since the 1960s.

TT Is it the cost that's keeping us from getting there, because I don't think it is technology anymore?

CR There are still several demonstrations going on with flow batteries to get the exact chemistry right. One of the utilities' feedback was to make sure the fluid is not hazardous to the environment. Ideally, we should come up with a couple of chemicals to use that are biodegradable and are not going to create all kinds of problems. If we can do that and try to get some membranes exactly right so that they have a long-lasting lifetime, I think it's more tweaking right now, but I do think we are on the brink of those going commercial in a big way.

Photo: Shutterstock

TT Chris, thank you for joining us for this interview.

Managing the Reliability of an Industrial or Commercial Electrical Power System

by **Chuck Baker**

Chuck Baker is the President of PowerPro 360, a company offering power system reliability assessment and reliability maintenance programs for Industrial and commercial organizations. Chuck entered the world of Substation and Power System Maintenance 36 years ago and has spent a majority of that career on the operations side of power and distribution system maintenance and the development of power system maintenance programs.

Cast in Order of Appearance

Andy ..... Reliability Manager of Electrical Power System
(just recently hired by Brian, the Plant RVP)

Tim ..... Electrical Engineer
(who reports to Andy)

Tina ..... Maintenance Manager
(who reports to Brian also)

Brian ..... Regional Vice President
(head person for this plant)

Kevin ..... Director of Reliability

Jill ..... Director of Operations

You are Andy, and you have recently been hired into a newly created position at Smith Industries as the Reliability Manager of the Electrical Power System within their industrial manufacturing plant. This new position was created after Brian, the Regional Vice President for the plant, returned from a Power Reliability Summit.

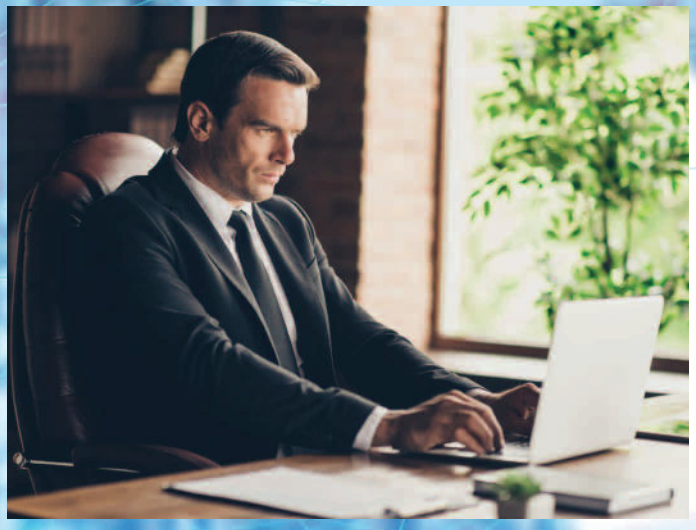
You get on-boarded, introduce yourself to the maintenance team and look over the team and their experience level.

Your first order of business is to sit down with Tim, your Electrical Engineer to find out as much as you can about the electrical system maintenance program history and the location of the maintenance files which include Dielectric Fluid Reports, Electrical Testing Reports and all services provided on the power system over the years.

Tim takes you to the maintenance office and you are shown to the file room where a long row of 6-inch 3-ring binders are located. They are labeled by substation and by year.

It is explained to you that after each test, they have corrected what they can afford to correct, however it is often normal for anything that is not an emergency to be postponed or the approval is denied. After all, money is tight and reactive maintenance comes first.

You ask if there is an updated one-line diagram for you to review. Tim walks over and pulls the binder that contains the one-lines for the plant.



He hands you the binder. Before you open it, you ask if he is aware of the last time it has been updated. He explains that he has been on board for 8 years and this is what was in place since his arrival. He further explains that they have not made any major changes to the system. You continue and ask him if he knows the date of the last arc flash study. This one he knows; the records and labeling show that it was performed in 2005 since he has seen that date on everything related to it.

Now it seems appropriate to add some additional team members to the meeting. You call over to the maintenance office and request that Tina, the Maintenance Manager, join you and Tim. Tina is glad to join, expressing her gratitude that she is getting some help since she is swamped with the production equipment maintenance and thinks adding an electrical system manager was probably a good move. She is excited to meet you.

Photo: Shutterstock

Your team assembles and your first question to the team is: Tell me how the reliability and maintenance of the power system flows?

Tim and Tina take turns explaining the process and it is very straightforward:

- Annually all transformers are sampled and inspected by the sample company. This company sends out their own technicians who do visual inspections, pull oil samples and send them to their lab.
- Results come in with recommendations for what to do in the case of anything that is either not acceptable or questionable. These results can be accessed via a web portal dashboard and can be trended, however Tim rarely accesses the dashboard and simply prints out the reports, filing them in one of the binders.
- The most serious problems are reviewed and a request for repair authorization is created and sent to purchasing after being reviewed and approved by the Maintenance Manager, Tina.
- Those requests that are approved are sent to several contractors for review and are completed according to the Contractor Program.
- Periodically we have reactive problems, like leaks and then we get emergency approval.
- We try to electrically test transformers, breakers and cables every three years, but because of the required outages it has been five to seven years since all of that has been done. When we did do the testing, we did all of the recommendations that the test companies provided.

You ask if there have been any major problems with the power system in recent years.

Tina jumps in and explains that there have been three major incidents in recent history. Four years ago, a distribution transformer in the transfer station faulted. It did some damage to the primary knife switch and there was a release of fluid throughout that section of the plant.

You ask her to explain the recovery and impact from that failure:

- Thankfully there were no injuries!
- The cleanup was performed by a hazmat team they had contracted.
- The transformer was replaced in two weeks with a new unit that had been located and was a perfect fit.
- The primary disconnect was rebuilt and returned to service at the same time as the transformer. Total down time was 16 days.

You asked about the final cost of the fault and they recalled that the total calculated loss and recovery was around $325,000.

They went on to explain that there had also been a cable fault and a low voltage breaker failure. Both the cable fault and breaker fault were repaired by your electrical contractor and did not result in any downtime. You thank them for their help and head back to your office.

What you have learned so far certainly points to the fact that the standards required for electrical system testing, maintenance and reliability are not well established, which means you have some work to do. You call Brian's Executive Assistant and request a two-hour meeting in two weeks. You request that the following people attend the meeting:

- Brian, Plant Regional Vice President
- Kevin, Director of Reliability
- Jill, Director of Operations
- Tim, the electrical engineer

An hour later she confirms that the meeting is set up for two weeks from Thursday at 1:30 but Brian has asked for you to provide a write up of the meeting purpose and desired conclusions by the end of today.

Photo: Shutterstock

You draft the email, read it over and send it to Brian cc'ing the Executive Admin and other attendees.

It reads as follows:

From: Andy
Subject: Special meeting to review electrical system program reliability
To: Brian

Brian,
as you know I have requested a meeting with those responsible for the reliability and safety of the power system and the required uptime for production. The points I would like to discuss are:

1. Who holds authority in the organization for Safety, Compliance, Reliability and the Maintenance Philosophy for Smith Industries?
2. Who holds the authority for approval of electrical system maintenance funding each year?
3. I would like to walk out of this meeting with unity in our reliability and maintenance strategy of our electrical system to avoid any more costly downtime.

The two-week period passes quickly, and you have your presentation complete. You walk into the scheduled meeting; all are present and after some polite chit-chat you begin your presentation.

You make the following key points as they listen intently:

"Tim knows the electrical power system very well and could answer every question I asked of him. Tina has excellent maintenance programs and approach. They just haven't made it into the power program at this plant. Thank you, both, your efforts are much appreciated."

You continue: "**The electrical power system in this plant is not reliable.** All equipment is treated as equal and it is clear that some components are critical, and some are not actually in active service, and a lot are in between those applications. There is no Criticality Analysis of the major assets." (Brian fidgets in his chair at this revelation.)

"Kevin and Jill, it looks as if you look at maintenance requests throughout the year and approve based on available funds, but since you are not provided with the probability or severity of failure, it makes approvals a very tough decision. There simply is not enough money to do everything."

"We have had three significant failures in the past five years totaling just under $500,000 in damage and lost production. Worse than that, I have spent many, many hours going through some of the binders of maintenance records and I am finding trending towards failure in some of the most critical assets, especially our transformers. While the reactive maintenance or repair requests are usually approved, there are some very critical preventative maintenance requests that are nearly ever approved."

"Kevin and Jill, from what I understand, Brian is assuming that the power system that produces the product and our revenue is secure and reliable. You have brought me on board to manage this for you and I have some significant recommendations to this team. Interested?"

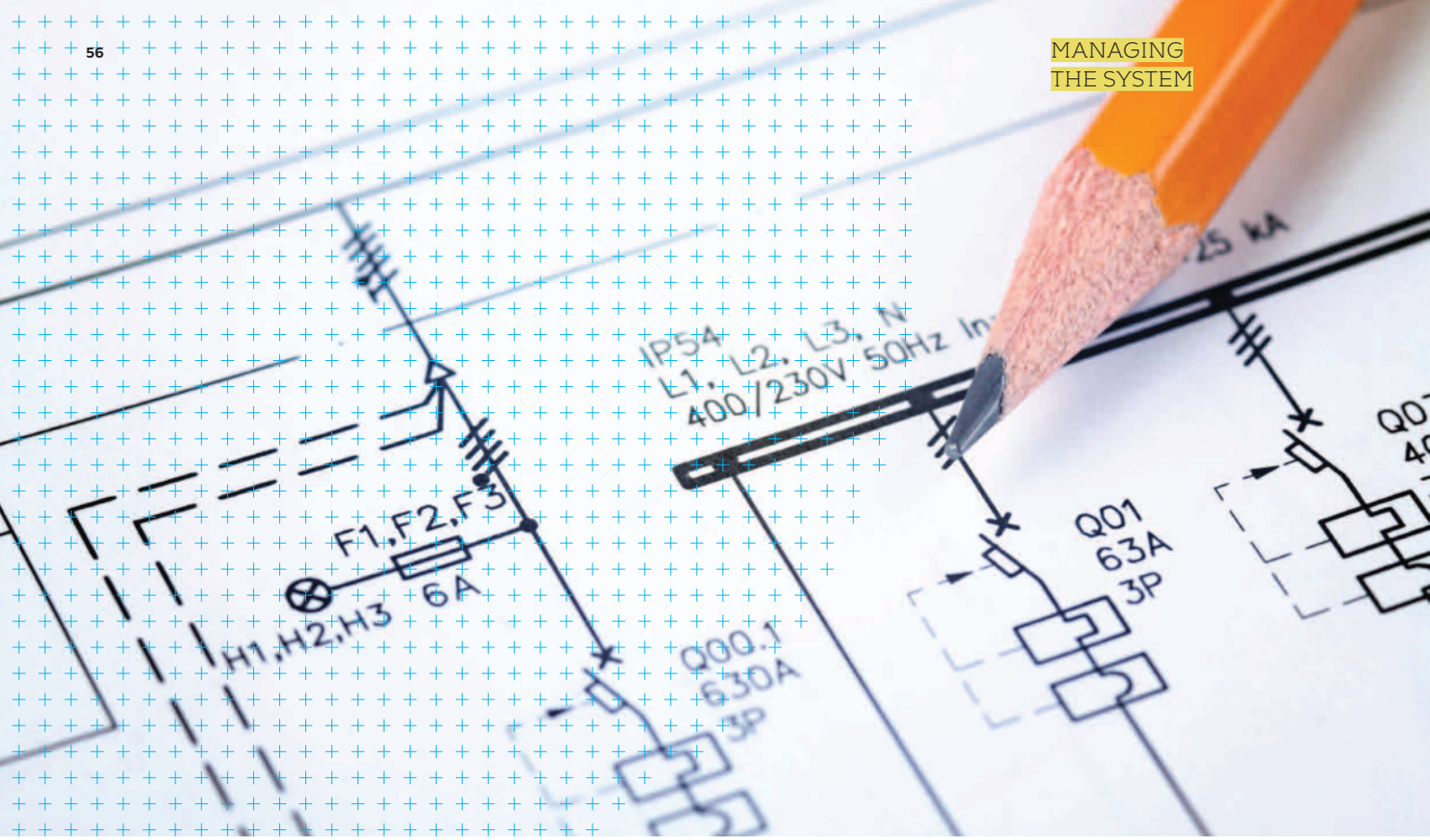
Within moments Brian replies:

From: Brian
Subject: Re: Special meeting
To: Andy

Andy,
I am looking forward to finding what you have discovered and what you propose.

Brian answers that question with a strong and resounding YES! He explains that his plant needs to be safe, compliant, reliable and run with maximum productivity. He asks you to continue.

You then walk them through your proposed stages of an ***Electric Power Reliability Program***.



1. Arc Flash Study

Your latest Arc Flash Study is significantly out of compliance. NFPA 70E states in Article 130.5 that an Arc Flash Study needs to be reviewed every five years or whenever there is a significant change in the electric system. The five-year interval is a straightforward requirement. Your last study was performed in 2005. I recommend that we contract for this immediately for two reasons:

a) Safety of our employees and the contractors we bring on site;
b) The Arc Flash Study requires some key steps which will be a real benefit to our power reliability maintenance program and includes:
   i. A review and update of our one-line drawings: NFPA 70B directs that this should be done every five or six years and is critical for our electrical department and contractors we use. Considering that this directs lockout/tagout, it needs to be accurate for the protection and safety of those who work with it.
   ii. Short Circuit Study: This is required for arc flash calculations to determine the magnitude of currents that flow during an electrical fault – a key point to the program.
   iii. Protective Device Coordination Study: There are two components to this study, and I am recommending both:
      1. What are the current settings, which is required for the study, and
      2. Which settings need to be changed to provide a safer system?

This will determine if the protective devices are the proper devices with the proper settings, which is valuable on many fronts from safety to compliance to proper protection.

2. Full maintenance program

Institute a base maintenance program that will contain three fundamental components:

a) **Our Standards:** Develop our electric power system maintenance standards that we all agree to. These can be customized depending on the criticality of each piece of equipment with approval from this Senior Maintenance Team. We need to adjust the maintenance budget to the reality of what we have and truly need.
b) **All Equipment Data:** All equipment data and all historic and current maintenance results need to be in a digital format, not in 3-ring binders. This will provide current state, risk of failure, and recommended services that should be performed via our established standards. This will also give us trending to determine when the maintenance services need to be provided.
c) **Reliability Prioritization:** We need to contract a study to determine what the risk is with each piece of equipment. This has three key steps:
   i. How healthy is this unit? Looking at load and past test reports, how does it compare to our establish standards? How much remaining useful life does it have?
   ii. What is the impact of failure? If it were to go down immediately, what is the impact and cost? This includes tracing the power feed to its conclusion, understanding impact on safety, production and the time required to reinstate the power. It will look at lost production and potential effect on output and potential product shortages. From this we will identify options to minimize these effects.

Photo: Shutterstock

iii. Prioritize the equipment by failure impact and current health. From this we will need to determine what actions we need to take to correct or prevent these problems and what contingency or preparation we can make for the inevitable failures: things like spare equipment, pre-qualified contractors, parts or components that we can have on site. In some cases, we will proactively correct or replace, and in others, we will accept the risk.

"We will then approve the program and begin to implement it. When I ask this team for approval of a budget, I will include the logic for the request. I will explain the importance of the equipment, the danger of the problem and the urgency to correct. If we can't fund all required repairs, we will place this current year's funding on our most critical issues. We want to make sure that what we spend has the biggest impact on our goal of total reliability."

"Finally, we want to be compliant and provide a reliable power system. This doesn't mean unlimited funding – it means having a program to understand condition and risk and to guide our decisions."

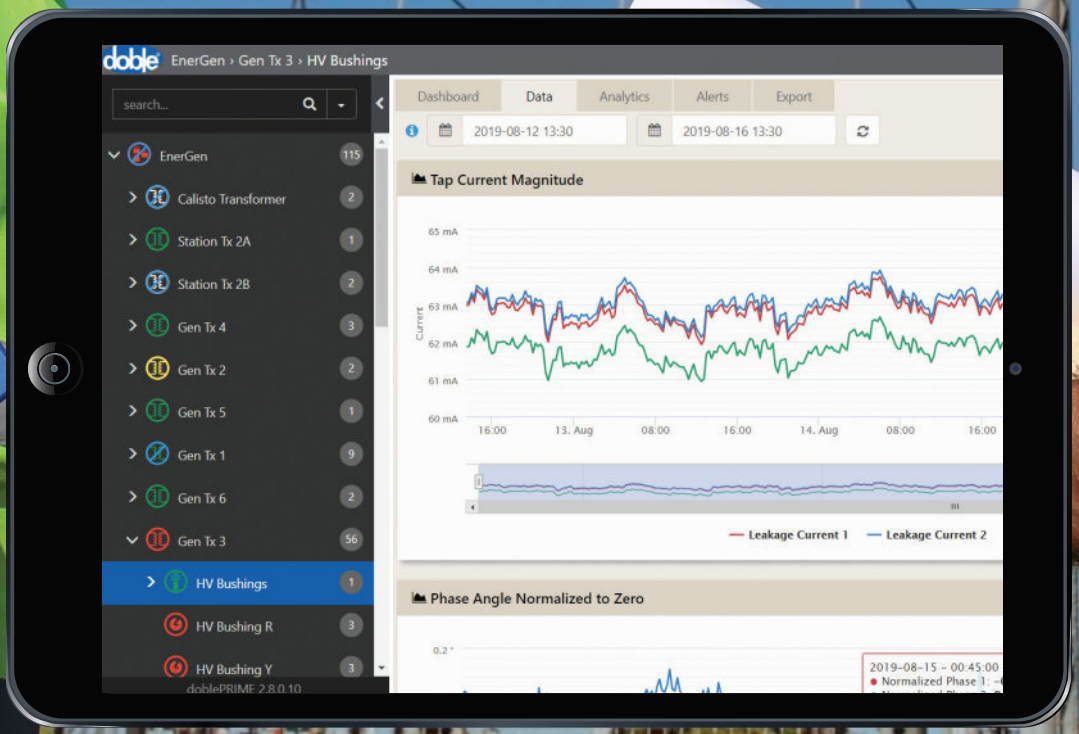
Brian responded by saying:
"I want this group back together in 30 days with a report on progress and a projection for completion of the plan. In addition, I want to know within 48 hours how and when you are going to do the arc flash study. Funding for that is approved, let's make sure we bring in a quality team to do the study and let's make sure we get it into something better than 3-ring binders. Meeting adjourned."

"Thank you, Andy, I had no idea how critical it was to bring you on board. I want you to attend the next electrical reliability conference because it was there that I realized how important this issue really is."

Bringing Clarity to the Complexity of Condition Monitoring.

DOBLE ON-LINE MONITORING SOLUTIONS

Identify Problems | Prevent Failures | Manage Risk



THE CHALLENGE

How do you get all the information you need to understand the condition of your transformers? You need condition monitoring tools that provide accurate data, robust analysis and reliable alerts. This allows you to effectively identify developing problems, prevent transformer and bushing failures, and manage risk.

CHOOSE DOBLE

Doble brings clarity to the complexity of condition monitoring. By choosing a Doble online monitoring system, you gain the power of knowing:

- Data is accurate and reliable
- Analytics are based on industry standards, best practices and nearly a century of Doble expertise
- Alerts and alarms are meaningful and useful
- Support is a phone call away

GETTING STARTED

Unsure about where to begin? We want to help make your condition monitoring program a success. We can work with you to help determine the most effective approach for your organization. We offer package and custom options to address all situations, whether you are looking to monitor large, generator step-up transformers or smaller distribution and industrial units. We also provide support options from commissioning through training and decision support.

Maximizing the Potential of Narrow Band DFR

by **Robert C. Breazeal**

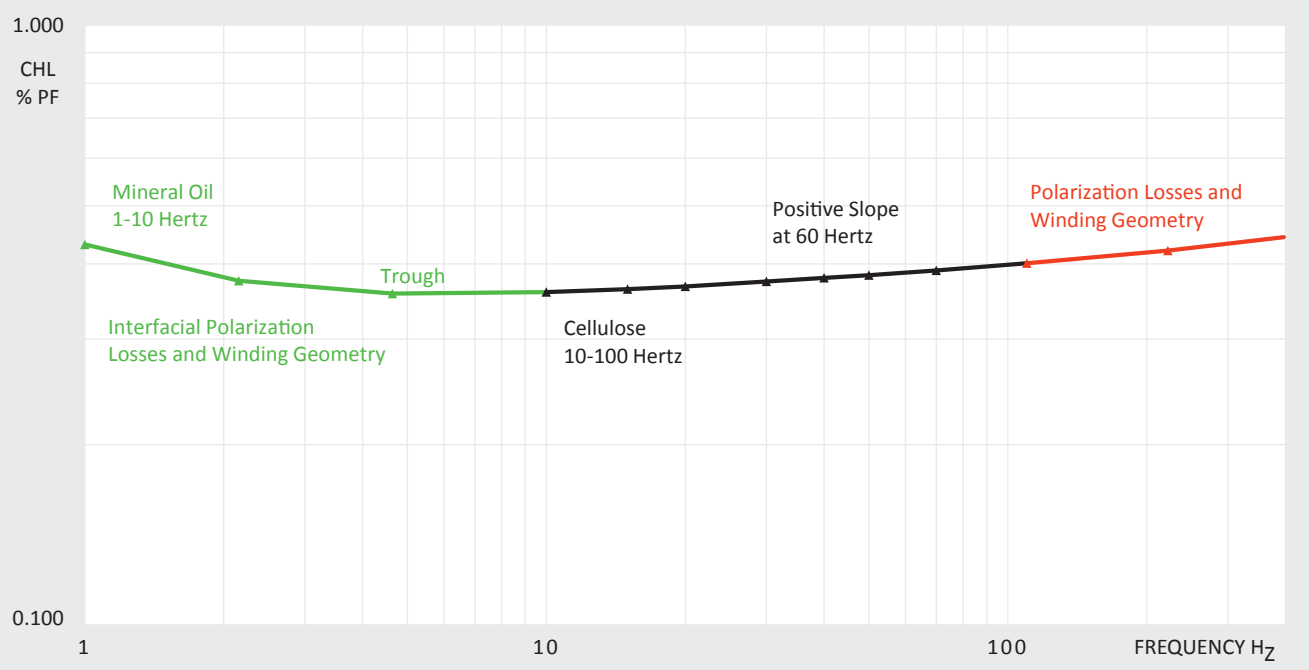
The NBDFR protocol consists of sequential insulation power factor measurements performed in a range of 1 - 400 hertz. The data derived from the series of CHL measurements constitutes the dielectric response for the winding. The subsequent evaluation consists of a geometric analysis of the plot where measured power factors and corresponding frequencies are graphed. On the basis of specific characteristics observed within the plot, definite assertions may be made in regard to the condition of the cellulose and oil. In 2015, Southern California Edison (SCE) began utilizing NBDFR for CHL measurements in condition assessment of used distribution class transformers. Beginning in 2016, SCE performed a series of controlled experiments where distribution transformers were subjected to prescribed overloads, while using NBDFR to document changes in the dielectric response as the oil and paper were thermally degraded.

Photo: Shutterstock

Robert Breazeal is a Senior Technical Supervisor at the Southern California Edison (SCE), Westminster Distribution Apparatus Facility. He has 35 years of experience in the repair and testing of power transformers. Robert currently provides technical oversight for the evaluation of distribution class transformers and switchgear. He has developed a number of advancements in insulation power factor testing and is a regular conference presenter. He has published a number of papers and articles detailing research pertaining to transformer diagnostics and condition assessment.

NBDFR represents a quantum leap forward in regard to winding condition assessment.

Figure 1. Typical response for new distribution transformer



Components of the Narrow Band Response

A single measurement at line frequency (50 or 60 hertz) is the conventional method of insulation power testing. This method is problematic in that the capacitive current at line frequency dominates the measurement, with the conductive component comprising a very small percentage of the measured current. In this scenario when a moderate increase in conductive losses occurs within the insulation system, the change in power factor at line frequency may be barely detectible. However, as the applied frequency is decreased, the magnitude of the capacitive component decreases proportionally while the magnitude of the conductive losses remains constant. An increase in watt losses becomes increasingly visible as frequency decreases, making the NBDFR method tremendously sensitive to small changes in winding condition [1]. Because of this characteristic, NBDFR represents a quantum leap forward in winding condition assessment.

Figure 1 illustrates a typical NBDFR trace for a new distribution transformer. This response is driven by the individual influences of the mineral oil, cellulose insulation, and winding geometry. The effects of mineral oil dominate the response from 1-10 hertz as illustrated in the green portion of the response. In this illustration the point of minimum magnitude (trough) is shown to be at 10 hertz. This geometric feature is an important marker used for tracking changes in winding condition. Even minimal degradation of the dielectric fluid will result in a noticeable increase in magnitude at the low frequencies. This sensitivity is also driven in part by interfacial polarization as a result of winding geometry. Cellulose dominates the response from 10-100 hertz as illustrated in the black portion of the response. The response above 100 hertz is dominated by static charge polarization losses and the effects of winding geometry as illustrated in the red portion of the response.

Response Interpretation

One prevailing viewpoint states that if the slope at line frequency is positive, the insulation system in question is in acceptable condition [2]. A deeper understanding of dielectric response however reveals that this is a significant oversimplification, in that the slope at line frequency is determined by the position of the trough [3]. The trough position in turn is driven by low frequency distortion of the trace which occurs as the insulation system degrades and watt losses increase. An increase in conductive and polarization losses has an exponential effect on the magnitude at 1 hertz.

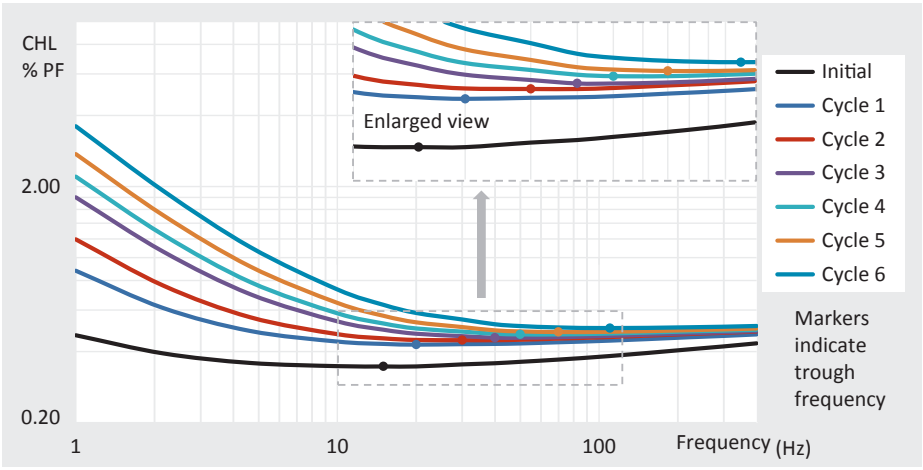
If the frequency at which the trough resides is monitored, this frequency may be used as a marker to track

changes in insulation condition which may not be reflected in the magnitude at line frequency [4]. In order to facilitate this method, extra test points can be inserted from 10-100 hertz. With smaller increments, subtle changes in trough position may be detected. If a robust data base is developed, condition classifications may be assigned for specific classes of transformers based on trough location [4].

The Effects of Aging as Reflected by Dielectric Response

In 2015, SCE began using the NBDFR method for condition assessment of distribution class transformers, and it became immediately apparent that low frequency distortion and trough migration in many cases was not reflected in the magnitude at 60 hertz [5]. In order to gain an understanding of the aging process as reflected in the dielectric response, SCE performed an experimental protocol where 12 transformers were energized with loads ranging from 90 to 135% of nameplate rating. The units were de-energized on a monthly basis, and NBDFR measurements were performed at ambient temperature. Units which were loaded at 90% of nameplate rating showed minimal changes both in terms of magnitude at 60 hertz and frequency of trough location. Distortion at low frequencies was also minimal. However, Figure 2 illustrates the overlaid NBDFR results for a unit operated at 135% for six months. An analysis of the data reveals that the magnitude at 60 hertz increased from 0.366% to 0.510% resulting in a difference of 0.144%. Conversely, the magnitude at 1 hertz rose from 0.469% to 3.601% resulting in a difference of 3.132%. While difference of 0.144% for CHL at 60 hertz for a distribution transformer returned from service would be fairly normal, the increase illustrated at 1 hertz would be cause for grave concern. Also significant is the fact that the trough migrated all the way from an initial frequency of 15 hertz to 110 hertz after cycle 6. The preponderance of evidence in this case would indicate that this load would not be sustainable in the long term.

Figure 2. NBDFR CHL responses for transformer loaded at 135% of nameplate rating [4]



If the frequency at which the trough resides is monitored, this frequency may be used as a marker to track changes in insulation condition which may not be reflected in the magnitude at line frequency.

Photo: Shutterstock

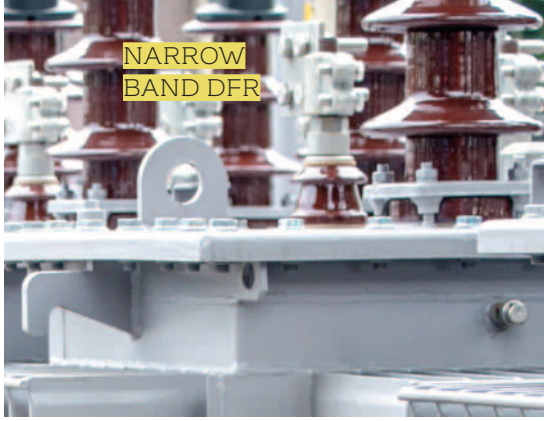
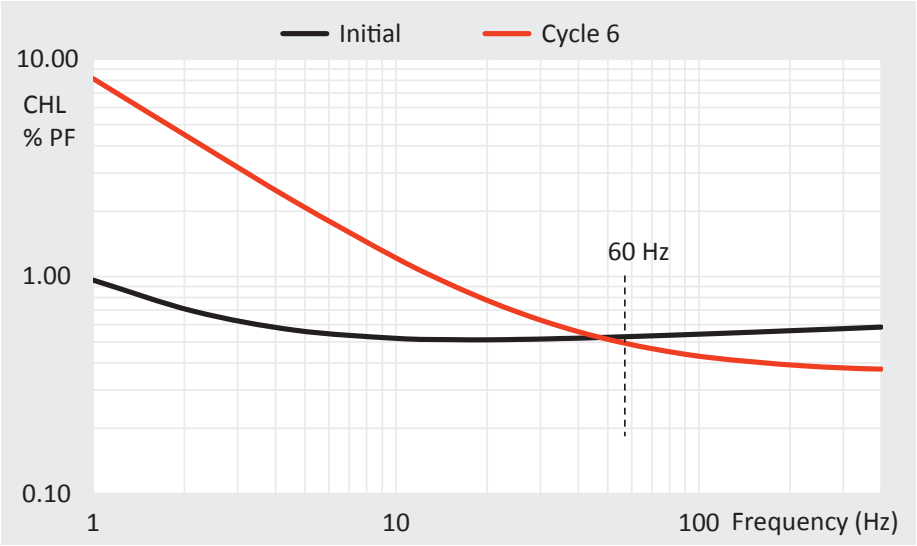
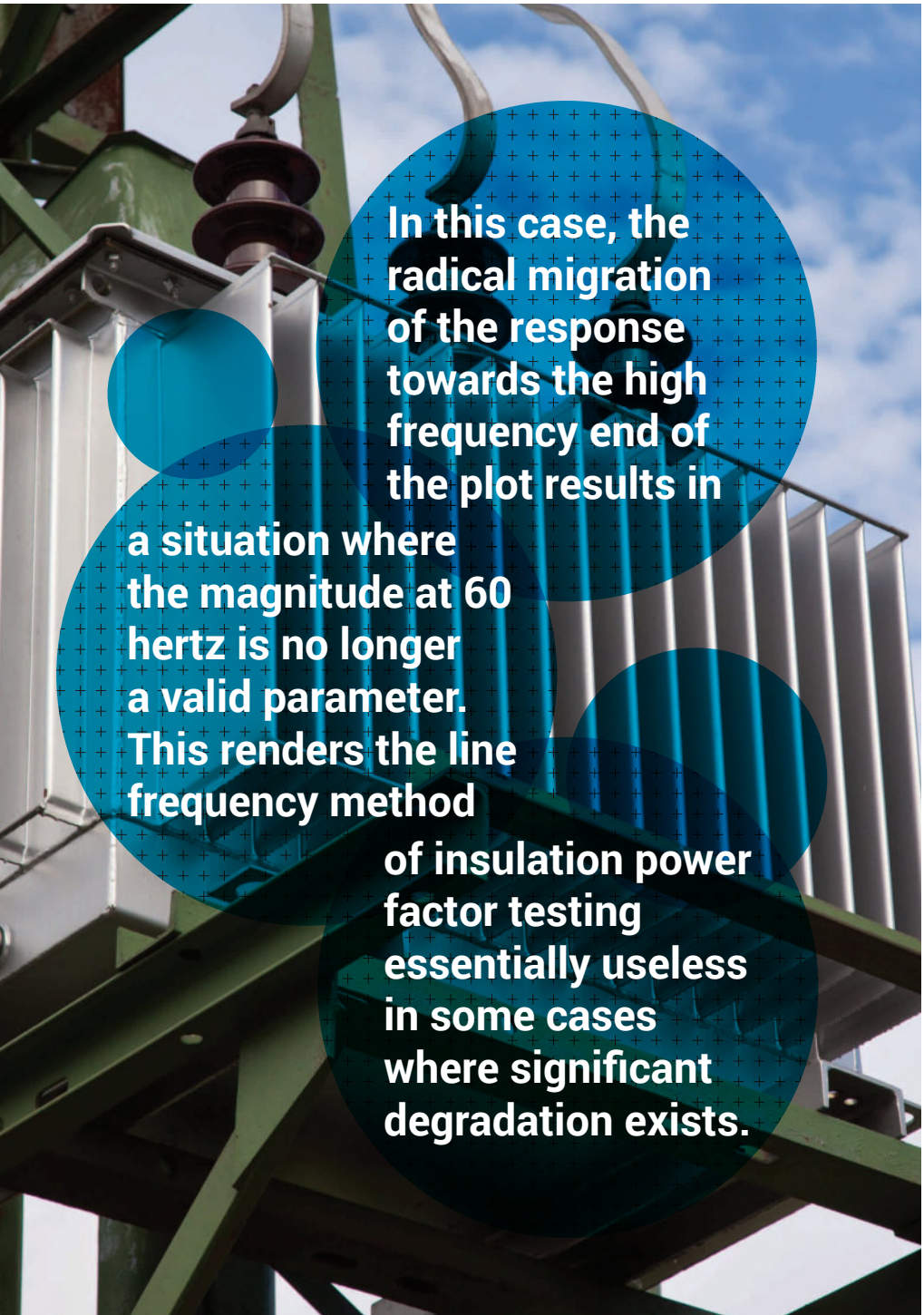


Figure 3. NBDFR CHL responses for transformer loaded at 150% of nameplate rating [4]





In this case, the radical migration of the response towards the high frequency end of the plot results in a situation where the magnitude at 60 hertz is no longer a valid parameter. This renders the line frequency method of insulation power factor testing essentially useless in some cases where significant degradation exists.

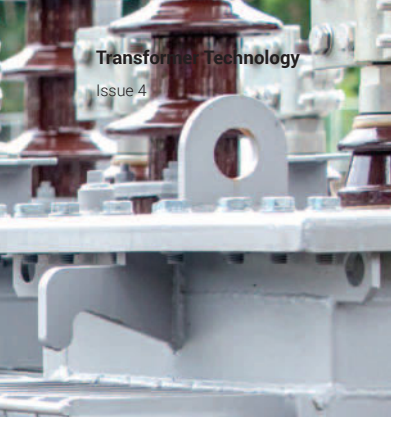
In a 2017 study, transformers were again subjected to overload in controlled conditions. Figure 3 illustrates the response traces for a unit operated at 150% of nameplate rating. The initial response is illustrated in black, with the month 6 response illustrated in red. After month 6 the magnitude at 1 hertz had risen to 8.14% which is clearly unsustainable. As would be expected, the trough migrated from an initial frequency of 20 hertz to a frequency of 446 hertz. The detail of overriding significance in this test case is the magnitude at 60 hertz after 6 months. With the highly elevated concentration of polar contaminants in the oil and cellulose, the assumption would logically be made that the magnitude at 60 hertz would reflect this situation. This, however, is not the case. **The magnitude at 60 hertz in this case actually decreased** from 0.530 % to 0.487%. In this case, the radical migration of the response towards the high frequency end of the plot results in a situation where the magnitude at 60 hertz is no longer a valid parameter. This renders the line frequency method of insulation power factor testing essentially useless in some cases where significant degradation exists.

Bandwidths and Graphic Analysis

Some NBDFR test sets utilize a frequency bandwidth ranging from 15 to 400 hertz. In addition, some equipment software displays the response data using a linear plot. In Figure 4 the responses from the specimen loaded at 150% are depicted using the 15-400 hertz linear plot method.

When the linear plot is utilized in conjunction with the 15-400 hertz bandwidth, the vital data below 15 hertz seen in Figure 3 is absent. Because of the linear style plot, the responses are compressed

Photo: Shutterstock



vertically; therefore, the trough frequencies in most cases cannot be determined without referencing the corresponding data table. In this case the response is sufficiently deteriorated to where it would still be identified as such, but in cases of mild degradation this bandwidth and format will prove to be problematic. The most obvious benefit of the logarithmic method is that the low frequency segment of the response is spread over a larger portion of the plot, making the critical information in the lower frequencies easier to extrapolate and analyze [6].

Figure 4. Responses from unit loaded at 150% depicted using the 15-400 hertz linear plot

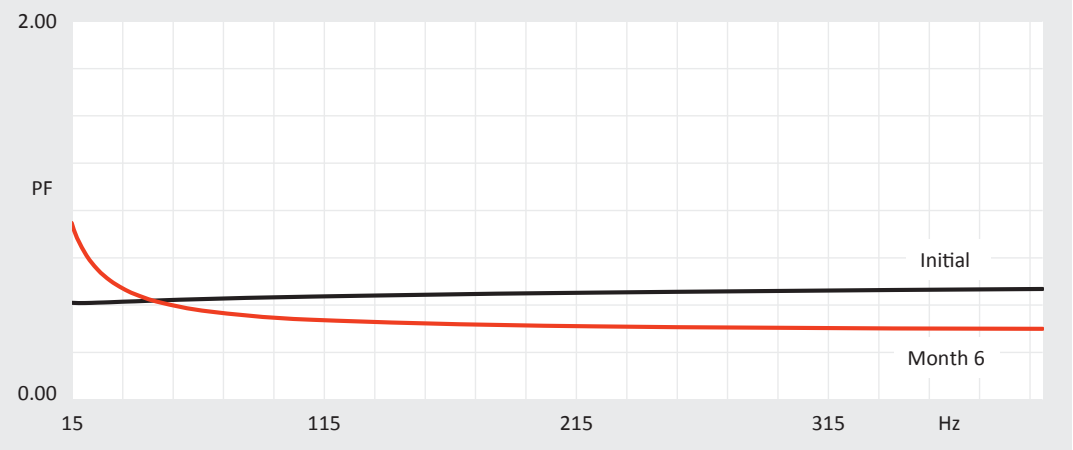
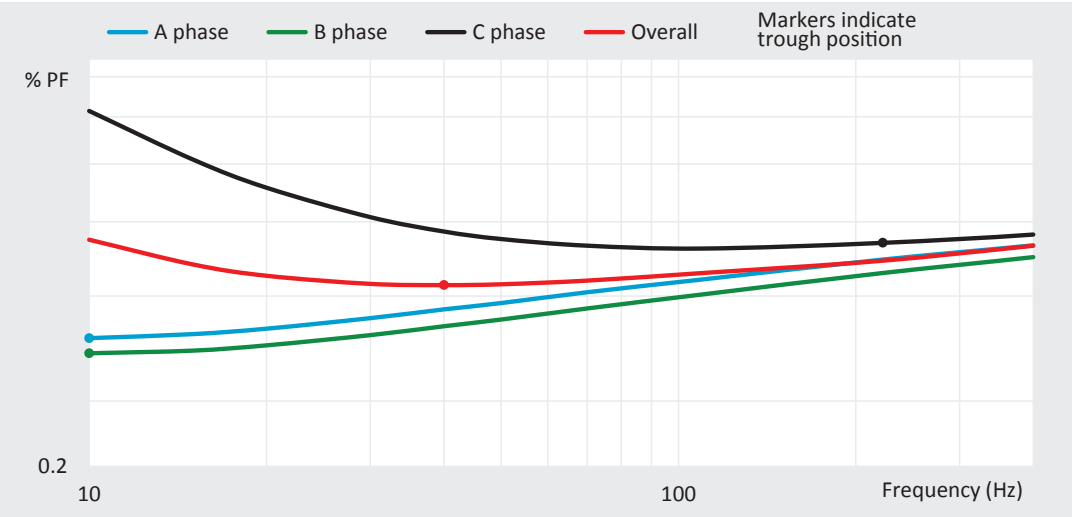


Figure 5. Overall and per phase responses for 1 MVA D-Y transformer [4]



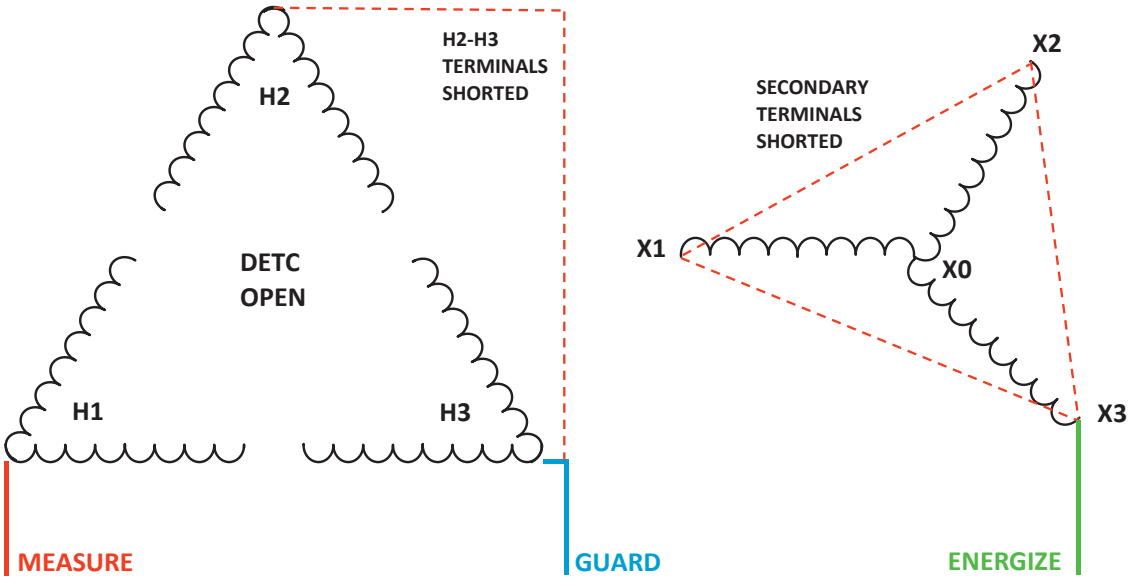
Single Phase Evaluation of Three Phase Transformers

SCE has used the CHL NBDFR measurements for condition assessment of three phase distribution (<750 kVA) and medium power (750-3,750 kVA) transformers with tremendous success. It should be noted however, that when overall CHL power factor measurements are performed on a delta or wye winding, the measured response is the composite average for the three individual windings. Because of this, traditional winding tests cannot discriminate between uniform winding condition vs the presence of a significant localized problem. There are two methods which may be used to overcome this inadequacy. The first is to sectionalize the winding insulation. The second is to test the winding insulation over a wide range of frequencies [7]. SCE utilizes a technique which combines both of these methods, using the Delta-Wye Open Tap Changer Crosscheck Method in combination with a DFR test set. This allows the operator to extract CHL NBDFR responses on a per phase basis.

In 2015, an overall NBDFR CHL measurement was performed on a 2.5 MVA Delta-Wye configured transformer using a test set which generated potential over a bandwidth of 10-400 hertz. The magnitude at 60 hertz was within the normal range, with a trough frequency of 40 hertz as illustrated by the red trace in Figure 5. Although the 60 hertz magnitude and trough frequency are acceptable, there still existed the possible that an anomaly could exist in one or more windings. The open tap changer delta-wye crosscheck protocol was performed to extrapolate per phase NBDFR CHL responses. As illustrated in Figure 6, the tap selector is placed between taps and the secondary terminals are shorted. The guard lead is connected to the shorted H2 and H3 terminals, and the UST measuring lead is connected the H1 terminal. The secondary winding is energized at 500 volts and a UST measurement is performed to measure CHL [8]. As depicted in the diagram, CHL data is collected only from the winding interface common to the H1 terminal [5].

The A and B phase windings were in essentially new condition with both trough frequencies at 10 hertz, as seen in the green and blue traces. Conversely the C phase dielectric response differed significantly, with an elevated magnitude at 60 hertz and the trough frequency at 110 hertz, as seen in the black trace. Very serious elevation at 1 hertz is seen for C phase. This localized problem would have been absolutely undetectable using conventional insulation power factor testing methods.

Figure 6. Test connections for open tap changer cross check method [8]



Conclusion

The NBDFR measurement in conjunction with a CHL measurement is the single most effective insulation quality test. However, in order to maximize the effectiveness of this analytical protocol, a robust data base must be established in order to establish normal magnitudes at 1 and 60 hertz, as well as normal trough frequencies for each transformer type in the utility inventory. Baseline responses for all new units should be recorded in order to facilitate the tracking of changes. When evaluating three phase transformers with a wye configured secondary winding, the crosscheck method should be utilized when the overall response differs from the previous test in order to verify that a localized problem is not developing.

The dielectric response will slowly migrate towards the high frequency end of the plot as temperature increases, so measurements should be taken as close to 20°C as possible. This effect is exacerbated in units which are degraded [9].

Photo: Shutterstock

References

[1] J. Duplessis, M. Ohlen, M. Hellquist, *Insulation Diagnostic Methods: Achieving a More Effective Test Program*, Megger, 2017

[2] J. Duplessis, *Electrical Field Tests for the Life Management of Transformers*, Omicron Electronics, 2013

[3] R. Breazeal, *Narrow Band Dielectric Frequency Response and Transformer Condition Assessment*, NETA, 2018

[4] R. Breazeal, *Effects of Loading on Insulation Degradation as Detected in Narrow Band Dielectric Frequency Response*, Weidmann, 2017

[5] R. Breazeal, *Advantages of the Delta Wye Crosscheck Method*, Doble Engineering, 2016

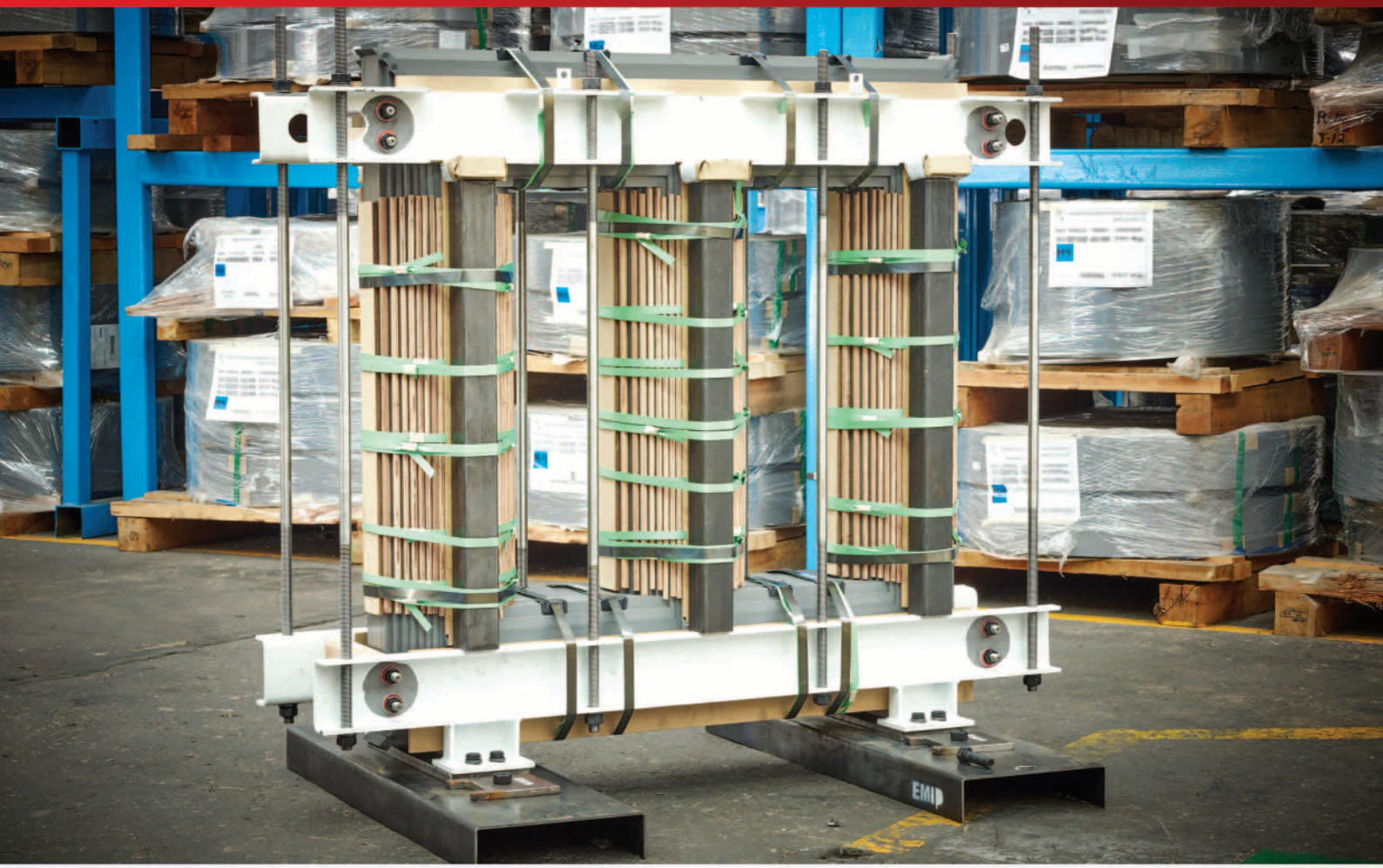
[6] R. Breazeal, D. Chhajer, "Expanding the Diagnostic Impact of Power Factor Testing," *Transformers Magazine*, Vol. 6 Issue 2, 2019

[7] R. Breazeal, J. Duplessis, *Pushing Past the Limitations of Power Factor Testing*, Megger, 2015

[8] D.J. Kopaczynski, R. Levi, *The Cross Check Test for Transformers – Review of an Old Technique with New Application to Delta Wye Transformers*, Doble Engineering, 1990

[9] R. Breazeal, "The Effects of Overload on Distribution Transformers," *Transformers Magazine*, Vol. 6, Issue 3, 2019

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

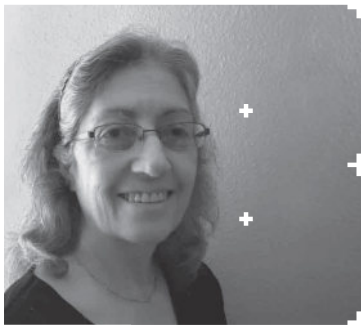
www.emid-usa.com

Failure Prevention of Distribution Transformers: Technology Types and Their Market

by **Shirin Sheppard**
and **Saqib Saeed**

Photo: Shutterstock

Transformers play a critical role in power generation, distribution and in industrial applications. Although transformers are known to be some of the most reliable pieces of equipment, failures will occur. Early in the transformer life, many of these failures are usually due to the quality of manufacturing or the use of inexpensive materials, or due to the lack of a good design, often caused by unclear or inadequate specifications. Later in life, the transformer will usually fail because of a lack of maintenance and eventually, due to its age and normal wear and tear (aging of insulation).



Shirin Sheppard is a senior analyst whose current focus is power equipment research. Her recent work includes research on power transformers market in South America, global electricity meters market, and various aspects of solar generation. Previously she worked for iSuppli and NASA contractor Northrup Grumman. Shirin has a BSc in Mechanical Engineering and a BSc in Aerospace Engineering from the University of Colorado.

Saqib Saeed is a principal analyst at Power Technology Research. He is an expert in power systems and power electronics market research. He has prior field experience in commissioning and maintenance of power systems. Since 2015, he has been involved in custom research projects with transmission and distribution (T&D) OEMs and utilities conducting online and offline market research to identify business opportunities for T&D equipment manufacturers. Saqib has a MSc in Power Engineering from Technical University of Munich.

Technology Types

Three types of distribution transformers are typically considered for different types of failure prevention:

- Dry type transformers (cast resin)
- Digital transformers
- Ester filled transformers

Dry type transformers use an insulating system that promotes air circulation instead of the cooling mineral oil typically used in oil-type transformers. Since they do not contain flammable oils, this transformer has a low fire risk and there are no concerns about spillage, making this type of technology preferred for indoor sites.

The global market for failure prevention transformers in 2018 was about US$1.4B. At 46%, the APAC region, driven by China, India and Indonesia, accounts for the largest share of the market with the Americas accounting for 35%.

A digital transformer is a digital platform which is adhered to either a dry-type or an oil-type transformer. An array of sensors collect data, such as top oil temperature, oil levels, ambient temperature, pressure, moisture, hydrogen, voltage and current, and then the data is transmitted over some form of communication (wi-fi or wired ethernet). This allows access to the data remotely without interrupting transformer operations. Gathering and analyzing this information can be used to optimize operations and to schedule maintenance.

Back in the 1970s, polychlorinated biphenyls (PCBs) which had been used as the dielectric fluid in power transformers were replaced with mineral oil and with silicon oil. Mineral-oil is flammable and although silicon oil is not, it is prone to leaking and is hard on the environment, taking a long time to degrade. In addition, with the price of silicon oil increasing, **ester fluid**, which has been in use over the past 20 years, can be a superior alternative. Ester fluid is biodegradable, free from corrosive sulfur compounds and has good dielectric characteristics. In regions with high temperatures, ester fluid has a lower viscosity than silicone, and it can tolerate moisture better before its dielectric properties are compromised. Transformer ester fluids can be natural, made from rapeseed, canola or soybean, or they can be synthetic.

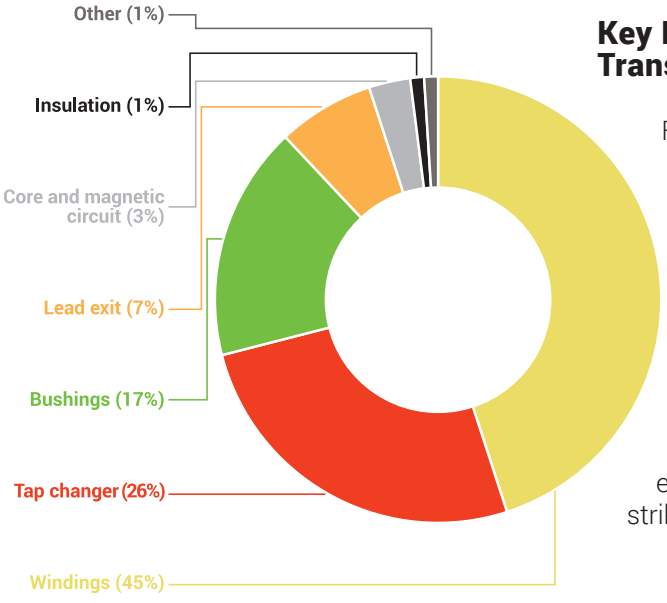
Failure Prevention Transformers: A Comparison of Strengths and Weaknesses

A comparison of transformer types is shown in Table 1, with the most favorable attributes indicated in green and the least favorable in red.

The average lifespan of a dry-type transformer is 15-25 years compared to 25-35 years of a mineral oil-type transformer. Using ester fluids has been shown to extend the life of cellulose insulation, increasing the life of the transformer – there is no oxidization problem. Even though the initial cost of a dry type transformer or an ester filled transformer is higher than your typical oil-type transformer, they offer cost savings in materials since these transformers can be installed closer to the location where they are used. In addition, the initial higher cost of an ester filled transformer can be offset by the increase in lifespan and other benefits.

Table 1. Comparison of transformer types (Source: Power Technology Research) [1]

	Dry type	Digital oil type	Digital dry type	Ester filled
Fire risk	🟢	🟠	🟢	🟢
Lifespan	🔴	🟢	🟠	🟢
Noise level	🔴	🟢	🔴	🟢
Recyclable option for parts	🟠	🟠	🟢	🟢
Environmental risks due to spillage	🟢	🔴	🟢	🟠
Electrical load losses	🔴	🟢	🔴	🟢
Operational cost	🔴	🟢	🔴	🟢
Annual maintenance = downtime	🔴	🟢	🟠	🟢
Cost – initial purchase price	🟠	🟢	🔴	🟢



Key Failures in Transformers

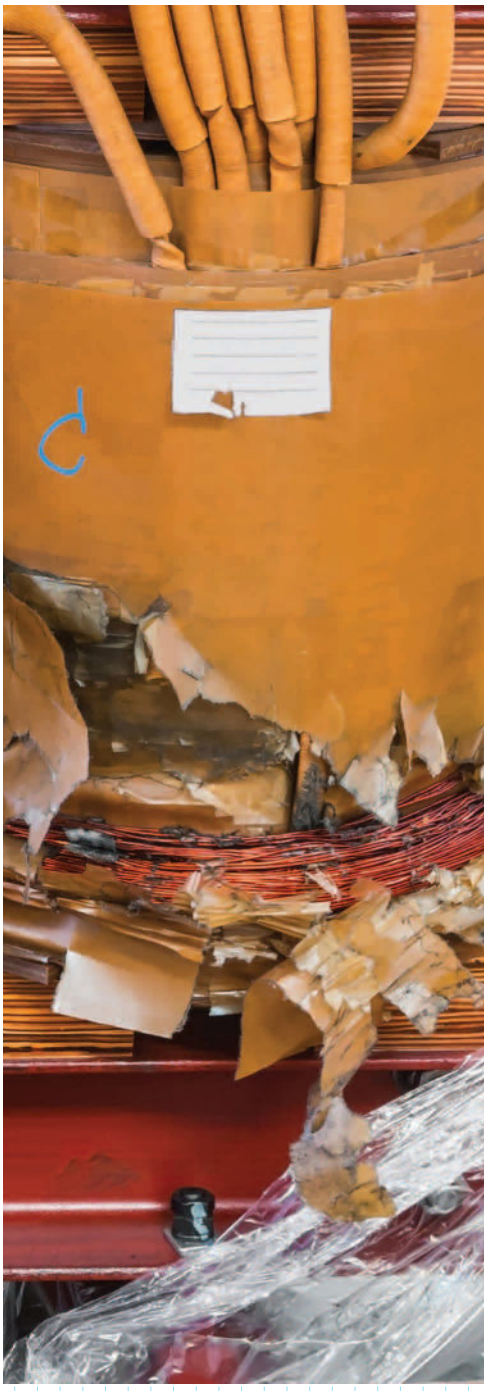
Failures come from a variety of sources and can include commonplace reasons such as electrical disturbances or overloads, but they can also come as a result of more unusual events such as lighting strike or even squirrel related events. Figure 1 shows the distribution of different causes of transformer failure. Digital transformers can play a key role in the indication of failure. With continuous monitoring, the array of data, (e.g. oil temperature increasing beyond certain limit, leakage current in bushings, etc.), can be fed into machine learning algorithms and used to predict failures before they happen. These transformers can reduce unplanned downtime.

Figure 1. Typical failure points in the transformer, Source: [2], [3]

Photo: Shutterstock

Key Applications and Requirements

Each application area requires a specific transformer design, but strict fire requirements have tended to be the major driving factor in many industries. With availability of continuous monitoring of digital transformers and the use of non-flammable fluids in ester filled transformers, there are more choices, especially for applications where there are stringent space limitations. This is also true for commercial applications where noise and space can be an issue.



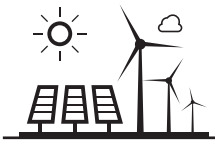
Shown below are additional considerations when selecting a transformer for different applications:

Chemical Plants:
Transformers can be installed indoors where there are space constraints, and there are rigorous fire requirements in this industry.

Underground Mining:
Transformers with smaller footprints (ester fluid and digital oil type) will fit the usual compact space in addition to strict fire safety requirements of this industry.

Commercial Buildings:
Besides the fire safety requirements in shopping centers, business parks and hospitals, there can be additional noise, space constraints making the ester fluid and digital oil type transformers a good fit.

Oil & Gas:
Safety is a big concern in oil & gas industry, even more so in offshore exploration than onshore, where space is limited as well.



Renewables:
Hydro plants close to sensitive waters, wind turbines requiring compact LV and MV transformers to be placed inside housing, and solar farms located in harsh environments, can all benefit from ester filled transformers and the closer monitored digital transformers.

Utilities:
In heavily populated areas like towns and cities, fire safety is of utmost concern for utilities, and dry type transformers have been typically used, but with the added features of ester fluid and digital oil type transformers, these can also be considered.

Usually in the distribution transformer segment, local manufacturers have a larger share of the market in their respective countries.

Market Analysis

The failure prevention transformer market is driven mostly by the addition of renewable power plants, industry and underground distribution in dense urban areas, but environment-driven replacement programs (transformer efficiency) have also had a crucial impact on the market. The global market for failure prevention transformers in 2018 was about US$1.4B [1]. At 46%, the APAC region, driven by China, India and Indonesia, accounts for the largest share of the market with the Americas accounting for 35%. Figure 2 shows the global market share for distribution transformers, and the map in Figure 3 shows the countries with the largest market share in each region.

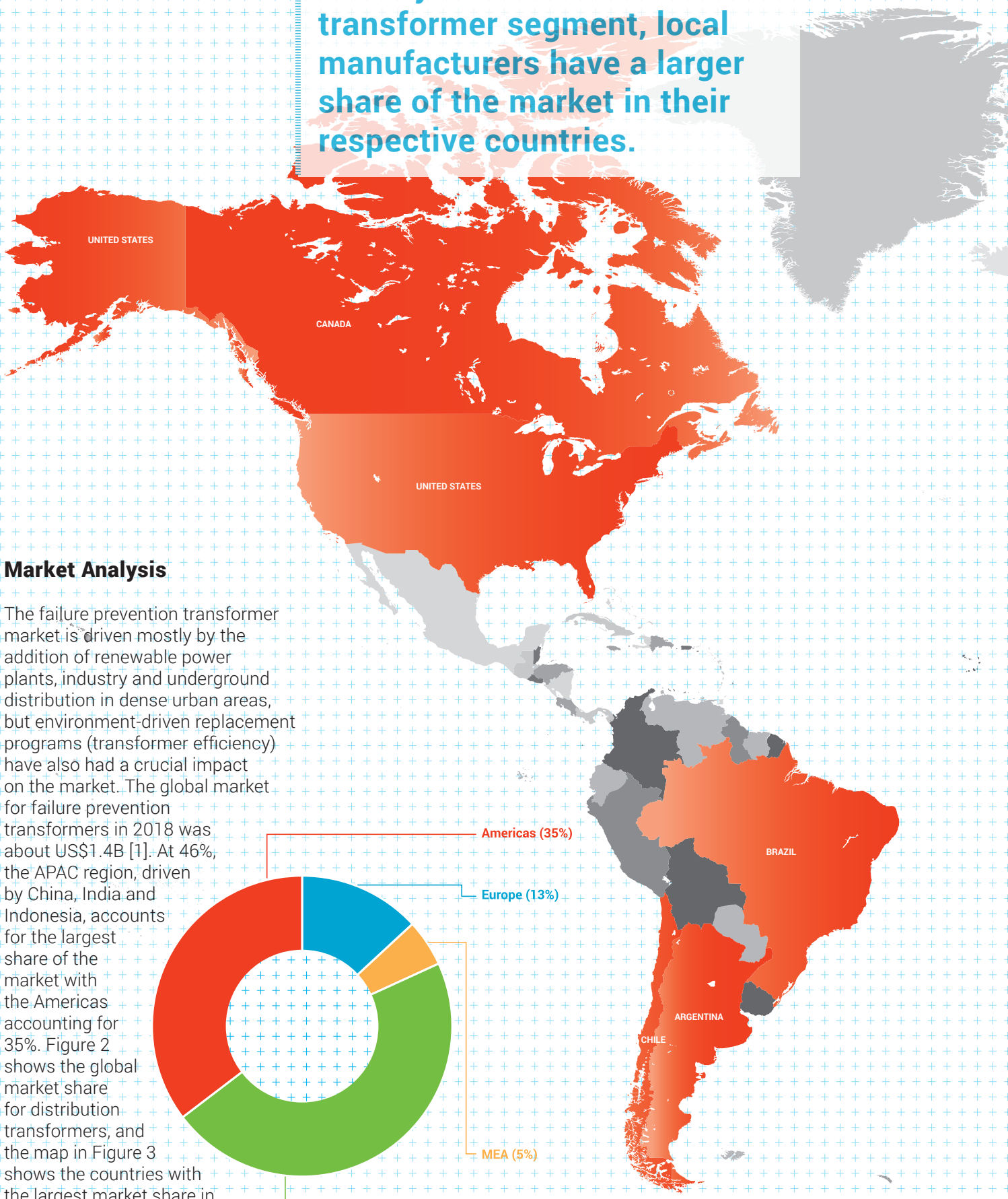
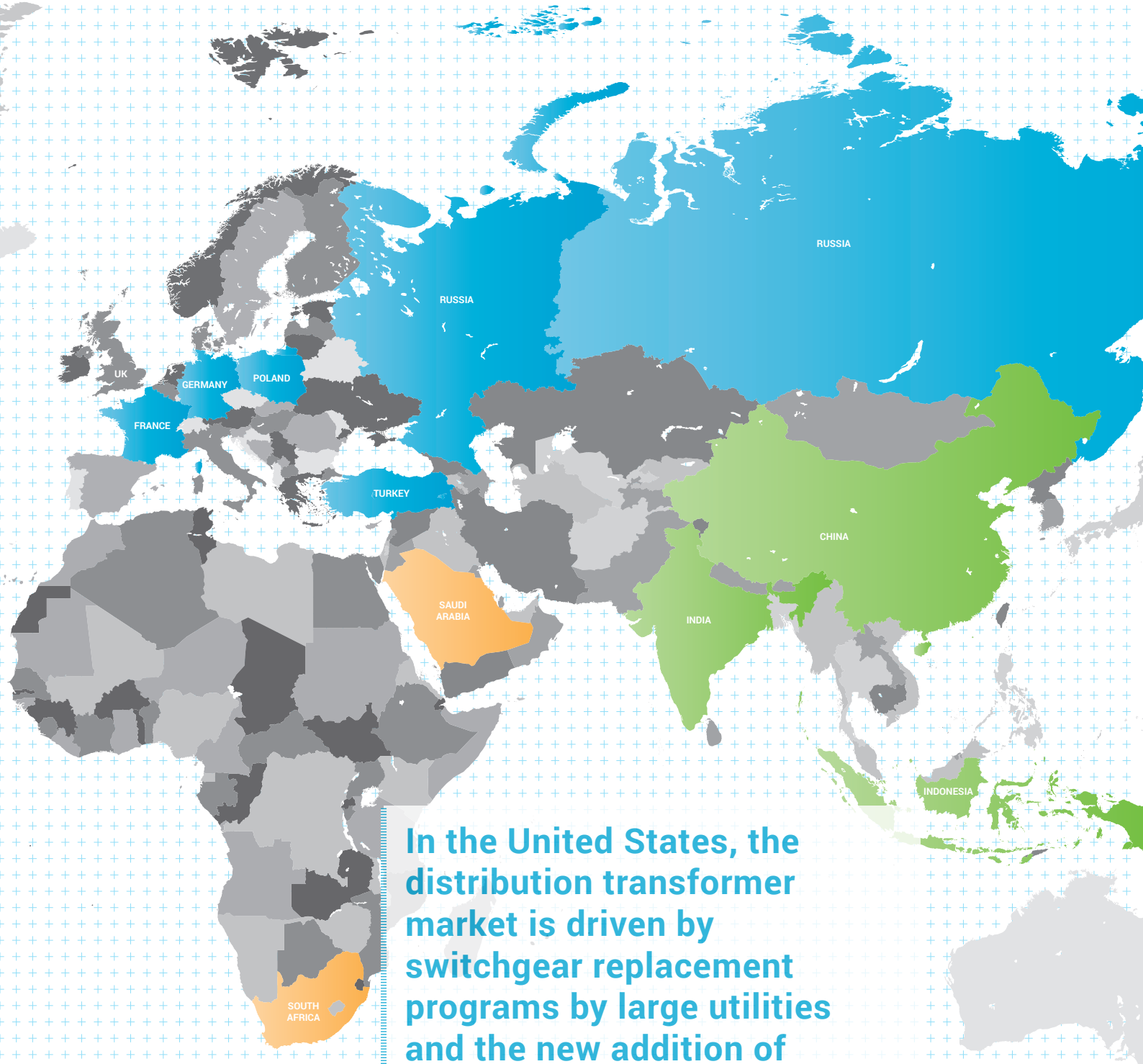


Figure 2. Failure prevention transformer market 2018: Regional market share [1]

Figure 3. Failure prevention transformer market: Key countries (countries with the largest market share in each region are highlighted in the region's color) [1]



In the United States, the distribution transformer market is driven by switchgear replacement programs by large utilities and the new addition of distributed generation sources. Many of the transformers being replaced are in urban settings requiring fire safety.

Demand Drivers

Here are some of the important demand drivers of these transformers in different regions.

Americas

In the United States, the distribution transformer market is driven by switchgear replacement programs by large utilities and the new addition of distributed generation sources. Many of the transformers being replaced are in urban settings requiring fire safety. In South America, Brazil's market is driven by a very high number of failure replacements while in Chile the mining sector is a driver.

Europe

The Eco-Design Directive from the European Commission defines the framework for environmentally friendly designs of all new transformers to be installed in the EU countries. This directive ensures that all transformers in the network adhere to strict efficiency requirements. Tier-1 regulations are already in place since July 2015, and Tier-2 stage with stricter requirements are planned to be put into action in 2021. Safety concerns, especially from utilities serving urban areas in Western European countries, are instigating the replacement of oil type distribution transformers with the dry type. Digitalization is also a priority in Europe where a modem (read connected) monitoring and control technologies at distribution level are a key objective for many utilities as part of their smart grid initiatives.

APAC

Electrification and urbanization are the two key factors driving the greenfield investments in the distribution grid for the Asia Pacific region (APAC). Additionally, developments in the power generation sector also require kVA capacity additions in the distribution grid for most of the countries in this region. China's renewable additions will be a key driving force for dry type transformers, while in India, the very high number of failure replacements will be a consideration.

MEA

After a decade with strong growth, the Middle East and Africa region (MEA) is relatively stagnant. In the case of Saudi Arabia, much was invested anticipating major infrastructure developments, but due to decreasing oil prices, projects have been put on hold.

The failure prevention transformer market is currently mostly comprised of dry type transformers. However, as we move forward, the share of ester filled and digital technologies will grow and will, to some degree, replace the demand for dry type transformers.

Table 2. Failure prevention transformer market: Top manufacturers and their global market share [1]

	Market share	Global presence	Product portfolio	Brand recognition
ABB	🟢	🟢	🟢	🟢
Siemens	🟢	🟢	🟢	🟢
Schneider Electric	🟢	🟢	🟢	🟢
Ormazabal	🟠	🟢	🟠	🟠
Crompton Greaves	🟠	🟠	🟠	🟠
SGB-SMIT	🔴	🔴	🟠	🟠
WEG	🔴	🔴	🟠	🟠

Photo: Shutterstock

Supply Side Overview

Global supply of transformer types discussed in this review is dominated by international manufacturers, some of whom do business in virtually all countries across the world. Usually for distribution transformer segment, local manufacturers have a larger share of the market in their respective countries. However, looking at the market through a global lens, and given the presence of international manufacturers in multiple markets (see Table 2), their overall share of the global supply becomes large. Top 5 players listed in Table 2, which include four European manufacturers, supply these distribution transformers across the globe and have some presence (with sales offices) in all the key markets. The bottom two manufacturers, SGB-SMIT and WEG are more specialized and have a relatively smaller global footprint, due to which they target only certain markets through different locations. This also explains their lower market share compared to other manufacturers.

Table 2 offers a comparison of the top manufacturers in failure prevention transformer distribution market based on their market share.

Conclusion

The failure prevention transformer market, for now, is mostly comprised of dry type transformers. Ester filled transformers and digital transformers have been introduced relatively recently in the market considering the timeline for change in the power grid sector. However, as we move forward, the share of these technologies will grow and will, to some degree, replace the demand for dry type transformers. However, the global supply landscape will not necessarily look very different with this change as almost all top suppliers are already active in the market of digital and ester filled transformers.

References

[1] *Distribution Transformers – Market Research, Power Technology Research.* Available: https://powertechresearch.com/services/grid/distribution-transformers/

[2] S. Tenbohlen, *"Transformer Reliability Survey Tutorial of CIGRE WG A2.37"*, 2011

[3] Marks, Joel, et al., *"An analysis of Australian power transformer failure modes, and comparison with international Surveys"*, Power Engineering Conference (AUPEC), 2016 Australasian Universities, IEEE, 2016.

5
sectors

70,000
sqm

1,300+
exhibitors

20+
pavilions

48,000+
attendees

128+
countries

Middle East Energy Dubai

3 – 5 March 2020 | Dubai World Trade Centre, UAE

Hosted by

UNITED ARAB EMIRATES
MINISTRY OF ENERGY & INDUSTRY

Uniting the Global Energy Community

Formerly known as

MIDDLE EAST ELECTRICITY

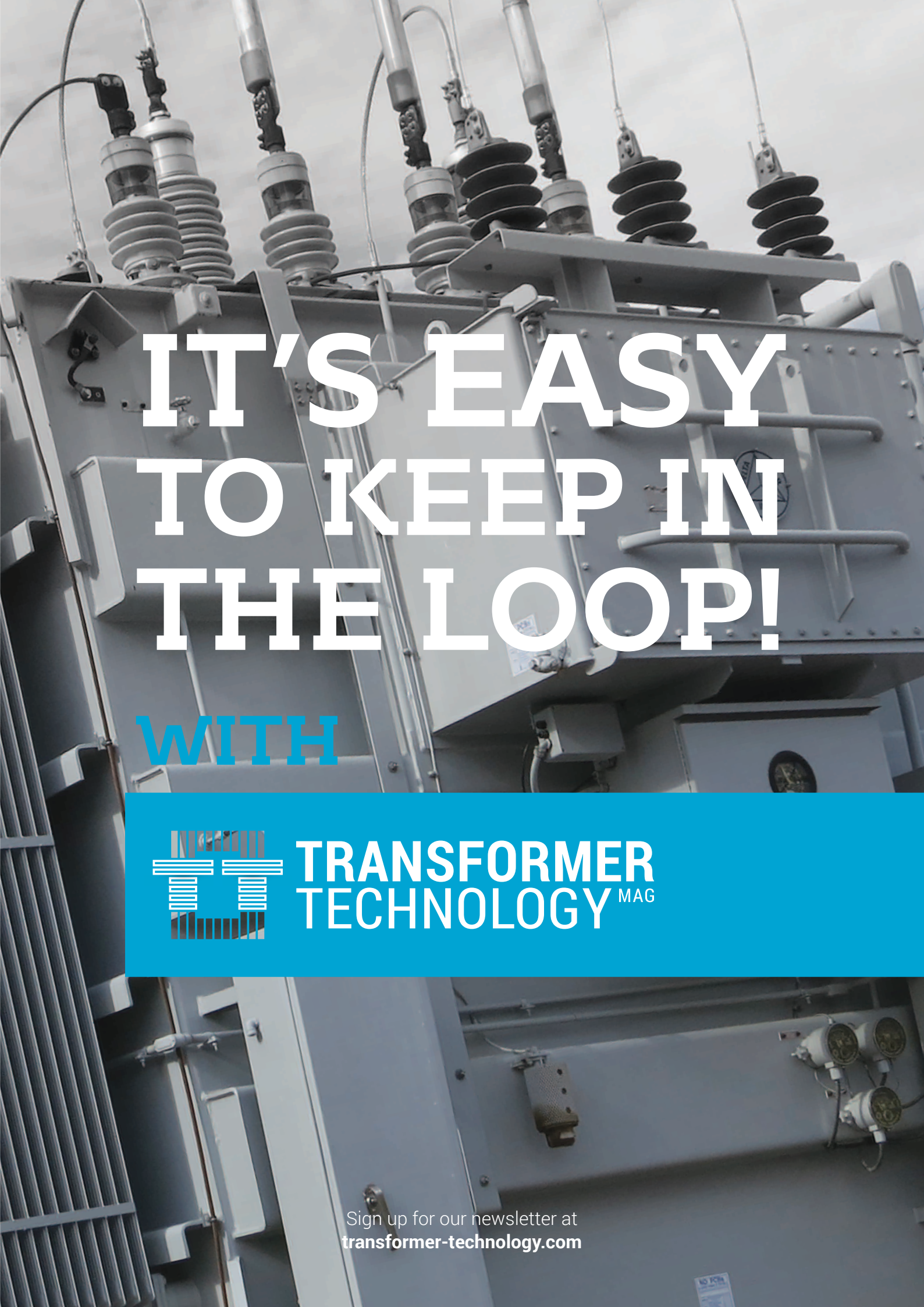
NEW THIS YEAR

Digitalisation Zone & Conference

150+
speakers

Energy Consumption & Management Zone
Smart Technologies in Action

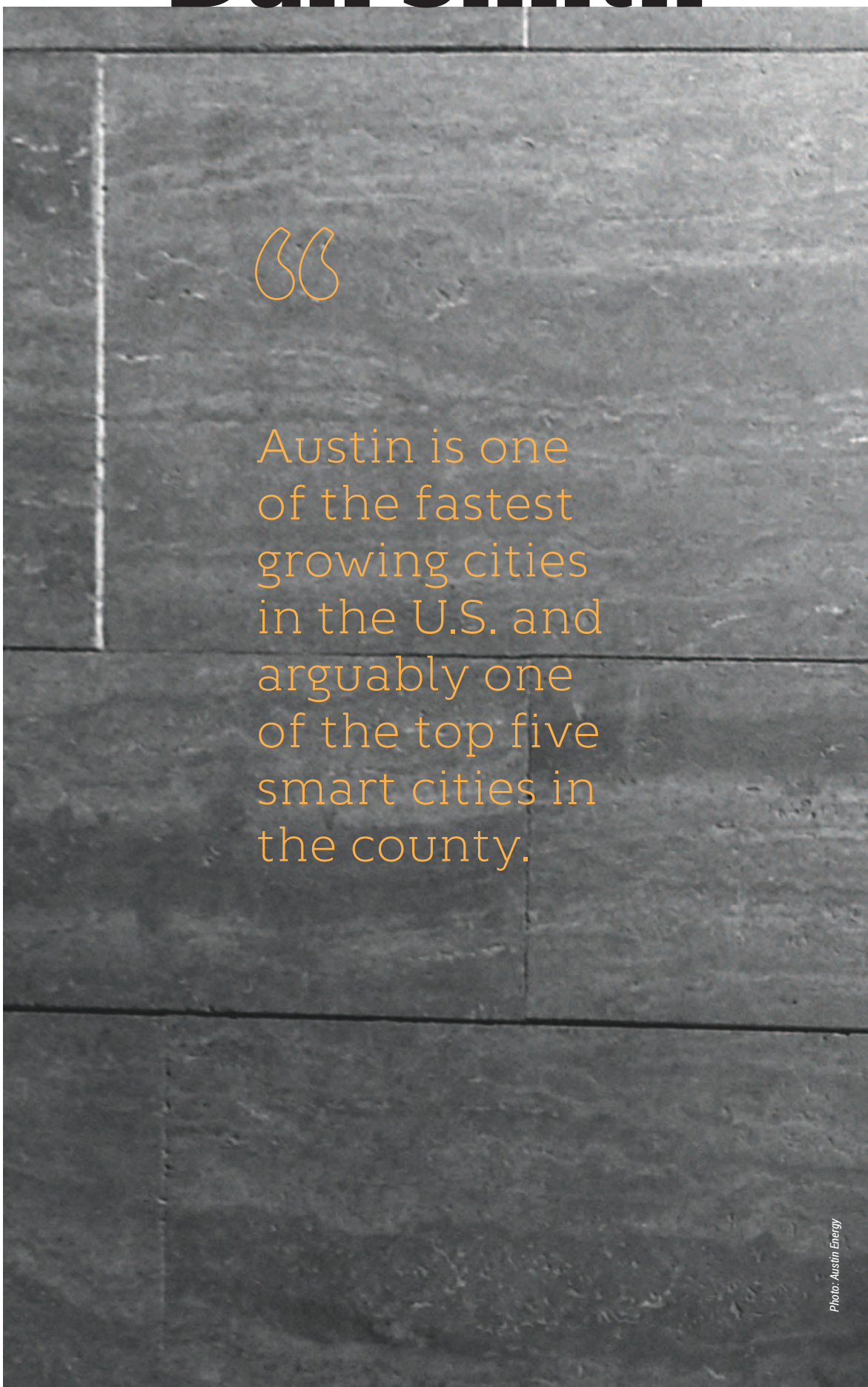
www.middleeast-energy.com


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

Dan Smith

VP of Electric Service
Delivery at Austin Energy

Interview with **Dan Smith**



> Austin is one of the fastest growing cities in the U.S. and arguably one of the top five smart cities in the county.

Photo: Austin Energy

Dan Smith is the vice president of electric service delivery at Austin Energy and whether he likes it or not, he is a Legend.

Dan Smith is the vice president of electric service delivery at Austin Energy and whether he likes it or not, he is a Legend. Dan is in charge of electric service reliability and he has done a number of roles at Austin Energy before growing into his current role. Alan Ross spoke with Dan recently and here are the highlights of that conversation, which we hope will enlighten and inspire you.

Transformer Technology: Austin is arguably one of the top five smart cities or leading cities. I think Austin is the fastest growing city in the country, as every time I go there, I see a new skyline. Can you tell me a little bit about when you started with Austin Energy and where you are now? Why do you have a love affair with Austin Energy and the city?

Dan Smith: I came to Austin Energy 16 years ago. At that time, I was working in the semiconductor industry in Austin, but I also had responsibilities in Germany and Japan. I got an opportunity to join Austin Energy as a substation relay engineering manager, but I didn't have a lot of utility experience other than just interfacing with them. But somebody thought that I had the leadership skills and the aptitude to come and learn it, and that really started a love affair on the utility side.

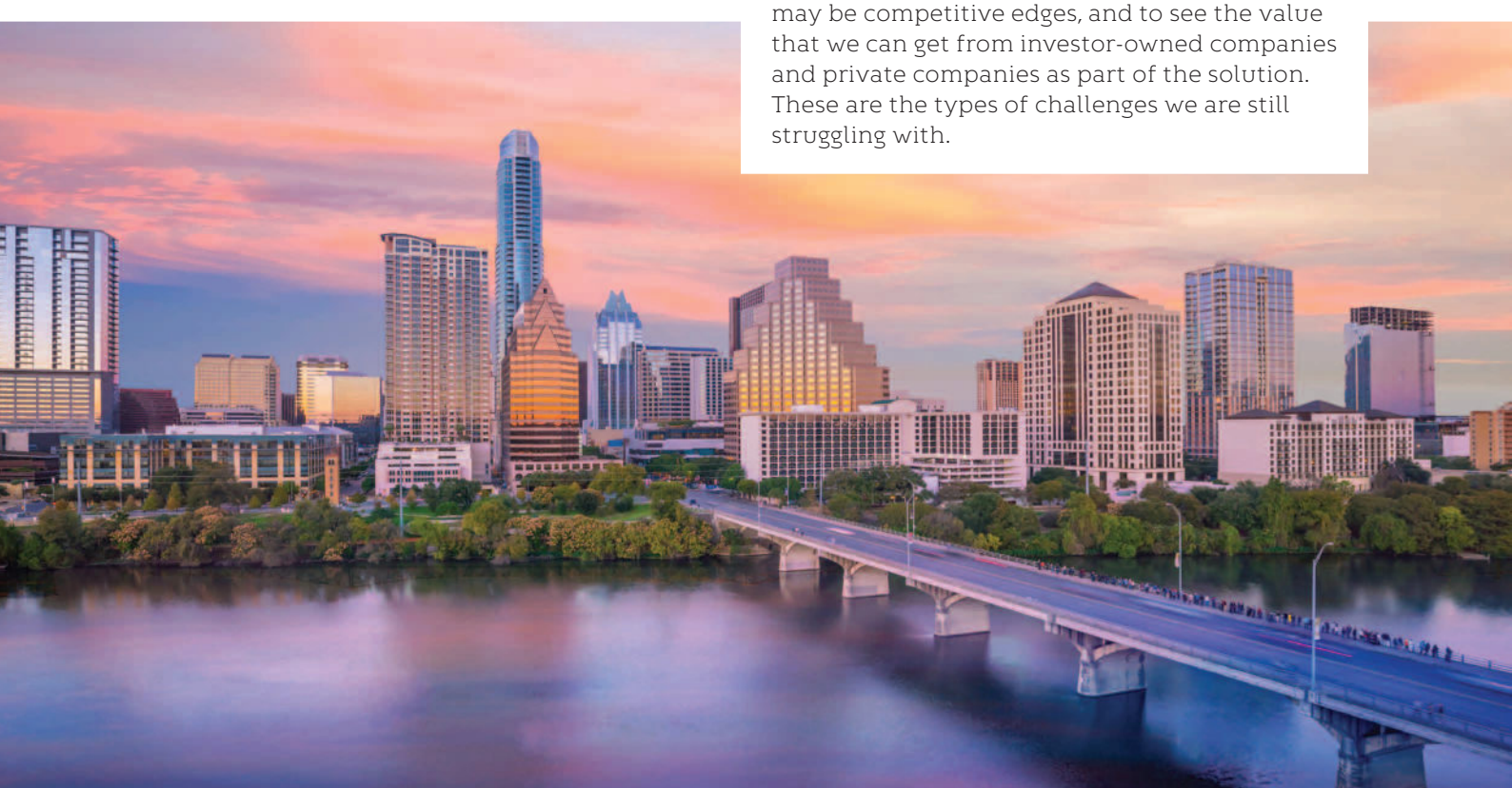
I've been in the electrical industry for over 30 years. However, it was during that transition to the utility business that I really felt at home and I've really enjoyed the opportunity to work for a community-based utility like Austin Energy and serve the community and a customer base in a more holistic way.

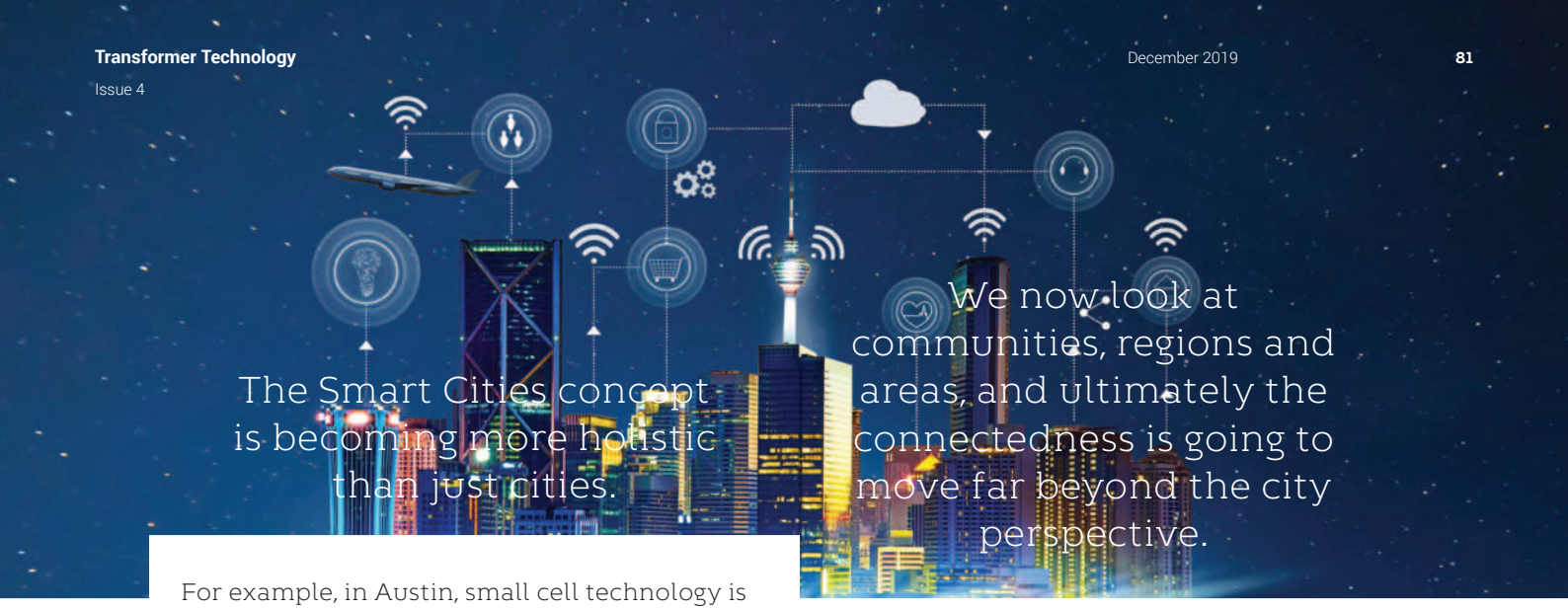
I worked in substation relay engineering for a number of years. Then I became the director of a transmission substation, moved on to become a smart grid system operations director and finally the Vice President over the T&D arm, electric service delivery.

TT You lead a field service group, but you also have a very innovative group for digital, diagnostics and innovation, which is more of a Smart Cities effort. Before we talk about Austin as a smart city, where do you think we are as a country in this effort? What does that even mean?

DS I think we are somewhat in an infancy stage. One of the interesting aspects is that the whole concept is becoming more holistic than just cities. We now look at communities, regions and areas, and ultimately the connectedness is going to move far beyond just the city perspective. And that becomes a real challenging element.

A real struggle for us is to get all these disparate organizations involved that span both the municipalities and the private and the public sectors to work together and deal with what may be competitive edges, and to see the value that we can get from investor-owned companies and private companies as part of the solution. These are the types of challenges we are still struggling with.





The Smart Cities concept is becoming more holistic than just cities.

We now look at communities, regions and areas, and ultimately the connectedness is going to move far beyond the city perspective.

For example, in Austin, small cell technology is something that's just now being introduced into our area, but that's a competitive space. So, how do you provide competitive opportunities while at the same time making sure that you are providing services for all?

A good example is downtown Austin, which is a targeted area, and then we have other outer portions of the city with underserved people where there are not the same revenue opportunities. So, this is the mix that a public entity and a municipality needs to be cognizant of when we are trying to roll out to smaller cities. It is about realizing that you're trying to provide services for all, not just for the ones who can afford it.

TT We know there is a move throughout the world to the smart city, but some of the older cities struggle with the idea of competing in a world where you have limited resources. Austin is unique in the fact that it has a lot of resources that other cities don't have. There are a lot of cities like Austin throughout the United States that are fast growing and while that offers opportunity, it's also a lot of challenge.

Last year you made a speech at the 2018 Electric Power Reliability Summit (EPRS) talking about distributed energy resource (DER). Can you tell us a little bit about how DER, solar and wind are affecting Austin?

DS I think in general terms we are managing quite well. What we have done at Austin Energy is try to incentivize levels of distributed energy resources, not only at the residential level but at the commercial level too. Then we are putting this out into the grid scale type of installations, although not at what I would call bulk utility or Power Purchase Agreements where you are dealing with hundreds of megawatts, but that is certainly part of the solution. What we are seeing moving forward is our ability to handle much more distributed energy resources than we initially thought we would.

Initially, we believed there were some limits to what you could do because of running into voltage and protection related issues, but we found that they have not been a constraint for us. And for the foreseeable future, we think we can technically manage that. I believe that the future opportunity is how we can use DER as a greater asset to us, which is posing the challenge of who controls that asset, or who at times may control the asset.

What we see is that the state of California is leading in this respect more than we are, as they use smart inverters. Smart inverters are able, for example, to both support feeding VARs into the system and provide opportunities for a utility to at least at times control the asset and incentivize the customer, which provides some unique opportunities that may help utilities avoid installing more traditional wired assets. What if we had the ability to better control certain assets that the customer may own? Those are some of the challenges that we see moving forward.

Still, at this particular juncture we are able to handle the amount of DER that is happening. However, I think part of the coming change is that while we have been focused on rooftop solar, new assets are beginning to sprout up - and these are energy storage systems and electric vehicles. They may turn out to be considered a distributed energy resource in and of itself.

Another asset to consider is load management tools. They have the ability to load shape through some of the traditional methods of smart thermostats. But then again, what if we were able to go further, either through signals or control and shape that load where you might operate certain appliances to times when it's non-peak and flatten the load out; or make it match closer to resources like renewable energy sources like solar and wind? That is another asset class that most of us in the utility world are now considering a DER as well.

Photo: Shutterstock

TT Here is one concern. We have a step-down grid. We generate power, step it across the nation, step it down, step it down, turn it into a 110 outlet and everybody is happy. Now with DER, the pattern is step down – step up, step down – step up! Is the smarter inverter going to fix this, considering that the asset that is being stressed the most is the poor transformer, however, the transformer is built to be a step-down unit, and now it's become a step everywhere asset. What is the impact of smart inverters and the change to DER on the heart of the system – the transformer?

DS This is a good question. We don't see the penetration of, for example, rooftop solar as a problem that could not be managed. What we do have more concern with is a ubiquitous charging system, which is becoming people's homes. As more and more people put an AV charger at home and are charging at night, and then you couple this with the air conditioning load and a hot summer evening – this is the point where we anticipate to start seeing transformer loading issues.

> Safety is the most important value in your organization that has to be built on desire and not compliance-based culture.

TT Moving on to safety, we understand this is a passion of yours. How do you affect true safety behavior amongst your staff?

DS Thank you for bringing that up because I am passionate about safety. I believe that for companies to be truly successful, whatever their mission and products or services they provide, their success will depend on how well they live out the principle that **safety is job one**. This is the most important value in your organization and what really starts to move the needle on this is culture. Regardless of how many policies, procedures and rules you put it, and the right tools you put in people's hands - what is really going to move the needle is changing the culture.

You want to move from what I call a compliance-based culture to a desire-based culture. Looking at it from this perspective, if you are focused on compliance, then everybody knows that there are rules and if you follow the rules, one: you will be safe; and two: you won't be disciplined. This is your upper limit, the compliance. But what do you do at two o'clock in the morning when there is nobody there watching you? You could do whatever you wanted, and probably get away with it.

So instead, you want to move to a place that is desire-based, so that the employees know what the company is ultimately trying to achieve and then they are after the same goals for their safety. And this is reflected in the quality of the work they do, and also in how they look out for their brother and sister that they are working with. They are looking at the public interest as it becomes limitless in a sense of what they can do to improve and get better.

From my perspective, 60% of my 560 employees work in the field, so a large percentage of my people are out there, in harm's way, all the time. I couldn't write enough procedures for them to just follow and be safe. That book would be bigger than the height of this room. Instead, they have to always be thinking, and desire to be safe. *Why do I do that easy task of doing a walk around my vehicle or putting a cone out front? Why do I do that?* For them to catch the why behind these actions is really significant and it changes things - and this is where you go from compliance-based to desire-based behavior. This is not only life-changing for them in regard to safety, but it also affects all aspects of their job to the point where they become the integral part to the success of the organization.

In the last five years we have significantly reduced the injury rate at Austin Energy, and even more significantly, we have reduced the severity of those injuries while at the same time we have increased reporting and learned from each other. And this is primarily down to the focus on the culture. We haven't rewritten that many policies, procedures and safety manuals. Instead we have been changing our culture and making it safe to challenge things, encourage each other, look beyond the obvious, and getting closer to that why.

Editor's Note:
Shortly after this interview Dan Smith retired from Austin Energy however his passion continues as he is now the Vice President of Transmission System Operations at the Lower Colorado River Authority (LCRA), in Austin, TX.

Photo: Shutterstock

7 TIPS FROM THE TRANS-FORMER DOCTOR

Constantly handling voltage takes a lot out of transformers, so regular check-ups are essential to ensuring that both they and their on-load tap-changers – the beating heart of this type of equipment – have a long and healthy life.

Richard Bates, Director of Asset Management Business at Reinhausen Manufacturing USA, worked as a technician, service manager, and operational manager in the field for several years, so he knows exactly what it takes to keep transformers running smoothly.

Richard Bates
is Director of Asset Management Business at Reinhausen Manufacturing USA. In addition to manufacturing tap changers, the subsidiary offers an extensive range of services including comprehensive diagnostics, tap-changer maintenance performed by premium service providers (also for tap changers produced by other manufacturers), turnkey retrofitting projects, as well as installation and commissioning of new transformers. It deploys around 50 service technicians to perform this work.

✉ **R.Bates@us.reinhausen.com**

OBSERVE MAINTENANCE INTERVALS Make sure that your on-load tap-changers are undergoing maintenance at the appropriate intervals. The date of a next maintenance appointment will depend on how long it has been in use or how many switching operations it has performed. As an example, some tap-changer types may be due for maintenance after seven years or 70,000 switching operations, whichever comes first.

USE QUALIFIED STAFF Performing maintenance on a transformer is a job for an expert—not just any technician will be familiar with the specific demands that transformers and tap changers pose. Having maintenance performed by qualified staff will make it possible to identify any irregularities in operation early on.

CHECK THE OIL Check the oil at least once a year. The state of the oil can shed some light on the fitness of a transformer—just like a blood test can give a doctor insights into a patient's health. For example, low water content, high surface tension, a high level of dielectric strength, and a low power factor are all indicators of good oil quality.

PERFORM A DGA An even more in-depth analysis involves an additional investigation of the gases. We recommend performing such a dissolved gas and oil analysis (DGA) once a year. This involves checking the ratio of dissolved gases in the oil. Each of the gases is generated in the transformer by a certain state or certain conditions. Once the analysis is complete, we can tell whether the transformer is in good condition.

CHECK THE OIL LEVEL Each oil chamber must have enough oil in it, so it is important to check the levels. This includes the main tank, the on-load tap-changer container, and the bushings. Checking oil levels is important because the oil acts as an insulating material, coolant, and lubricant all at the same time.

CHECK THE DEHUMIDIFICATION Check the dehumidification unit regularly to ensure that no impermissible moisture is entering the oil expansion vessel from the outside, because moisture in the oil will shorten the transformer's service life. Have an expert check whether the device is working reliably. It may be that the silica gel—which is vital for removing water—needs to be replaced.

HAVE REGULAR INSPECTIONS CARRIED OUT Regular inspections are extremely important. Our specialists check all of the installed components—including bushings, fans, displays, valves, motor-drive units, and control cabinets—for issues such as leaks or corrosion in order to detect them early on. Function checks on protective devices allow us to ensure that the transformer will switch off immediately in the event of a fault.

Photo: Mitchell Kearney

WHY Monitor Network Transformers

by **Chris Rutledge**

Chris Rutledge is currently an Applications Engineer at Dynamic Ratings, Inc. He joined the Dynamic Ratings team in July 2019. Prior to his present position, he served as Substation Asset Manager and chairman of the Substation Safety Committee at Memphis, Light, Gas and Water. He has 27 years of experience in the utility industry, primarily focused on the installation, service and maintenance of both substation and distribution equipment. He has done extensive research and published multiple papers concerning the interpretation of dissolved gas analysis testing. Chris is dedicated to assisting customers in finding creative cost-effective solutions for improving safety and reliability across their entire electrical system.

A transformer vault explosion

Photo: Dynamic Ratings

Due to their relatively low cost, network transformers pose a unique challenge when attempting to quantify return on investment of online monitoring and justify the expense associated with it.

While the application of online monitoring has become common for most big-ticket substation items, from large power transformers to high voltage circuit breakers, little attention has been given to equipment outside the fence, as the relatively low cost of distribution equipment makes it difficult to justify the expense associated with online monitoring. However, network transformers pose a unique challenge when attempting to quantify this return on investment. Low voltage secondary network systems are used to increase reliability in the downtown areas of most major cities across the world, requiring these transformers to serve highly critical infrastructures such as hospitals and large office buildings, placing them in close proximity to large segments of the general public. These factors significantly increase the need to observe the *why* when considering the implementation of online monitoring on network transformers.

Low voltage network transformers used in downtown areas of most major cities across the world serve highly critical infrastructures such as hospitals and large office buildings, which is a significant factor when considering the why of implementing online monitoring on this equipment.

Over the last decade, improvements in intelligent electronic devices designed for online assessment of electrical equipment have markedly improved asset owner's real-time awareness of equipment condition, allowing for increasingly effective predictive maintenance programs to be implemented. However, despite all these advancements in monitoring technology, I feel that perhaps the most critical component of any asset management system is the understanding of the why. This understanding of why can encompass numerous variables and ultimately determines the level of success or failure of the desired outcome. This article presents several of the whys associated with monitoring network transformers.

Failure within the cable compartment generally results in damage significant enough to require replacing the entire transformer and can often be catastrophic, potentially injuring anyone nearby and causing damage to the surrounding structures.

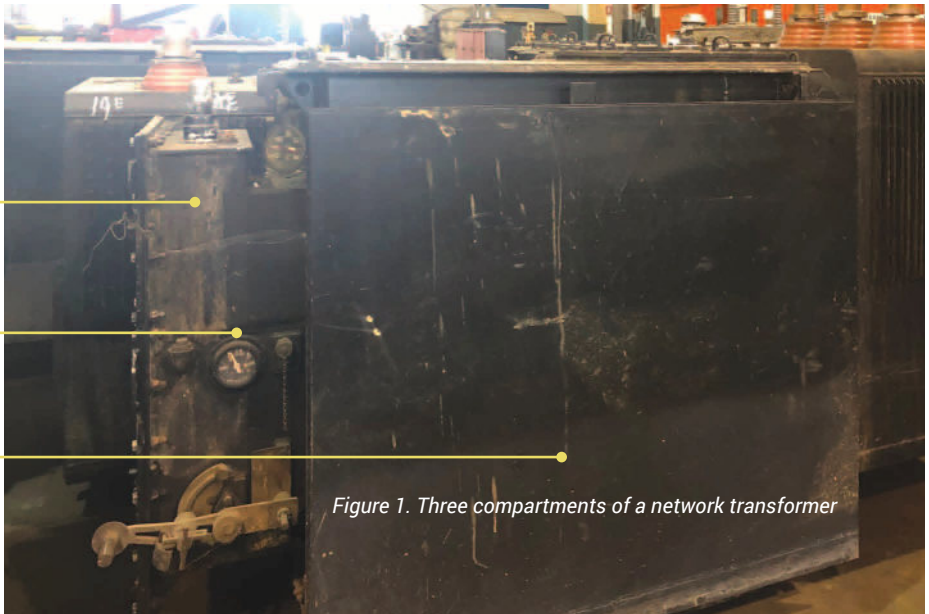


Figure 1. Three compartments of a network transformer

Photo: Dynamic Ratings

Why #1: Network Transformer Monitoring

Why does it fail? This is the most important why of any when determining the most effective approach to applying online monitoring to any equipment and should be answered before we proceed any further.

It seems simple enough, but a practical understanding of why a particular piece of equipment most commonly fails is the most critical component of any online monitoring application. An excellent example of this is the online monitoring of substation transformers. It is quite common to see multi-gas DGA monitors being utilized to monitor the internal conditions of the transformer. While this device is highly effective at detecting the presence of internal faults related to the transformer, it offers little to no indication of problems concerning the transformer's bushings or the power protection system, both of which can be attributed to a large percentage of transformer failures. So, despite the effectiveness of the DGA device, the asset owner is still left with a large blind spot to conditions that could lead to sudden failure of the transformer. As this relates to network transformers, you first need to understand how the overall design varies from that of other transformers.

Network transformers consist of three separate compartments (two in some of the newer designs), the cable termination compartment, the switch compartment, and the main tank, see Figure 1. Typically, these compartments are isolated from one another, each with its own insulating medium and headspace.

So, there are three compartments to be concerned with as opposed to the single compartment design that is common to most transformers. Monitoring all three compartments is key to avoiding undetected development of conditions that could lead to failure.

At this point, let's take a closer look at the function of each compartment. The cable termination compartment is designed to connect the transformer to the primary feeder coming from the substation. This compartment is usually filled with insulating oil and has small bushings in the bottom to transition from the cable compartment to the switch. There are several potential points of failure with this compartment. Many of these transformers have been in service for a long time, placing the cable and terminations in the compartment at a high risk of failure. Also, this compartment is relatively small, placing the cable within inches of a potential ground source should the cable insulation or the insulating oil start to deteriorate, reducing dielectric strength. The size of the compartment also makes it susceptible to ambient temperature variations, causing it to go into a significant vacuum during winter and causing excessive pressure during the heat of summer. This pressure variation can overtime compromise the compartments gaskets, increasing the potential for moisture, which in turn accelerates the degradation rate of the insulating systems. These combined factors present a lot of potential failure modes for this compartment and account for a large percentage of failures common to network transformers.

The switch compartment consists of another small oil filled compartment that houses a grounding switch connected to an electrical interlock to prevent operation while the transformer is energized. With the introduction of the switch, there is the possibility of contact overheating from contact wear or contact misalignment, the potential failure of moving parts, and the size of the compartment, leaving it vulnerable to the same pressure variations associated with the cable compartment. While the failure of the switch isn't as common as the cable compartment, it is still a potential failure point and should be observed.

When monitoring network transformers, there are three compartments to be concerned with as opposed to the single compartment design that is common to most transformers. Monitoring all three compartments is key to avoiding undetected development of conditions that could lead to failure.

The main tank houses the core and coil assembly. Failure risks for this part of the transformer are common to any core and coil assembly such as excessive mechanical and electrical forces from exposure to through faults, cellulose degradation due to excessive heat or moisture and flaws in design and manufacturing. The type of loads these transformers service also leaves them much more susceptible to the influence of harmonics, which can cause excessive heating of the core and coil assembly, leading to accelerated degradation of the cellulosic insulation system.

As previously illustrated, all these compartments present a potential failure risk. Therefore, any online monitoring or maintenance program implemented must consider all three compartments to be truly effective.

Why #2: Network Transformer Monitoring

Why would a specific piece of equipment need to be continuously monitored? Several factors play into this decision such as the cost of the equipment being monitored, the criticality of the equipment, loss of revenue and the possible consequences of a catastrophic failure.

For instance, I have a 50 KVA pad mount which supplies power to my house and two others on my street. If that transformer fails, it will likely only result in me and a couple of my neighbors having to sit in the dark for a few hours. While my wife may vehemently argue about the implications of that event, the consequences hardly justify placing $10,000 worth of monitoring on a $1,000 pad mount. However, when determining the cost-effectiveness of monitoring on a network transformer, the consequences of catastrophic failure are much more serious than in most transformer applications. Network transformers are usually located in vaults under the sidewalks and buildings of downtown areas. This places them near areas with a lot of foot traffic, significantly increasing the chances of causing serious injury or death should a catastrophic failure occur. This location in underground vaults also increases the cost associated with having to replace one of these transformers, as it can be a logistical nightmare to set up a crane in the middle of downtown, disrupting both traffic and commerce for extended periods. Network vaults are also susceptible to occasional flooding, making it paramount to ensure that the transformer always holds positive pressure and maintains its submersible integrity. These factors, combined with the criticality of the load these transformers service, which are generally some of the most critical infrastructures in any major city, provide a solid justification for the expense associated with online monitoring.

Network transformers are usually located in places near areas with a lot of foot traffic, in buildings or in vaults under the sidewalks susceptible to occasional flooding. These factors, combined with the criticality of the load these transformers service provide a solid justification for the expense associated with online monitoring.

Photo: Dynamic Ratings

Why #3: Network Transformer Monitoring

Why use a particular monitoring technology? The user must consider the cost-effectiveness of the monitoring and what it is they hope to accomplish.

When deciding about online monitoring, the options can range from simply monitoring top oil temperature to a comprehensive diagnostic system including power factor, loading, partial discharge, thermal modeling, multi-gas DGA, etc. with price points varying from $100 to $100,000+. The cost of the equipment being monitored is a major factor in determining the type of system to install, but the asset owner should also consider the purpose of the monitoring. If the purpose of the monitor is to gather the level of data required to perform advanced analytics, then a multi-gas monitor would be the minimum level of monitoring that could be used. This would provide information concerning the production of hydrogen and the relevant hydrocarbon gases. With this data, the asset owner can access thermal conditions, such as arcing, using the ratio of acetylene to ethylene, or the deterioration of the cellulosic insulation system through trending of the CO/CO_2 ratio.

Partial discharge is another useful tool in detecting and determining the severity of insulation breakdown in its earliest stages through the use of coupling capacitors, RFCT or UHF sensors to detect high-frequency impulses. Though both technologies are highly useful in accessing the equipment condition and performing diagnostics, they are at a high price point, which may not be justifiable for most distribution level applications. In addition, when considering the three-compartment design of network transformers, it would require a monitor to be installed on each compartment to ensure incipient conditions were detected before leading to failure. Hydrogen monitoring is likely the most useful type of monitoring for network applications due to its lower cost and ability to detect any abnormal operation which generates thermal conditions in excess of 1500C. While not capable of providing the level of data required to perform diagnostics, hydrogen monitoring does provide a sort of smoke detector for the transformer, alerting the asset owner to the development of incipient faults, thereby allowing the transformer to be taken off-line for more conclusive testing. However, hydrogen monitoring would still need to be installed on each compartment to provide reliable protection of the transformer. Since network transformers are normally set in vaults that can be subjected to flooding for extended periods, placing the transformer in a highly corrosive environment, pressure monitoring to verify the integrity of each compartments tank and gaskets would also be advised. This combination of pressure and hydrogen monitoring should be adequate to provide early warning of conditions which could ultimately lead to transformer failure.

The cost of the equipment being monitored is a major factor in determining the type of system to install, but the asset owner should also consider the purpose of the monitoring.

Conclusion

While this article primarily addresses the concerns associated with network transformers, these principles can be applied to any level of asset management. A good understanding of why failures most commonly occur and the indicators which precede them must be the central focus of any successful preventative maintenance and monitoring program. With this knowledge, the asset owner can determine the most effective approach to achieve desired levels of reliability, rather it be the application of high level comprehensive monitoring to detect an adverse change of conditions in their earliest stages for extending the life of large substation equipment or merely trying to prevent in-service failure of distribution equipment through minimal monitoring and routine inspections.

A good understanding of why failures most commonly occur and the indicators which precede them must be the central focus of any successful preventative maintenance and monitoring program.

DVtesting Voltage Regulators

by **Edis Osmanbasic**

Edis Osmanbasic is the lead engineer for transformer testing at DV Power, Sweden. His work involves analysis and development of test methods for transformer condition assessment and he has published several studies in this field. He is responsible for DV Power Consulting, Education and Training Services. Edis is also involved in DV power transformer test equipment field application and diagnostics of transformer test results. Edis obtained his master's degree in electrical engineering from the University of Sarajevo, Bosnia and Herzegovina.

Photo: DV Power

When diagnostic testing is applied to voltage regulators, it includes dynamic tests on tap changers. As regulators have a specific construction, where at neutral point turns ratio is 1:1, familiar dynamic test graphs look very different. This article is an overview of voltage regulator condition assessment using DVtest methodology, also known as dynamic resistance measurement (DRM).

Introduction

DVtest, or Dynamic Resistance Measurement (DRM) testing, is an off-line, non-destructive test in which a DC current is injected through a transformer winding and tap changer as it moves through all of its positions [1]. Results from the current signatures are examined and compared against previous tests, or similar unit test results. This test on a regulator may be used to detect problems such as slow tap changer transition time, contact problems, and open circuits, among others [2].

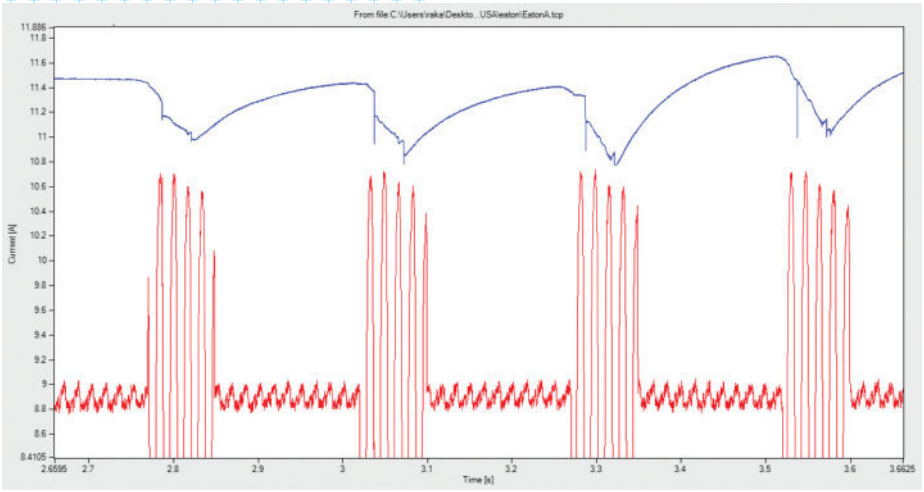
Voltage Regulators

Regulators are low cost regulating transformers (or, more precisely, regulating autotransformers). Some utilities do not like to put expensive power transformers in danger of failing by placing a relatively unreliable on-load tap changer (OLTC) in the main tank, or even in an adjacent compartment. The OLTC is the only moving part under voltage in a transformer, thus its low relative reliability compared to a power transformer.

Some utilities have a need for voltage regulation closer to the load, which is why we find so many regulators in the USA networks. Most have 33 positions and regulate the voltage +/-10%. The most common configuration is 16 steps of 5/8% (0.625%) each, for both raise and lower position.

The OLTC is the only moving part under voltage in a transformer, thus its low relative reliability compared to a power transformer.

Figure 1. Four transitions in one second of a fast regulator

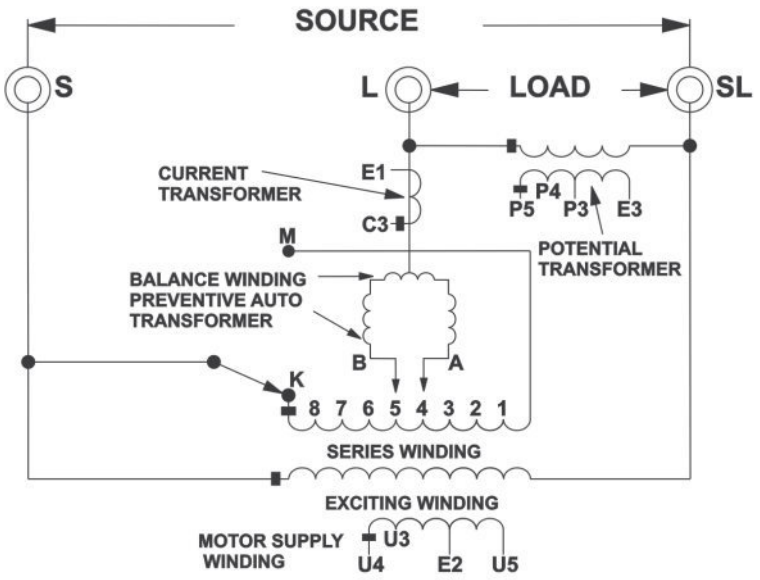


Regulators can be divided into two categories: Large three-phase units, and smaller single-phase units. While larger three-phase units have all the characteristics of an autotransformer with a normal tap changer, smaller ones may be equipped with super-fast tap changers, some of which operate within 250 msec and are able to change four tap positions within one second (Figure 1).

One side of the regulator is called SOURCE and the other is called LOAD. The voltage is varied at either side as required. The neutral point/bushing is usually called SL or S0L0. Type A, as per ANSI standard, varies the voltage at the load side while keeping the source voltage constant, while type B does the inverse, changing the source voltage while the load side is kept constant (Figure 2). This is achieved by placing the tap changer in the load or in the source side; that is important when deciding how to test a tap changer in a typical regulator.

A major difference in their design characteristic, when compared with an autotransformer, is the resistance and inductance at the tap changer neutral position. The winding resistance of the neutral position can be down as far as 2 mΩ, while the end tap – position 16 – would measure an order of magnitude higher resistance than the neutral tap. This is due to the fact that at the neutral position regulator provides regulation of 1:1 and no regulating winding is in the circuit, only the tap changer contacts and connections. At the extreme tap positions, we have a complete regulating winding in the circuit.

Figure 2. Schematic of two single-phase regulators type A (top), and type B (bottom)



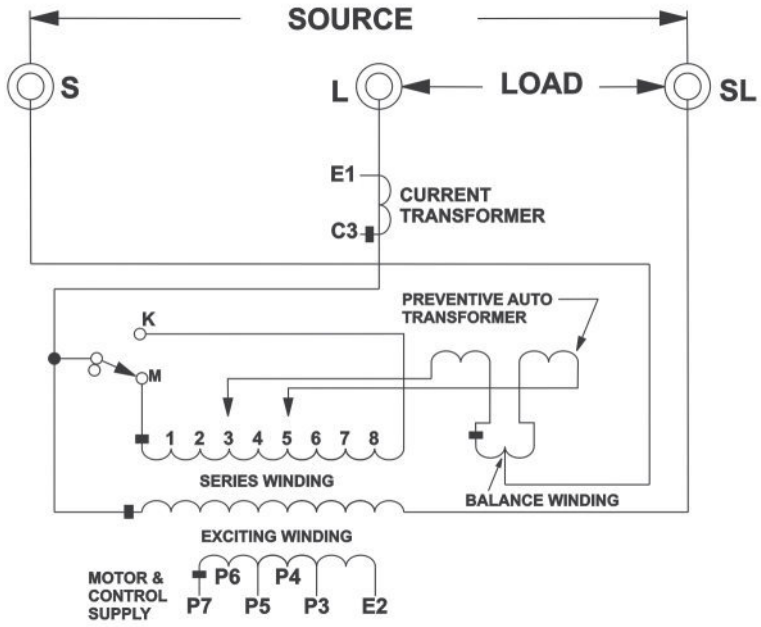
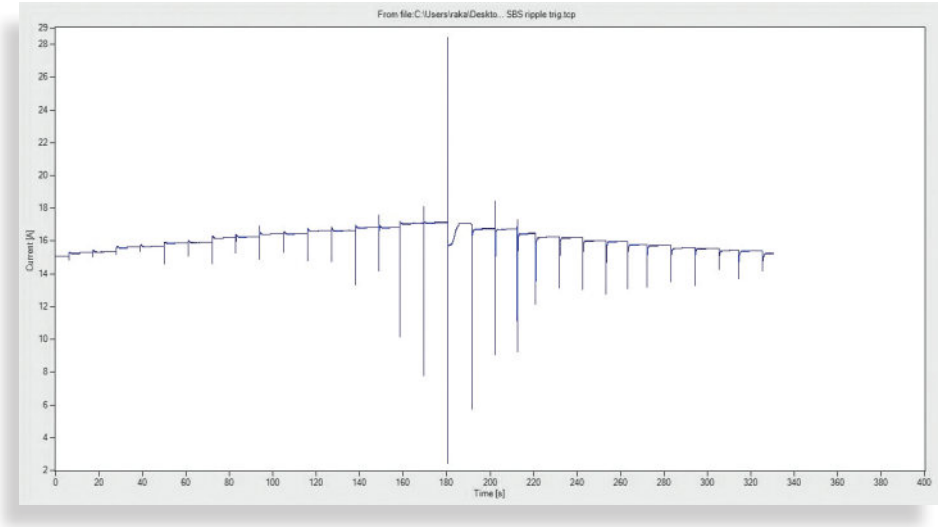


Photo: DV Power

Figure 3. DVtest graph of a typical functional regulator

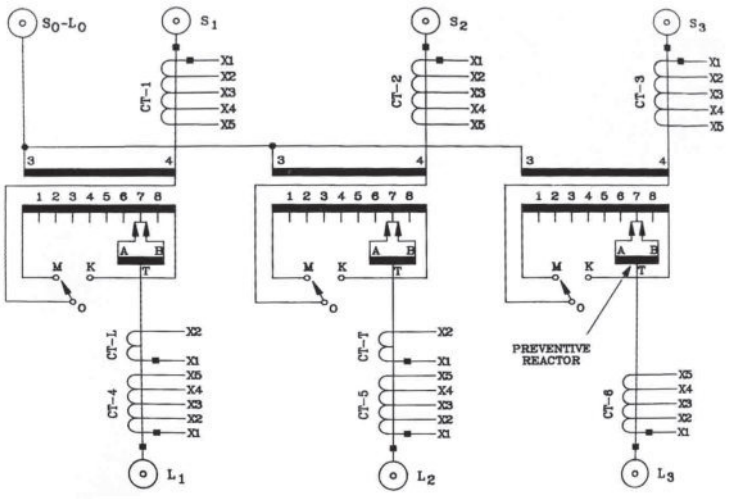


DVtesting Tap Changer of a Regulator

The DVtest, or the dynamic recording of the test current, provides a very different overall graph when compared to a power transformer. The ripples change their value from small to very large value at the neutral position (Figure 3), and then getting smaller again as the other extreme position is approached.

Regulators can be equipped with tap changers of either reactor or resistor types. The reactor type tap changers are predominant in the USA networks. The ripple shape is characteristic for each construction of the tap changer. Regulator ripples are very much the same shape but a different magnitude to that of their transformer counterparts. For that reason, attention should be paid to the type and manufacturer of the tap changer itself during the result evaluation.

Figure 4. Schematic of a three-phase regulator



Type A ANSI regulator varies the voltage at the load side while keeping the source voltage constant, where type B does inversely, changes the source voltage while the load side is constant.

Three-phase

The DVtest on a three-phase regulator may be performed using a single-phase instrument or a three-phase DV Power instrument like TWA40D. This three-phase instrument allows connection to all bushings at the same time time, and then we would consider the S (source) side as the HV side, and the L (load) side as a LV or secondary winding. Both neutral test leads are connected in the same way as an autotransformer, to the S0L0 bushing.

Three-phase instruments provide three options: LV, HV, and BOTH [3]. Selecting the appropriate option requires reading and understanding the nameplate schematic. In the schematic example in figure 4, testing the HV winding (S0L0 to S) would not provide ripples as the current is going through the common winding only. Testing LV (in this case S0L0 to L) is the correct way to perform the DVtest in order to obtain the desired graph.

For investigative tests, one can use the three-phase instr uments in a single-phase test mode and perform any type of connection permutation.

Single-phase

Performing a test using one of the single-phase winding resistance instruments allows for selecting the connections of test leads the way we want. Normally one lead is connected to the S side, while the other is connected to the L side. Alternatively, one would be connected to the common SL terminal, but then attention should be paid that the tap changer is indeed in the test loop (see note about A type and B type). If not, the graph obtained would be just a straight line.

Testing between S and L has one disadvantage: very low resistance and inductance of regulating winding only, while testing between SL (neutral bushing) and S or L terminal includes the common winding in the test loop and makes the ripple smaller and response time different.

Figure 5. DVtest graph using S to L connection showing very high ripple

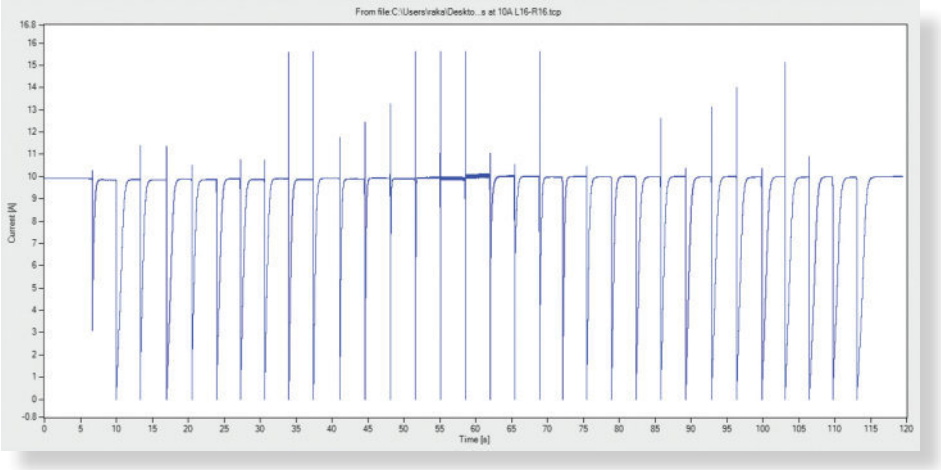


Figure 6. DVtest graph using SL to L connection showing normal ripples

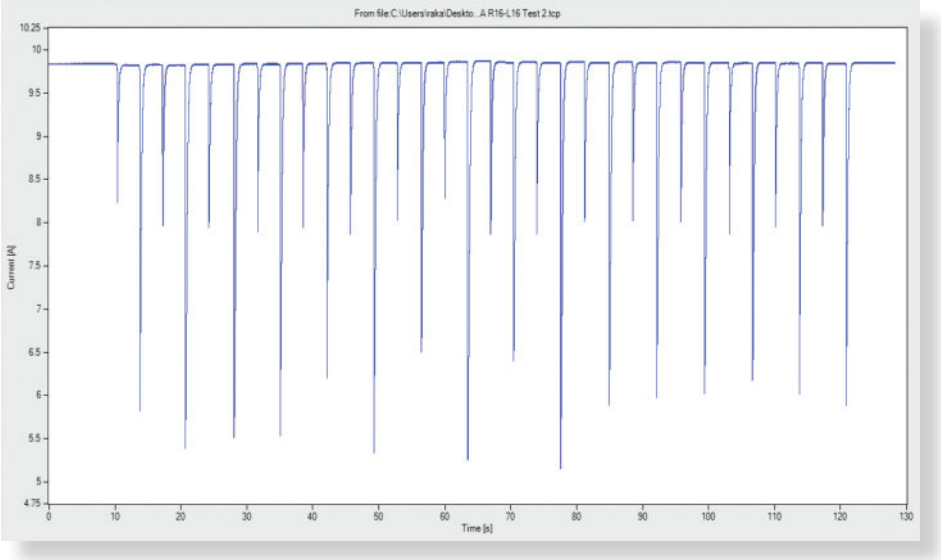
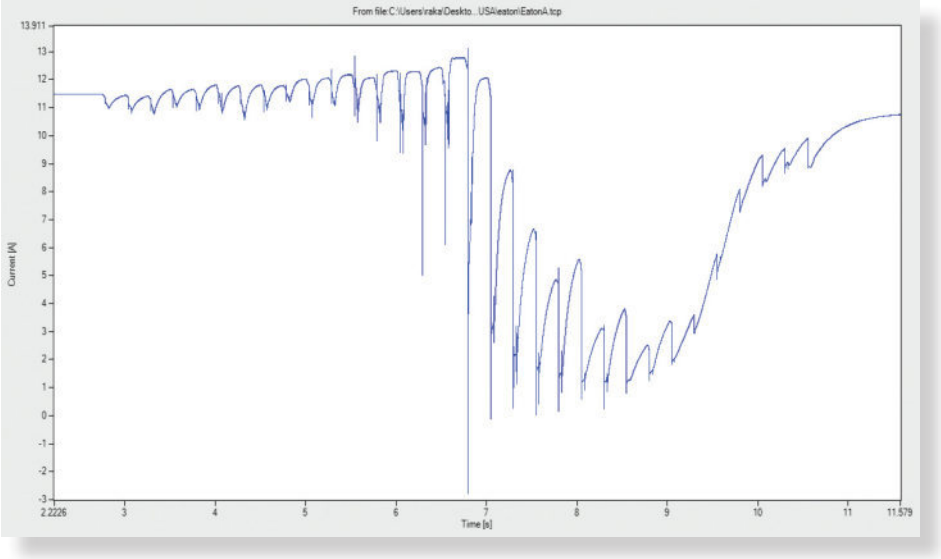


Figure 7. Slow recovery after neutral position



Issues

With inherent low resistance/inductance at the neutral position, regulators create several issues that a tester needs to understand in order to properly evaluate results.

The specifics of a fault could be too high of a ripple, as in Figure 5. Almost all ripples reach 100% on that graph. The reason is the construction characteristics of the regulator and test connection used: S to L. In that case the recommendation is to change the connection. As the ripple may show 100% — which is not the real situation as the current oscillates — an alternative test connection should be applied.

Once the test connection was changed to record the current between SL and L terminals, the same regulator responded differently. Figure 6 shows the ripple values that are in the order of 20-50% but never reaching 100%.

Another specific issue at neutral on regulators is slow recovery time. As the test is performed using DC current, the inductance of the regulator winding once introduced into the test loop following the neutral position, where inductance is zero, makes an increasingly slow current. This is visible in Figure 3 to a smaller degree, while in Figure 7 it is extreme. Figure 3 shows a slow tap changer, recorded by waiting for a few seconds between transitions. Figure 7 shows data recorded with a high-speed regulator and where transitions last very short and time to re-establish current after changing taps through neutral position is few seconds. This is significantly longer than it takes to switch from position N (17) to 33; for this particular regulator about 4 seconds.

Direction Up/Direction Down Testing

Performing a DVtest is possible either when the OLTC is moving in direction UP or direction DOWN, but our recommendation is to always perform both UP and DOWN tests. Defining the direction of the test makes a significant difference of the ripple shapes, especially for the reactor type tap changers. Figure 8 includes both UP and DOWN graphs, presented by different color traces. The difference between the two is significant, and one may say that they look like mirror images of each other.

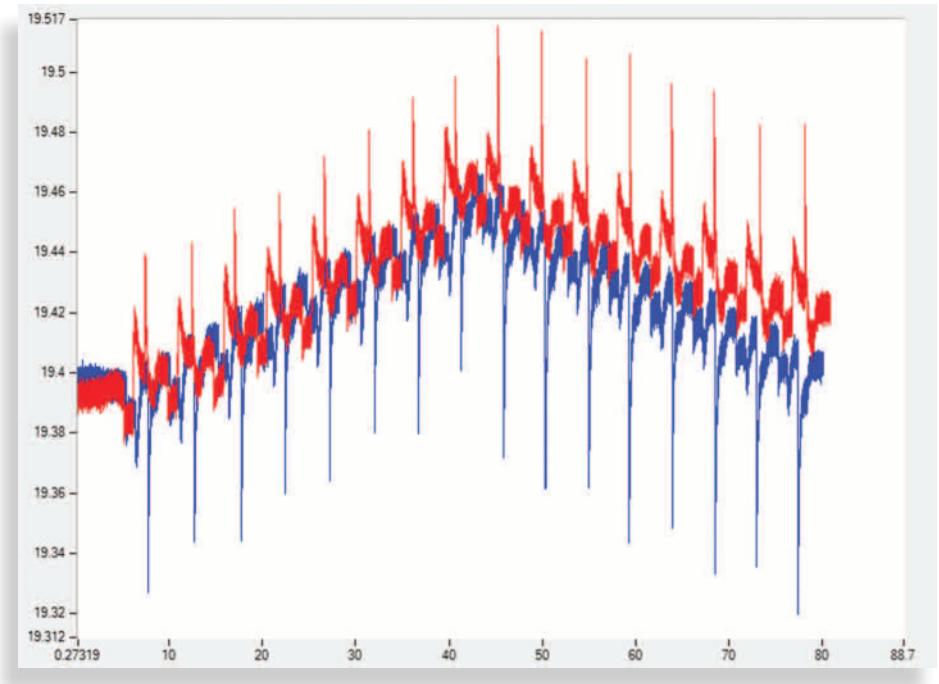
Conclusion

Performing the DVtest on a voltage regulator is a useful condition assessment procedure and it should act as a good diagnostic tool for condition assessment of the tap changer. Many problems can be detected, including mechanical and electrical faults, issues with contacts, and issues with control, among others. The graph is specific when analyzing it. Pay attention to how the test leads are connected and be aware about neutral specifics.

References

[1] R. Levi and B. Milovic, *Proceedings TechCon USA*, 2011.
[2] R. Levi, G. Milojevic, *From the AMforum Knowledge-base: Case studies of OLTC problems detected by DVtest*, presented at TechCon – Training Track, Sacramento, CA, US, February 2015.
[3] *Instruction manual TWA40D*, DV Power, Lidingö, Stockholm, 2015.

Figure 8. Direction UP (blue) and direction DOWN (red trace)



Performing the DVtest on a voltage regulator is a useful condition assessment procedure and it should act as a good diagnostic tool for condition assessment of the tap changer.

Which fluid to use: The latest advances in transformer fluids

The reliability of an asset is largely determined at its design stage. Every component must be evaluated as part of a greater whole – as part of a reliable asset, and then that asset needs to be evaluated as part of a reliable system.

Whew! That was a long explanation of why the selection of every component in transformer design is critical, and one of those components in liquid filled transformers is the choice of the insulating liquid.

Our February Issue will look at many of the critical decisions that must be made when deciding which fluid to use in a new transformer, or which fluid to retro-fill in an older unit. The decision criteria include performance characteristics, life expectancy, impact on environment and safety, biodegradability, operating characteristics and more.

We will also look at the requirements for getting the most from our fluid test data as well as several test cases of the impact of natural esters in larger power transformers. Our authors will present the latest advances in fluids, a much-needed treasure trove of information for manufacturers, procurement professionals or designers.

Along with two great interviews from senior leaders in transformer testing, maintenance and manufacturing, our February Oils & Fluids issue is a must read for anyone associated with transformers.

THINKING ABOUT STRENGTHENING YOUR POSITION IN THE MARKET?

THINK ABOUT YOUR PRODUCT

THINK ABOUT YOUR COMPETITION

THINK ABOUT YOUR SERVICE

THINK ABOUT YOUR TIME

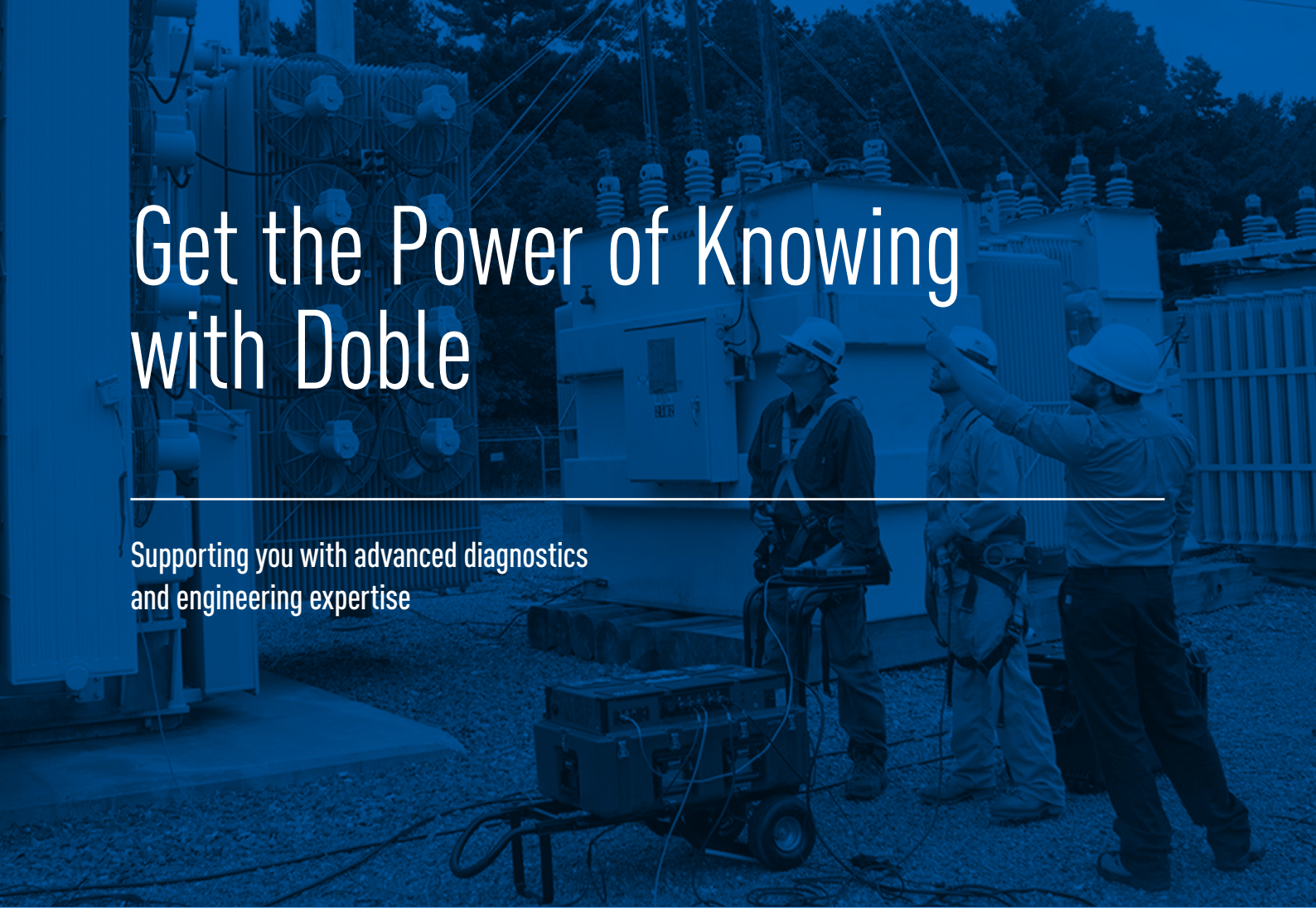
THINK ABOUT...

DON`T THINK ABOUT MARKETING

LET US DO IT FOR YOU

TRANSFORMER TECHNOLOGY MAG

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



Get the Power of Knowing with Doble

Supporting you with advanced diagnostics and engineering expertise

Doble is here to support you with the tools, training, and information you need to perform effective diagnostic testing and asset management.

From application specific test equipment through advanced consulting, we are here to answer your questions and help make testing simple, safe, and efficient.

Did you know?
Manta Test Systems, Morgan Schaffer and Vanguard Instruments are now part of Doble.

With an expanded portfolio, our wide range of hardware, software, and services include:

- Off-line Testing
- In-Service Testing
- On-line Monitoring
- Protection Testing
- Consulting Services
- Cybersecurity Programs
- Enterprise Asset Management

Learn more about how our team can support you with your testing needs.
www.doble.com

MANTA™ TEST SYSTEMS
A DOBLE COMPANY

MORGAN® SCHAFFER
A DOBLE COMPANY

Vanguard Instruments
A DOBLE COMPANY

doble®